The *Audio Cyclopedia* defines *acoustics* as “a science dealing with the production, effects and transmission of sound waves; the transmission of sound waves through various mediums, including reflection, refraction, diffraction, absorption and interference; the characteristics of auditoriums, theaters and studios, as well as their design.” We can see from this description that the proper acoustic design of music recording, project and audio-for-visual or broadcast studios is often no simple matter. A wide range of complex variables and interrelationships often come into play in the creation of a successful acoustic and monitoring design. When designing or redesigning an acoustic space, the following basic requirements should be considered:

- **Acoustic isolation**: This prevents external noises from transmitting into the studio environment through the air, ground or building structure. It can also prevent feuds that can arise when excessive volume levels leak out into the surrounding neighborhood.

- **Frequency balance**: The frequency components of a room shouldn’t adversely affect the acoustic balance of instruments and/or speakers. Simply stated, the acoustic environment shouldn’t alter the sound quality of the original or recorded performance.

- **Acoustic separation**: The acoustic environment should not interfere with intelligibility and should offer the highest possible degree of acoustic separation within the room (often a requirement for ensuring that sounds from one instrument aren’t unduly picked up by another instrument’s microphone).

- **Reverberation**: The control of sonic reflections within a space is an important factor for maximizing the intelligibility of music and speech. No matter how short the early reflections and reverb times are, they will add an important psychoacoustic sense of “space” in the sense that they can give our brain subconscious cues as to a room’s size, number of reflective boundaries, distance between the source and listener, and so forth.

- **Cost factors**: Not the least of all design and construction factors is cost. Multi-million-dollar facilities often employ studio designers and construction
teams to create a plush decor that’s been acoustically tuned to fit the needs of both the owners and their clients. Owners of project studios and budget-minded production facilities, however, can all take full advantage of the same basic acoustic principles and construction techniques and apply them in cost-effective ways.

This chapter will discuss many of the basic acoustic principles and construction techniques that should be considered in the design of a music or sound production facility. I’d like to emphasize that any or all of these acoustical topics can be applied to any type of audio production facility and aren’t only limited to professional music studio designs. For example, owners of modest project and bedroom studios should know the importance of designing a control room that’s symmetrical and hopefully feels and sounds good. It doesn’t cost anything to know that if one speaker is in a corner and the other is on a wall, the perceived center image and frequency balance will be screwy. As with many techno-artistic endeavors, studio acoustics and design are a mixture of fundamental physics (in this case, mostly dimensional mathematics) with an equally large dose of common sense and dumb luck. More often than not, acoustics is an artistic science that melds physics with the art of intuition and experience.

**STUDIO TYPES**

Although the acoustical fundamentals are the same for most studio design types, differences will often follow the form, function and budgets required by the tasks at hand. Some of the more common studio types include:

- Professional music studios
- Audio-for-visual production environments
- Audio-for-gaming production environments
- Project studios

**The Professional Recording Studio**

The *professional recording studio* (Figure 3.1) is first and foremost a commercial business, so its design, decor and acoustical construction requirements are often much more demanding than those of a privately owned project studio. In some cases, an acoustical designer and experienced construction team are placed in charge of the overall building phase of a professional facility. In others, the studio’s budget is just too tight to hire such professionals, which places the studio owners and staff squarely in charge of designing and constructing the entire facility. Whether you happen to have the luxury of building a new facility from the ground up or are renovating a studio within an existing shell, you could easily benefit from a professional studio designer’s experience and skills. Such expert advice sometimes proves to be cost effective in the long run, because errors in design judgment can lead to cost overruns, lost business due to unexpected delays or the unfortunate state of living with mistakes that could have been avoided.
The Audio-for-Visual Production Environment

An audio-for-visual production facility is used for video, film post-production (often simply called “post”) and includes such facets as music recording for film or other media (scoring), score mixdown, automatic dialog replacement (ADR—the replacement of on- and off-screen dialog to visual media) and Foley (the replacement and creation of on- and off-screen sound effects). As with music studios, audio-for-visual production facilities can range from high-end facilities that can accommodate the posting needs of network video or feature film productions (Figure 3.2) to a simple, budget-minded project studio that’s equipped with video and a digital audio work station. As with the music studio, audio-for-visual construction and design techniques often span a wide range of styles and scope in order to fit the budget needs at hand.

The Audio-for-Gaming Production Environment

With the ever-increasing popularity of having the gaming experience in the home, budgets and the need for improved audio in newer game releases, production facilities have sprung up that deal exclusively with the recording and post-production aspects of game audio. These can range from high-end facilities that resemble the high-end music studio, to production houses that deal with the
day-to-day creation and programming of the hundreds of thousands of audio clips that go into a modern game. Although the production needs of audio-for-gaming is quite different from music production, the required skills and need for attention to technical detail demand a high level of skill and dedication, as a single production schedule can easily last for several months.

The Project Studio

It goes without saying that the vast majority of audio production studios fall into the project studio category. This basic definition of such a facility is open to interpretation. It’s usually intended as a personal production resource for recording music, audio-for-visual production, multimedia production, voice-overs—you name it. Project studios can range from being fully commercial in nature to smaller setups that are both personal and private (Figure 3.3). All of these possible studio types have been designed with the idea of giving artists the flexibility of making their art in a personal, off-the-clock environment that’s both cost and time effective. Of course, the design and construction considerations for creating a privately owned project studio will often differ from the design considerations for a professional music facility in two fundamental ways:

- Building constraints
- Cost
Generally, a project studio’s room (or series of rooms) is built into an artist’s home or a rented space where the construction and dimensional details are already defined. This fact (combined with inherent cost considerations) often leads the owner/artist to employ cost-effective techniques for sonically treating any deficiencies within the room. Even if the room has little or no treatment, keep in mind that a basic knowledge of acoustical physics and room design can be a valuable and cost-effective tool, as your experience, production needs and business abilities grow.

