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Introduction to Acoustics of Sound-Reinforced Performance Spaces

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Course Content

Acoustical design of performance spaces can be separated into three broad categories. These three categories are sound isolation, mechanical noise analysis, and room acoustics. The sound isolation and the mechanical noise determine the background noise level of the room.

BACKGROUND NOISE LEVELS

The background noise must be at an appropriate level for the desired use of the room. A recording studio should have lower background noise than a woodworking shop, for example. A set of curves known as Noise Criteria (NC) is the most common method used in North America to compare background noise levels. These curves specify the allowable sound pressure levels measured in octave bands. An NC rating allows the background noise spectrum to be quantified as a single number by comparing the noise spectrum to the NC curves. The closest curve that just exceeds the noise level at all frequency bands gives the single number value. The rating system accounts for the reduced sensitivity of the human ear at lower frequencies. There are NC design goals for various types of rooms; these goals are widely accepted and the information is published in a number of locations. (Army/Air Force manual, 1995: ch. 2 p. 4; Cavanaugh/Wilkes,1999: p. 38; Knudsen and Harris, 1978: p. 199). Table 1 contains a summary of some of this data.

TYPE OF SPACE	NOISE CRITERIA (NC)
Recording Studio	NC10-NC20
Cinemas	NC25-NC30
Churches	NC25-NC35
Conference Rooms, Executive Offices	NC25-NC35
General Classrooms, Libraries	NC30-NC40
Retail Shops, Restaurants	NC35-NC45
Public Lobbies, Corridors, Circulation Spaces	NC40-NC50

Table 1. Typical Noise Criteria Ranges for Various Spaces

There are two newer systems of measurement that are being used to quantify the level or “quality” of background noise. The first system is the Balanced Noise Criteria (NCB) curves and the second is the Room Criteria (RC) curves. Both of these approaches use numbers that are similar to the NC curves but add a descriptive term such as “neutral”, “rumbly” or “hissy” in order to provide a description of the frequency content of the noise. These two systems of measurement were developed during the 1980s and 1990s to further account for how people respond to the frequency content of mechanical system noise (Cavanaugh/Wilkes,1999: p. 36-37) .The NC curves were developed in the 1950s and are still commonly used since they were the standard for so many years.

There are two reasons that a lower background noise level is required in a performance space. The first reason to keep the noise level low is that a quiet environment will provide the maximum dynamic range for the program. Dynamic range is the difference in level between the loudest sounds and the softest ones. At some point the sound will become uncomfortably loud so we want to reduce the noise floor in order to make low level sounds audible. This will allow the quiet passages of speech or music to be heard as clearly as the louder passages. Maximizing the dynamic range capability allows the audience to become more immersed in the performance and to experience the wide range of sound levels that are common in real life. By comparison, a classroom environment experiences a much smaller dynamic range since audio in the classroom is typically limited to speech only.

Another reason to minimize the noise level is that the level of speech has to be maintained 25 decibels (dB) above the level of background noise or intelligibility will suffer (Davis and Davis, 1987: p. 238). A noisy space makes listening fatiguing, especially for patrons who have some amount of hearing loss. The audience has to work harder to follow the spoken word in the presentation. This effort detracts from the immersive environment that we are trying to create.

The author is reminded of an experience that occurred several times while he was involved with the commissioning of IMAX® Theatre sound systems. A group of people would make their way into the theatre while we were working and someone would make a comment to the others about how great the acoustics were and that they could easily understand spoken word that was coming from the opposite side of the theater. I believe that they felt that the room surfaces were responsible for this effect when actually it was the NC-25 or lower background noise level that enhanced their ability to hear. The room itself was acoustically dead and did little to support the speech that they were hearing from a distance.

SOUND ISOLATION

The room must be free of distractions caused by external sound sources. Noise sources could consist of aircraft flying overhead, traffic on a nearby street, or unusual noise sources such as ship horns or emergency vehicle sirens. If there is a concern that external noise sources might be an issue for our performance space, then a site noise survey should be performed at the property. This noise survey will account for the sound level, time interval between events, and frequency content of these sources. Measurements are made over a time period as the amount of noise may vary during the hours of day and night. The detailed information from the site noise survey is then used to design the exterior walls of the building. A statistical approach is used so that sounds that occur very infrequently do not drive the design to be overly conservative. The walls aren’t the only concern for sound isolation; the roof of the structure may be the weak link due to the lightweight roofs that are frequently used in modern buildings.

Conversely, the powerful sound system in our performance space can prove to be a noise source for activities in an adjacent room or even for the neighbors that live nearby. These factors must be considered in the design of the building. The best way to deal with rooms that may interfere with each other is to place non-critical buffer spaces between the two performance spaces. These buffer spaces could be hallways, restrooms, storage areas, or equipment rooms. A word of caution must be given about selecting an equipment room as a buffer space since the equipment room may prove to be a source of noise itself.

