“Room EQ” is a misnomer

- We can only modify the signals supplied to loudspeakers in the room.
- Reflections cannot be added or removed
- Reverberation time cannot be changed
- Seat-to-seat variations in bass cannot be reduced
- We cannot change the frequency-dependent directivity (DI) of loudspeakers, or the frequency-dependent absorption of acoustical materials and furniture.
- We must not EQ room curve irregularities caused by non-minimum-phase phenomena.

109

In small rooms, ***below the transition frequency,*** a special strategy is needed:

- All rooms will be different
- All seats in the room will be different
- Bass quality and quantity is about 30% of our assessment of overall sound quality.

Normally, EQ can attenuate the minimum-phase low frequency room resonances but only at a single seat.

110

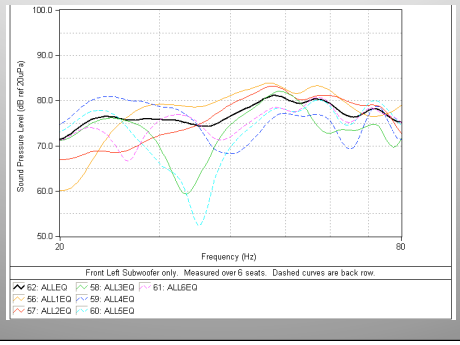
With our present knowledge of room modes/standing waves:

- Using multiple subwoofers we can selectively amplify or attenuate specific low frequency modes in rooms.
- In *rectangular rooms* certain arrangements of two or four subwoofers can reduce seat-to-seat variability in a central listening area.
- In *rooms of arbitrary shape*, multiple subwoofers, measurements and signal processing can attenuate most room modes, providing even better seat-to-seat consistency. Harman’s “Sound Field Management” is one such solution.
- Then EQ can be beneficial for several seats.

Toole, *Sound Reproduction*, Focal Press, 2008, Chapter 13

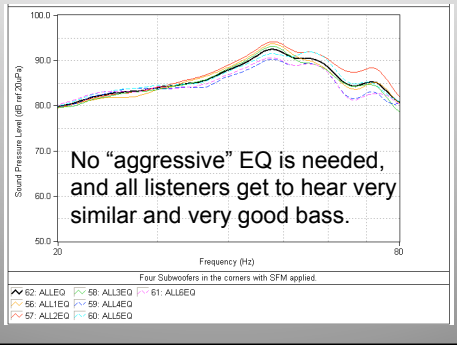
111

A typical example: front left subwoofer only



112

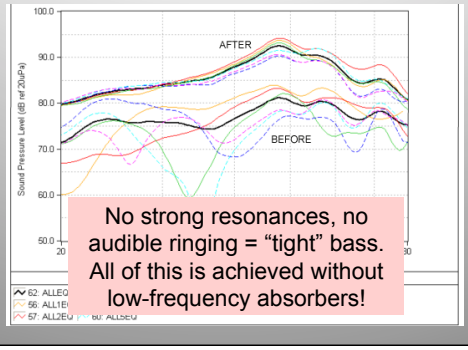
Four subwoofers with Sound Field Management



No “aggressive” EQ is needed, and all listeners get to hear very similar and very good bass.

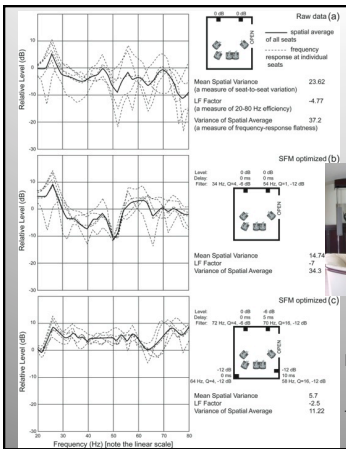
113

A Direct Comparison

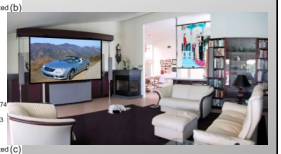


No strong resonances, no audible ringing = “tight” bass. All of this is achieved without low-frequency absorbers!

114



My own listening room



Note the signal levels!

Toole, *Sound Reproduction*, 2008, Figure 13.18

So we think we understand something about the physical sound field in rooms.

Does any of this translate into being able to anticipate better sound reproduction?

116

A definitive test: part one

- Perform double-blind listening tests on 70 loudspeakers of many brands, sizes and prices.
- The result: subjective ratings on a scale of 10.

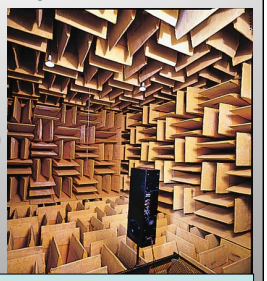
These are ratings of sound quality *in a normal room!*

117

A definitive test: part two

- Develop a model for predicting subjective ratings from an analysis of “Spinorama” anechoic measurements on the 70 loudspeakers.

Rating = 12.69 – 2.49*NBD_ON – 2.99*NBD_PIR – 4.31*LFX + 2.32*SM_PIR



These are descriptions of the sound source *only!*

118

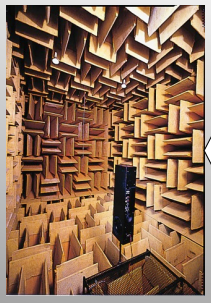
A definitive test: part three

- Correlate the real subjective ratings with the calculated preference ratings.
- The result: a correlation coefficient of 0.86
- 1.0 would be perfect; this is almost there!

