The Importance of Room Acoustics for a Quality Sound System

by Curt Taipale
Bose Corporation commissioned professional audio consultant Curt Taipale to prepare this paper. Its goal is to help you better understand professional sound systems and to provide information about planning and choosing a sound system for your house of worship.

We hope you find it helpful.
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Biography

Curt Taipale enjoys decades of experience in audio as a recording and live sound engineer, a consultant, educator, and author. He contributed three chapters to the Yamaha Guide to Sound Systems for Worship, has written numerous articles for several magazines, and is the Church Editor for Live Sound International.

Curt and his wife, Jeanna, launched their ministry web site, www.ChurchSoundcheck.com, in 1997. Their CSC Discussion Group brings together thousands of people in countries throughout the world on a daily basis to help each other achieve technical excellence in their local churches.

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Introduction

Do the acoustics of your worship center complement your current worship services, or do strong echoes and reverb constantly get in the way? Maybe it’s just the opposite, where the music seems dull and lifeless, and congregants have trouble hearing one another sing. Maybe you constantly strain to understand the spoken word.

The source of each of those issues can be traced back to the room acoustics. In fact, there are many auditoriums that either have never truly served the purpose for which they were built, or the worship music style has changed over time and the room acoustics no longer complement the music. Current loudspeaker technology can go a long way towards overcoming certain acoustic issues, but that doesn’t fix the problem at the core.

Your worship center provides a space in which you communicate a life-changing message on a weekly basis. I think we could all agree that comfortable seating, quiet air conditioning, good lighting and structural integrity are all important foundational, base-building goals for your auditorium. The same is true whether it is a new construction project or the renovation of an existing auditorium.

But always remember that you’re creating an “auditorium,” which, by definition, is a “place for hearing.” Incorporating design for the room acoustics that is appropriate for your style of worship services must be considered as an equally important base building goal. It cannot be taken lightly, nor treated as a “let’s wait and see if we need it” option. Rather, it is as important to the success of your worship services as the concrete or the steel.
Room Acoustics—What is It?

The term “room acoustics” describes how sound behaves in an enclosed space, and one could devote a lifetime to its study. On the surface, it considers the direct sound, reflections and reverberation—while deeper study can lead to discussions of mechanical noise and sound isolation.

Why so complicated? Imagine someone standing on the main platform at your house of worship, talking to the congregation. The sound waves travel out and strike a multitude of surfaces—the floor, ceiling, walls, chairs or pews, windows, people, and so on. Depending on the makeup of each surface being struck, a portion of that sound will be reflected back into the room, a portion will be absorbed by the material, and some of the sound may even travel through that material.

So imagine you’re sitting in the audience. The sound of the speaker’s voice not only reaches your ears but also reaches the ears of those sitting around you. In fact, just a tiny fraction of the sound reaches you directly, while the rest of the wave spreads out across the room and ends up as reflections, many of which may eventually find their way back to your ears.

Of course, we are concerned about the direct sound that arrives at your ears, but the acoustician and sound system designer must also be concerned about what happens to all of that reflected sound. Do we have a way to control those reflections, or will they create problems for the listeners? And that goes back to how the loudspeaker system and the room acoustics work together.

Good Reflections vs. Bad Echoes vs. Reverberation

When talking about room acoustics, it is important to understand the difference between a good reflection, a bad echo and reverberation. You may be familiar with some of the terminology, but let’s examine how those properties can impact the experience in your house of worship. We’ll look at the following: what’s the difference between a good reflection and a bad echo? What on earth is a flutter echo? When do reflections become reverberation?

Good Reflections

We’ve all done it. Well, if you’re the least bit curious about sound, you have. Maybe you have walked into a large, empty room and noticed with glee the echoes of your footsteps or voice. Or you have stood overlooking the Grand Canyon and couldn’t resist the impulse to shout out “Hello!” just to hear the echo of your voice coming back moments later. Just like in the movies. For that matter, maybe you can hear similar echoes in your own worship center!?! If a strong sound reflection arrives back at your ears more than about thirty milliseconds after the original sound source was heard, a person with a trained ear, listening analytically, is just able to perceive the reflection as a separate arrival. Double the travel time to around sixty milliseconds, and the average listener can start to pick out those reflections as separate arrivals.