Sound isolation problems are typically most severe at the lower or bass part of the frequency range. We have all experienced the sound from a passing car with a powerful sound system or from an apartment neighbor who plays his stereo too loud. In both these cases it is only the bass frequencies that make it all the way to our ears since the higher frequencies are attenuated more easily by walls or other types of enclosures. Higher frequencies also suffer from air absorption over distances of several hundred feet or more.

In general, it takes mass or a combination of mass and airspace to block low frequency sound transmission. This is because low frequencies can induce vibration into the wall structure and that vibration is then conveyed through to the opposite side of the wall and radiated as sound into the receiving room. A requirement for a high sound transmission loss wall can be met by using a concrete construction (mass) or a double sheetrock wall construction with multiple layers of sheetrock (mass plus airspace). A further requirement when using high transmission loss walls is that flanking paths must be eliminated so that the full sound isolation potential can be achieved. A flanking path could consist of a path over the top of the wall, a route around the wall by going through the rooms to either side, or flanking under the wall by going through the floor structure. A mechanical duct that serves two rooms could also provide a flanking path around the wall. The sound would enter the register that is located in the first room and then efficiently propagate through the duct to the register in the second room where it would radiate back into free space.

Penetrations through the wall can compromise the performance as well. These penetrations could consist of a door or something less obvious such as an electrical box in the wall or a plumbing penetration that was not completely sealed during construction. Gaps around these penetrations provide much more of a flanking path than is commonly realized. A good analogy is to think about the process of using weather-strip materials to minimize energy loss. A 100 square foot brick wall would normally have a transmission loss (TL) of 40 decibels (dB) but this value would be reduced to 30 dB if there was a crack or gap equal to only .1% of the total wall area. For the 10 foot by 10 foot wall, this would equate to a gap of .03 inch in width if that gap ran all the way around the perimeter of the wall (Cavanaugh and Wilkes, 1999: p.27). To give another example, holes in a heavy metal plate that equate to a total of 13% open area would allow 97% of the sound to pass through (a TL of only 0.25 dB). (Everest, 2001: p. 167). As a final example of this type, a one inch square hole would pass the same amount of sound energy as 100 square feet of a concrete wall that is 6” thick (Army/Air Force manual, 1995: ch.6-p.4).

Doors and windows constitute an especially important subset of wall penetrations. These items are an issue because they have less mass than the surrounding wall structure and because the requirement for operability makes it more difficult to achieve an air-tight seal around the door or window. For these reasons, efforts should be made to eliminate doors and windows in critical sound walls if at all possible.

If the doors cannot be avoided, doors with high acoustical ratings are available but these doors are very expensive. It is still important that proper thresholds and gaskets are used to seal the door airtight so that the rated value of the door is not compromised. Obviously, the TL of the door and the door seal requirement must increase as the sound isolation requirement for the wall is increased.

These sound-rated doors can also be difficult to close and the seals and closures will require periodic adjustment in order to maintain performance. Another option that may be preferable is to replace the door with a vestibule or sound lock. The vestibule will often provide sufficient sound transmission loss using two standard doors, particularly if there is some spacing between the doors and the surfaces inside the vestibule are covered with sound absorbing material. For situations where access is required very infrequently, a sound rated wall hatch could be substituted for the sound rated door and would yield a considerable cost savings.

Fortunately, the door in our sample wall does not need to have the same sound rating as the wall since it makes up such a small percentage of the total wall surface. For a forty foot wall with an eleven foot ceiling that contains a 7x3 foot door and where the wall has 15 dB more transmission loss than the door, the door compromises the wall performance by only four dB instead of by the full 15 dB (Insul Sound Insulation Prediction Software).

ABSORPTIVE MATERIALS AND SOUND ISOLATION

One common misconception about wall isolation is that an absorptive material (such as an acoustical panel) can be added to a wall surface and this material will significantly reduce the amount of sound that goes through the wall. Let’s run through an example and take a look at this situation in detail. Before we start the example, it should be pointed out that we need to evaluate the sound transmission loss over the range of frequencies that can be present in the noise signal. This is typically done by looking at the transmission loss in a series of six octave bands that span the majority of the range of human hearing. The octave bands are defined so that the upper frequency of each band is twice the lower frequency of the band. The standard octave band center frequencies are 125, 250, 500, 1000, 2000, and 4000 Hertz (Hertz is the unit of measure for frequency and is abbreviated as ‘Hz’). Data from the 63 Hz band is very desirable for evaluating conditions at the lowest bass frequencies but data from this band is not always available.

For simplicity, the transmission loss of materials or constructed assemblies is often expressed as a single number called the Sound Transmission Class (STC). The transmission loss test data for the particular material or assembly is fitted to standardized curves in order to determine the STC rating. The standardized curves are weighted to favor the frequency range between 500 and 2000 Hz. This range contains the majority of the sound energy that is found in speech so the STC rating is a good metric for comparing speech privacy. The STC rating does not account for the lower frequencies that are quite pronounced in music and therefore care must be taken when evaluating structures that will be exposed to music energy. Two construction techniques that are being compared could have the same STC rating but one approach might be much better for stopping low frequency bass energy.

