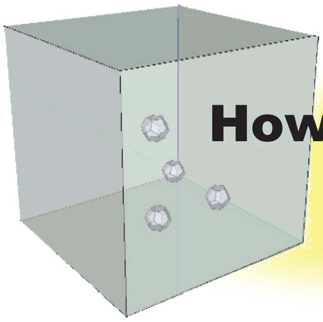


TOOLS OF THE TRADE - BY PAT BROWN

How Boundaries Affect Loudspeakers

It's nearly impossible to mount a loudspeaker in a room without placing it near a room boundary. Some logical questions arise:

1. Does this affect the response?
2. Is the effect good or bad?
3. Can I use the boundary to my advantage?
4. Will treatment help?

Can a room boundary be a "tool of the trade" for the audio practitioner? This study will provide some answers to these questions, and will probably generate a few more.

Space-Loading

Space-loading loudspeakers means that the otherwise spherical radiation is limited by a boundary or boundaries. Some common scenarios are shown in Figure 1, and are often described by the fraction of a sphere to which the radiation is confined. Since these are fractions the correct usage would be "1/n-space" but I have used the common descriptors that omit the "1/".

The classical theory states that the effective gain realized from incoherent summing due to radiation confinement is +3dB for each additional boundary, and that +9dB relative to the free-field response can be achieved by "corner-loading" a loudspeaker. In acoustics the results are never that ideal, so part of my motivation was to determine when this or something different happens. We would certainly expect the boundary interaction be frequency-dependent, and indeed it is. This makes the answers to the boundary questions the usual "it depends."

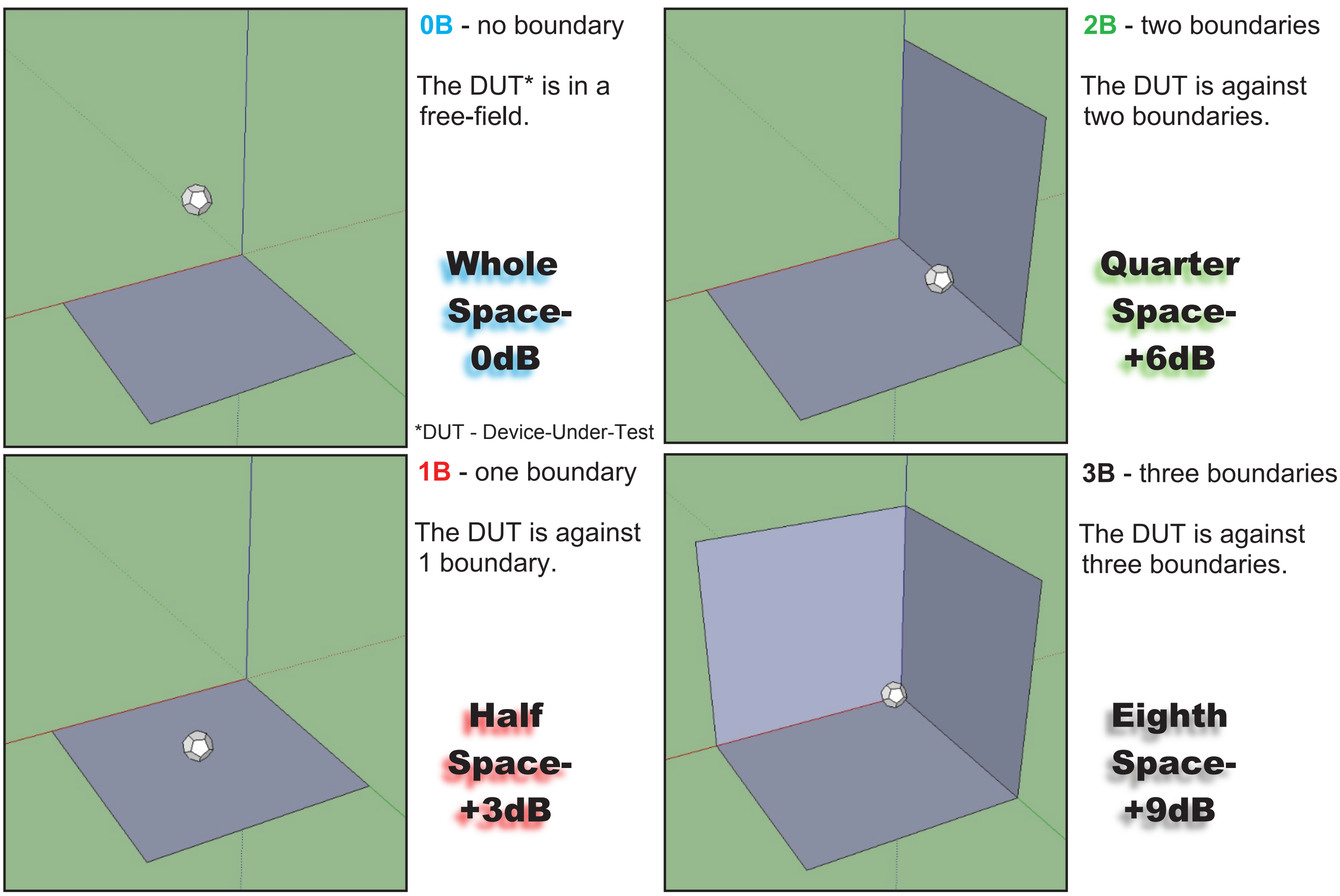
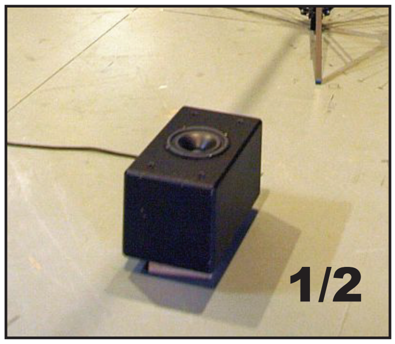


