LISTENING ROOM - CORNER LOADED BASS TRAP

by Arthur Noxon • Presented at the 79th AES Convention
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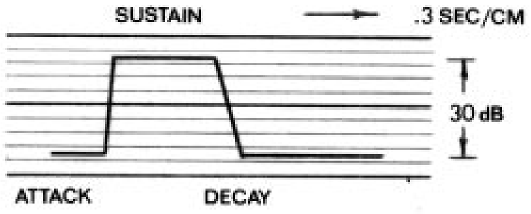
Summary

This paper discusses the physics behind how corner loaded bass traps work. It was written over 20 years ago, just as the ASC TubeTrap had recently been introduced for use in hi-fi audio. The idea of bass trapping was limited to recording studios at the time, and were huge and expensive boxes. However, the idea of corner loading with bass traps had never been considered and was a revolutionary concept at the time.

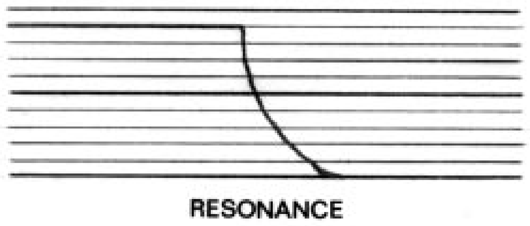
Good evening,

We're going to talk tonight about the musical tone burst and its transients, and about small rooms and their corners. We'll blend these topics together into the problem area of low frequency room articulation and then show how bass traps help the situation. Finally, we'll discuss the new generation of bass traps we've developed over the last two years.

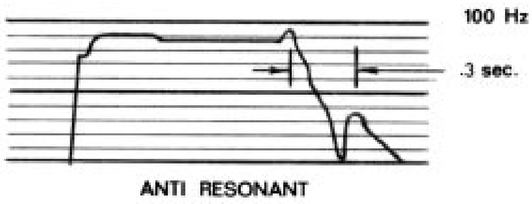
Traditional testing of rooms utilizes both pink noise and slow sine sweeps to evaluate the suitability of the room for listening. Music is neither noise nor steady state tone. The ability of the room to articulate music is closely related to its ability to track the details of each discrete tone burst.



The typical listening room is frequently without proper low frequency decay constants. Instead of actively tracking the tone burst, the room distorts both of the burst transient: attack and decay.

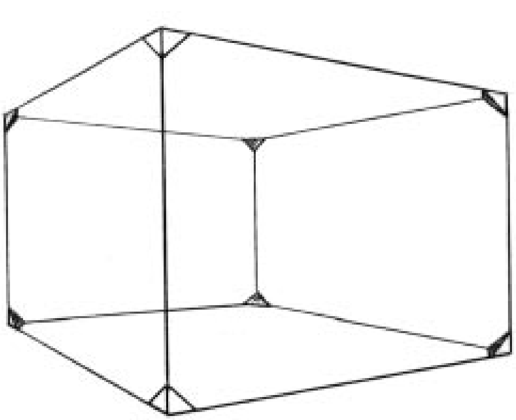


Let's start by looking at the tone burst decay. In a furnished room without bass traps the low end tone burst decay will vary between two extreme characteristics, first there can be the prolonged decay -- that boomy sound -- because the frequency of the tone burst matches one of the room's resonant mode frequencies.



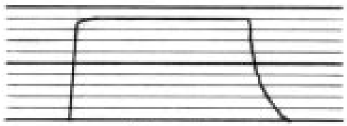
The second decay extreme occurs when the room is driven at a non-resonant frequency. This so-called anti-resonant frequency decay is characterized by an initial very rapid decay rate, followed by a resurgence of sound to within 10 dB of the original level. Detailed observation shows that the resurgent sound has changed frequency of a nearby resonant mode -- that is some components of a musical chord actually change frequency during the decay, resulting in 'room coloration' of the music.

The location of bass traps in a room needs to facilitate the damping of all resonant modes. There are eight places in each rectangular room where high sound levels exist for all from resonance modes. There are the tri corners-for example, the intersection of 2 walls and the floor. Each tri corner is part of each of the three sets of parallel walls that determine the room’s resonance mode. Properly designed bass traps can be installed in the tri corners to dampen all resonances.

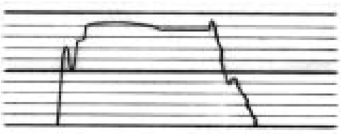


TRICORNER LOCATION

Rooms sound better when bass trapping is added. Prolonged resonant frequency decay times are reduced; non-resonant frequency rapid decay time is increased, and frequency shifted resonant boom is eliminated. Clearly, bass trapping in the listening room does equalize the tone burst decay constants, in that both the mean and the deviation of decay constants are reduced frequency to frequency.