Sean Olive: AES preprint 6113, 2004, preprint 6190, 2004

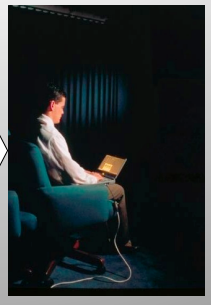
119

From anechoic data, we have predicted in-room subjective ratings



Correlation coefficient

0.86!



And the best loudspeakers sound best!

Leveling the playing field makes the result even more impressive

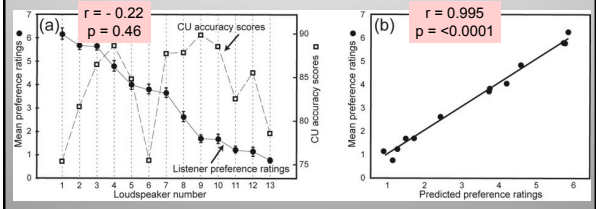
- The 70 loudspeakers in the original test population included expensive ($20k/pr) floor-standing models (full bandwidth) as well as small inexpensive bookshelf models (restricted bass).
- The following data show a comparison of similarly sized and priced bookshelf units – the same 13 models used in a contemporary Consumers Union (CU) published comparison test.

121

CU calculated accuracy scores from 1/3-octave sound-power measurements and these were the principal factor in their ratings, best to worst, down the page of the magazine. No subjective evaluations.

The listener preference ratings shown below are from balanced double-blind, positional substitution, evaluations.

The predicted preference ratings are from Olive’s processing of Spinorama data.

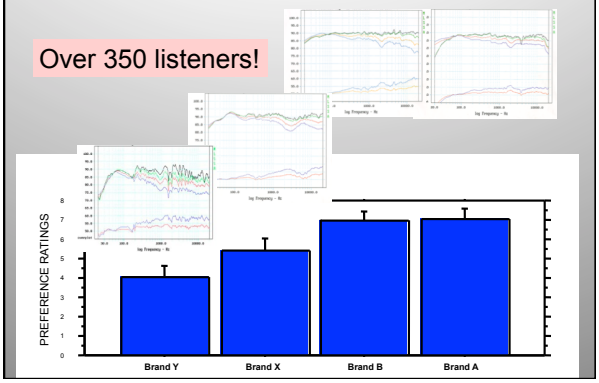


After these results were published, CU interrupted loudspeaker evaluations and upgraded their process.

122

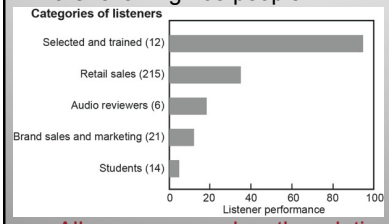
Persuasive visual correlations

Over 350 listeners!



Whose opinion can we trust?

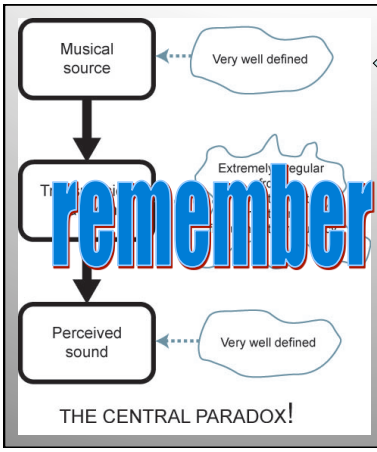
The previous test included over 350 listeners by the time it was terminated. Among them were the following 268 people:



Listener performance is based on the F_L statistic, a measure of the consistency of repeated judgments and the strength of rating differentiation.

All groups agreed on the relative rankings of the products. (Olive, JAES, pp.806-825, 2003)

124



remember this?

If we can adequately describe the [illegible] be able to predict what is perceived in a room.

125

What does Olive’s predictive algorithm tell us about loudspeakers?

- For music, a smooth, flat on-axis response is preferred.
- The DI should be smooth and relatively constant.
- Smooth on and off-axis curves – i.e. absence of resonances – yields higher scores. [Spatial averaging of measurements separates resonances (bad) from acoustical interference (not always bad).]
- 1/20-octave data yield better correlations than 1/3-octave data. Conclusion: fine details are audible.
- Bass performance accounts for about 30% of the factor weighting.

126

A parallel with musical instruments?

- Jürgen Meyer, at PTB in Braunschweig, 30 years ago told me that a basic indicator of excellence in musical instruments was a uniform acoustical output over the playable frequency range. They had elaborate schemes to measure it.
- In 2008 Bissinger (JASA) tells us that “the best violins . . . are more “even” across the measured range, and strong in the lowest range”.
- To me this sounds remarkably like:
  “a flat frequency response and good bass”

127

Can we predict sound sound quality from manufacturers’ specifications?

