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The Oldest Tool in the Modern Acoustician's Toolbox

By
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(United States)

When most people hear the words "acoustical treatment," they immediately think of the fuzzy stuff on the walls that deadens a room's sounds. The fuzzy stuff acts as acoustical absorption. While it's certainly not the only tool in the modern acoustician's tool box, absorption was the first tool to be scientifically quantified.

In 1895, Harvard University's Physics Department was asked to improve the school's Fogg Lecture Hall, which had impossibly bad acoustics. The senior faculty considered the assignment as impossible as the acoustics and passed it off to a young professor named Wallace Clement Sabine.

After carefully listening to the difference between Fogg Lecture Hall and rooms considered more acoustically acceptable, Sabine concluded that the critical factor was the time required for a sound spoken at a normal conversational level to decay to inaudibility. He called this the room's reverberation time (RT). Fogg Lecture Hall was found to have a 5.5-s RT, which was long enough for 12 to 15 words to be spoken before the first word faded away. By comparison, good lecture halls had RT's below 1 s.

Working with a team of his students, Sabine measured the effects of seat cushions, rugs, and people on Fogg Lecture Hall's RT. He understood that sound pressure level (SPL) is closely related to air molecules' kinetic energy and by subjecting the air molecules to friction—such as that provided by upholstery padding, fabric, or rugs—the kinetic energy would be absorbed more rapidly and the sound would decay faster. By applying acoustical absorption to Fogg Lecture Hall in the correct amounts and locations, Sabine succeeded in markedly improving the lecture hall's sound. As a result of his efforts, he was selected as the acoustical consultant for Boston's Symphony Hall, which is now considered one of the world's finest concert halls.

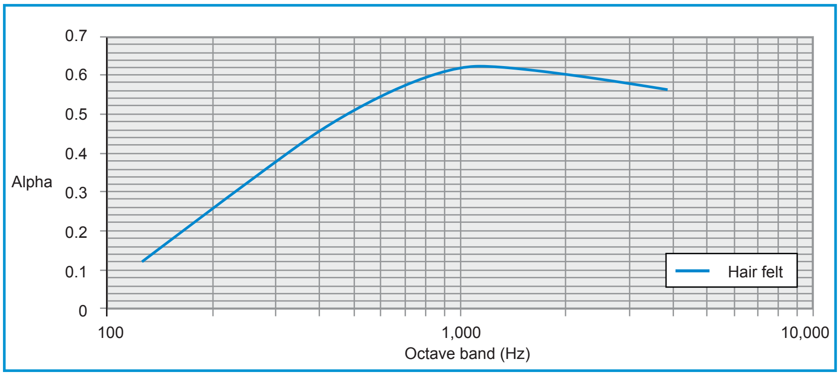

Figure 1: The acoustical absorption of hair felt varies with frequency.

Acoustical Absorption

When a sound wave strikes a material, some of the sound energy will pass through the material, some will be absorbed, and some will reflect back. The acoustical performance is quantified by the acoustical absorption coefficient, symbolized by α (alpha). Alpha can have a value anywhere from zero (completely reflective) to one (completely absorptive). It is listed as a decimal fraction. For example, the alpha of a 0.375″ pile carpet laid on concrete is 0.21 (21% absorption) in the 500-Hz octave

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band. Most materials' alpha changes greatly with frequency (see **Figure 1**). For example, the alpha of 0.375" carpet on concrete varies from 0.09 in the 125-Hz octave band to 0.37 in the 5,000-Hz band.

For a quick idea of a material's absorption in the most important voice frequencies, materials are rated with a noise reduction coefficient (NRC). The NRC is the average, rounded to the nearest multiple of 0.05, of the material's alphas in the 250-, 500-, 1,000-, and 2,000-Hz octave bands.

Sabine's analysis of the effects of acoustical absorption led to the development of his famous equation that enables the prediction of a room's RT from knowledge of its physical dimensions and its acoustical absorption:

$$RT = \frac{0.161\ V}{\sum S\alpha}$$

where V = the room's volume in cubic meters and the denominator of the fraction signifies the summation of the products of the area (S) and absorption (α) of each material. The product Sα is the acoustical absorption, measured in sabins.