Depending on how loud those reflections are, and how long it takes for them to arrive back at your ears, they can either enhance intelligibility and provide a more spacious sound character, or they can seriously degrade speech intelligibility and rhythmic music.

Many acousticians consider reflections that arrive within the first eighty milliseconds after the direct sound from the source is heard to be “good” because they can actually aid speech intelligibility.

A simple experiment bears this out. Walk into your backyard or a large open space outdoors with a friend, stand with about thirty feet between each of you, and talk to one another. See how well you can understand what’s being said. Now, go back into the house and continue the conversation. You should be able to hear each other better. It’s those “early” sound reflections off the nearby floor, walls and ceiling in the room that allow you to understand one another better. It’s when those walls are much farther away from you, such as in a large room, that the reflections can become a problem.

Problematic Echoes

Echoes can happen indoors or outdoors. Point a loudspeaker at a wall, and the sound is going to come back to you. The bigger the wall, the more of the sound that will return.

The greater the distance between your listening location and the reflecting surface, the longer it takes for that reflection to arrive at your ears, and the more noticeable the reflection becomes. Beyond about eighty milliseconds (less than 1/10th of a second) we start to consider those late-arriving reflections—those echoes—a problem.

What does all of this mean to you? Here’s an example. If your auditorium will seat approximately 800 people, then it’s likely the distance from the platform to the back wall is about 100 feet. We already know that any sound source produced on the platform, or reinforced by the main loudspeakers, is going to reflect quite solidly off the back wall.
Scientists have determined that a sound wave travels at roughly 1,130 feet per second, so we can expect the reflection to arrive back at the platform roughly 177 milliseconds later. If it’s a strong reflection, it can seriously degrade the intelligibility of what’s being said. Hearing such a strong echo arriving so late in time also can be quite distracting for the person speaking.

A sound mixer’s natural reaction to not being able to understand the spoken word is to turn up the sound volume of the person talking. But that won’t help because the loudness of the reflection comes with it, as would the reverberant sound field. The echo, in effect, becomes a noise that we would like to get rid of, but can’t. Listeners do their best to tune out the reflection by mentally focusing on the direct sound of the person speaking, yet, over time, that becomes fatiguing.

Another type of problematic reflection is the flutter echo, so-called because the time between arrivals of multiple repeating echoes is so short that one could mimic the sound by fluttering your tongue. The typical flutter echo is set up when sound is produced between two parallel walls.

Walk out into your favorite gymnasium, clap your hands and see if you can hear several rapidly repeating echoes that diminish over a short time span. Those are flutter echoes, and if you’re hearing them, that is one sign that your construction firm did a good job of building those walls perfectly parallel. It’s also a sign that you didn’t have an acoustician onboard during the design of the room, because a good acoustician would have foreseen that problem and recommended a way to mitigate those problematic echoes.

**Reverberation**

Now, if you’re really curious about sound, you’ve slammed your car door shut really hard in a large parking garage just to hear how long it takes for the sound to fade away. That, my friends, is reverberation. And it’s really nothing more than thousands of discrete echoes, having bounced off of a number of surfaces near and far, all arriving at your ears so closely spaced in time that our ear/brain system can’t distinguish the individual arrivals.

So we lump that blending of sound together and call it reverberation. The time it takes for that reverberation to fade away to where we can’t hear it anymore is called the reverb time, or decay time.

Every auditorium of any appreciable size has a reverberant field, with its own unique decay time. There’s nothing you can do to change that built-in decay of your auditorium unless you are willing to invest in a significant amount of acoustic treatment materials.

In general terms, a reverb time of about one second works well for fast-tempo songs. For slow-tempo songs, a reverb time approaching two to three seconds may be preferred. So the question is, does the decay time of the reverberant field in your auditorium help or hinder your worship music?

If your worship music style is contemporary and uses strong rhythm instruments, then a highly reverberant room and/or one with strong echoes would certainly detract from the worship experience. By comparison, if your worship music style uses piano, organ and choir, then a room with a short reverb time might make the music seem dull and lifeless.