Table 2 lists the sound transmission loss in octave bands for a typical wall partition. If 2” thick fabric wrapped fiberglass panels are installed on one side of this wall, the transmission loss would increase by two decibels at 125 Hz and by eight decibels at 4000 Hz (Everest, 2001: p. 169). This sound reduction compares to the values of 17 decibels and 44 decibels from the Table for the wall construction itself. As can be seen, the addition of the fiberglass panel adds only minimal improvement to the transmission loss of the wall at the low frequencies where the TL is most needed.

FREQUENCY	TRANSMISSION LOSS (dB)
63	10
125	17
250	26
500	34
1000	40
2000	46
4000	44
8000	48

Table 2- Transmission loss in octave bands for a wall assembly that consists of a single layer of ½” sheetrock on either side of 2”x4” wood studs on 16” centers.

The transmission loss values for the acoustical panels also assume 100% coverage of the wall, a scenario that is not practical in most situations. The panels would need to extend from floor to ceiling without any air gaps at the many panel boundaries. It would be very labor intensive to achieve this level of finish around all the items that would break up the wall surface. Also, the acoustical panels would be mounted in locations where they would experience a great deal of wear over time. By comparison, the addition of an extra layer of sheetrock to one side of the wall would improve the transmission loss by almost 5 dB at 125 Hz and by 4 dB at 4000 Hz as shown in Figure

1 (Insul Sound Insulation Prediction Software). Also, this layer of sheetrock can be sealed airtight much more easily than the wall covering of fabric-wrapped panels. The additional sheetrock approach is practical, is more effective at low frequencies, can be scaled to some extent, and is lower in cost than the acoustical panels.

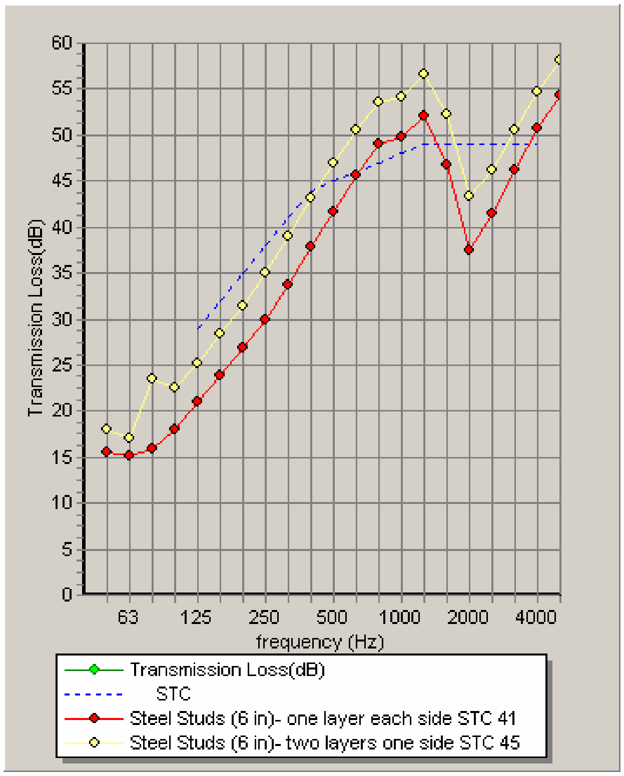

Figure 1- Improvement in Sound Transmission Loss when a second layer of 5/8" sheetrock is applied to one side of a wall assembly built from six inch studs (Insul software).

Adding absorptive material to the outside of the wall does provide a couple of benefits that we haven't examined yet. On the side of the wall where the noise source is located, a significant amount of absorption in the room will reduce the overall sound level in the source room. This occurs because some of the sound energy is absorbed as the sound impacts wall surfaces as it bounces around the room. The result is that a lower level of sound energy actually makes it to the wall in question. The amount of acoustical treatment must be substantial in order to achieve this effect and it needs to be attached to multiple wall surfaces.

On the receiver side of the wall, a large amount of absorption on the wall surfaces will not significantly reduce the sound energy coming through the wall but it will reduce the sound volume in the receiving room as the listener moves farther away from the wall. This occurs because the level of direct sound drops with distance as the listener moves further away from the wall just as it would for sound experienced in an outdoor environment. The difference in the indoor case is that the reflected (reverberant) sound is also present so that the level drop is less pronounced than it would be outdoors. The reverberant sound level is constant throughout the room so the reverberant component begins to dominate as the measurement point moves further away from the wall. The level of the reflected sound can be reduced by the absorption that is present on the wall surfaces in the room. The result of adding absorptive treatment is that the noise level is reduced as the listener moves further away from the wall in question.

Another way to look at this is to say that the sound energy will have multiple encounters with the distributed absorptive surfaces in a short amount of time as it reflects around the room. If we only look at the sound traveling through the wall that has an acoustical panel mounted on the outside then the sound only makes one pass through the panel.