Even though many acoustical absorbers resemble thermal insulation, and in some cases may act as thermal insulation, acoustical absorption is not the same as acoustical insulation. Failure to understand this distinction can cause miscommunication. Just as thermal insulation prevents the movement of thermal (heat) energy, acoustical insulation prevents the movement of acoustical energy. Thus, heavy concrete walls are good acoustical insulators and compressed fiberglass is a good thermal insulator, but not vice-versa.

Absorption Material

During Sabine's time, few materials were available for use as acoustical absorption in a room. Most of them (e.g., hair felt, carpet fabrics, and raw wool) depended on the material's internal friction to convert the air molecules' kinetic energy to heat. Many acoustically absorptive materials currently available use the same principle.

Probably the most common acoustically absorptive material now used in buildings is acoustical ceiling tile (ACT). There are several ACT variations. Contrary to lay opinion, not all suspended ceiling tiles provide significant acoustical absorption. In fact, each ACT manufacturer provides a few products that have almost no absorption.

The most common materials used to make ceiling tiles are mineral fiber and fiberglass covered with perforated plastic film. **Figure 2** compares the absorption of mineral fiber and fiberglass ACT. An absorptive ACT panel's surface usually depends on porosity to enable air molecules to enter the material and convert their kinetic energy to heat. Thus, much of the acoustical performance is lost if the tiles are painted after installation.

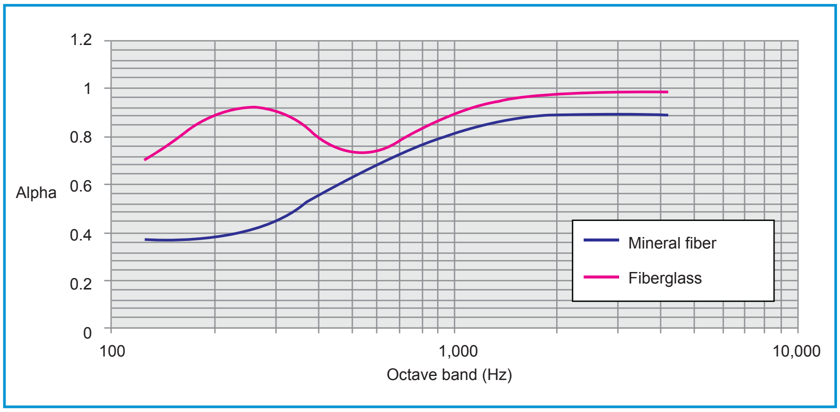

Figure 2: Fiberglass ACT provides more absorption than mineral fiber ACT.

Perforated hard materials such as pegboard are often used with a fiberglass backing to provide acoustical absorption. Contrary to common opinion, it is the fiberglass backing that provides the absorption, not the pegboard.

Using a perforated face material such as wood or MDF with a fiberglass or acoustical foam backing provides good acoustical absorption while offering an interesting visual effect. These products offer an option that pleases the architect's eye and the acoustician's ear (see **Photo 1**).

Any building material provides some acoustical absorption. In some cases, a common material's performance has desirable characteristics that enable it to be used as an acoustical treatment. The most common materials for this purpose are draperies and carpets. While they both can provide useful absorption, in some cases these materials' acoustical value is often overestimated (see **Figure 3**).

Many common building materials have little

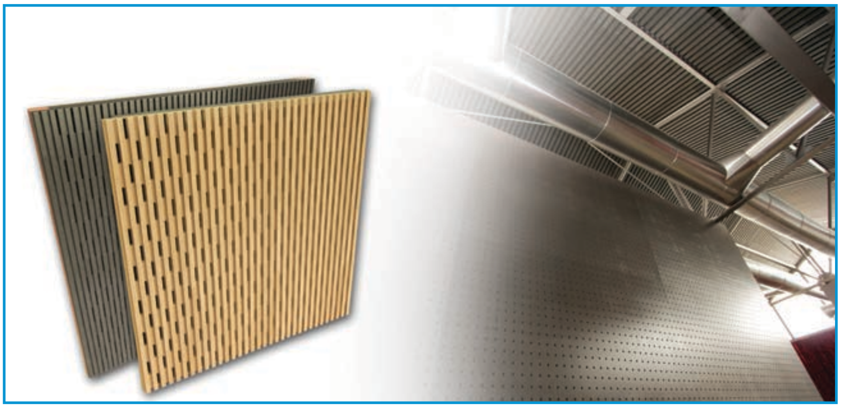

Photo 1: Jocavi's Addsorb uses a perforated MDF face backed with acoustical foam, combining an attractive appearance with acoustical absorption. (Photo courtesy of the Jocavi Group)

