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 sym-
metrically 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 3.23a). Should space or other room considerations come into play, centering the listener/monitoring position at a 45° angle within a symmetrical corner.

**FIGURE 3.23** Various acceptable symmetries in a monitoring environment: (a) Acoustic reflections must be symmetrical about the listener’s position. In addition, orienting a control room along the long dimension can extend the room’s low-end response. (b) Placing the listening environment symmetrically in a corner is another example of how the left/right imagery can be improved over an off-center placement.
(Figure 3.23b) is another example of how the left/right imagery can be largely maintained.

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 3.24). 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.

While we’re on the subject of the relationship between the room’s acoustic layout and speaker placement, it’s always wise to place nearfield 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 build-ups that acoustically occur at boundary and corner locations. In addition to strategic speaker placement, homemade or commercially available isolation pads (Figure 3.25) can be used to reduce resonances that often occur whenever enclosures are placed directly onto a table or flat surface.
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.

**Frequency balance**

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 3.26). 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.

**REFLECTIONS**

FIGURE 3.25
Speaker isolation pads can help to reduce speaker/stand resonances. (a) Auralex MoPAD™ speaker isolation pad (courtesy of Auralex Acoustics, www.auralex.com); (b) Primacoustic Recoil Stabilizer pad (courtesy of Primacoustic, www.primacoustic.com).

FIGURE 3.26
Sound reflects off a surface at an angle equal (and opposite) to its original angle of incidence, much as light will reflect off a mirror.
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 90° 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 costs” 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 3.27). 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 3.28). 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.

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 3.29) 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 msec or more) can have its echoes spaced far enough apart in time that the discrete reflections produce echoes that actually interfere with the intelligibility of the direct sound, often resulting in a jumble of noise. In these cases, the 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 3.30) argues for the fact that the rear of the room should be largely reflective (Figure 3.31), providing for a balanced environment that can help reinforce positive reflections that can add acoustic “life” to the mix experience. The front of the room would tend more toward the absorptive side in a way that would reduce standing-wave and flutter reflections that would interfere with the overall response of the room.
FIGURE 3.29
Commercial diffuser examples: (a) T’Fusor™ sound diffusers (courtesy of Auralex Acoustics, www.auralex.com); (b) SpaceArray sound diffusers (courtesy of pArtScience, www.partscience.com); (c) open-ended view of a Primacoustic™ Razorblade quadratic diffuser (courtesy of Primacoustic Studio Acoustics, www.primacoustic.com).
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 is a good thing.
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 3.32). 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.
## Table 3.2 Absorption coefficients for various materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick, unglazed</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Carpet (heavy, on concrete)</td>
<td>0.02</td>
<td>0.06</td>
<td>0.14</td>
<td>0.37</td>
<td>0.60</td>
<td>0.65</td>
</tr>
<tr>
<td>Carpet (with latex backing, on 40-oz hair-felt or foam rubber)</td>
<td>0.03</td>
<td>0.04</td>
<td>0.11</td>
<td>0.17</td>
<td>0.24</td>
<td>0.35</td>
</tr>
<tr>
<td>Concrete or terrazzo</td>
<td>0.01</td>
<td>0.01</td>
<td>0.015</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Wood</td>
<td>0.15</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Glass, large heavy plate</td>
<td>0.18</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Glass, ordinary window</td>
<td>0.35</td>
<td>0.25</td>
<td>0.18</td>
<td>0.12</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Gypsum board nailed to 2 x 4 studs on 16-inch centers</td>
<td>0.013</td>
<td>0.015</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Plywood (3/8 inch)</td>
<td>0.28</td>
<td>0.22</td>
<td>0.17</td>
<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Air (sabins/1000 ft³)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2.3</td>
<td>7.2</td>
</tr>
<tr>
<td>Audience seated in upholstered seats</td>
<td>0.08</td>
<td>0.27</td>
<td>0.39</td>
<td>0.34</td>
<td>0.48</td>
<td>0.63</td>
</tr>
<tr>
<td>Concrete block, coarse</td>
<td>0.36</td>
<td>0.44</td>
<td>0.31</td>
<td>0.29</td>
<td>0.39</td>
<td>0.25</td>
</tr>
<tr>
<td>Light velour (10 oz/yd² in contact with wall)</td>
<td>0.29</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>Plaster, gypsum, or lime (smooth finish on tile or brick)</td>
<td>0.44</td>
<td>0.54</td>
<td>0.60</td>
<td>0.62</td>
<td>0.58</td>
<td>0.50</td>
</tr>
<tr>
<td>Wooden pews</td>
<td>0.57</td>
<td>0.61</td>
<td>0.75</td>
<td>0.86</td>
<td>0.91</td>
<td>0.86</td>
</tr>
<tr>
<td>Chairs, metal or wooden, seats unoccupied</td>
<td>0.15</td>
<td>0.19</td>
<td>0.22</td>
<td>0.39</td>
<td>0.38</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*Note: These coefficients were obtained by measurements in the laboratories of the Acoustical Materials Association. Coefficients for other materials may be obtained from Bulletin XXII of the association.*

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:

$$A_{ave} = \frac{s_1a_1 + s_2a_2 + \ldots + s_na_n}{S}$$

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, 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 (Figure 3.33).

Low-frequency absorption
As shown in Table 3.2, materials that are absorptive in the high frequencies 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 3.34). Rooms that haven’t been built to the shape and dimensions to properly handle the low end will need to be controlled by using bass traps that are tuned 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.

The **quarter-wavelength trap** The quarter-wavelength bass trap (Figure 3.35) 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 3.36) 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
Primary Factors Governing Studio and Control Room Acoustics

FIGURE 3.34
Low-frequency absorption. (a) A carefully designed pliable surface can be used to absorb low frequencies. (b) Primacoustic™ Polyfuser, a combination diffuser and bass trap (courtesy of Primacoustic Studio Acoustics, www.primacoustic.com).

FIGURE 3.35
A quarter-wavelength bass trap: (a) physical concept design; (b) sound is largely absorbed as heat, since the particle velocity (motion) is greatest at the trap’s quarter-wavelength opening.
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 3.37) 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. Figure 3.38 shows how these traps can be used in the studio to break up reflections and reduce bass buildup.

**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 gives 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:

- Direct sound
- Early reflection
- Reverb.

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:

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

where RT is the reverberation time (in sec), \( V \) is the volume of the enclosure (in \( \text{ft}^3 \)), \( A \) is the average absorption coefficient of the enclosure, and \( S \) is the total surface area (in \( \text{ft}^2 \)). 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 nonreflective 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 1960s and 1970s 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 1980s 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 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 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 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 (Figure 3.39).
- 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 chamber 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 effect back to stereo tracks on the DAW. The options and limitless experimentations are totally up to you!