Another option on the use of absorptive material is to place the absorptive material inside the wall cavity as shown in Figure 2. This approach will have a greater effect on the wall isolation than applying the absorptive material to the outside of the wall. The treatment inside the wall is more effective because some of the sound is reflected back and forth between the two inner surfaces and this effect causes the sound to make multiple passes through the absorptive material. The wall treatment also dampens the vibrations and resonance that may be present in the wall construction. A sheetrock wall normally has a resonant frequency due to the flexing of the sheetrock between the studs and the ensuing compression of the airspace inside the cavity. The fiberglass in the cavity reduces the resonance and broadens the frequency content.

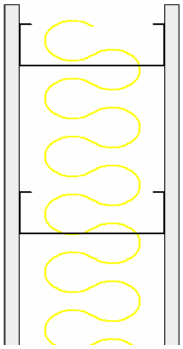

Figure 2- Fiberglass Batts Lining the Wall Cavity

For wall constructions where staggered studs or double studs are used to decouple the two sides (leaves) of the wall, the addition of absorptive material in the cavity can improve the STC value of the wall by ten to fifteen decibels (Everest, 2001: p. 173). The effect is less pronounced for a wall where the two leaves are rigidly connected. Timber studs are not as flexible as light gauge metal studs so single wall assemblies fabricated from light weight metal studs would benefit more from absorptive material in the cavity. In either case however, the batts of absorptive material are low enough in cost that a significant “bang for the buck” is achieved. It should be noted that the absorptive batt should be suspended loosely in the cavity so that it does not compact and “bridge” or couple the two sides of the wall together.

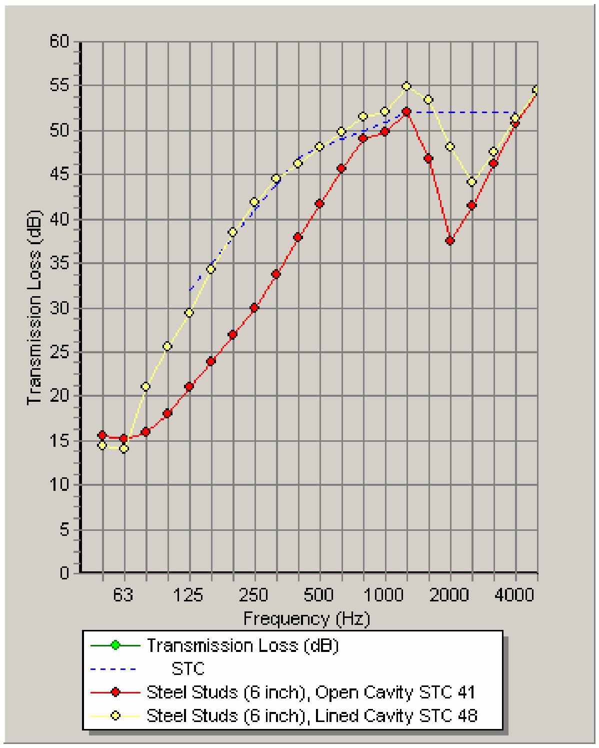

Figure 3- Comparison of Sound Transmission Loss for a Sheetrock Wall With and Without Cavity Fill.

Figure 3 is a graph from the Insul sound transmission loss software that shows a 7 dB increase in the STC rating when fiberglass is added to the cavity of a wall that is built from six inch steel studs with a single layer of 5/8” sheetrock on either side. As can be seen from the graph, the cavity fill improves the performance over a wide range of frequencies.

MECHANICAL SYSTEMS NOISE

The HVAC mechanical systems are frequently a source of noise in performance spaces. These systems produce a range of sounds that are a distraction to the presentation. The low frequency rumble will also mask the detail of higher frequency sounds that are part of the presentation with a resulting loss of impact and speech intelligibility.

There are four paths that allow noise to propagate from the mechanical equipment to the performance space. These four paths are duct propagation, duct breakout, direct path from the unit, and structure vibration. Duct propagation is the most obvious path as noise just travels straight down the duct and goes out through the register at the end.

This mode of noise is attacked by using absorptive lining inside the duct, typically 1” to 2” in thickness depending on the size of the duct. Eliminating the register will help as well by reducing register turbulence and by allowing a useful effect called end reflection loss to occur (Army/Air Force manual, 1995: ch. 7 p. 5).

The second source of noise coupling is duct breakout. Since the duct is composed of lightweight sheet metal, the noise can escape directly through the sides of the duct into the performance space. Rectangular ductwork is more susceptible to this effect than is spiral ductwork since the rectangular ductwork is less rigid. The main problem with the breakout effect is that the noise escapes from the duct before the absorptive lining has a chance to attenuate it. Breakout noise can be addressed by encasing the duct in sheetrock or by wrapping it with a multilayer lagging material. Commercially available lagging material combines an absorptive layer with a heavy mass layer such as a loaded vinyl material. Another very effective technique is to route the ductwork through a non-critical space before it enters the performance space. The breakout is then allowed to occur naturally within the non-critical space.