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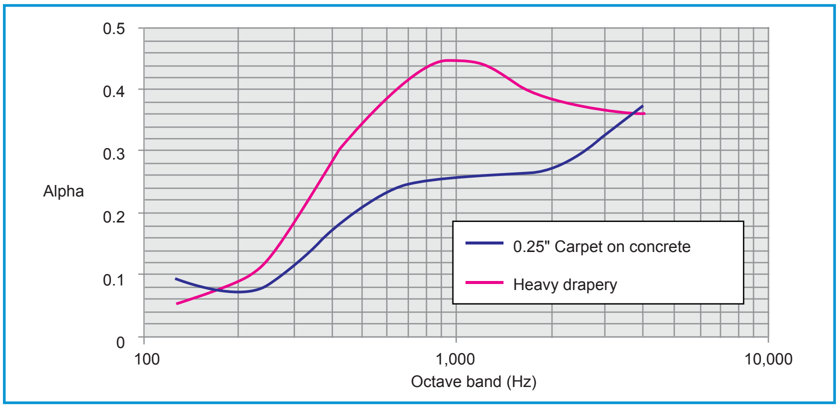

Figure 3: Draperies and carpets provide useful absorption at higher frequencies.

acoustical absorption at low frequencies. This can require the use of thick wall panels and/or expensive ceiling treatments, since thin panels (e.g., 1″ fiberglass or foam) generally provide useful absorption only in and above the 250-Hz octave band. An exception is thin wood paneling and gypsum wall board (GWB). These materials provide diaphragmatic absorption, in which the sound causes the whole panel to vibrate. As a result, sound energy dissipates as heat due to the material's internal friction. **Figure 4** shows the alpha of several such materials. The curves show a wall with 0.5″ gypsum on one side, 3.625″ air space without absorptive batts, and 0.0625″ gypsum on the other side; a wall with a 0.25″ wood panel over a 2.5″ air space; and a wall with 0.625″ gypsum on both sides and a 3.5″ air space with batts.

Important variables controlling the wall materials' acoustical behavior are the framing's on-center spacing, the material's thickness, the framing's thickness (controlling the airspace between the wall panels), and the presence or absence of absorptive materials (usually fiberglass batts) in the air space. Since the RT depends on the product of **S** and **α**, a small change in a wall's α can have a large effect on RT, due to the wall's large area. For example, the effect of a 7-m × 3-m wall having a 0.1 **α** is the same as that of a 2.97-m^2 (4′ × 8′) panel with a 0.707 **α**.

Other specialized acoustical materials have been developed that replace common materials. For example, acoustical plasters that absorb sound were introduced in the 1920s. These plasters incorporate fibers or aggregate materials into their formulation. In some cases, these plasters provide alphas in excess of 0.5 at some frequencies, which can have major effects on RT when used for whole walls and/or ceilings. More recently, composite materials—such as Baswaphon, which is made of compressed fiberglass skinned with acoustical plaster—have been introduced. These materials can provide almost 100% absorption over much of the audible frequency range.

Adding Acoustical Absorption

In treating an existing room, one seldom has the option of replacing whole walls. Any added acoustical absorption must be provided by the use of ceiling and/or wall panels. The most common acoustically absorbing wall panels are made of tangled wood fibers, melamine or polyurethane foam, or fiberglass.