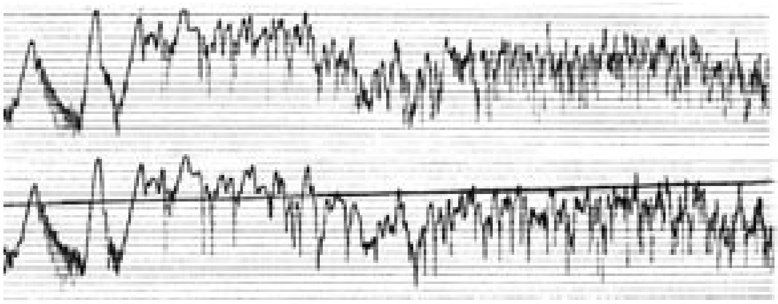


Resonant



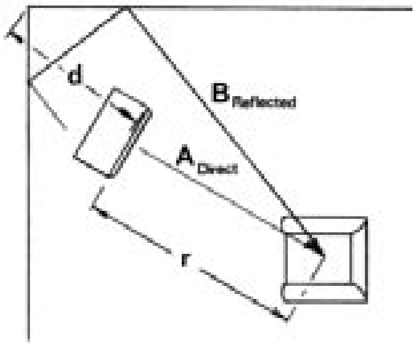
Anti-Resonant

Pink noise tests are typically used to EQ a room. Curiously, only a minimal 1-2 dB readjustment towards equalization in the mid bass is noticed after the transient features of the burst have been suitably controlled by trapping. The slow sine sweeps tests of a trapped room will show a slight 1-2 dB reduction in peaks and similar increase in levels of the valleys of the response curve. The curve’s fine structure however, is obviously cleaned up and sharpness of the variations is softened. This change means the ‘q’ of the room has been reduced, and typically measured to be a factor of 4.



We’ve been discussing the decay transient of the tone burst. Now we move onto the second significant feature of the tone burst, it’s leading edge, the attack. The critical element in the tone burst attack is phase alignment. It’s been long established that the phase shifting of components of a complex musical tone is not discernable for the steady state condition. But phase alignment is easily noticed in the attack transient.

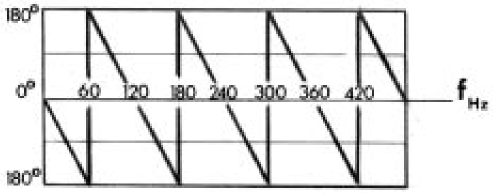
If we analyze the case of a speaker near a corner, we see that two wave trains are simultaneously heard at the listener’s position. The direct signal from the speaker is laced with the weaker signal reflected off the nearby corner. If we compare the phase of the reflected wave train with that of the direct wave train, we see that the reflected wave runs through a series of relative phase shifts with frequency due to its turn-around path distance and subsequent time delay.



$$\frac{P_B}{P_A} = \frac{(1/(2d+r))^2}{(1/r)^2} = \frac{1}{(1+2d/r)^2} = \frac{1}{4}\ ,\ \begin{matrix} d = 1.2\text{m} \\ r = 2.3\text{m} \end{matrix}$$

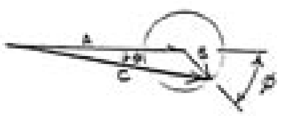
$$T_B - T_A = \Delta t = \frac{2d+r}{c} - \frac{r}{c} = \frac{2d}{c} = 7\text{ms delay}$$

$$\emptyset = \Delta t_w = 360\ \Delta t_f = 3f^\circ\text{ phase}$$



Now, at low frequency this first reflected wave is not heard as an ambiance effect, but rather as a simple sum effect. When we add two same-frequency wave trains together we get a resultant amplitude and phase shifted wave train that has frequency dependant features, as this formal calculation shows.

$$C(\phi,t) = A\sin\omega t + B\sin(\omega t+\phi) =$$



$$= A\left(1+2\frac{B}{A}\cos\phi + \left(\frac{B}{A}\right)^2\right)^{\frac{1}{2}}\sin\left[\omega t + \tan^{-1}\frac{B}{A}\frac{\sin\phi}{\left(1+\frac{B}{A}\cos\phi\right)}\right]$$