128

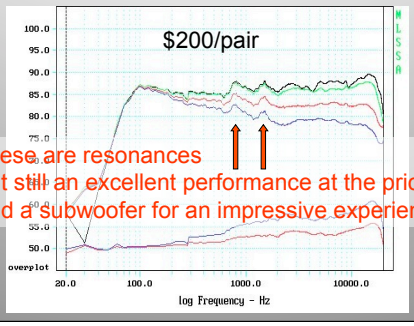
$200/pair

“Frequency response: 58 Hz – 22 kHz ± 3 dB”

The curve contains more information

129

But, more is learned when we see *all* of the curves



These are resonances
But still an excellent performance at the price.
Add a subwoofer for an impressive experience.

130

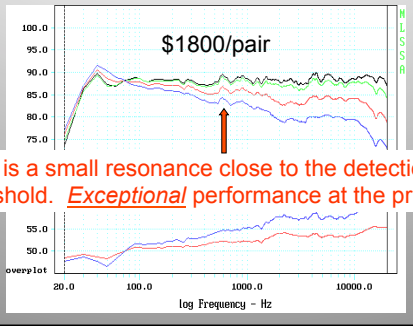
$1800/pair

“Frequency response: 28 Hz – 22 kHz ± 3 dB”

This curve is better than the specification suggests!
The marketing department slavishly followed the ± 3 dB industry tradition.

131

But, more is learned when we see *all* of the curves

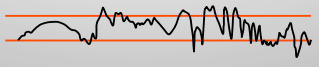


This is a small resonance close to the detection threshold. *Exceptional* performance at the price!

132

$11,000/pair

“Frequency response: 28 Hz – 22 kHz, ±3dB”

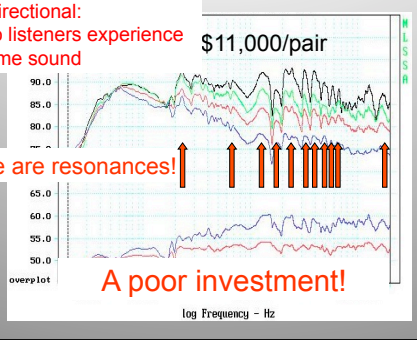


With substantial spectral smoothing, maybe . . . but that would be cheating!

133

But, more is learned when we see *all* of the curves

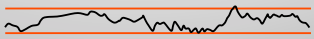
Very directional:
No two listeners experience the same sound



134

$20,000/pair

“Frequency response: 32 Hz – 28 kHz ± 3 dB on reference axis”

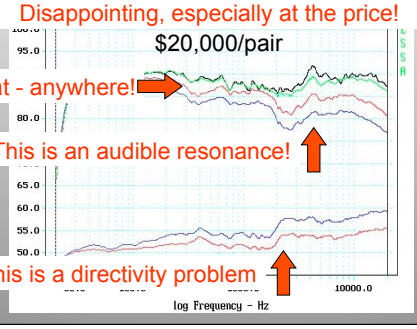


Meets the spec, but no prizes.

135

But, more is learned when we see *all* of the curves

Disappointing, especially at the price!



136

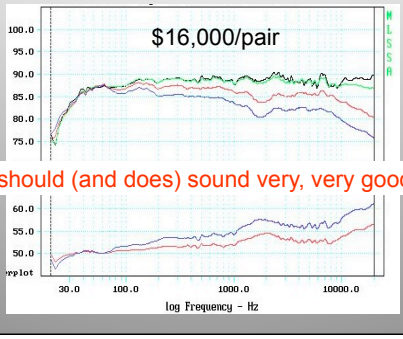
$16,000/pair

“Listening window response: 33 Hz - 20 KHz *± 1.0 dB”*

An aggressive specification, but how does it sound?

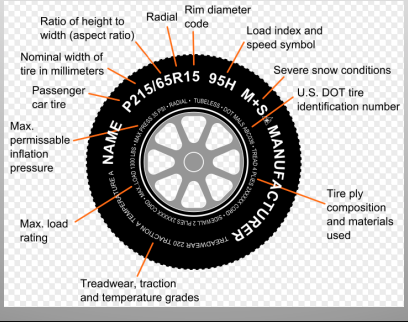
137

But, more is learned when we see *all* of the curves



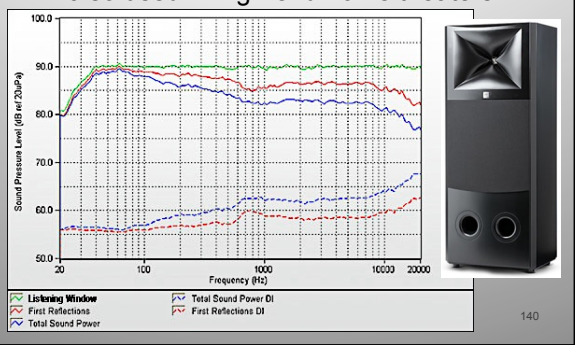
138

There is more *useful and reliable* information on the side of a tire than in most loudspeaker specifications!



139

An example of the state-of-the-art.
An active professional control-room monitor also used in high-end home theaters



140

The future is here.
It’s just not widely distributed yet.
William Gibson

ANSI/CEA Standard

Standard Method of Measurement for In-Home Loudspeakers

ANSI/CEA-2034

November 2013

But this new standard incorporating the spinorama method should help . . .