The third source of noise coupling is the direct sound that propagates out through the sides of the mechanical equipment itself. This noise is known as casing noise. The sound transmission loss of the structure that separates the mechanical equipment from the performance space will determine the level of noise that reaches the audience. Casing noise can be an issue when mechanical rooms are located adjacent to a performance space or perhaps most critically when large mechanical units are located above a lightweight roof system.

The fourth source of noise coupling is vibration. In this process, vibration from the mechanical equipment is coupled into the metal structure of the building. Sound travels much more efficiently in metal than it does in air so this sound vibration can easily travel through the structure into the performance space where it is radiated back into the air by a wall surface. Vibration noise is typically a problem at the lowest audible frequencies. The locations in a building that are most susceptible to induced vibration from mechanical equipment are places where the potential deflection of the structure is highest. Therefore, the practice of placing mechanical units over large performance spaces where the roof is supported by long span beams should be avoided. It may also be necessary to decouple indoor mechanical equipment (pumps and compressors) from structure, especially when the equipment is not located on the ground floor of the building.

All four modes of noise coupling can be reduced by placing the mechanical equipment in non-critical areas that are separated from the performance space. This distance allows for longer ductwork with more attenuation. The section of ductwork that is closest to the equipment and therefore has the highest potential for breakout noise is now outside of the performance space. Walls and buffer spaces allow the casing noise to be attenuated. Finally, the mechanical equipment is placed in an area where it is not supported by the longer span beams that are prone to the higher deflections.

One of the most common examples where mechanical noise becomes an issue is in the case of a rooftop unit (RTU) located over a performance space. The unit is supported on long span beams so vibration coupling is a concern. The casing noise from the unit will also propagate down through the roof directly into the performance space. The lightweight roof constructions that are very common today provide little attenuation for this casing noise. The RTU is bottom-discharge so the ductwork goes straight down through the roof. The high noise energy in this first section of ductwork is then free to breakout through the sides of the duct right into the performance space. Also, the runs to the supply and return registers are relatively short so the duct attenuation may not be adequate to attenuate the fan noise to acceptable levels before it escapes through the register.

Methods to address noise generated by an RTU that has been placed over a performance space do exist but these methods must be applied carefully during design and construction as there is little margin for error. The unit can be placed on spring isolators that have enough deflection to prevent the vibration from being introduced into the structure. Mass can be added to the roof in the vicinity of the RTU to provide increased sound transmission loss for the casing noise. The unit can be ordered in a side discharge version so that the first section of ductwork (where breakout noise is most critical) is now above the roof. If the length of the ductwork will not provide adequate absorption to handle the propagation noise then a silencer (similar to a muffler) or plenum box with thick absorption can be added to the ductwork above the roof.

In conclusion, placing the mechanical units in a less critical space away from the performance space will probably increase the cost of the ductwork but the cost and complexity of the noise mitigation measures is reduced. Another disadvantage of implementing the complex noise mitigation techniques is that the construction process must be carefully monitored as the mitigating elements can be rendered ineffective or bypassed in a variety of ways.

Another common scenario that is often encountered in performance spaces is the desire to use a fabric ducting system. DuctSox Corporation is one manufacturer of such a system. There are two main concerns with the use of this type of air distribution system. The first concern is that the duct will tend to move and even bounce on the suspension system as it inflates. The movement creates a significant amount of distracting sound energy. This undesirable situation can be easily avoided however by maintaining the duct in a constant state of pressurization by running the fan continuously while events are taking place in the room.

The second area of concern is the amount of sound energy that is propagating down the duct. The duct itself is typically not a source of noise if the duct is properly selected and operated within the range of velocities for which it is intended. The problem occurs due to noise sources that are farther upstream in the system. Standard rectangular or round ductwork will contain the equipment noise and provide some amount of absorption as the air propagates down the duct. This absorption is the last line of defense before the noise is released into the room itself. In the case of the fabric duct, this last sound mitigating element is not available. As soon as the air enters the fabric duct within the room, any noise that is present escapes out through the sides of the duct. All of the necessary attenuation must occur outside of the performance space itself. While it is certainly practical to do this, the margin for error has been reduced and systems that have not been specifically engineered for low noise performance may give undesirable results. It is not uncommon for rooms with fabric ductwork to have an undesirable amount of noise that noticeably originates on the side of the room where the mechanical equipment is located.

ROOM ACOUSTICS OF CLASSICAL PERFORMANCE SPACES (NATURAL SOUND)

Up to this point in our study, the acoustical criteria that we have covered could be optimized in much the same way for a classical performance space or for a performance space where a sound reinforcement system is used. In the classical space, the good sound isolation and quiet mechanical system keep the noise floor low in order to achieve the maximum benefit from the limited energy of the sound source. The low noise floor allows every detail of a quiet passage in the program to be heard without any distractions. In the electronic space, the low noise floor determines one end of the dynamic range and provides for the same enjoyment of quiet passages as in the classical space. In addition, the good sound isolation prevents other spaces from receiving unwelcome sounds during the loud passages that the sound reinforcement system is capable of recreating.