Figure 1 - Space-loading using room boundaries

Figure 2 - Right: The devices measured from left to right: Dodecahedron loudspeaker, bookshelf loudspeaker, subwoofer, medium-format horn. The microphone and a T-square (24") for scale are in the foreground. The remaining photos show the device placements relative to the rigid boundaries.



Overview

The test environment is a large, open space with very rigid boundaries on three surfaces. I select a loudspeaker line-up with some devices commonly used by contractors - a bookshelf loudspeaker, a subwoofer and a medium-format horn (Figure 2). A microphone and dodecahedron were added to round out the field.

Each loudspeaker was first measured on a 12' Genie-lift with the measurement mic in the approximate far-field (1/1-space). Next it was placed on the floor with the mic placed overhead (1/2-space). The floor-wall junction provided the 2-boundary condition (1/4-space), and the floor-wall-wall junction the 3-boundary condition (1/8-space). The mic-to-loudspeaker distance was kept the same for each placement.

The Results

It is always both interesting and educational to compare ideal theory with actual measurements. Some of the results were as expected. Some were as expected with some interesting caveats. There were also a few surprises. The following pages present the data for each device along with some commentary. Some points-of-interest have been highlighted in the plots.

A general conclusion from the measurements is that if your objective is accurate sound reproduction with minimal coloration, it is bad news to place a loudspeaker anywhere near a boundary. *The striking exceptions are that of the horn/driver and the in-wall.* While I often hear horns condemned as "unmusical" or "harsh," they are the only devices that we have that can be placed near boundaries without detrimental effects. How "musical" is a low-directivity loudspeaker whose response is dominated by severe comb filters?