Or what about a *cappella* services where the singing and teaching may not easily co-exist in the same acoustic environment?

**Differing Perspectives on Reverberation in Today’s Houses of Worship**

Opinions abound regarding the best acoustic environment for a house of worship. It stems back to one’s point of reference. The primary discussion revolves around the preferred reverb decay time, which is different for each style of worship music, in particular the tempo of the songs.

Talk with classically trained organists who minister from a pipe organ, and they will share with you how significantly they consider the acoustics of the room to be part of the instrument. For their purposes, a room with a reverb time of two to three seconds is considered wonderful. To support the sound of the organ, the organ builder may tell the architect to provide all hard surfaces, with no sound-absorbent materials (no carpet, drapes, pew cushions, etc.) in the room.

Then go talk with seasoned sound system designers, and they will share with you how important they consider the room acoustics to be with regard to their design of the loudspeaker system. If leadership leans toward a contemporary worship music style, then the room acoustic design will lean toward a short reverb time with minimal echoes. If the style is called “blended,” then the question will be “weighed to which side, contemporary or traditional?” The reality is that we can always achieve better results by starting with a room where the acoustics are designed to match the intended program.
Notice that in each case, the design objective is a bit different. The organ builder is focused on and motivated by how a long, smooth reverberant decay is going to enhance the sound character of the organ, and they’re less concerned about achieving speech intelligibility of the spoken word. The loudspeaker system designer is focused on and motivated by achieving a high degree of speech intelligibility. That speech intelligibility is simple to achieve in a room with a short (one second) reverb time, but can be very difficult to achieve in a room with a long reverb time (greater than two seconds), and even harder if the room has strong, late-arriving echoes.

Talk with experienced worship leaders and they may share with you horror stories of the rooms they have tried to lead worship in where they had to battle the long reverb times, strong echoes, the loudspeaker system or all of the above. It seems that the bad experiences with room acoustics far outweigh the positive experiences. At least that’s how they remember them.

Regardless of whether we are dealing with problematic echoes or a reverb decay that is too long, the reality is that we can’t fix the room acoustics electronically. In the case of a strong echo off the back wall, or too long (or too short) of a reverb time, mitigating the problems means dealing with the room acoustically. It can be a complicated design task—a blend of art and science—and the cost of the investment can be quite significant. So your acoustician is in the best position to choose the right solution to achieve the results you’re looking for. Following his or her advice will save you money, time and heartache in the long run.

**Design Follows Function**

A common concern we find today is in houses of worship that have gone through a change in their style of worship music. It could be that the acoustic signature of their auditorium was just right for the style of music they used when the room was built. But now, many years later, their choice of music has changed and the room no longer supports that style.

Or consider a congregation that enjoys a highly rhythmic style of worship music, but they just purchased an existing church building from a congregation that embraced a music style that did not use percussive instruments. The acoustics might have been designed to support an organ and choir, and switching overnight to a set of drums and electric guitars might bring some acoustic challenges.

I suppose that no house of worship goes into a building project with any thought that their worship music style might change over time. Wouldn’t it be great if we had that much foresight? So the question to ask at that crossroad is how to make the best of the acoustic situation you find yourself in. In this case, the need is to pursue the room acoustic signature that will properly enhance the new music style.

And that goes back to the basics of designing for room acoustics. That could simply mean adding acoustic finishes that will bring the reverberation time down to the desired goal, and mitigate any issues with problematic echoes. A more significant pursuit may involve physically changing the shape of the room along with other solutions that require significant construction methods.

**What is the “Right” Acoustic Design For Your House of Worship?**

The answer is whatever works best for your programming needs. If we focus just on the metric of reverb time, then a reverb time of roughly 1.0 to 1.5 seconds will likely work very well for speech, for contemporary and even blended worship styles. If your interest is traditional with some blended worship styles, then 1.5 to 2.0 seconds may be reasonable. And for strictly traditional or liturgical services, especially where pipe organ is an element, 2.0 to 3.0 seconds will be appreciated.

Consider blanket statements regarding acoustics with a grain of salt. Narrow design philosophies are fine, but only if they line up with your acoustic needs.