EXACT

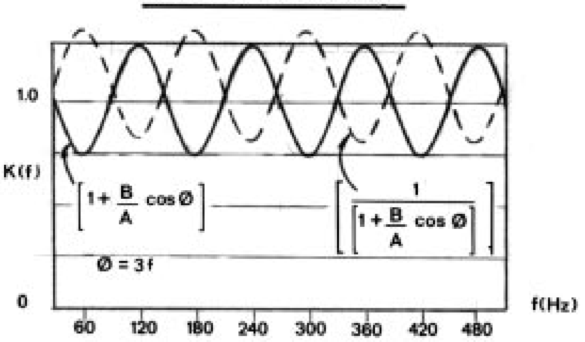
If the reflected wave sound pressure is less than 1/4 of the sound pressure of the direct wave measured at the listener's position, a simplification can be written accurately to 3%.

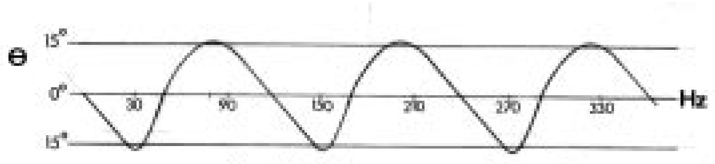
$$C_{(\theta,t)} = \underbrace{A\left(1+\frac{B}{A}\cos\theta\right)}_{\text{AMPLITUDE COEFFICIENT}}\sin\left[wt + \frac{B}{A}\frac{\sin\theta}{\left(1+\frac{B}{A}\cos\theta\right)}\right],\quad \frac{B}{A} < \frac{1}{4}$$

3% accuracy

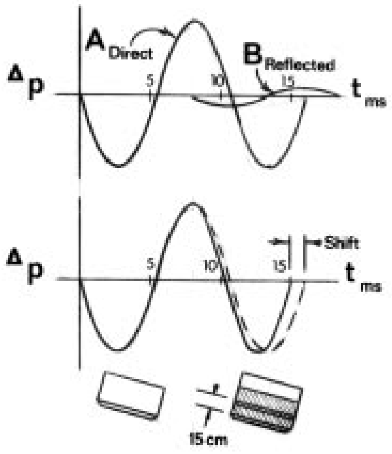
Here both the amplitude and phase distortion in the resultant wave are shown to have a B/A dependence, (the pressure ratio of reflected to direct wave), and also vary with frequency. We can plot these two distortion terms to watch the effects with frequency. For a typical situation, where the speaker is 1 1/4 meters from the corner, we see an amplitude distortion of 25% or +/- 1 dB and a phase distortion of 16* or 9%.

AMPLITUDE COEFFICIENT

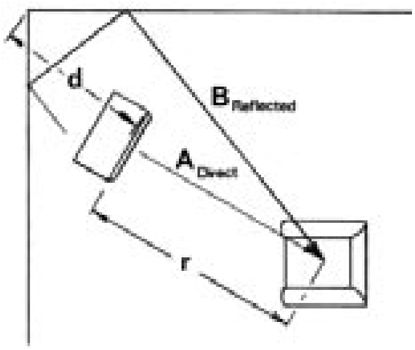




$$\Theta^\circ = \left[\frac{180}{\pi}\right]\left[\frac{B}{A}\right]\left[\frac{\sin Ø}{1+B/A\cos Ø}\right] = 16^\circ\left[\frac{\sin Ø}{1+B/A\cos Ø}\right]$$



Leading edge of the tone burst will be usually under 20 ms. Of time. The second harmonic of a complex tone transient might be 90 Hz and whose first reflection is delayed some 9 ms. The composite wave misinforms the listener that the 90 Hz tone source quickly stepped forward 15cm, in the middle of the tone burst attack transient. By reducing the strength of the lst reflection, the transient phase distortion and resulting image position jitter is eliminated.



This problem, fortunately, is also easily controlled. The B/A coefficient of the oscillatory parts or both the amplitude and phase components of the resultant wave needs to be reduced. This is accomplished by reducing the strength of the reflected (B) wave rebounding out of the corner.