Acoustically absorbent wall panels made of tangled wood fibers with a specific mineral treatment are manufactured under the trade name Tectum. Tectum provides a cost-effective, durable option for gymnasia and similar spaces. **Photo 2** shows

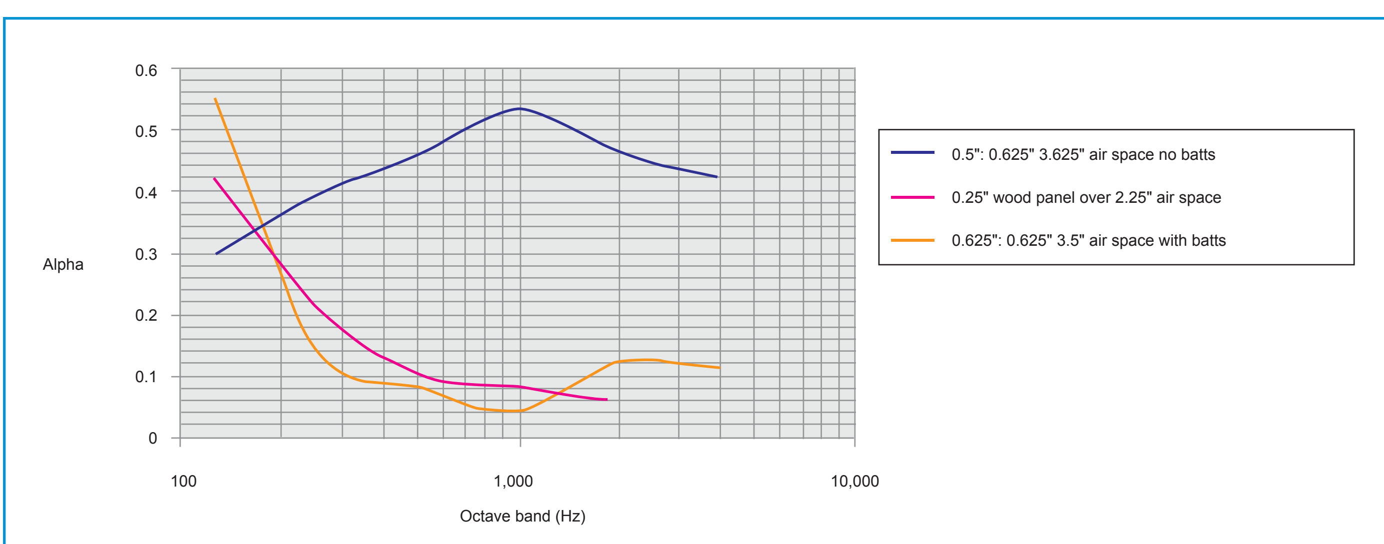

Figure 4: Wall materials can provide significant absorption at some frequencies.

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a Tectum panel. Tectum's low-frequency acoustical absorption depends greatly on the mounting method. If furred more than 40 to 80 mm of air or fiberglass batts, Tectum is quite an effective absorber down to the 125-Hz octave band. Mounted directly to a hard wall, the 125-Hz alpha is less than 0.1.

Fiberglass panels come in four major varieties: plain, cloth-covered, vinyl-wrapped, and hardened-surface. Plain fiberglass panels are the least commonly used for wall treatment. When plain fiberglass is wrapped with acoustically transparent cloth, it becomes aesthetically attractive with almost no effect to the absorptive properties.

Vinyl wrapping increases low-frequency absorption through diaphragmatic absorption, at the expense of some high-frequency absorption. Hardened-surface fiberglass provides a durable surface of about 2.5 mm of hard fiberglass adhered to a compressed fiberglass substrate. It is impact-resistant and also provides a diaphragmatic effect that enhances low-frequency absorption. **Photo 3** shows the construction of each of these types of fiberglass panels. **Figure 5** shows the absorption characteristics for plain, vinyl-wrapped, and hardened-surface 2" thick fiberglass panels.

Many manufacturers use melamine or polyurethane foams to make acoustical absorption. The foam can be obtained as flat panels or with various sculpted surfaces. Foam must be used in greater thicknesses than fiberglass to achieve the same low-frequency absorption, but it is available in many shapes and colors. It is also lightweight (see **Photo 4**).

Photo 2: This Tectum material is made of tangled aspen-wood fibers treated with specific minerals. (Photo courtesy of Tectum)

In recent years, many manufacturers have introduced microperforated wood acoustical absorbers, in which tiny perforations permit good acoustical absorption, especially in the 500- and 1,000-Hz octave bands, while presenting the appearance of solid wood (see **Photo 5**). Other products are also available as planks, lay-in ceiling tiles, V-groove wall panels, and in other decorative forms.