Modern-day digital audio workstations (DAWs) have squarely placed the Mac and PC in the middle of almost every pro and home project studio (Figure 3.4). In fact, in many cases, the DAW is the project studio. With the advent of self-powered speaker monitors, cost-effective microphones and hardware DAW controllers, it’s a relatively simple matter to design a powerful production system into almost any existing space.

**Figure 3.4**
Mark Needham’s production room which centers around two Raven MTX touch screen controllers. (Courtesy of Slate Pro Audio, www.slateproaudio.com)

**PRIMARY FACTORS GOVERNING STUDIO AND CONTROL ROOM ACOUSTICS**

Regardless of which type of studio facility is being designed, built and used, a number of primary concerns should be addressed in order to achieve the best possible acoustic results. In this section, we’ll take a close look at such important and relevant aspects of acoustics as:

- Acoustic isolation
- Symmetry in control room and monitoring design
- Frequency balance
- Absorption
- Reflection
- Reverberation
Although several mathematical formulas have been included in the following sections, it’s by no means necessary that you memorize or worry about them. By far, I feel that it’s more important that you grasp the basic principles of acoustics rather than worry about the underlying math. Remember: More often than not, acoustics is an artistic science that blends math with the art of intuition and experience.

**Acoustic Isolation**

Because most commercial and project studio environments make use of an acoustic space to record sound, it’s often wise and necessary to employ effective isolation techniques into their design in order to keep external noises to a minimum. Whether that noise is transmitted through the medium of air (e.g., from nearby auto, train or jet traffic) or through solids (e.g., from air-conditioner rumbling, underground subways or nearby businesses), special construction techniques will often be required to dampen these extraneous sounds (Figure 3.5).

**FIGURE 3.5**
Various isolation, absorption and reflective acoustical treatments for the construction of a recording/monitoring environment. (Courtesy of Auralex Acoustics, www.auralex.com)

If you happen to have the luxury of building a studio facility from the ground up, a great deal of thought should be put into selecting the studio’s location. If a location has considerable neighborhood noise, you might have to resort to extensive (and expensive) construction techniques that can “float” the rooms (a process that effectively isolates and decouples the inner rooms from the building’s outer foundations). If there’s absolutely no choice of studio location and the studio happens to be located next to a recycling factory, just under the airport’s main landing path or over the subway’s uptown line you’ll simply have to give in to destiny and build acoustical barriers to these outside interferences.
The reduction in the sound-pressure level (SPL) of a sound source as it passes through an acoustic barrier of a certain physical mass (Figure 3.6) is termed the transmission loss (TL) of a signal. This attenuation can be expressed (in dB) as:

$$TL = 14.5 \log M + 23$$

where TL is the transmission loss in decibels, and $M$ is the surface density (or combined surface densities) of a barrier in pounds per square foot (lb/ft$^2$).

Because transmission loss is frequency dependent, the following equation can be used to calculate transmission loss at various frequencies with some degree of accuracy:

$$TL = 14.5 \log f \quad - 16$$

where $f$ is the frequency (in hertz).

Both common sense and the preceding two equations tell us that heavier acoustic barriers will yield a higher transmission loss. For example, Table 3.1 tells us that a 12-inch-thick wall of dense concrete (yielding a surface density of 150 lb/ft$^2$) offers a much greater resistance to the transmission of sound than can a 4-inch cavity filled with sand (which yields a surface density of 32.3 lb/ft$^2$).

From the second equation ($TL = 14.5 \log f \quad - 16$), we can also draw the conclusion that, for a given acoustic barrier, transmission losses will increase as the frequency rises. This can be easily illustrated by closing the door of a car that has its sound system turned up, or by shutting a single door to a music studio’s control room. In both instances, the high frequencies will be greatly reduced in level, while the bass frequencies will be impeded to a much lesser extent. From this, the goal would seem to be to build a studio wall, floor, ceiling, window or door out of the thickest and most dense material that’s available; however, expense and physical space often play roles in determining just how much of a barrier can be built to achieve the desired isolation. As such, a balance must usually be struck when using both space- and cost-effective building materials.
WALLS
When building a studio wall or reinforcing an existing structure, the primary goal is to reduce leakage (increase the transmission loss) through a wall as much as possible over the audible frequency range. This is generally done by:

- Building a wall structure that’s as massive as is practically possible (both in terms of cubic and square foot density)
- Eliminating joints that can easily transmit sound through the barrier
- Dampening structures, so that they are well supported by reinforcement structures and are free of resonances

The following guidelines can be helpful in the construction of framed walls that have high transmission losses:

- If at all possible, the inner and outer wallboards should not be directly attached to the same wall studs. The best way to avoid this is to alternately stagger the studs along the floor and ceiling frame (i.e., framing 2 × 4 studs

### Table 3.1 Surface Densities of Common Building Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (inches)</th>
<th>Surface Density (lb/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>4</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>80.0</td>
</tr>
<tr>
<td>Concrete (lightweight)</td>
<td>4</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>100.0</td>
</tr>
<tr>
<td>Concrete (dense)</td>
<td>4</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>150.0</td>
</tr>
<tr>
<td>Glass</td>
<td>—</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>11.3</td>
</tr>
<tr>
<td>Gypsum wallboard</td>
<td>—</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>2.6</td>
</tr>
<tr>
<td>Lead</td>
<td>1/16</td>
<td>3.6</td>
</tr>
<tr>
<td>Particleboard</td>
<td>—</td>
<td>1.7</td>
</tr>
<tr>
<td>Plywood</td>
<td>—</td>
<td>2.3</td>
</tr>
<tr>
<td>Sand</td>
<td>1</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>32.3</td>
</tr>
<tr>
<td>Steel</td>
<td>—</td>
<td>10.0</td>
</tr>
<tr>
<td>Wood</td>
<td>1</td>
<td>2.4</td>
</tr>
</tbody>
</table>
onto a 2 × 6 frame), so that the front/back facing walls aren’t in physical contact with each other (Figure 3.7).