141

Two problems:

- Many manufacturers do not have the capability of making the necessary measurements.
- Some manufacturers, when they see such data on their products, would not want it to be made public.

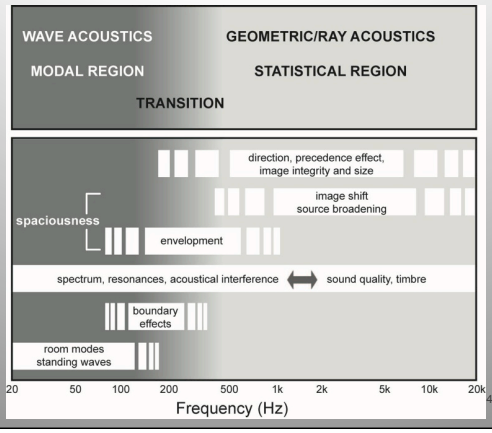
This sets the stage for some independent evaluators with access to competent measurements. It could be a game changer.

142

PART 2: Room Acoustics

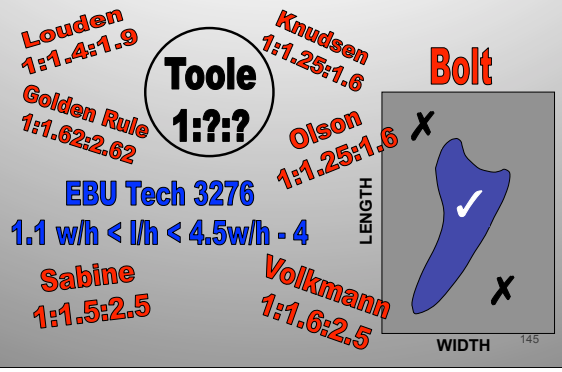
The loudspeaker, the room and the listener form a *system.* The loudspeaker is the dominant factor, but the room cannot be ignored.

143



144

Is There an “Ideal” Room Shape?



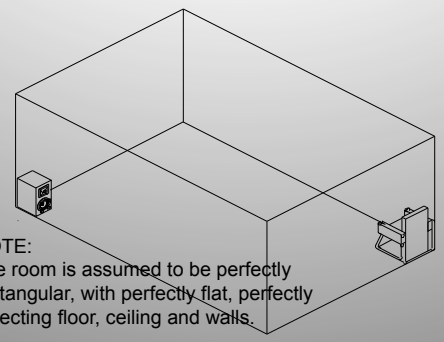
145

Not wrong, but *irrelevant* in sound reproduction

- Assumption: that all room modes are equally energized by the speakers –they are not.
- Assumption: that all of the modes are equally heard by the listener(s) – they are not.
- Assumption: that all classes of modes – axial, tangential and oblique – are equally important – they are not.
- The only modes that matter are those involved in the transfer of sound energy from the loudspeakers to the listener(s).

146

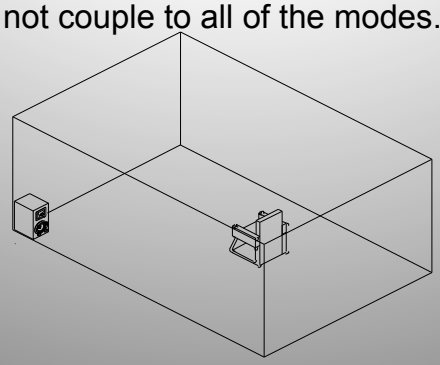
The listening arrangement assumed for ‘ideal room’ calculations – all modes are energized and heard.



NOTE:
The room is assumed to be perfectly rectangular, with perfectly flat, perfectly reflecting floor, ceiling and walls.

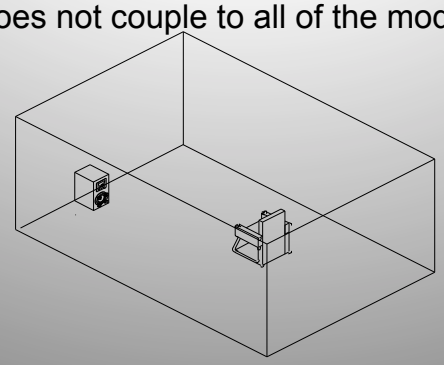
147

A practical listening location does not couple to all of the modes.



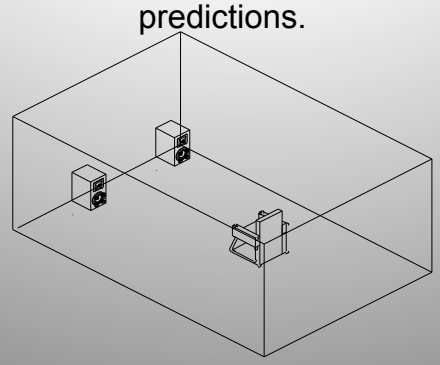
148

A practical loudspeaker location does not couple to all of the modes.



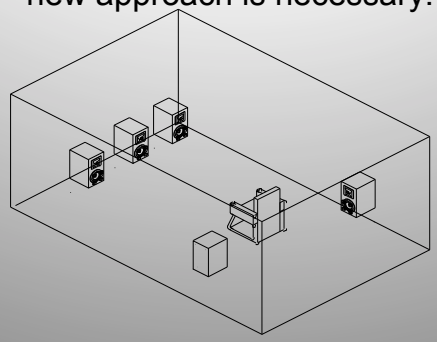
149

Two loudspeakers void the predictions.