As we begin to look at the interior acoustics of the room and how to optimize the experience for the audience, the requirements will start to differ between the classical space and the amplified space. In classical acoustical design, the room surfaces are part of the transmission system used to convey or “funnel” the sound from the stage to the listeners. There is no acoustical separation between the stage and the house so that unity of experience (sound level and tone) from seat to seat is achieved by a total lack of separation (McCarthy, 2007: p. 185). The application could be for acoustical instruments on the stage of a symphony hall or for a presenter in a lecture room at a university. In the classical approach, the walls and ceiling are positioned, angled, and constructed from materials that will allow the sound to be directed to specific seats. The ceiling is often broken into segments from front to back that are built at different angles so that sound is directed towards the back of the seating area or balcony. These techniques are used primarily because the power of the sound source is limited. The acoustical reflections supplement the direct sound at any seat to increase the sound level and therefore produce a feeling of intimacy with the performers.

The room must be carefully designed however as these reflections can go from beneficial to detrimental as the time delay and reflection strength increases. The room surfaces can be used to reinforce speech in medium sized rooms such as lecture halls if the time delay and level of each specific reflection is carefully controlled to fall within a relatively narrow window. Larger spaces such as concert halls and arenas do not support speech well. It is for this reason that a liturgical worship style was developed during the Middle Ages for use in the gothic cathedrals where speech intelligibility was low.

The room is such an active part of the sound transmission process that it has a big part in defining the sound (McCarthy, 2007: p. 185). Since this is the case, the design of the room becomes very application specific for a particular kind of music or performance. The large spaces that are used for symphonic performance utilize wall reflections to provide ambiance and directionality to the sound in addition to the benefit of increased sound level. The key to the approach is to make the reflection pattern so dense that individual reflections won't stand out or be perceived as distortion by the listeners. One cause of distortion is a cancellation/addition effect between the direct and reflected signals called comb filtering. Dense comb filtering patterns caused by multiple reflections smooth out the sound when music is the source. The comb filtering hurts speech intelligibility since the comb filtering confuses our ear/brain system as it tries to distinguish individual consonant and vowel sounds (McCarthy, 2007: p. 194). A performance space that is good for symphonic music is not good for speech.

One further concern with these reflection patterns is the potential for the tone of the sound to be tilted or colored towards the low or high end of the frequency spectrum by the reflections. The wall surfaces that are generating these reflections must exhibit the same amount of reflectivity across the frequency spectrum. For example, a wall surface that was covered with carpet or a thin acoustical panel would absorb sound at high frequencies but not at midrange or low frequencies. In the same way, it is necessary in the design of symphony halls to make sure that the wall surfaces are rigid so that they do not absorb too much of the low frequency sound. Wood paneling on the walls will vibrate and absorb sound at low frequencies while it will provide useful reflections at high frequencies. The frequency response of the reflection will be modified so that the resulting final sound summation at the listener seat has less low frequency content. A majority of the audience members would then say that the room lacks warmth. Therefore, it is necessary to make sure that this type of thin material is not used in symphony halls.

Although reflections at appropriate time delays are extremely desirable in the natural sound environment, these reflections do provide an opportunity for an effect known as acoustical glare. This effect occurs when strong high frequency reflections occur from flat, smooth surfaces and gives the sound a brittle or harsh quality. The acoustical glare is addressed by adding fine irregularities to the surfaces or curving them so that the high frequencies are dispersed over a wider area. Older buildings avoided this problem with ornate carvings or plaster ornamentation. (Beranek, 1996: p. 24).

The acoustics of symphony halls have been studied in detail and a variety of metrics have been developed that allow the acoustical performance of a particular room design to be evaluated. These metrics correlate well with subjective listener tests that have been conducted in the finished spaces. The classic text in this field is Concert and Opera Halls: How They Sound by Leo Beranek. This book evaluates the performance criteria for 80 existing concert halls and opera houses in a variety of locations around the world.

ROOM ACOUSTICS OF ELECTRONIC REINFORCED SPACES (AMPLIFIED SOUND)

By contrast, a room with a good Public Address (PA) system has the capability to produce an amount of sound energy that can seem almost unlimited. Reflections to support this direct energy are not required. In these systems, multiple loudspeaker locations are utilized so that each listener can be close to a loudspeaker which will provide direct sound energy to that seat. The speakers provide controlled coverage to localized isolated zones of the audience and stage. The unity of experience (sound level and tone) from seat to seat is achieved by an abundance of separation or isolation between the unmatched speaker zones. Strong reflections from room surfaces compromise this isolation (McCarthy, 2007: p. 186). Multiple microphones are used to capture the individual sound sources so that the sound sources are isolated. Transmission support by the room is an optional ambiance enhancement only and must be used carefully since it can’t be turned off.