- Each wall layer should have a different density to reduce the likelihood of increased transmission due to resonant frequencies that might be sympathetic to both sides. For example, one wall might be constructed of two 5/8-inch gypsum wallboards, while the other wall might be underplayed with soft fiberboard that’s also surfaced with two 3/4-inch gypsum wallboards.
- If you’re going to attach gypsum wallboards to a single wall face, you can increase transmission loss by mounting the additional layers (not the first layer) with adhesive caulking rather than by using screws or nails.
- Spacing the studs 24 inches on center instead of using the traditional 16-inch spacing yields a slight increase in transmission loss.
- To reduce leakage that might make it through the cracks, apply a bead of non-hardening caulk sealant to the inner gypsum wallboard layer at the wall-to-floor, wall-to-ceiling and corner junctions.

Generally, the same amount of isolation is required between the studio and the control room as is required between the studio’s interior and exterior environments. The proper building of this wall is important, so that an accurate tonal balance can be heard over the control-room monitors without promoting leakage between the rooms or producing resonances within the wall that would audibly color the signal. Optionally, a specially designed cavity, called a soffit, can be designed into the front-facing wall of the control room to house the larger studio monitors. This superstructure allows the main, far field studio monitors to be mounted directly into the wall to reduce reflections and resonances in the monitoring environment.

It’s important for a soffit to be constructed to high standards, using a multiwall or high-mass design that maximizes the density with acoustically tight construction techniques in order to reduce leakage between the two rooms. Cutting corners by using substandard (and even standard) construction techniques in the building of a studio soffit can lead to unfortunate side effects, such as wall resonances, rattles, and increased leakage. Typical wall construction materials include:
- **Concrete:** This is the best and most solid material, but it is often expensive and it’s not always possible to pour cement into an existing design.

- **Bricks (hollow-form or solid):** This excellent material is often easier to place into an existing room than concrete.

- **Gypsum plasterboard:** Building multiple layers of plasterboard onto a double-walled stud frame is often the most cost- and design-efficient approach for reducing resonances and maximizing transmission loss. It’s often a good idea to reduce these resonances by filling the wall cavities with Rockwool or fiberglass, while bracing the internal structure to add an extra degree of stiffness.

Studio monitors can be designed into the soffit in a number of ways. In one expensive approach, the far-field speakers’ inner enclosure cavities are literally the walls of the control room’s front wall concrete pour. Under these conditions, resonances are completely eliminated. Another less expensive approach has the studio monitors resting on poured concrete pedestals; in this situation, inserts can be cast into the pedestals that can accept threaded rebar rods (known as all-thread). By filing the rods to a chamfer (a sharp point), it’s possible to adjust the position, slant and height of the monitors for final positioning into the soffit’s wall framing. The most common and affordable approach uses traditional wood framing in order to design a cavity into which the speaker enclosures can be designed and positioned. Extra bracing, plasterboard and heavy construction should be used to reduce resonances.

**Floors**

For many recording facilities, the isolation of floor-borne noises from room and building exteriors is an important consideration. For example, a building that’s located on a busy street and whose concrete floor is tied to the building’s ground foundation might experience severe low-frequency rumble from nearby traffic. Alternatively, a second-floor facility might experience undue leakage from a noisy downstairs neighbor or, more likely, might interfere with a quieter neighbor’s business. In each of these situations, increasing the isolation to reduce floor-borne leakage and/or transmission is essential. One of the most common ways to isolate floor-related noise is to construct a “floating” floor that’s structurally decoupled from its subfloor foundation.

Common construction methods for floating a professional facility’s floor uses either neoprene “hockey puck” isolation mounts, U-Boat floor floaters (Figure 3.8a), or a continuous underlay, such as a rubberized floor mat. In these cases, the underlay is spread over the existing floor foundation and then covered with an overlaid plywood floor structure. In more extreme situations, this superstructure could be covered with reinforcing wire mesh and finally topped with a 4-inch layer of concrete (Figure 3.8b). In either case, the isolated floor is then ready for carpeting, wood finishing, painting or any other desired surface.

An even more cost- and space-effective way to decouple a floor involves layering the original floor with a rubberized or carpet foam pad. A 1/2- or 5/8-inch layer
of tongue-and-groove plywood or oriented strand board (OSB) is then laid on top of the pad. These should not be nailed to the subfloor; instead, they can be stabilized by glue or by locking the pieces together with thin, metal braces. Another foam pad can then be laid over this structure and topped with carpeting or any other desired finishing material (Figure 3.9).

It is important that the floating superstructure be isolated from both the underflooring and the outer wall. Failing to isolate these structures allows sounds to be transmitted through the walls to the subfloor, and vice versa (often defeating the whole purpose of floating the floor). These wall perimeter isolation gaps can be sealed with pliable decoupling materials such as widths of soft mineral fiberboard, neoprene, silicone or other pliable materials.