150

And with five loudspeakers a whole new approach is necessary!



151

Which is why none of these matter!

Louden 1:1.4:1.9

Knudsen 1:1.25:1.6

Golden Rule 1:1.62:2.62

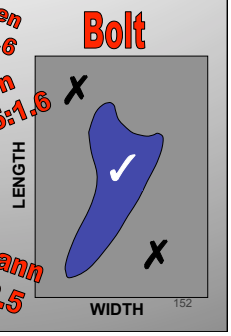
Olson 1:1.25:1.6

EBU Tech 3276

1.1 w/h < l/h < 4.5w/h - 4

Sabine 1:1.5:2.5

Volkmann 1:1.6:2.5

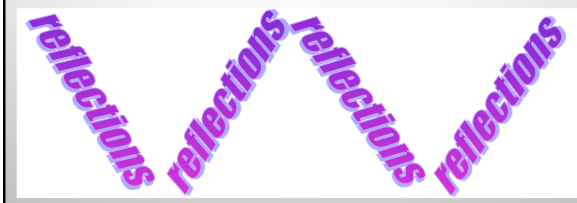


152

This is why it is sensible to employ multiple-woofer strategies to manage the standing waves/ modes below the transition/ Schroeder frequency.

Above this frequency we must focus on the audible effects of reflected sounds.

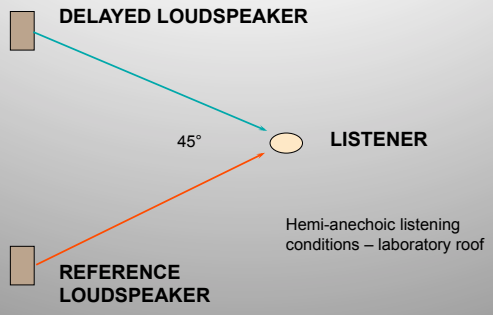
153



The story begins with Precedence / Haas / First-Wavefront effect.

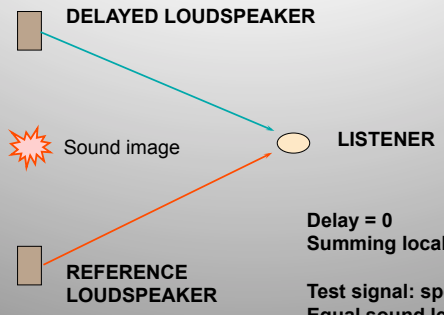
154

The basic experiment set up by Haas (1949) and others before and since.



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

155

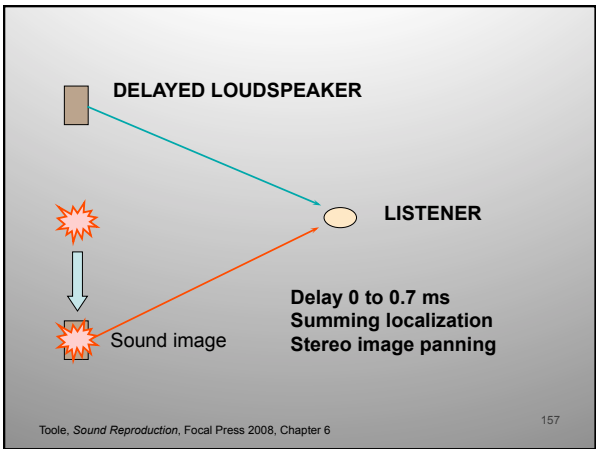


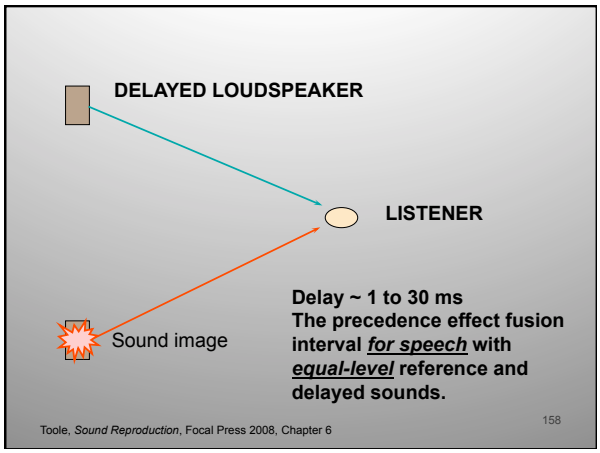
Delay = 0
Summing localization

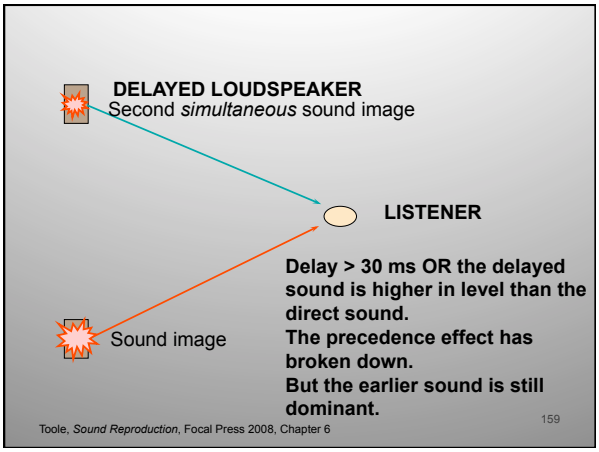
Test signal: speech
Equal sound levels both channels

