119th AES Convention, NY, October, 2005 - Tutorial

T1 - The Acoustics and Psychoacoustics of Loudspeakers in Small Rooms: A Review

Presenter:
Floyd Toole, Harman International Industries, Inc. - Northridge, CA, USA

Abstract:
The physical measures by which acousticians evaluate the performance of rooms have evolved in performance spaces—concert halls, opera houses, and auditoria. They rely on a set of assumptions that become progressively less valid as spaces get smaller and more acoustically absorptive. In live performances, sound sources radiate in all directions and the room is a part of the performance. In sound reproduction, loudspeakers tend to exhibit significant directivity, and what we hear should ideally be independent of the listening room. What, then, should we measure in small rooms? What configuration of loudspeakers and acoustical treatment is appropriate for multichannel audio reproduction? To what extent can we "eliminate" the room? Or, do we need to? Is there a point beyond which the human hearing system is able to adapt to the listening space—hearing "through" the room and "around" the reflections to accurately perceive the source? A certain amount of the right kind of reflected sound appears to enhance the music listening experience and, interestingly enough, to improve speech intelligibility. In this tutorial we review some of the basic science, using existing knowledge to provide guidance for choosing and using loudspeakers in rooms, and pointing out gaps in our knowledge— subjects for future research.

Excerpt from a review article in Multimedia Manufacturer Magazine, March/April 2006, about 'Conventioneering' by David J. Weinberg

http://www.multimediamanufacturer.com/articles/weinberg-conventioneering.pdf

The Acoustics and Psychoacoustics of Loudspeakers in Small Rooms: A Review.
For example, Floyd Toole gave this much more technical and extended version of his CEDIA talk. From the convention program tutorial synopsis: "The physical measures by which acousticians evaluate the performance of rooms have evolved in performance spaces. They rely on a set of assumptions that become progressively less valid as spaces get smaller and more acoustically absorptive. In live performances, sound sources radiate in all directions, and the room is a part of the performance. In sound reproductions, loudspeakers tend to exhibit significant directivity, and what we hear should ideally be independent of the listening room. What, then, should we measure in small rooms?—To what extent can we eliminate the room? Or do we need to? Is there a point beyond which the human hearing system is able to adapt to the listening space—hearing through the room and around the reflections to accurately perceive the source? A certain amount of the right kind of reflected sound appears to enhance the music listening experience and, interestingly enough, to improve speech intelligibility."

Toole has concluded that normal reflections in a typical small living room seem not to interfere with perception of the recorded space. He has also determined that early lateral reflections (<50ms) have a beneficial effect on intelligibility similar to raising the dialog level, and that the reflection pattern is more important than reverberation.

This has led to Toole's recommendation that too many or too few reflections can be a problem. In particular, acoustic absorption, diffusion, and reflection must be broadband, ideally starting below 200Hz. He pointed out that the typical 1″ or 2″ sound panel most often affixed to walls works only at relatively high frequencies, and acts to effectively turn down the tweeter with no effect on the midrange or upper bass, thus unbalancing the sound.

Toole reminded us that many of the practices to deaden a room's acoustics came from standards for broadcast and recording control rooms, where sound details must be heard more clearly, not for general listening rooms.

Harman testing has shown that sonic anomalies which are audible while the listener is moving around become much less obvious once the listening position is essentially fixed (the listener sat down!). Toole spoke of comb filtering, and has deduced that it is an artifact of measurement, not an audible problem in normal listening. We are less sensitive to room resonances in music than in broadband noise—our hearing is sensitive to the frequency response effects, not the time domain ringing, particularly in a reflective space, due to our "multiple looks" at the signal (except in the bass range, where both are factors). Audibility thresholds decrease with repetition and duration in reflective rooms.

Humans seem to be able to adapt to a room's acoustics, up to a point. Thus, we should be able to predict real-room performance from a proper set of anechoic measurements, except for bass issues below about 300Hz. In Harman's listening tests, low-frequency performance accounts for about 30% of a speaker's rating.

Harman testing has shown that speakers with a fairly flat on-axis response and with a smooth and gentle off-axis level fade and roll-off are preferred by expert and amateur listeners. A speaker with an off-axis response that differs substantially from its on-axis response cannot be corrected with an equalizer. In-room measurements lower the accuracy of the data since they include a mix of direct and reflected sound. Since with most speakers the reflected sound has a different frequency response than the direct sound, an equalizer will cause more problems than it will cure.

He also noted that spatial-averaging of speaker measurements is critical —single-point measurements are erroneous and meaningless. Also, many types of measurements are required to characterize the sound, and that 20th-octave data is necessary to unmask narrow-bandwidth frequency response problems that would be averaged out and masked in third-octave measurements.

Regarding bass, the Schroeder frequency is that threshold above which room resonances are considered so close together that they can be ignored with respect to frequency response anomalies. Toole has found that this works for large rooms, but the formula for its calculation yields too low a frequency for small rooms. In fact, Toole believes that calculation of room resonances is irrelevant in real home listening rooms, because not all modes have an equal effect or are heard equally, since there are multiple sources (speakers), and because all the formulas are based on a source in a corner with the measurement taken in the opposite corner (where there is never a listener). This has led to Harman's recommendation to use four subwoofers in the center of each wall to provide the most uniform bass over the largest listening area in the widest range of small-room sizes; it reduces, and sometimes eliminates, the need for bass EQ.

(Underlined emphasis added by SL)