**RISERS**

As we saw from the equation \( TL = 14.5 \log Mf - 16 \), low-frequency sound travels through barriers much more easily than does high-frequency sound. It stands to reason that strong, low-frequency energy is transmitted more easily than high-frequency energy between studio rooms, from the studio to the control room.
or to outside locations. In general, the drum set is most likely to be the biggest leakage offender. By decoupling much of a drum set’s low-frequency energy from a studio floor, many of the low-frequency leakage problems can be reduced. In most cases, the problem can be fixed by using a drum riser. Drum risers are available commercially (Figure 3.10a), or they can be easily constructed. In order to reduce unwanted resonances, drum risers should be constructed using 2 × 6-inch or 2 × 8-inch beams for both the frame and the supporting joists (spaced at 16 or 12 inches on center, as shown in Figure 3.10b). Sturdy 1/2- or 5/8-inch tongue-and-groove plywood panels should be glued to the supporting frames with carpenter’s glue (or similar wood glue) and then nailed or screwed down (using heavy-duty, galvanized fasteners). When the frame has dried, rubber coaster float channels or (at the very least) strips of carpeting should be attached to the bottom of the frame, and the riser will be ready for action.

CEILINGS

Foot traffic and other noises from above a sound studio or production room are another common source of external leakage. Ceiling noise can be isolated in a number of ways. If foot traffic is your problem and you’re fortunate enough to own the floors above you, you can reduce this noise by simply carpeting the overhead hallway or by floating the upper floor. If you don’t have that luxury, one approach to isolating ceiling-borne sounds is to hang a false structure from the existing ceiling or from the overhead joists (as is often done when a new room is being constructed). This technique can be fairly cost effective when
spring or “Z” suspension channels are used (Figure 3.11). Z channels are often screwed to the ceiling joists to provide a flexible, yet strong support to which a hanging wallboard ceiling can be attached. If necessary, fiberglass or other sound-deadening materials can be placed into the cavities between the overhead structures.

WINDOWS AND DOORS

Access to and from a studio or production room area (in the form of windows and doors) can also be a potential source of sound leakage. For this reason, strict attention needs to be given to window and door design and construction. Visibility in a studio is extremely important within a music production environment. For example, when multiple rooms are involved, good visibility serves to promote effective communication between the producer or engineer and the studio musician (as well as among the musicians themselves). For this reason, windows have been an important factor in studio design since the beginning. The design and construction details for a window often vary with studio needs and budget requirements and can range from being deep, double-plate cavities that are built into double-wall constructions (Figure 3.12) to more modest prefab designs that are built into a single wall. Other more expensive designs include floor-to-ceiling windows that create a virtual “glass wall,” as well as those impressive ones which are designed into poured concrete soffit walls.

FIGURE 3.12
Detail for a practical window construction between the control room and studio.
(a) Simplified drawing.
(b) Detailed drawing.
(Courtesy of Russ Berger Design Group, Inc., www.rbdg.com)

Access doors to and from the studio, control room, and exterior areas should be constructed of solid wood or high-quality acoustical materials (Figure 3.13a), as solid doors generally offer higher TL values than their cheaper, hollow counterparts. No matter which door type is used, the appropriate seals, weather stripping, and doorjambs should be used throughout so as to reduce leakage through the cracks. Whenever possible, double-door designs should be used to
Primary Factors

form an acoustical sound lock (Figure 3.13b). This construction technique dramatically reduces leakage because the air trapped between the two solid barriers offers up high TL values.

ISO-ROOMS AND ISO-BOOTH

Isolation rooms (iso-rooms) are acoustically isolated or sealed areas that are built into a music studio or just off of a control room (Figure 3.14). These recording areas can be used to separate louder instruments from softer ones (and vice versa) in order to reduce leakage and to separate instrument types by volume to maintain control over the overall ensemble balance. For example:

- To eliminate leakage when recording scratch vocals (a guide vocal track that’s laid down as a session reference), a vocalist might be placed in a small room while the rhythm ensemble is placed in the larger studio area.
- A piano or other instrument could be isolated from the larger area that’s housing a full string ensemble.
- Vocals could be set up in the iso-room, while drums are being laid down in the main room. The possibilities are endless.

An iso-room can be designed to have any number of acoustical properties. By having multiple rooms and/or iso-room designs in a studio, several acoustical environments can be offered that range from being more reflective (live) to
absorptive (dead), or a specific room can be designed to better fit the acoustical needs of a particular instrument (e.g., drums, piano or vocals). These rooms can be designed as totally separate areas that can be accessed from the main studio or control room, or they might be directly tied to the main studio by way of sliding walls or glass sliding doors. In short, their form and function can be put to use to fit the needs and personality of the session.

Isolation booths (iso-booths) provide the same type of isolation as an iso-room, but are often much smaller. Often called vocal booths, these mini-studios are perfect for isolating vocals and single instruments from the larger studio. In fact, rooms that have been designed and built for the express purpose of mixing down a recording will often only have an iso-booth . . . and no other recording room. Using this space-saving option, vocals or single instruments can be easily overdubbed on site, and should more space be needed a larger studio can be booked to fit the bill.

ACOUSTIC PARTITIONS

Movable acoustic partitions (also known as flats or gobos) are commonly used in studios to provide on-the-spot barriers to sound leakage. By partitioning a musician and/or instrument on one or more sides and then placing the mic inside the temporary enclosure, isolation can be greatly improved in a flexible way that can be easily changed as new situations arise. Acoustic partitions are currently available on the commercial market in various design styles and types for use in a wide range of studio applications (Figure 3.15). For those on a budget, or who have particular isolation needs, it’s relatively simple to get out the workshop tools and make your own flats that are based around wood frames, fiberglass, Rockwool or other acoustically absorptive materials—and then decorate them with your favorite fabric coverings (Figure 3.16a).