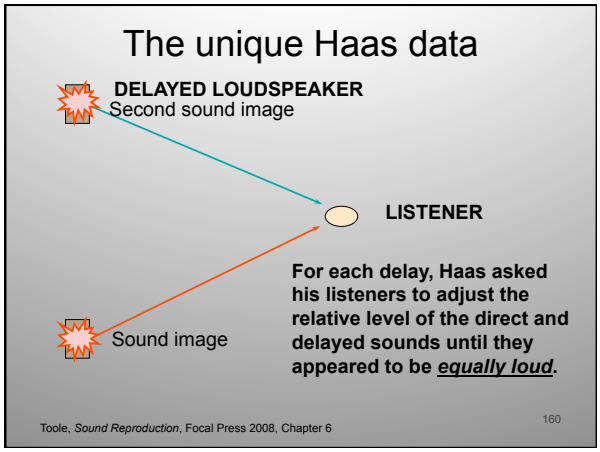
Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

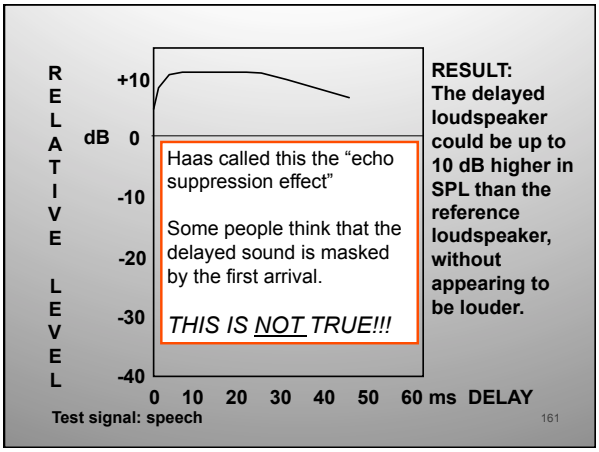
156

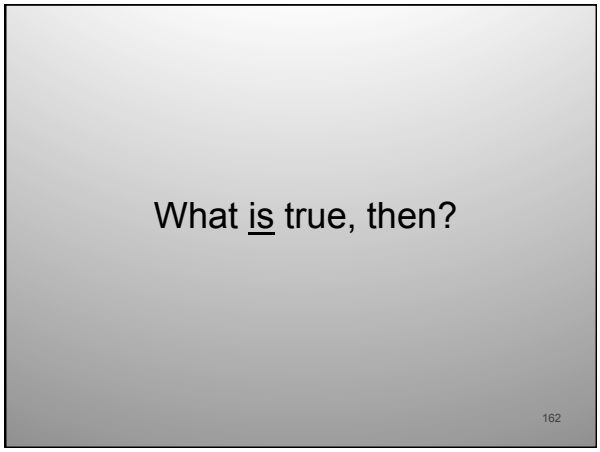

DELAYED LOUDSPEAKER
LISTENER
Sound image
Delay 0 to 0.7 ms
Summing localization
Stereo image panning
Toole, Sound Reproduction, Focal Press 2008, Chapter 6
157

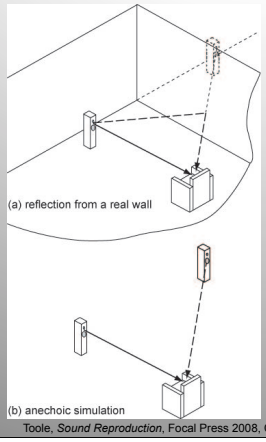

DELAYED LOUDSPEAKER
LISTENER
Sound image
Delay ~ 1 to 30 ms
The precedence effect fusion interval for speech with equal-level reference and delayed sounds.
Toole, Sound Reproduction, Focal Press 2008, Chapter 6
158


DELAYED LOUDSPEAKER
Second simultaneous sound image
LISTENER
Sound image
Delay > 30 ms OR the delayed sound is higher in level than the direct sound.
The precedence effect has broken down.
But the earlier sound is still dominant.
Toole, Sound Reproduction, Focal Press 2008, Chapter 6
159


The unique Haas data
DELAYED LOUDSPEAKER
Second sound image
LISTENER
Sound image
For each delay, Haas asked his listeners to adjust the relative level of the direct and delayed sounds until they appeared to be equally loud.
Toole, Sound Reproduction, Focal Press 2008, Chapter 6
160


RELATIVE LEVEL
dB
+10
0
-10
-20
-30
-40
0 10 20 30 40 50 60 ms DELAY
Haas called this the “echo suppression effect”
Some people think that the delayed sound is masked by the first arrival.
THIS IS NOT TRUE!!!
RESULT:
The delayed loudspeaker could be up to 10 dB higher in SPL than the reference loudspeaker, without appearing to be louder.
Test signal: speech
161