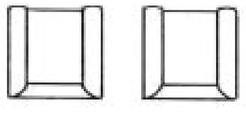
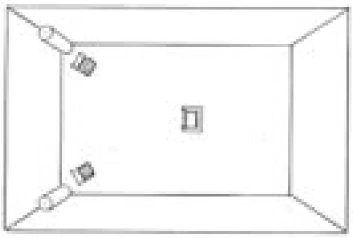


Image Jitter

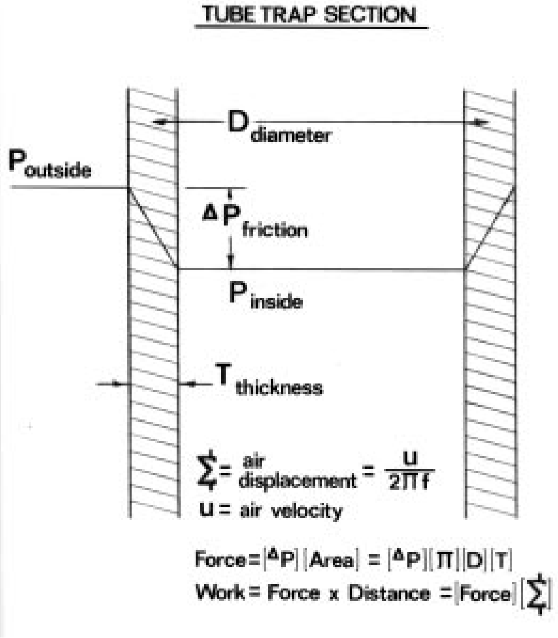


We've now covered problems and remedies involved in accurately tracking both tone burst transients. We can combine the remedies to control both the attack and decay transients of the tone burst simply by locating a good bass trap in the tri corner behind the speaker. We can simultaneously damp the strength of the first reflected wave, thereby correcting for attack phase distortion, and also damp the resonant modes of the room, thus correcting for decay distortions. We see that both transients of the musical tone burst can be cleaned up through bass trapping in the corner behind the speaker.

Well, so far everything seems to be getting better. The traps are to be located in zones of maximum pressure fluctuations, the tri corners of the room. Unfortunately, few devices extract energy directly from pressure changes. The most common method for sound absorption is friction -- friction due to the air-motion part of the sound wave that is scrubbing through some micro-porous piece of material, usually fiberglass.

Now, air-motion is very small in zones of pressure fluctuation, by definition. For example, at 100 dB, 100 Hz, it's on the order of 1/10 the diameter of 5 micron fiberglass fibers. Prospects for developing friction look poor unless we first transform energy. We'd like to convert the pressure fluctuations into substantial air motion, and then dissipate acoustic energy by friction against the air motion.

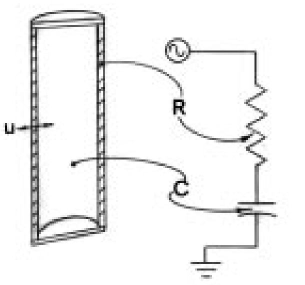
A new device uses this approach with considerable success. It is tubular in form and is supplied in 3 foot sections, hence its generic name: TUBE TRAP. It is comprised basically of two distinct elements: an internal air chamber and a porous wall. The ends of the tube are sealed. The Tube Trap is, in fact, a sealed chamber with a resistive opening to its interior void. Its length is incidental and now functional to its operation. Air pressure fluctuations outside the tube impart motion to the air in the porous tube wall where friction operates.



It is interesting to note the pressure distribution associated with the operation of the Tube Trap. When pressures outside the tube are higher than those inside, a pressure gradient across the wall of the tube results from friction as air is driven inwards through the wall. The difference in pressure across the wall is the measure of the force that is being transferred into frictional energy. The thickness of the wall tells us the distance over which that force is developed. Their combination tells us how much work is being done. We like as much force to occur over a large distance to get as much work out of each half cycle pressure fluctuation as possible.

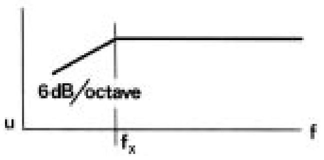
If for example, the tube has a thin but highly resistive wall, the pressure drop would be very steep -- but the distance of the action would be too small for any real work to be done. Conversely, if the tube were simply full of loose fiberglass, the gradient would be too small, though the distance of the action would be large; again, the work would be minimal. The variables of wall material bulk flow resistance and the wall thickness, along with the air chamber volume can be manipulated to access any low frequency with optimal efficiency.