If you can’t get a flat when you need one, you can often improvise using common studio and household items. For example, a simple partition can be easily made on the spot by grabbing a mic/boom stand combination and retracting the boom halfway at a 90° angle to make a T-shape. Simply drape a

FIGURE 3.15
Acoustic partition flat examples: (a) S5–2L “Sorber” baffle system. (Courtesy of ClearSonic Mfg., Inc., www.clearsonic.com); (b) piano panel setup. (Courtesy of Auralex Acoustics, www.auralex.com)
primary factors

blanket or heavy coat over the T-bar and voilà—you’ve built a quick-’n’-dirty dividing flat (Figure 3.16b).

When using a partition, it’s important to be aware that musicians need to be able to see each other, the conductor and the producer. Musicality and human connectivity almost always take precedence over technical issues.

Noise isolation within the control room

Isolation between rooms and the great outdoors isn’t the only noise-related issue in the modern-day recording or project studio. The proliferation of computers, multitrack tape machines and cooling systems has created issues that present their own Grinch-like types of noise, Noise, NOISE! This usually manifests itself in the form of system fan noise, transport tape noise and computer-related sounds from CPUs, case fans, hard drives and the like.

When it comes to isolating tape transport and system fan sounds, budget and size constraints permitting, it’s often wise to build an iso-machine room or iso-closet that’s been specifically designed and ventilated for containing such equipment. An equipment room that has easy-access doors that provide for current/future wiring needs can add a degree of peace-’n’-quiet and an overall professionalism that will make both you and your clients happy.

Within smaller studio or project studio spaces, such a room isn’t always possible, however, with care and forethought the whizzes and whirrs of the digital era can be turned into a non-issue that you’ll be proud of. Here are a few examples of the most common problems and their solutions:

- Place the computer(s) in an isolated case, alcove or room (care needs to be taken to provide ventilation and to monitor the CPU/case temperatures so as not to harm your system).
- Connect the studio computers via a high-speed network to a remote server location.
- Replace fans with quieter ones. By doing some careful Web searching or by talking to your favorite computer salesperson, it’s often possible to install CPU and case fans that are quieter than most off-the-shelf models.
Symmetry in Control Room Design

While many professional studios are built from the ground up using standard acoustic and architectural guidelines, most budget-minded production and project studios are often limited by their own unique sets of building, space and acoustic constraints. Even though the design of a budget, project or bedroom control room might not be acoustically perfect, if speakers are to be used in the monitoring environment, certain ground rules of acoustical physics must be followed in order to create a proper listening environment.

One of the most important acoustic design rules in a monitoring environment is the need for symmetrical reflections on all axes within the design of a control room or single-room project studio. In short, the center and acoustic imaging (ability to discriminate placement and balance in a stereo or surround field) is best when the listener, speakers, walls and other acoustical boundaries are symmetrically centered about the listener’s position (often in an equilateral triangle). In a rectangular room, the best low-end response can be obtained by orienting the console and loudspeakers into the room’s long dimension (Figure 3.17a). Should space or other room considerations come into play, centering the listener/monitoring position at a 45° angle within a symmetrical corner (Figure 3.17b) is another example of how the left/right imagery can be reasonably maintained.

With regard to setting up any production/monitoring environment, I’d like to first draw your attention to the need for symmetry in any critical monitoring environment. A symmetrical acoustic environment around the central mixing axis can work wonders toward creating a balanced left/right and surround image. Fortunately, this generally isn’t a difficult goal to achieve. An acoustical and speaker placement environment that isn’t balanced between the left-hand and right-hand sides will allow for differing reflections, absorption coefficients and variations in frequency response. This can adversely affect the imaging and balance of your final mix. Further information on this important subject can be found later in this chapter, however, consider this your first heads-up on an important topic.
Should any primary boundaries of a control room (especially wall or ceiling boundaries near the mixing position) be asymmetrical from side to side, sounds heard by one ear will receive one combination of direct and reflected sounds, while the other ear will hear a different acoustic balance (Figure 3.18). This condition can drastically alter the sound’s center image characteristics, so that when a sound is actually panned between the two monitor speakers the sound will appear to be centered; however, when the sound is heard in another studio or standard listening environment the imaging may be off center. To avoid this problem, care should be taken to ensure that both the side and ceiling boundaries are largely symmetrical with respect to each other and that all of the speaker level balances are properly set.

**Figure 3.18**
Center symmetry.
(a) Placing the monitoring environment off-center and in a corner will affect the audible center image, and placing one speaker in a 90° corner can cause an off-center bass buildup and adversely affect the mix’s imagery. (b) Shifting the listener/monitoring position into the center will greatly improve the left/right imagery.

While we’re on the subject of the relationship between the room’s acoustic layout and speaker placement, it’s always wise to place near-field and all other speaker enclosures at points that are equidistant to the listener in the stereo and surround field. Whenever possible, speaker enclosures should be placed 1 to 2 feet away from the nearest wall and/or corner, which helps to avoid bass buildups that acoustically occur at boundary and corner locations. In addition to strategic speaker placement, homemade or commercially available isolation pads can be used to reduce resonances that often occur whenever enclosures are placed directly onto a table or flat surface.