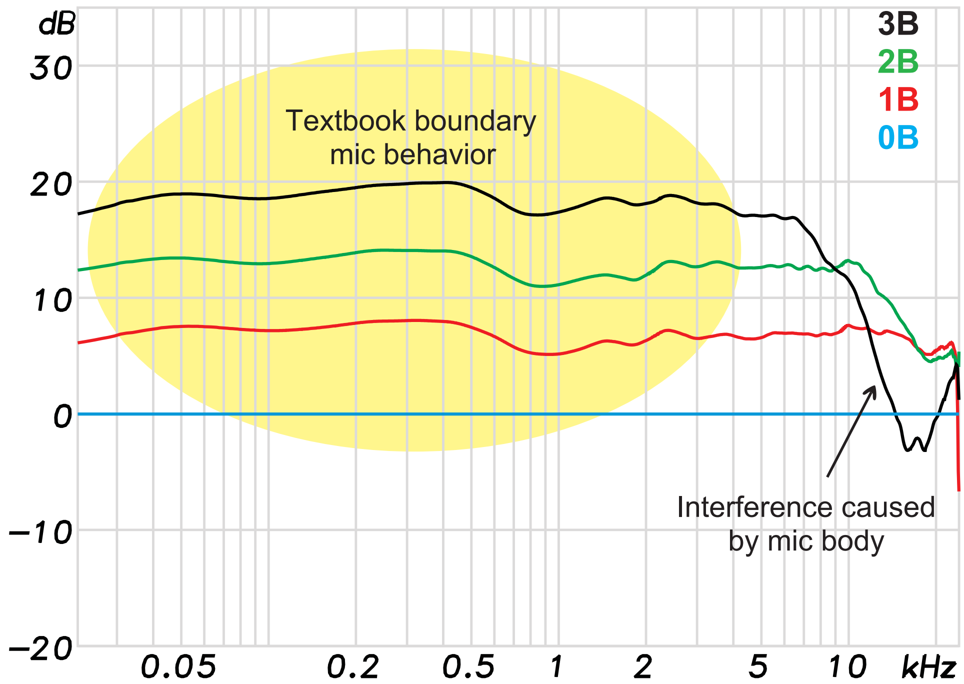
Another conclusion from the study is that equalization is generally inadequate for dealing with boundary interactions. While a "less worse" response may be achieved, far better results come from flying the loudspeaker in free space. Of course there are many applications where such colorations are acceptable, but in ones where they aren't then free space mounting, in-wall or horn loading should be considered.

Boundary loading is often touted as being desirable for subwoofers. While some impressive gains were seen at very low frequencies, it's not likely that the boundaries available for such placements are sufficiently large and rigid to realize these benefits. Room modes will also dominate the subwoofer response in most applications. So, the ear remains the final authority on benefits of boundary-loading subs.

An interesting sidebar to boundary loading a sub is to consider that if the sub is placed on the Genie-lift (shown above) and the mic is placed on the floor (and the mic-to-loudspeaker distance is held constant), there is no increase in level as the sub is lowered toward the floor. Since listeners in an auditorium are near the floor, there may be no net increase in level if the subs are "ground planed" as opposed to flown.

And lastly, from a loudspeaker specification point-of-view, I often seen loudspeaker sensitivities measured in a free-field (correct method for most) and then increased by 6dB and specified as a "half-space sensitivity." The data shows that this is both erroneous and misleading. A graph of the sensitivity will show any benefits or detriments.

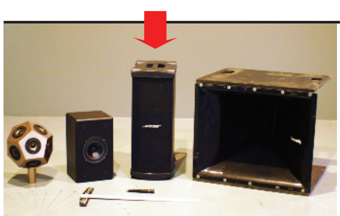
Microphone



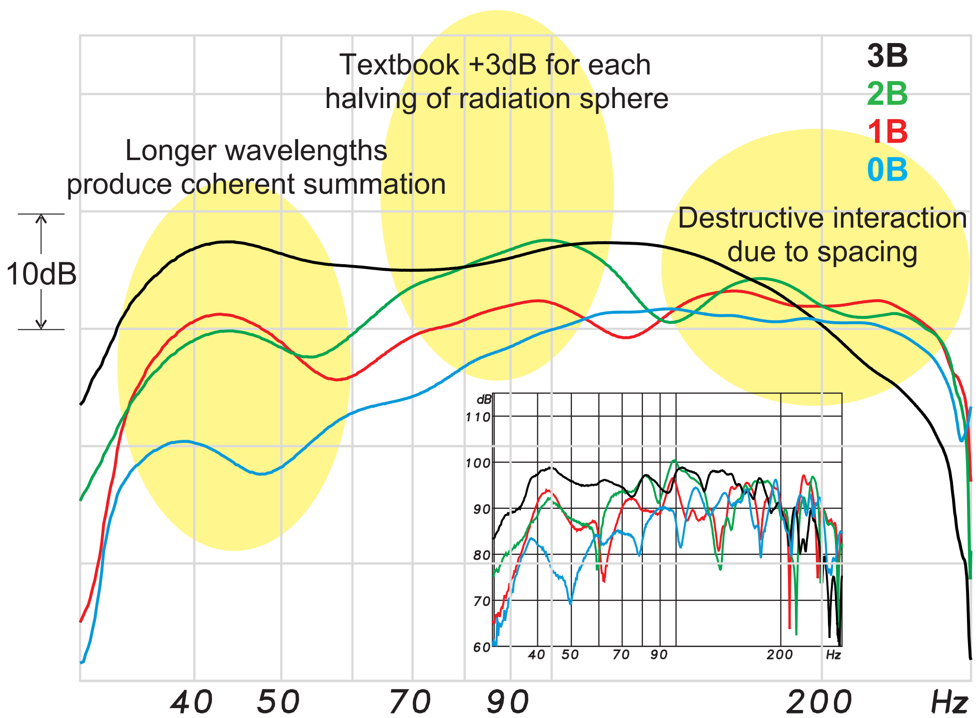
The device tested was a DPA 4007 microphone. A 6" coaxial loudspeaker was used as the sound source. The mic was placed on the HF axis and in the far-field for each measurement. The free-field measurement was used as a reference (0 dB line in the graph at left) and each subsequent measurement shows the *difference* caused by the boundary condition.