What is true, then?
162

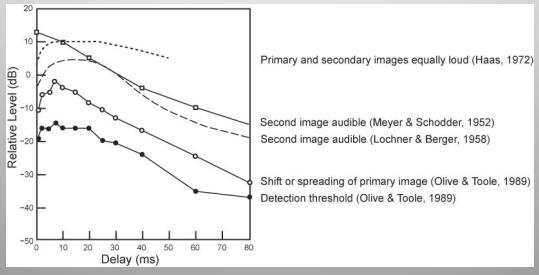


Experiments investigate the audible effects of individual reflections

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

163

The audible effects of a single lateral reflection for speech



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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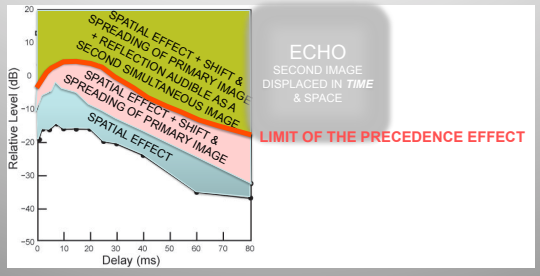
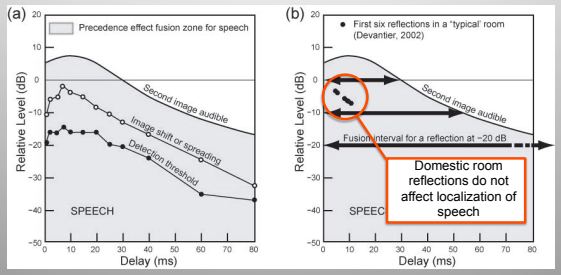
The audible effects of a single lateral reflection for speech



165

The precedence effect fusion interval and zone *for speech*



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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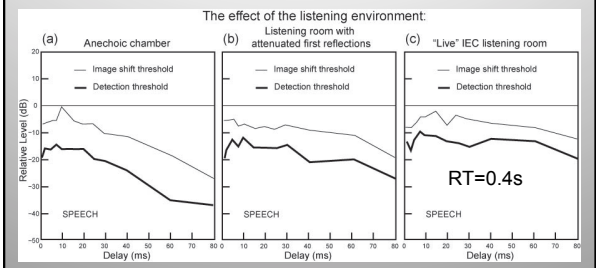
The effects of other room reflections on the audibility of an individual lateral reflection



Reflections in rooms elevate all thresholds

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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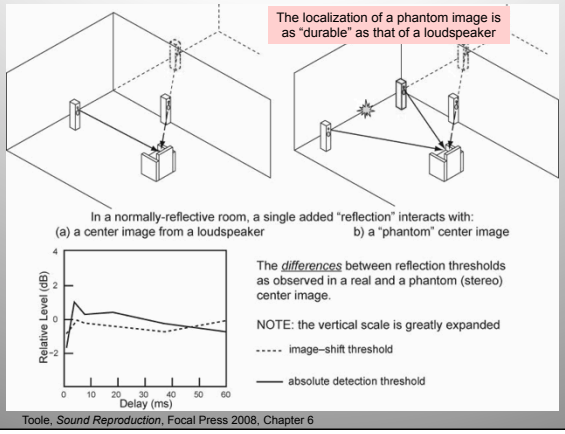
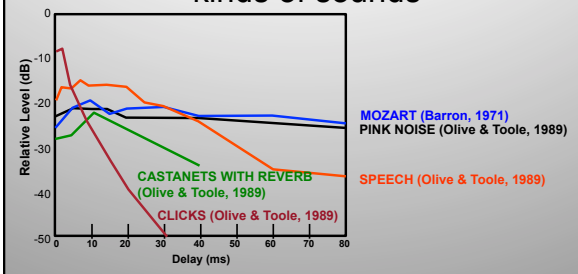


Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

Detection thresholds for different kinds of sounds



There is a progression from continuous to discontinuous sounds

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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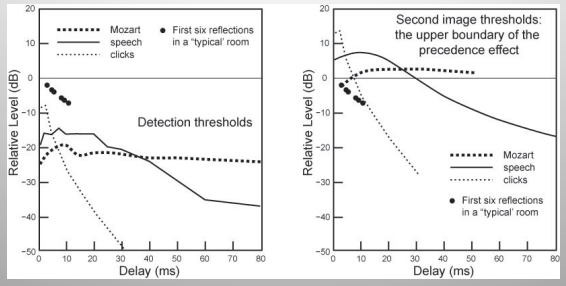
Single reflections in small rooms



They are all audible . . .

but not loud enough to disrupt the precedence effect

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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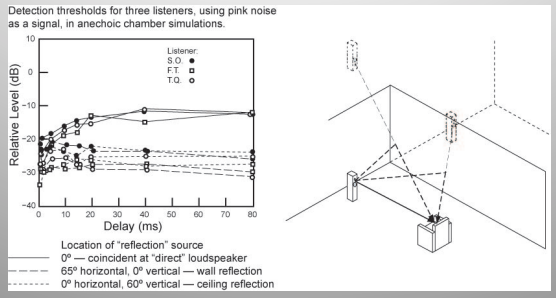
The effect of incident angle