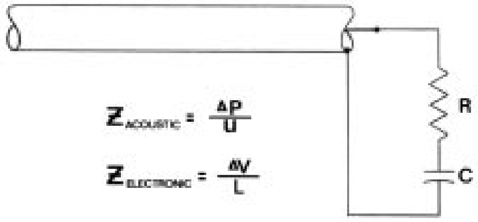
We’ve been looking at the conceptual mechanical side of the Tube Trap. There is also the acoustical circuit model of that subject, rather like an electrical circuit. The Tube Trap itself is comprised of a compliant volume (the electrical capacitor) surrounded by a resistive surface (the electrical resistor). Their combination forms the acoustic equivalent of a series RC circuit. As such, the Tube Trap is in effect a high pass filter with its own distinct time constant. The cutoff frequency, for example is 37 Hz for the 11” diameter tube trap. Air motion in the wall of the tube is restricted at a rate of 6 dB per octave below that cutoff frequency. A 20 Hz model will soon be in production and custom traps have been built to 5 Hz.



$$T = \sqrt{RC} \quad , \quad f_x = \frac{1}{2\pi T}$$

Acoustic impedance is defined as air pressure divided by bulk air velocity. Bulk air is in effect a distributed impedance transmission line. However, when a wall or corner is involved, this impedance becomes very large because the wave-propagative material has become acoustically stiff. The corner of a room usually has high pressure fluctuations and little air motion. When the Tube Trap is in place, pressure is reduced and air motion is allowed at the surface of the tube, thus the impedance of the corner is reduced by the presence of the trap. This is equivalent to installing an impedance matching termination circuit to the end of an open-ended transmission line.



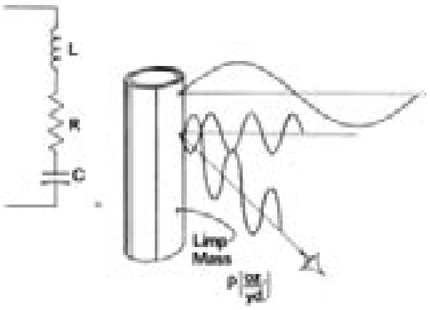


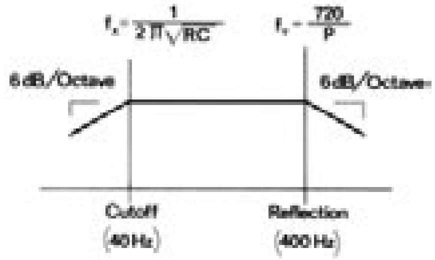
$$Z_{ACOUSTIC} = \frac{\Delta P}{U}$$

$$Z_{ELECTRONIC} = \frac{\Delta V}{L}$$

Energy continues to be transferred down the line, not because of continued radiation but rather due to resistive dissipation. This process accounts for the name ‘acoustic window’ given to the model of tube trap we manufacture for monster cable.

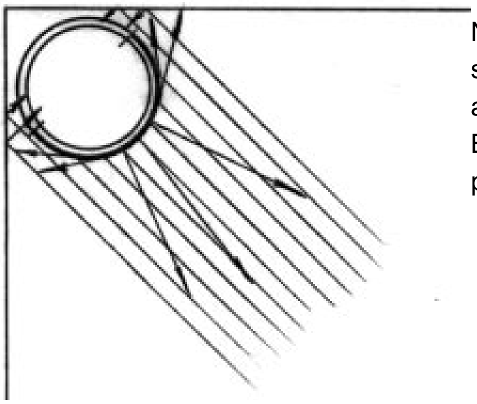
One feature of the trap has yet to be mentioned, Limp mass diffusion panels are installed, permitting low frequency pressure to pass into the resistive wall, but reflecting sound of the midrange frequencies and above. In general 100% of the tube surface is absorptive to low frequencies and 50% of its surface is reflective to mid and high frequencies. This crossover panel brightens the sound of the tubes.



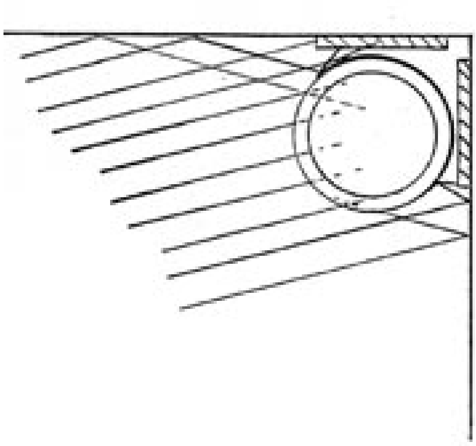


The crossover rate is 6 dB per octave, appropriate to limp mass, and begins at 320 Hz for the 11” diameter units. The complete acoustical circuit of the tube trap has finally evolved into a series LRC circuit. The design, however, is deliberately so leaky that no Lc resonance is possible.