The interference above 8kHz for **2B** and **3B** plots is caused by masking/reflections from the microphone body. This is the result of mic capsule being placed at the boundary intersection, which puts the microphone body between the diaphragm and the sound source. This interference could be completely removed by using a very small microphone. The **1B** placement is often used for equalizing loudspeakers that are suspended above large, flat planes (i.e. gym floor).

The gain is +6dB/boundary due to the *coherent* summation of the sound fields. Coherent means that the direct and reflected sound are in-phase at all frequencies of interest. Microphones with small-diameter elements work best for use with boundary techniques.



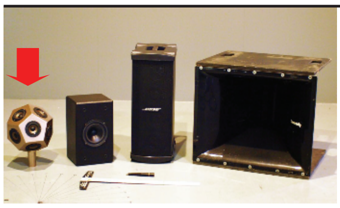
Subwoofer



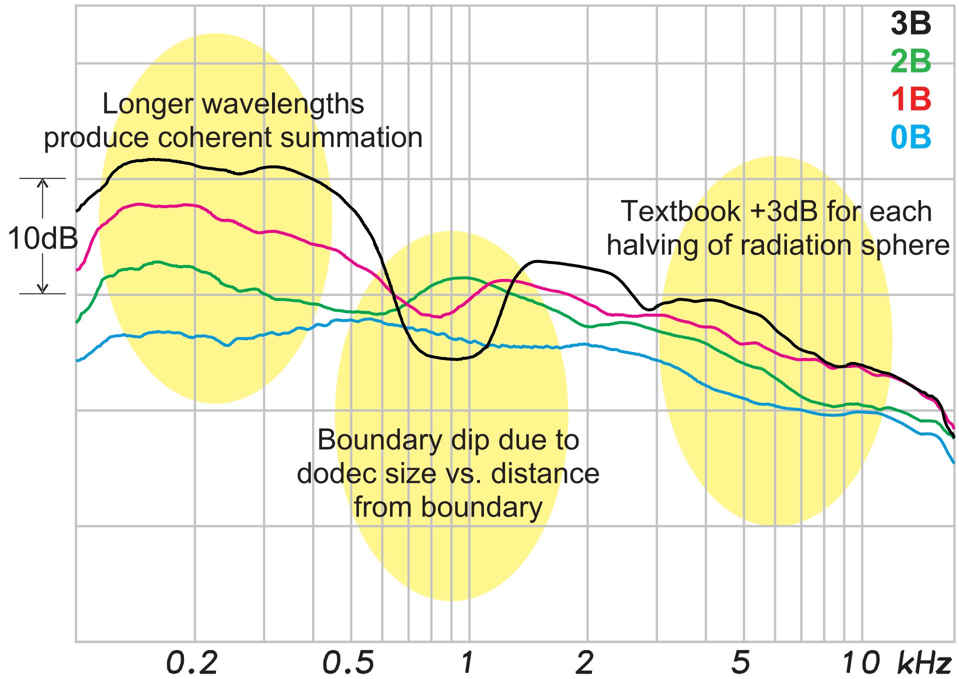
The device tested was a Bose MB4 subwoofer. Each measurement was made in the test room with no time window. This was necessary to achieve adequate resolution at the lowest frequencies. As such, the effects of room modes can be clearly seen in the measured data (see inset plot). I used 1/1-octave smoothing to facilitate observation of the boundary gain. The interference/interaction could be avoided if the tests were made in a larger space, but the size required for true free-field evaluation of a subwoofer would be massive indeed.