In a room that uses natural sound reinforcement only, the sources (instruments) are spread out over the stage. Therefore, a selected room surface has a somewhat different geometric relationship to each individual sound source. The sound that reflects from that surface spreads out over a section of the room with the sound from different instruments going to different seats. A different pattern exists for a second wall surface and so forth. For a room with a sound system, a loudspeaker acts as a point source for all of these individual sound sources. Therefore, the reflection will focus to a smaller area than for the case where the sound sources are spread out. The loudspeaker is also more directional than the musical instrument and this concentrates the sound further. This concentration of the reflection increases the sound level to the point where it may cause disruptive interference (McCarthy, 2007: p. 195). These strong reflections can be very damaging to imaging and frequency response.

Within the natural sound scenario, another facet of the reflection that is generated from the widely spread multiple sound sources is that a particular seat may be positioned so that it only receives the reflection for one instrument from our wall surface in question. The reflection may distort the one instrument but the sound from the other instruments is not affected (McCarthy, 2007: p. 195). If the reflection contains multiple instruments then the sound from each instrument has a slightly different distortion which results in a less audible effect to the listener. The point source loudspeaker sound that reflects from a wall surface would produce a more similar distortion for each instrument.

Another primary reason that reflective surfaces cause problems in a room with a PA system is that the open microphones multiply the number of reflections that occur. Assume a system with one loudspeaker. One set of reflections from room surfaces is generated by the direct sound coming from the instruments on the stage. A second set of reflections is generated from the signal that is received at the first microphone on the stage and then propagates through the electronics and loudspeaker chain. A third set of reflections is generated from the off-axis loudspeaker sound that bleeds back into this open microphone (if the signal becomes too great in level then feedback results). A fourth set of reflections is generated from a second microphone on the stage that is picking up the direct sound from the instruments. As a side note, this last set of reflections is the reason why it is preferable to physically space these two microphones or isolate them as otherwise they can pick up the same instrument but with a difference in time and timbre. The summation of the signals from the two microphones then results in additions and cancellations that cause distortion. A fifth set of reflections is generated by the off-axis loudspeaker sound that bleeds back into this second microphone.

Next we add a second loudspeaker and a new set of reflections are generated from this second speaker position plus this second loudspeaker bleeds black into the open microphones as well. Typically more than two loudspeakers are required for adequate coverage and to add stereo imaging so the reflections continue to increase well beyond what would be experienced in a situation with natural acoustical reinforcement only. The open microphones in the amplified sound scenario serve as multipliers of the room reflection pattern. This compares to a room with natural acoustics where the quantity of reflections increases by addition only (McCarthy, 2007: p. 190). We haven’t considered monitor loudspeakers on stage but these devices add to the reflection summation as well. All of the additional reflections increase the level of the reverberation and give the impression that the acoustics of the room are much livelier than they really are. This impression becomes more pronounced as the sound system approaches feedback.

Another way to describe the situation is that the sound energy coming from the speakers in the amplified system already contains multiple summations (reflections) due to the multiple open mics and open sources (loudspeakers/monitors). Each reflection from a wall surface will therefore consist of multiple secondary and higher order reflections as compared to the single source energy from the stage impacting the wall in the natural reinforcement situation. These reflections have built-in time delays due to the spacing of the loudspeakers and microphones in the room. The additional delay created by the time to traverse the increased path length from the reflective surface to the listener seat (as compared to the path of the direct sound) can lead to total time delays that are long enough to be disruptive and to create an echo or sonic coloration.

As you can see, instead of connecting the stage to the audience as in the case of a passive room, the wall surfaces should be disconnected from the process in order to allow the direct sound from the loudspeakers to reach the listeners. “Since the amplified sound model will have additional sources, it must decrease the role of the room in proportion to the other summation avenues.” Any desired reverberation can then be added electronically in a controlled manner (McCarthy, 1995: p. 186-187). Turning the speaker level up increases the quantity of reflections that are above the noise floor. It also increases the level of undesired sound energy that bleeds back into the microphones.

The loudspeaker system can be designed to attempt to keep the sound off the walls in order to minimize the reflections. This approach is typically followed as much as possible although the primary design goal has to be to provide direct sound to every seat in order to maintain intelligibility. Horn-loaded loudspeakers provide for pattern control at high frequencies but pattern control is difficult to provide at low frequencies. The lowest frequencies are radiated in an omni-directional manner which results in low frequency sound energy impacting more of the room surfaces as a consequence.

Even with pattern control, it is difficult to keep sound from impacting the rear wall of the room. This is due to the way that the loudspeakers have to be aimed in order to minimize the variation in sound level across the seating area. The center of the loudspeaker pattern is typically aimed to the back row of seats as this directs the highest energy output of the speaker towards the seats where the volume will be lowest due to the distance. The system designer will balance the decreasing distance from the loudspeaker as we move forward in the room with the reduced output of the loudspeaker as we move below center axis of the horn pattern. The unfortunate side effect is that the top “half” of the loudspeaker pattern is not used to cover the audience but is instead directed at the back wall of the room.