The front half of each tube trap is mid-range reflective, and the back half is broad-band absorptive. To create a 100% dead corner one installs the type so that its absorptive side faces the room. We usually find that experienced listeners choose the reflective side towards the room; they hear the difference and prefer the brightness.



Notice that when the reflective insert faces the room it does not reflect sound directly into the wall because the space between the Tube Trap and the wall is not bordered by two reflective surfaces facing each other. Because of this detail tube/wall sonic interaction is prohibited and any potential tonal resonance due to the tube trap installation is avoided.



The ease of adjusting brightness of rotating the tube seems to entrance some users. But careful listening for undue coloration is in order. A safe way to have the adjustable brightness feature without risk of coloration is to install flat wall panels in the corner behind the tube, thereby canceling any potential for interaction between the cross-over panel and the wall surface.

The bottom end absorption of the Tube Trap is controlled by the RC time constant. There is the cross-over panel that chokes its absorption some 3 octaves above. There is one other physical factor- the volume of the room. A corner loaded trap pulls energy out of the fluctuating pressure zone in which it is located. The rate of energy drain from the room is proportional to the rate of the number of trapped zones to the total number of zones in the room. The bigger the room the more zones (n) there are for any given frequency.

$$N = \frac{8V}{\lambda^3} + \frac{12V^{2/3}}{\lambda^2} + \frac{6V^{1/3}}{\lambda} + 1$$

M = # of Traps
F = Resonant Mode Frequency
λ = Wavelength

$$T_{60} = \frac{-3}{F \operatorname{Log}(1 - M/N)}$$

$$= \frac{3V^{2/3}}{20M\lambda} \cdot \frac{1}{2} < \frac{V^{1/3}}{\lambda} < \frac{5}{2}$$

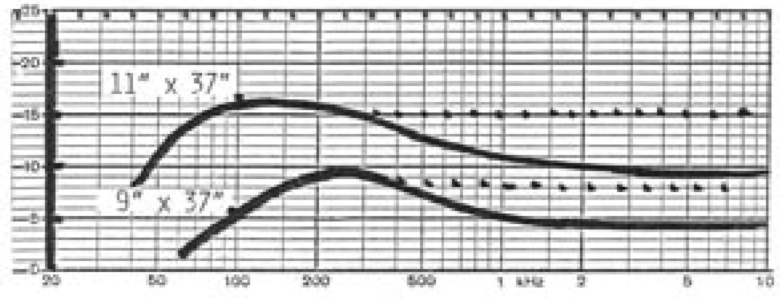
$$T_{60} = \frac{2000^{2/3}}{6.7 \times 8 \times 10} = 0.4 \text{ sec}$$

A decay formula based on discrete 1/2 wavelength absorption is derived for resonant RT-60 decay times. It is simplified into a linear approximation good to 10% for the first 21/2 octaves of major room resonances. A 2000 ft/3 concrete chamber with only 8 tube traps, one in each tri corner will have a RT-60 of 0.4 seconds at 113 Hz. This demonstrated the strength of low end trapping for major room resonances.

The basic items involved in our technique of corner loaded bass trapping have been reviewed and the remaining problem area for controlling room acoustics has been bared by implication: upper bass (250-400Hz). There are too many pressure zones for the field to effectively be depleted. Parallel wall standing waves can exist for a long time even if all the corners of the room had been cut out. For this reason, the standing of 9” diameter trap columns on 3 foot centers along the perimeter of the wall has been one or the many ways the Tube Traps have found use in non-corner applications. We now have developed a flat wall panel Tube Trap, basically a half tube section that provides mixed dispersion and absorption down to 200 Hz.

There is an easy demonstration of the tube trap to show the efficiency of its corner coupling. When a tube is moved out of the corner the mid bass becomes rapidly less damped, while the low bass damping is more slowly reduced. This effect is so strong that moving the traps some 2 feet out from the corner allows the room to sound as if no traps were present.

The last question to answer is how many tubes to use? Calculations and our experience show that one three-foot section per 500 ft/3 room is effective for general listening, and as much as one section per 300 ft/3 treats highly damped control rooms. The 11” Tube Trap provided 15 sabines of absorption per 3-foot section when corner loaded.



SABINES vs FREQUENCY

The Tube Trap is a new acoustic tool that provides access to low end sound control in a manner heretofore unavailable. It is patented here and pending abroad and I am tempted to say that “now, we have a corner on room acoustics control.” The Tube Trap can be listened to in a variety of suites at the show: JBL-UREI, TANNOY, and MONSTER CABLE.

Thank you very much.