Encloses spaces (rooms) have a profound effect on the response of a subwoofer, as does the proximity of the subwoofer to the boundary(ies). An ideal 18dB of gain for coherent summation occurs when the wavelengths are very large relative to the subwoofer size and its proximity to the boundary (40-50Hz). A more modest ~10dB is realized in the upper region of the sub's bandpass (100-125Hz).

The use of room boundaries for subwoofer space-loading should be weighed against even coverage and imaging issues when being considered by the designer.



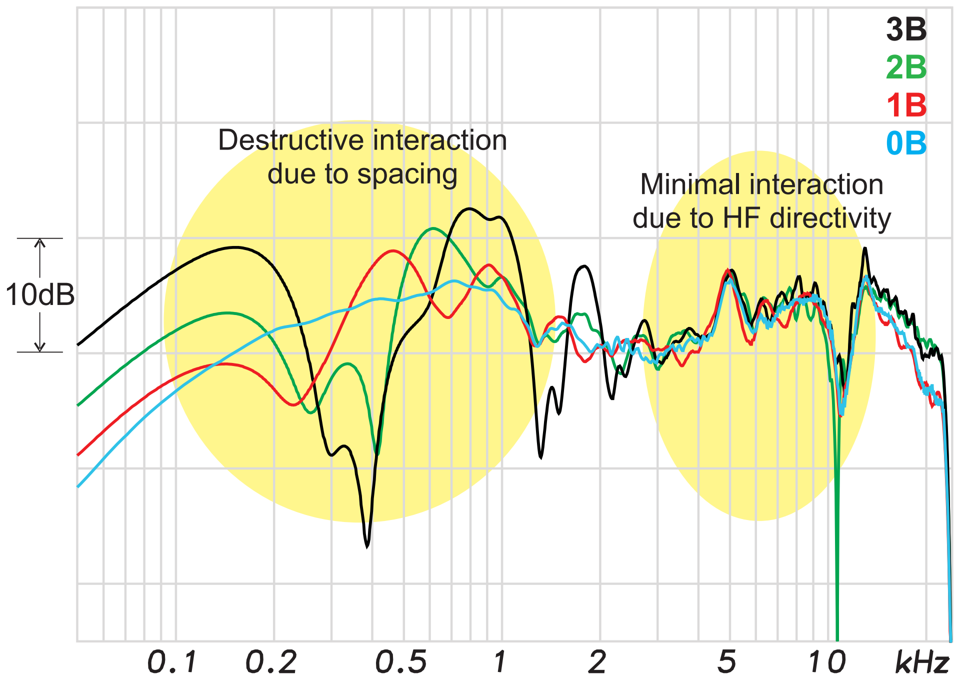
Dodecahedron



The device tested was a dodecahedron (12-sided) loudspeaker. These are often considered omnidirectional for the purpose of making room measurements. Due to the very erratic response, I measured a 9 point grid (2ft square) for each placement and averaged the results. 1/1-octave smoothing was used to produce the final plots for comparison. This was necessary because dodecs inherently exhibit massive comb filtering at HF due to the multiple transducers, and even more so when you add the boundaries. The HF response of the dodec is the "textbook" case for gain due to space-loading for non-coherent summation. Using the free-field response as the reference (0dB), the directivity index increases by 3dB for each additional boundary, with DI = 9dB representative of a corner placement.

This is a good place to point out that massive interference always results from placing low directivity devices near boundaries. In small rooms this may be considered acceptable or even desirable since it results in reduced localization of the sound source. The use of this technique in large, live or reverberant spaces usually results in poor speech intelligibility for the same reason.