**Frequency Balance**
Another important factor in room design is the need for maintaining the original frequency balance of an acoustic signal. In other words, the room should exhibit a relatively flat frequency response over the entire audio range without adding its own particular sound coloration. The most common way to control the tonal character of a room is to use materials and design techniques that govern the acoustical reflection and absorption factors.
REFLECTIONS

One of the most important characteristics of sound as it travels through air is its ability to reflect off a boundary’s surface at an angle that’s equal to (and opposite of) its original angle of incidence (Figure 3.19). Just as light bounces off a mirrored surface or multiple reflections can appear within a mirrored room, sound reflects throughout room surfaces in ways that are often amazingly complex. Through careful control of these reflections, a room can be altered to improve its frequency response and sonic character.

In Chapter 2, we learned that sonic reflections can be controlled in ways that disperse the sound outward in a wide-angled pattern (through the use of a convex surface) or focus them on a specific point (through the use of a concave surface). Other surface shapes, on the other hand, can reflect sound back at various other angles. For example, a 90º corner will reflect sound back in the same direction as its incident source (a fact that accounts for the additive acoustic buildups at various frequencies at or near a wall-to-corner or corner-to-floor intersection).

The all-time winner of the “avoid this at all possible cost” award goes to constructions that include opposing parallel walls in its design. Such conditions give rise to a phenomenon known as standing waves. Standing waves (also known as room modes) occur when sound is reflected off of parallel surfaces and travels back on its own path, thereby causing phase differences to interfere with a room’s amplitude response (Figure 3.20a). Room modes are expressed as integer multiples of the length, width and depth of the room and indicate which multiple is being referred to for a particular reflection.

Walking around a room with moderate to severe mode problems produces the sensation of increasing and/or decreasing volume levels at various frequencies throughout the area. These perceived volume changes are due to amplitude (phase) cancellations and reinforcements of the combined reflected waveforms at the listener’s position. The distance between parallel surfaces and the signal’s wavelength determines the nodal points that can potentially cause sharp peaks or dips at various points in the response curve (up to or beyond 19 dB) at the affected fundamental frequency (or frequencies) and upper harmonic intervals (Figure 3.20b). This condition exists not only for opposing parallel walls but also for all parallel surfaces (such as between the floor and ceiling or between two reflective flats). From this discussion, it’s obvious that the most effective way to prevent standing waves is to construct walls, boundaries and ceilings that are nonparallel.
Standing waves within a room. (a) Reflective parallel surfaces can potentially cancel and reinforce frequencies within the audible spectrum, causing changes in its response. (b) The reflective, parallel walls create an undue number of standing waves, which occur at various frequency intervals \( f_1, f_2, f_3, f_4, \text{and so on} \).

If the room in question is rectangular or if further sound-wave dispersion is desired, diffusers can be attached to the wall and/or ceiling boundaries to help break up standing waves. Diffusers (Figure 3.21) are acoustical boundaries that reflect the sound wave back at various angles that are wider than the original incident angle (thereby breaking up the energy-destructive standing waves). In addition, the use of both nonparallel and diffusion wall construction can reduce extreme, recurring reflections and smooth out the reverberation characteristics of a room by building more complex acoustical pathways.

**Flutter echo** (also called *slap echo*) is a condition that occurs when parallel boundaries are spaced far enough apart that the listener is able to discern a number of discrete echoes. Flutter echo often produces a “boingy,” hollow sound that greatly affects a room’s sound character as well as its frequency response. A larger room (which might contain delayed echo paths of 50 m/sec or more)
can have its echoes spaced far enough apart in time that the discrete reflections produce echoes that can actually interfere with the intelligibility of the direct sound. This will often result in a jumble of noise, and in these cases, a proper application of absorption and acoustic dispersion becomes critical.

When speaking of reflections within a studio control room, one long-held design concept relates to the concept of designing the room such that the rear of the room is largely reflective and diffuse in nature (acoustically “live”), while the front of the room is largely or partially absorptive (acoustically “dead”). This philosophy (Figure 3.22) argues for the fact that the rear of the room should be largely reflective providing for a balanced and diffuse environment that can help reinforce positive reflections which can add acoustic “life” to the mix experience (Figure 3.23). The front of the room would tend more toward the absorptive side in a way that reduces standing-waves, flutter reflections and reflections from the rear of the speakers that would interfere with the overall response of the room.
It’s important to realize that no two rooms will be acoustically the same or will necessarily offer the same design challenges. The one constant is that careful planning, solid design and ingenuity are the foundation of any good-sounding room. You should also keep in mind that numerous studio design and commercial acoustical product firms are available that offer assistance for both large and small projects. Getting professional advice can be a good thing.

**ABSORPTION**

Another factor that often has a marked effect on an acoustic space involves the use of surface materials and designs that can absorb unwanted sounds (either across the entire audible band or at specific frequencies). The absorption of acoustic energy is, effectively, the inverse of reflection (Figure 3.24). Whenever sound strikes a material, the amount of acoustic energy that’s absorbed relative to the amount that’s reflected can be expressed as a simple ratio known as the material’s absorption coefficient. For a given material, this can be represented as:

\[ A = \frac{I_a}{I_r} \]

where \( I_a \) is the sound level (in dB) that is absorbed by the surface (often dissipated in the form of physical heat), and \( I_r \) is the sound level (in dB) that is reflected back from the surface.

The factor \((1 - a)\) is a value that represents the amount of reflected sound. This makes the coefficient a decimal percentage value between 0 and 1. If we say that a surface material has an absorption coefficient of 0.25, we’re actually saying that the material absorbs 25% of the original acoustic energy and reflects 75% of the total sound energy at that frequency. A sample listing of these coefficients is provided in Table 3.2.