Before you implement any such ideas, may I encourage you to get to know their frame of reference first before you invest real money in the solution? It is best not to assume anything, and to clearly communicate to your acoustician precisely what type of acoustic signature you want the finished room to have. That discussion happens in the “programming” meetings where you talk about the types of events and music styles you expect to engage in your worship center.

Consider blanket statements regarding acoustics with a grain of salt. Narrow design philosophies are fine, but only if they line up with your acoustic needs.
Can the Right Loudspeaker "Fix" a Bad Room?

It’s so easy to think about and talk about loudspeakers, yet forget to mention the room acoustics. You call and ask your friends at other houses of worship “So what’s your favorite loudspeaker?” They will extol the virtues of their latest discovery, but what they may not be equipped to share is that the acoustic environment where that loudspeaker is installed has a major impact on how it performs in the space, and may possibly be why it was chosen over another. In other words, it may not be appropriate for your room.

Okay, so back to reality. Let’s say that you find yourself in an auditorium with room acoustics that fight your style of worship music. Can loudspeaker technology fix that? Well, technically, no. The proper solution is to fix the room through an acoustical overhaul. But there are loudspeaker solutions that can make the situation “less worse.”

There are some very good loudspeakers on the market today. It may be that you would be pleased with any of three choices for your project. There are pros and cons to each type of loudspeaker technology, multiple variables to consider, and each application is unique.

Pattern Control Rules

The first rule of loudspeaker system design is to put the sound where the listeners are. The second rule of loudspeaker system design is to not put sound where listeners aren’t, like the ceiling, walls and so forth. So the ability of a particular loudspeaker to direct sound in a very controllable manner is important in any design. In the case of a highly reverberant room, tight pattern control is absolutely essential to the success of the system.

To deliver clear, highly intelligible speech to a room with a reverberant field that has such a long decay time, the seasoned loudspeaker system designer may use physically large-mouth horns, or they may turn to a type of loudspeaker called the line array.

The typical loudspeaker is a point-and-shoot device. We aim it at the seating area and “most” of the sound goes where we point it. Its dispersion pattern might be, for example, 60 degrees wide by 40 degrees vertical, and it is likely that we will need two or more such loudspeakers to cover all listener areas evenly.

The dispersion pattern of a typical line array is very wide in the horizontal plane (~120 degrees), yet very tight in the vertical plane (as little as 10 or 15 degrees). How does that help us in a reverberant space? The horizontal pattern ensures good coverage over a large area of listeners, and the tight vertical pattern control minimizes how much “stray” sound energy goes up into the ceiling where it would unnecessarily excite the reverberant field.

A Quiet Backdrop for Worship

One must consider all aspects of the acoustic environment to ensure an enriching worship experience, and there are many. We can create a beautiful worship center, mitigate all problematic echoes and deliver the perfect reverb time for our worship music style, but if the heating and air conditioning system serving that auditorium is noisy, it can seriously dampen the experience. If the congregation is distracted by hearing running water or buzzing lights during the service, that careful work to create a great worship environment is lost.

So the work of the acoustician should also include a study of the potential for mechanical noise as well as the need for sound isolation.

Mechanical noise includes any unwanted noise created by the heating, ventilation and air conditioning (HVAC) system. The acoustician is not responsible for designing the HVAC system. That system is typically designed by the Mechanical/Electrical/Plumbing (MEP) engineering team working with the architect. However, the acoustician can examine the mechanical engineer’s design, calculate the estimated noise a listener in the auditorium will experience based on that design, and then offer recommendations for adjustments to the design that can decrease the noise heard in the auditorium.
Mechanical noise can be measured, and, in fact, there are some generally accepted criteria for how much mechanical noise is considered acceptable. One commonly adopted practice is to use what is known as the Noise Criteria. It is a method of evaluating the background noise in a room that takes the discussion beyond the subjective and lets you know that the design and the installation of the HVAC system have been done properly.

Scenario 1: Let’s say your HVAC system designer has agreed to design the system so that, while operating, it will be “quiet.” Opening day arrives, you hear the HVAC system in operation and it seems loud to you. It may well be loud, but that’s purely subjective. As long as the system is heating or cooling the air in the room as required, you have little recourse (other than spending more money) to have the noise performance of the system corrected to your liking.