Bookshelf



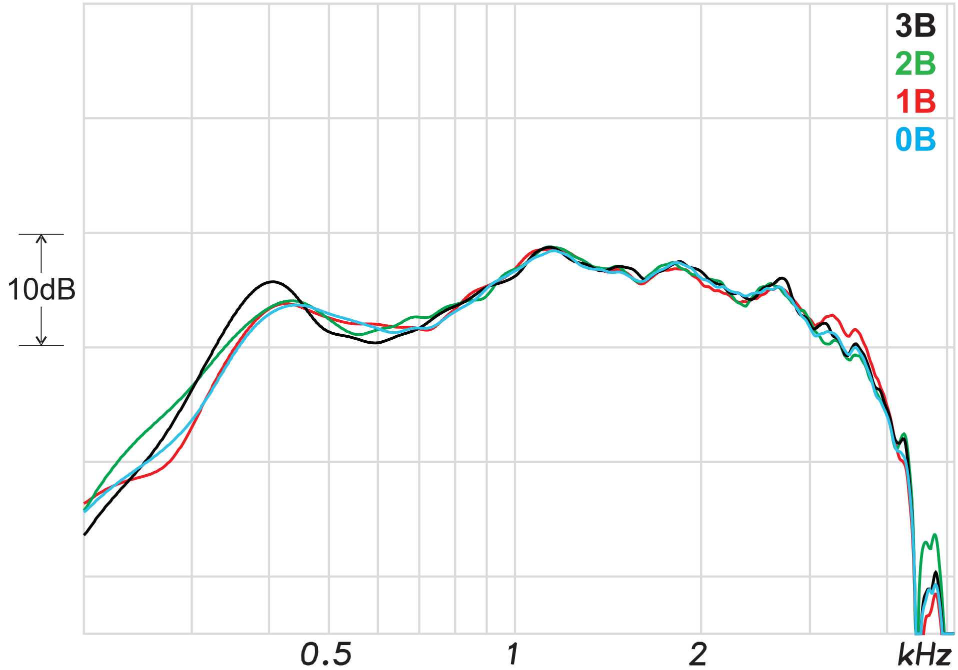
The device tested was a Bag End M-6 coaxial studio monitor - a bookshelf loudspeaker. Each measurement was made on the HF axis. The **1B** measurement was made with the loudspeaker's back against the floor. The **2B** and **3B** measurements were made with the loudspeaker at 45deg to the boundary, such as it might be mounted at the intersection of a wall and low ceiling.

Note that above 3kHz there is negligible boundary interaction, since the loudspeaker becomes so directional that the HF energy misses the boundary altogether. At LF there is gross interaction, including "boundary dip" and some significant bumps. Equalization is sometimes used to smooth the bump and compensate for the LF rise seen below 200Hz.

This presents a particularly bothersome dilemma since bookshelf-sized loudspeakers are the most common types used in small rooms, and it's almost a given that they will be located near room boundaries. If accurate sound reproduction is an objective then the system designer is faced with a challenge.

Two solutions to the interference problem are presented on page 9.

Mid-Range Horn



The device tested was a Community 60x40 medium-format horn with M200 mid-range driver. The size is large enough to provide pattern control through 500Hz. This device could be used stand-alone for paging, or augmented with a HF and LF for full-range applications.

The horn offers some significant benefits for sound reinforcement applications, so I have devoted more space to describe the tests and benefits.

The pattern control afforded by the horn prevents the sound energy from hitting the boundary. The result is almost no change in response, irregardless of the boundary condition. If this loudspeaker were equalized off-site for a flat axial frequency response magnitude, it would still be flat after the loudspeaker is installed, negating the need for additional equalization. Also, only a couple of parametric filters would be required to flatten the direct field response.

Horns combine space-loading with increased efficiency. The horn acts as an acoustic transformer to increase power transfer to the air. This results in much higher levels than space-loading alone would produce.

Frequency-dependence

The benefits of horn loading can be extended to other portions of the spectrum, both above and below the mid-range data shown for this device. It's just a matter of scale. A smaller horn can be used for HF pattern control and a larger one for LF pattern control. With horns, size is everything.

One Scenario, Two Solutions

Imagine the typical scenario of the need to mount a full-range loudspeaker at the ceiling/wall junction (1/4-space). The first device considered is the typical front-loaded multi-way box, selected for its "musicality" and compact size. The data shows that we can expect massive interference from interactions with the boundaries. Neither equalization nor treatment can be used to restore the free-field response of the loudspeaker. Even the popular and highly-regarded line array would have massive interference if placed near, but not in, a boundary.