To determine the total amount of absorption that’s obtained by the sum of all the absorbers within a total volume area, it’s necessary to calculate the average absorption coefficient for all of the surfaces together. The average absorption coefficient \((A_{ave})\) of a room or area can be expressed as:
where \( s_1, s_2, \ldots, s_n \) are the individual surface areas; \( a_1, a_2, \ldots, a_n \) are the individual absorption coefficients of the individual surface areas, and \( S \) is the total square surface area.

On the subject of absorption, one common misconception is that the use of large amounts of sound-deadening materials will reduce room reflections and therefore make a room sound “good”. In fact, the overuse of absorption will often have the effect of reducing high frequencies, creating a skewed room response that is dull and bass-heavy, as well as reducing constructive room reflections that are important to a properly designed room. In fact, with regard
to the balance between reflection, diffusion and absorption, many designers agree that a balance of 25% absorption and 25% diffuse reflections is a good ratio that can help preserve the “life” of a room, while reducing unwanted buildups.

**High-Frequency Absorption**

The absorption of high frequencies is accomplished through the use of dense porous materials, such as fiberglass, Rockwool, dense fabric and carpeting. These materials generally exhibit high absorption values at higher frequencies, which can be used to control room reflections in a frequency-dependent manner. Specially designed foam and acoustical treatments are also commercially available that can be attached easily to recording studio, production room or control room walls as a means of taming multiple room reflections and/or dampening high-frequency reflections.

In addition to buying commercial absorbers, it’s very possible to put your handy shop tools to work by building your own cost-effective absorber panels (of any shape, depth and style). One straightforward way of making them is by using Rockwool as the basic ingredient for your homemade absorber:

1. Measure the dimensions that you’ll need to build your absorbers. Buy 1” × 4” fir boards that add up to your required dimensions (often, the hardware store will even cut them to suit your needs). You might also want to buy and measure your Rockwool bats at the same time (this might help you with determining your overall dimensions).
2. Lay the boards out on your workbench or protected table and drill pilot holes to the top and bottom frame edges, then using a 2” sheetrock or other type of screw, screw the frames together.
3. Make your measurements for the amount of fabric that you’ll want to stretch over the entire surface and around the edges, so that they stretch around the newly made box. The fabric can be of practically any type, but a nice, inexpensive fabric of your favorite color works well.
4. It always helps to iron the fabric, before mounting it, just to get the wrinkles out.
5. Before attaching the fabric, you might want to see how the Rockwool fits into each frame. If all’s ok, then begin carefully attaching the fabric to the frame with a heavy-duty staple gun, taking care that the fabric is tight, straight and looks good.
6. Once the fabric is attached and the Rockwool is inserted, it’s ready to hang in your control room/studio wall.

When done right, these absorbers (Figure 3.25) can look professional and fit your specific needs at a fraction of their commercial equivalents, sometimes with better results.
Low-Frequency Absorption

As shown in Table 3.2, materials that are absorptive in the high frequency range often provide little resistance to the low-frequency end of the spectrum (and vice versa). This occurs because low frequencies are best damped by pliable materials, meaning that low-frequency energy is absorbed by the material’s ability to bend and flex with the incident waveform (Figure 3.26). Rooms that haven’t been built to the shape and dimensions to properly handle the low end may need to be controlled in order to reduce the room’s resonance frequencies.

Another absorber type can be used to reduce low-frequency buildup at specific frequencies (and their multiples) within a room. This type of attenuation device (known as a bass trap) is available in a number of design types:

- Quarter-wavelength trap
- Pressure-zone trap
- Functional trap
- Active trap
The quarter-wavelength trap: The quarter-wavelength bass trap (Figure 3.27) is an enclosure with a depth that’s one-fourth the wavelength of the offending frequency’s fundamental frequency and is often built into the rear facing wall, ceiling or floor structure and covered by a metal grating to allow foot traffic. The physics behind the absorption of a calculated frequency (and many of the harmonics that fall above it) rests in the fact that the pressure component of a sound wave will be at its maximum at the rear boundary of the trap when the wave’s velocity component is at a minimum. At the mouth of the bass trap (which is at a one-fourth wavelength distance from this rear boundary), the overall acoustic pressure will be at its lowest, while the velocity component (molecular movement) will be at its highest potential. Because the wave’s motion (force) is greatest at the trap’s opening, much of the signal can be absorbed by placing an absorptive material at that opening point. A low-density fiberglass lining can also be placed inside the trap to increase absorption (especially at harmonic intervals of the calculated fundamental).

Pressure zone trap: The pressure-zone bass trap absorber (Figure 3.28) works on the principle that sound pressure is doubled at large boundary points that are at 90° angles (such as walls and ceilings). By placing highly absorptive material at a boundary point (or points, in the case of a corner/ceiling intersection), the built-up pressure can be partially absorbed.
Functional trap: Originally created in the 1950s by Harry F. Olson (former director of RCA Labs), the functional bass trap (Figure 3.29a) uses a material generally formed into a tube or half-tube structure that is rigidly supported so as to reduce structural vibrations. By placing these devices into corners, room boundaries or in a freestanding spot, a large portion of the undesired bass buildup frequencies can be absorbed. By placing a reflective surface over the portion of the trap that faces into the room, frequencies above 400 Hz can be dispersed back into the room or focal point.