Tuned Bass Traps

In small rooms such as recording/broadcast control rooms, resonant modes can cause problems by emphasizing specific narrow frequency bands of sound, especially in the frequency range below 150 Hz. Since the room's purpose heavily depends on the engineer's ability to accurately hear what

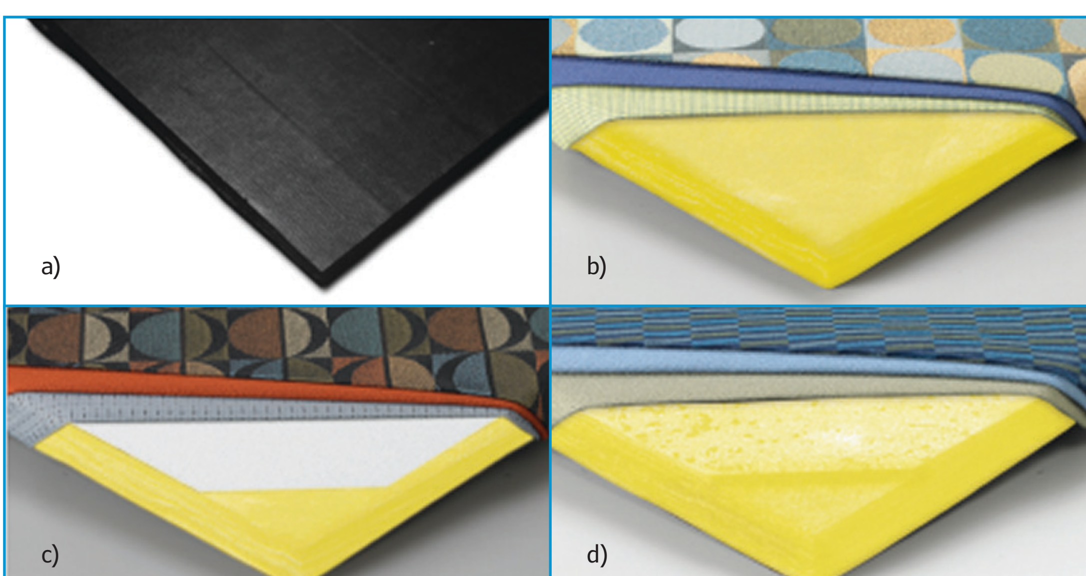

Photo 3: Fiberglass treatment is available in several varieties: plain fiberglass—black "theater board" (a), cloth-wrapped fiberglass (b), vinyl-wrapped fiberglass (c), and hardened-surface fiberglass (d). (Photos courtesy of G&S Acoustics)

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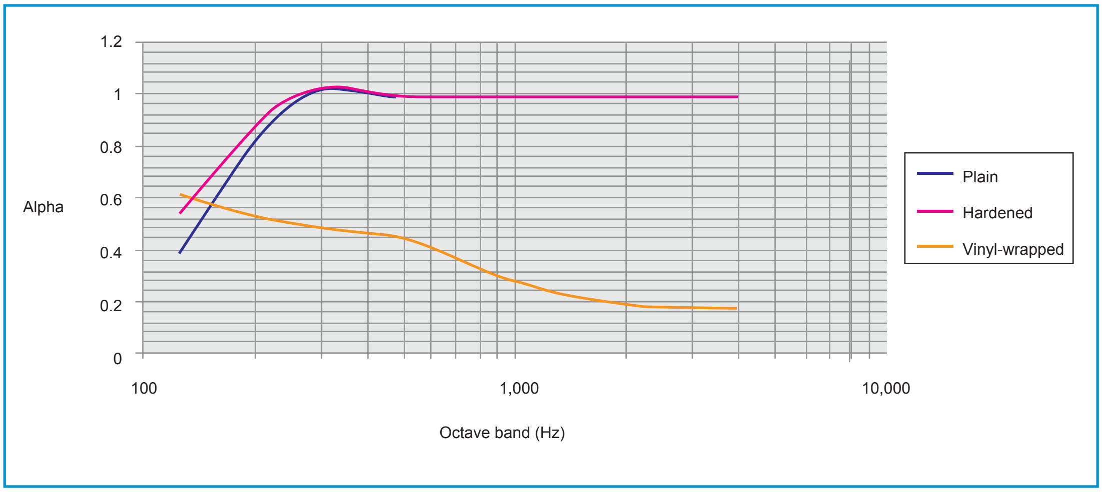

Figure 5: Different varieties of fiberglass panels provide different absorption profiles.