Next, let's use two of the boundary interference solutions described in this study. A large-format horn is used to extend the pattern control down to 250Hz. The device is large, so it can be recessed into the boundary if necessary (Figure 3). A coaxial, co-entrant or "synergy horn" is added to extend the response to the desired HF limit. If a subwoofer were placed at the same location it would realize some boundary size-dependent space loading and a significant increase in efficiency.

This is truly a broad band solution to the problem and illustrates what was concluded at the EQ07 Workshop - equalization begins at the drawing board stage of a project. If you want smooth response you have to design for it. Failure to consider loudspeaker/boundary interactions can result in uneven frequency response, spotty coverage, poor intelligibility and over-equalized sound systems.

The bottom line? Horns are immune from boundary effects and boundary affects are one of the biggest detriments to high quality sound. *pb*

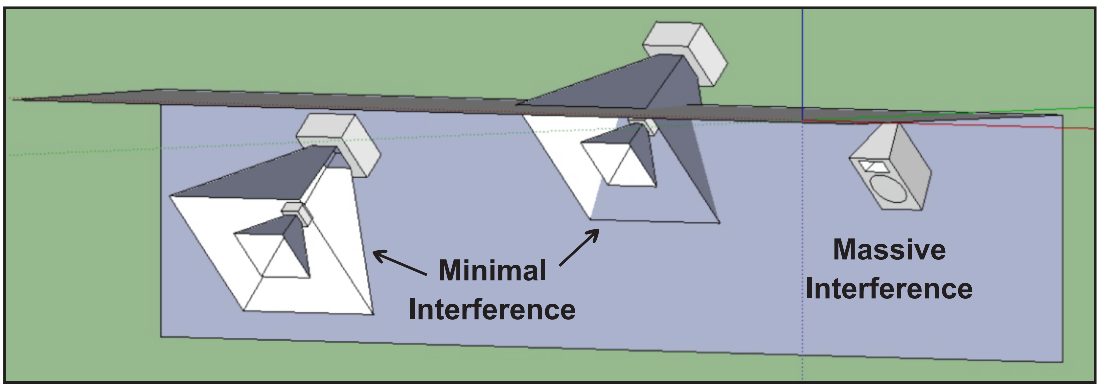


Figure 3 - Good physics and clever engineering can exploit the benefits of pattern control and boundary interaction avoid the destructive interference that plagues so many sound systems.

Boundary Interference Solutions

The Problem

Let's face it. There are many applications where the loudspeaker must be mounted near a boundary. Since I had things setup anyway, I decided to try some methods often used to tame the boundary interaction. The bookshelf loudspeaker was measured since it is often used in small-room systems. Figure 1 shows a comparison of the free-field response, one-quarter space response and treated response. While it can be said that the treatment produced a change, I would not call it a fix. Also, this is far more aggressive treatment than would typically be used in an actual sound system, where 1" mineral wool panels are sometimes used to "clean up" the boundary interference.

I thought it would be a shame to not go one step further and test an in-boundary mounting. One wall of the test room has a cut-out used for testing ceiling loudspeakers. I cut an insert from MDF and mounted the bookshelf loudspeaker in the cutout (Figure 2). Voila! One can see why this method is a favorite of recording studios and other critical listening environments. There is no boundary interaction at HF, and the LF response rises as the boundary comes into the equation. This response rise can be corrected with equalization, restoring the loudspeaker response to that measured in a free-field. I had intended to also try some absorption on the boundary, but decided that the effect would be minimal.

A third solution is to keep the loudspeaker away from the boundary altogether. Studios sometimes use "near-field" monitors for this purpose, meaning that they are placed in close proximity to the listener. This leaves only the reflection from the console face to interfere with the direct field.