Scenario 2: Let’s say that during the design phase, you have communicated to the HVAC system designer that the system must meet a Noise Criteria of, e.g., NC25 while operating. The system designer and installer have agreed in writing to meet that specification. Now, on opening day, if the HVAC system seems loud to you, we can simply reach for a high-quality sound-level meter and record the noise performance of the system over a range of frequencies to determine if it meets the NC25 specification. No more speculation, no more subjective terms. It either meets the criteria or doesn’t.

At an NC25, the average listener will barely know the HVAC system is even turned on. That is very quiet. The noise criteria goal for a high-quality recording studio might be on the order of NC15. The lower the number, the more costly the HVAC system will be.

I’ve heard and personally measured Noise Criteria in worship spaces as high as NC70, so loud that the HVAC system should be turned off during the presenter’s message just to understand what he was saying. It’s not that the sound system couldn’t get louder than the noise, but who wants to listen to a low-frequency roar in the background while trying to focus on the message being shared? In the project I’m thinking about here, the building funds were limited and no requirements were placed on the HVAC company. As a result, the air temperature in the room is quite comfortable, but the noise performance is horrendous. Fixing that now would be prohibitively expensive.

Another element to factor into the acoustic design of an auditorium is the potential need for sound isolation. Such a study looks at the proposed construction of the walls, floors and ceilings to determine if the sound isolation between rooms in the facility is adequate. The primary focus is generally on the main auditorium, with particular attention paid to rooms along the perimeter of the worship center.

A sound isolation study also considers the potential for problems of sound spilling from the building out into the surrounding outside areas (especially important if your auditorium is situated in a residential neighborhood), and it considers the potential for outdoor sounds (rain, truck traffic, airplanes, etc.) being heard inside the facility.

Sometimes the techniques for improving sound isolation involve simple adjustments to the floor plan, like moving an entrance further down the corridor. More often, they involve serious construction techniques. Delivering an HVAC system that runs efficiently and yet quietly certainly adds to its cost, as do construction techniques that deliver useful sound isolation between spaces. To some, those techniques might seem like an unnecessary expense. But that is only when they aren’t factored into the original base-building budget estimates for the project. Clearly, in the long run, both will be greatly appreciated for their contribution to an enriching worship experience.

One should keep such things in mind and also know that a seasoned acoustician can help take care of this, and ensure all factors are addressed at the beginning of a project, whether new construction or a renovation of an existing auditorium.

Engage the Acoustic Design of the Room Early

Isn’t it unfortunate that so many building committees leave the room acoustics to chance, or take a “wait and see” approach rather than setting aside budget for acoustic finishes? More often than not, they assume the architect has planned for room acoustic finishes in their design when typically that is not the case.

And unless someone on the project team presses the issue of room acoustics early in the conceptual design phase, the project may move forward with the committee thinking that everything is being handled, only to be disappointed when they hear their room for the first time.

We discussed this topic at some length in our previous white paper titled “Is Sound Quality Important in a House of Worship? And if So, How Do You Achieve It?” Download your free copy at http://pro.bose.com/worship.

References

Summary & Closing Comments

Your worship center provides a space in which you communicate an important message on a weekly basis. Incorporating design for the room acoustics appropriate for your style of worship music must be viewed as a base-building goal, and as important to the success of your worship services as the concrete or the steel.

Choosing a “wait and see” approach to room acoustics will only make opening day a disappointment, and will ultimately cost you more money than if you had chosen to get it right the first time. Better to delay the purchase of a few seats than to build or renovate a room that fights your every attempt to communicate that message through voice and song.

Opinions abound regarding the best acoustic environment for a house of worship. It stems back to one’s point of reference. So along the way, be careful who you believe. If you use a contemporary style of worship music, but you ask a pipe organ company to design your room acoustics, you may end up with a room that is unusable for your style of worship.

The bottom line is that including an acoustician on your design team is pivotal to the success of your project.
“The Importance of Room Acoustics for a Quality Sound System”
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To contact Bose Professional Systems Division,
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