Rear wall reflections are very detrimental as they focus sound energy back to the front of the room with a considerable time delay. These reflections are distracting for the audience in the front row and even more so for the presenters on the stage. The reflection begins to be perceived as an echo as the time delay increases. Side wall reflections are less problematic in comparison because the path lengths and therefore time delays are shorter. Some side wall reflections will harmlessly reach an absorptive back wall without impacting any audience seats, depending on the reflection geometry. A side wall reflection cannot be directed back to the stage without impacting other room surfaces first.

Another aspect of the sound and the way that it interacts with the room is the beat of the music. Rock music has a faster beat than symphonic or organ music. The sound energy of each beat must be allowed to decay or drop down to a low level before the next beat comes along. If a room allows a high number of reflections then the resulting dispersion in sound energy over time will not allow the sound to decay sufficiently before the next beat comes along. This effect reduces the definition of the musical notes and prevents lower level notes from being heard at all (Beranek, 1996: p. 33).

Providing enough low frequency absorption to allow the sound level to decay between beats can be problematic. There is a large amount of low frequency energy in the room due to the multiple loudspeakers that are radiating energy in a nearly omni-directional manner. The surface materials in the room that have absorptive properties at midrange frequencies are generally not thick enough to provide any significant absorption at these low frequencies. Carpet is a prime example of this type of material. Even with a thick pad behind the carpet, low frequency absorption is not provided. Draperies and acoustical ceiling tiles are other materials that provide high frequency absorption but not low frequency absorption. By contrast, a sheetrock wall would have minimal absorption at most frequencies. The sheetrock wall will begin to provide absorption at the lowest subbass frequencies due to vibration of the panels between the studs. This effect is known as diaphragmatic absorption. Most of the bass region falls between where the thin absorptive materials stop working and the diaphragmatic absorption begins. The result is that the sound in the room takes on a “boomy” quality due to the lack of low frequency absorption.

Acoustical panels or other specialty materials and techniques are required to provide this needed low frequency absorption. Even two inch thick acoustical panels have limited absorption at the lower end of this frequency range. Many rooms have high frequency absorption that is more than adequate but the low frequency absorption is not sufficient. This can lead to a room that is “dry” but still has the boomy characteristic.

This dry/boomy quality to the acoustics that is experienced in many performance spaces has given absorptive materials a bad name in the mind of many who do not totally understand the complete picture of how they should be utilized.

Specific treatment strategies and arrangement of materials to control reflections is beyond the scope of this course. The best solution can seem to be a mixture of art and science at times and is an area where research and development continues. There are other concerns that will come into play in many situations and will affect the solution chosen. These other concerns are aesthetics, budget, building codes, coordination with other building systems, and reinforcement of congregational singing in worship facilities.

Finally, what if the performance space will be used for both natural sound events and amplified sound events? The first thought might be to compromise the two approaches but this philosophy did not work well for a number of performance halls that were designed in the 1960s and 1970s. Many of these performance halls have been modified or demolished since the result was not satisfactory. If half the reflections are removed then the classical events aren't supported as well and the amplified events still have far too many reflections (McCarthy, 1995: p. 198). An interesting analogy could be made with the multi-purpose football/baseball stadiums that were constructed in this same time period. All of those stadiums have been replaced with newer facilities that are designed specifically for baseball or football. Another approach to making the acoustics work in multi-purpose performance spaces is discussed in the new developments section below.

NEW DEVELOPMENTS

Acoustical modeling programs are available that allow the generation and analysis of a room model on the computer. In this case, statistical parameters can be calculated. Also, individual patterns of reflections can be viewed and analyzed. EASE Software© is an example of this type of program. These programs continue to develop in sophistication and accuracy. They are also capable of taking a sound source file and generating an auralization of what a listener would hear when seated at a specific seat in that room model. Headphones are used to listen to the auralization so that the listening room does not affect the output of the room model.

Another new area of development is systems that provide artificial reverberation in a room. Until recently, variable acoustics had to be achieved by a complex and expensive system of rotating panels or moving drapes. With the new electronic systems, a set of supplemental loudspeakers is provided in addition to the main PA system that is still included in the room. The room is constructed to be very absorptive. Small loudspeakers are then placed at many locations on each wall surface and on the ceiling. The loudspeakers could be hidden by a scrim. Audio from the sound source is then fed to each of these loudspeakers with appropriate processing and delay to generate the feel of reflections from these surfaces. The result is that any desired acoustical signature for the room can be generated and this acoustical signature can be adjusted electronically at a moment's notice. The term "electronic architecture" has been used to describe these systems. The systems are effective but are still very expensive. They are applied most typically to rooms that must have the ability to vary the acoustics to support a wide variety of events. One such system is the Constellation system manufactured by Meyer Sound.

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