Treatment

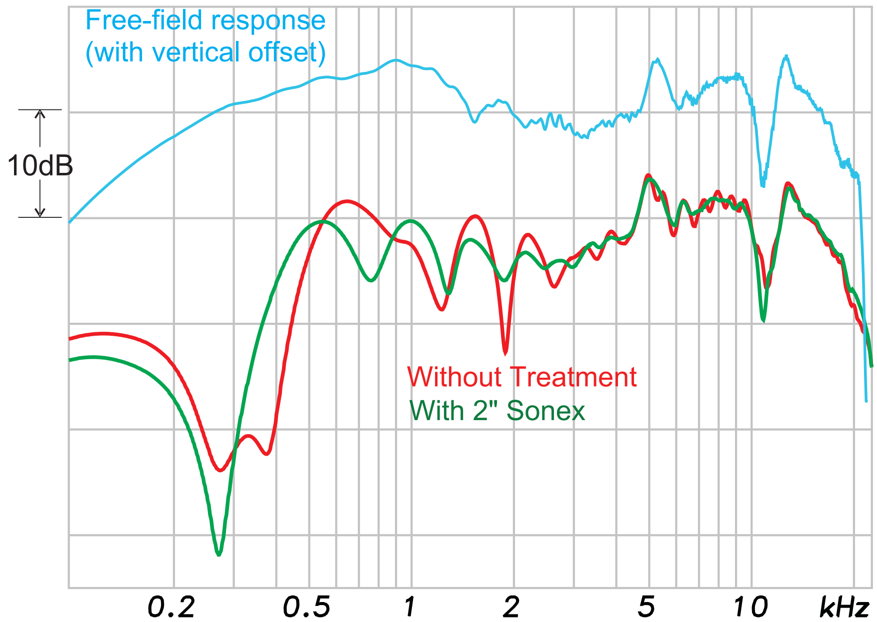
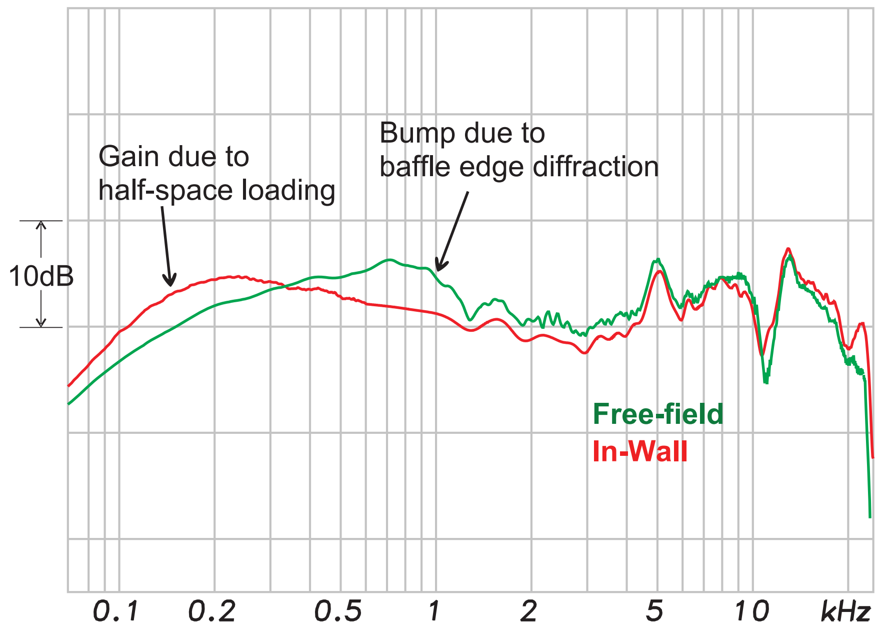


Figure 1 - Treated boundaries

In-Wall



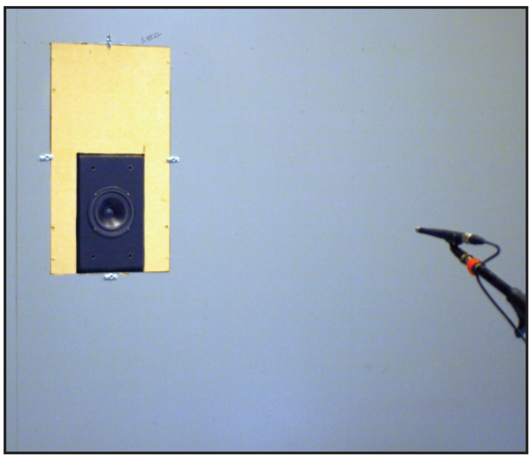


Figure 2 - In-wall mounting of bookshelf loudspeaker