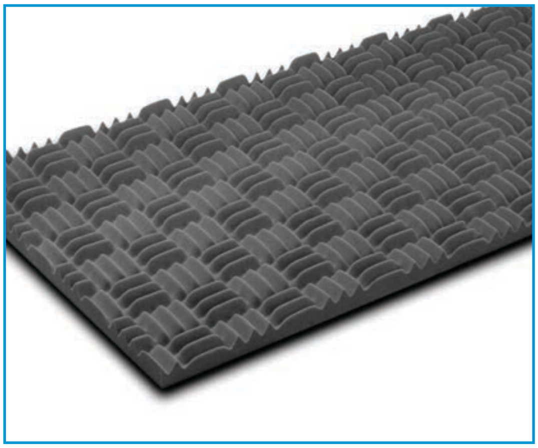

Photo 4: Acoustical foam is available in many colors and shapes. (Photo courtesy of Sonex Acoustics)

Photo 5: This Topperfo Micro perforated panel has a solid wood appearance, coupled with good acoustical absorption. (Photo courtesy of RPG Diffusor Systems)

is recorded or broadcast, having certain notes unnaturally boosted is highly detrimental. Not only is broadband absorption expensive if low-frequency absorption is desired (due to the necessary thickness of 10 cm or more), but broadband absorption does not really address the problem of narrow-band boosting of certain frequency ranges.

The solution most appropriate for this issue is tuned bass traps. Many of these devices work on the principle of a Helmholtz resonator. A Helmholtz resonator consists of an enclosed volume of air that opens to the outside through a neck. A jug played in some forms of folk music is a good example. The Helmholtz resonator is a mechanical mass-spring oscillator. If a mass is placed atop a spring and then displaced, the mass will bounce at a frequency given by:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where f = the frequency of oscillation, k = the spring constant in newtons of force per meter of displacement of the spring, and m = the mass.

In a Helmholtz resonator, the spring function is provided by the air's compressibility in the enclosure and the mass is the air's mass in the neck. This leads to the following equation for a Helmholtz resonator's resonant frequency:

$$f = \frac{c}{2\pi}\sqrt{\frac{A}{V_0 L}}$$

where c = the speed of sound in air (345 m/s), A = the cross-sectional area of the neck in m^2, V_0 = the volume of the enclosed air in m^3, and L = the length of the neck in m.

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Photo 6: This commercial bass trap is designed for use in a room's corner. (Photo courtesy of the Jocavi Group)

If absorptive material such as fiberglass is placed inside the enclosure, the resonator's sound energy will be converted to heat. Thus, sound energy at and near the resonant frequency can be removed from the room. A Helmholtz resonator used in this way is one form of resonant bass trap.

This form of bass trap is a common DIY project for home studios. In such projects, a shallow box is topped with a perforated material such as pegboard and the box is partially filled with fiberglass. The pegboard's holes and thickness serve as the necks of an array of coupled Helmholtz resonators and the portion of the enclosed volume behind each hole acts as the air volume.

Another type of bass trap uses the diaphragmatic absorption provided by a plywood sheet affixed at the edges to form the top of a shallow box that is loosely filled with fiberglass. If the box is 3″ deep, a 4′ × 8′ piece of 0.25″ plywood will resonate about 110 Hz; 0.125″ plywood, 150 Hz; and 0.375″ plywood, 87 Hz. Using a piece of uninsulated 14-gauge wire as a spacer between the plywood and the box at the attachment points enhances the resonant action. A variant on the panel absorber is the membrane absorber, which also uses diaphragmatic action. Many manufacturers produce bass traps using the Helmholtz or diaphragmatic principles (see **Photo 6**).

Bass traps are not magical: They cannot suck bass out of anywhere in the room. For optimum operation, place a bass trap where the air pressure is greatest. For the lowest-frequency modes (often the most problematic), this location is a corner of wall/wall/ceiling or wall/wall/floor. Wall/wall corners are also effective. The third option—on a short wall—primarily helps with longitudinal modes, which represent sound bouncing back and forth along the room's length. Most manufacturers offer guides as to optimum placement of their bass traps.

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