Active trap: An active bass trap system (Figure 3.29b) makes use of a microphone, low-frequency driver and a fast acting, band-limited amplifier to effectively create an inverse pressure wave that electronically “absorbs” low-end frequencies. Such a unit is actually capable of creating an effective area of absorption that is up to 40 times greater than its actual size.

ROOM REFLECTIONS AND ACOUSTIC REVERBERATION

Another criterion for studio design is the need for a desirable room ambience and intelligibility, which is often contradictory to the need for good acoustic separation between instruments and their pickup. Each of these factors is governed by the careful control and tuning of the reverberation constants within the studio over the frequency spectrum.

Reverberation (reverb) is the persistence of a signal (in the form of reflected waves within an acoustic space) that continues after the original sound has ceased. The effect of these closely spaced and random multiple echoes give us perceptible cues as to the size, density and nature of an acoustic space. Reverb also adds to the perceived warmth and spatial depth of recorded sound and plays an extremely important role in the perceived enhancement of music.

As was stated in the latter part of Chapter 2, the reverberated signal itself can be broken down into three components:
The direct signal is made up of the original, incident sound that travels from the source to the listener. Early reflections consist of the first few reflections that are projected to the listener off of major boundaries within an acoustic space. These reflections generally give the listener subconscious cues as to the size of the room. (It should be noted that strong reflections off of large, nearby surfaces can potentially have detrimental cancellation effects that can degrade a room’s sound and frequency response at the listening position.) The last set of signal reflections makes up the actual reverberation characteristic. These signals are composed of random reflections that travel from boundary to boundary in a room and are so closely spaced that the brain can’t discern the individual reflections. When combined, they are perceived as a single decaying signal.

Technically, reverb is considered to be the time that’s required for a sound to die away to a millionth of its original intensity (resulting in a decrease over time of 60 dB), as shown by the following formula:

\[
RT_{60} = \frac{V \times 0.049}{AS}
\]

where RT is the reverberation time (in sec), V is the volume of the enclosure (in ft\(^3\)), A is the average absorption coefficient of the enclosure, and S is the total surface area (in ft\(^2\)). As you can see from this equation, reverberation time is directly proportional to two major factors: the volume of the room and the absorption coefficients of the studio surfaces. A large environment with a relatively low absorption coefficient (such as a large cathedral) will have a relatively long RT\(_{60}\) decay time, whereas a small studio (which might incorporate a heavy amount of absorption) will have a very short RT\(_{60}\).

The style of music and the room application will often determine the optimum RT\(_{60}\) for an acoustical environment. Reverb times can range from 0.25 sec in a smaller absorptive recording studio environment to 1.6 sec or more in a larger music or scoring studio. In certain designs, the RT\(_{60}\) of a room can be altered to fit the desired application by using movable panels or louvers or by placing carpets in a room. Other designs might separate a studio into sections that exhibit different reverb constants. One side of the studio (or separate iso-room) might be relatively non-reflective or dead, whereas another section or room could be much more acoustically live. The more reflective, live section is often used to bring certain instruments that rely heavily on room reflections and reverb, such as strings or an acoustic guitar, to “life.” The recording of any number of instruments (including drums and percussion) can also greatly benefit from a well-designed acoustically live environment.

Isolation between different instruments and their pickups is extremely important in the studio environment. If leakage isn’t controlled, the room’s effectiveness becomes severely limited over a range of applications. The studio designs of
the 1970s and 1980s brought about the rise of the “sound sucker” era in studio design. During this time, the absorption coefficient of many rooms was raised almost to an anechoic (no reverb) condition. With the advent of the music styles of the 1990s and a return to the respectability of live studio acoustics, modern studio and control-room designs have begun to increase in size and “liveness” (with a corresponding increase in the studio’s RT60). This has reintroduced the buying public to the thick, live-sounding music production of earlier decades, when studios were larger structures that were more attuned to capturing the overall acoustics of a recorded instrument or ensemble.

**Acoustic Echo Chambers**

Another physical studio design that was used extensively in the past (before the invention of artificial effects devices) for re-creating room reverberation is the *acoustic echo chamber*. A traditional echo chamber is an isolated room that has highly reflective surfaces into which speakers and microphones are placed.

The speakers are fed from an effects send, while the mic’s reverberant pickup is fed back into the mix via an input strip of effects return. By using one or more directional mics that have been pointed away from the room’s speakers, the direct sound pickup can be minimized. Movable partitions also can be used to vary the room’s decay time. When properly designed, acoustic echo chambers have a very natural sound quality to them. The disadvantage is that they take up space and require isolation from external sounds; thus, size and cost often make it unfeasible to build a new echo chamber, especially those that can match the caliber and quality of high-end digital reverb devices.

An echo chamber doesn’t have to be an expensive, built-from-the-ground-up design. Actually, a temporary chamber can be made from a wide range of available acoustic spaces to pepper your next project with a bit of “acoustic spice.” For example:

- An ambient-sounding chamber can be built by placing a Blumlein (crossed figure-8) pair or spaced stereo pair of mics in the main studio space and feeding a send to the studio playback monitors.
- A speaker/mic setup could be placed in an empty garage (as could a guitar amp/mic, for that matter).
- An empty stairwell often makes an excellent chamber.
- Any vocalist could tell you what’ll happen if you place a singer or guitar speaker/mic setup in the shower.

From the above, it’s easy to see that ingenuity and experimentation are often the name of the makeshift echo/reverb game. In fact, there’s nothing that says that the chamber has to be a real-time effect—for example, you could play back a song’s effects track from a laptop DAW into a church’s acoustic space and record the space to stereo tracks on the DAW, where they can be later placed into the mix. The limitless experimental options are totally up to you!