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 6

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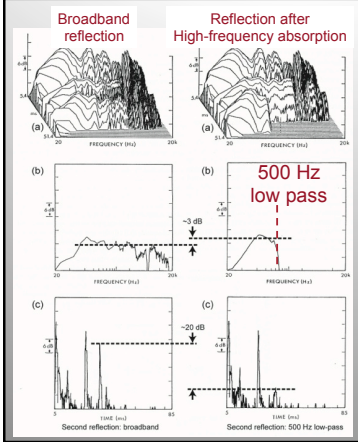


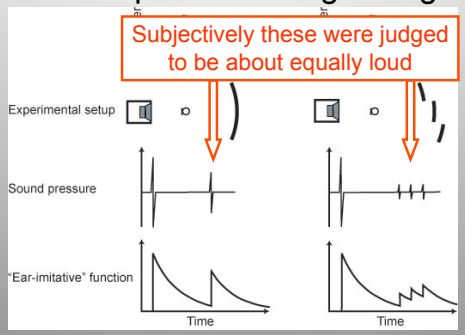
The effect of spectrum

The detection threshold of a reflection is more reliably revealed by *spectrum level* than by a broadband, spectrally “blind” impulse response or ETC.

The audible effect will be different but it will still be audible.

Toole, *Sound Reproduction*, Figure 6.18

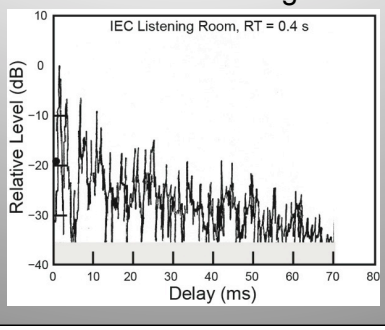
Does breaking a reflection into smaller “pieces” change things?



Cremer &Müller (Schultz), 1982, Fig.1.16

173

So, when we look at evidence like this broadband ETC can we be confident about what it is telling us?



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The Precedence Effect –work in progress

- Is a COGNITIVE effect. Learning and adaptation play roles in what we perceive.
- It takes a short time to build up and as long as 9s for the effect to disappear.
- A change in the pattern of reflections – number, timing or spectrum – initiates a new build up, without removing the old one. We can remember up to 5 ‘scenes’.
- With training, listeners can become desensitized to it.
- In terms of their influence on timbre and loudness, all delayed sounds appear to contribute to our perceptions – there is opportunity for *much* new research.

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An interesting note:

- The Precedence Effect appears to be most effective when the spectra of the direct and reflected sounds are similar.
- This is an argument for:
  - *constant-directivity loudspeakers* and
  - *frequency-independent (i.e. broadband) reflectors, absorbers and diffusers.*

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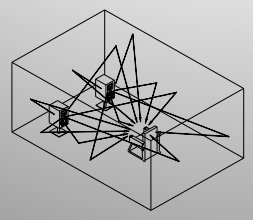
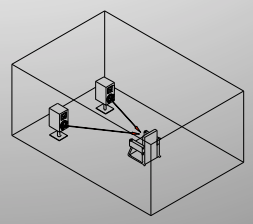
In terms of localization ONLY

Initial perception

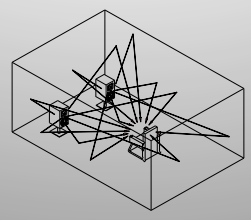


After build up



177

In all other respects: timbre, loudness, spaciousness, etc. everything is still there



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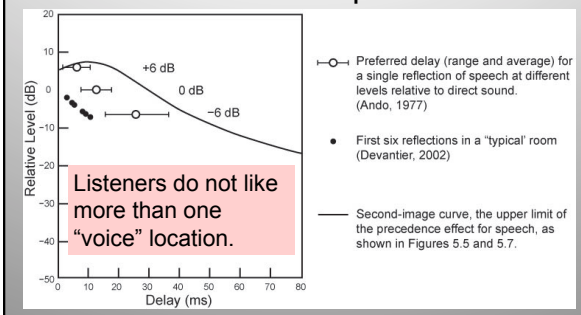
Reflection levels *preferred* by listeners for speech



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 7

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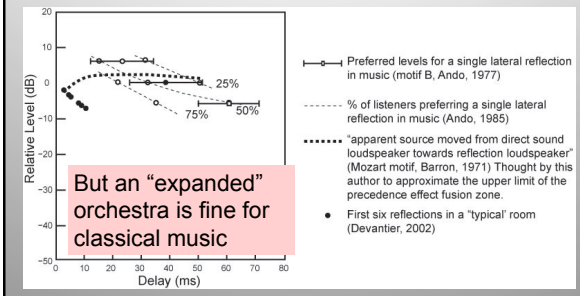
Reflection levels *preferred* by listeners for classical music



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 7

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Observations:

- Listeners like the spatial embellishments added by reflections
- For speech they stayed within the bounds of the precedence effect – only one image.
- For classical music they went beyond the precedence effect, allowing the spatial extent of the sound stage to be expanded.
- The reflections that they like are higher in level than those that can be provided by natural reflections in the listening room.
- We *need* multichannel audio!

181

How many channels and where?

- Two significant investigations:

1. A subjective comparison of simple loudspeaker arrangements with a 24-channel system asking listeners to rate the “degree of impairment” of perceived envelopment (LEV).

Hiyama, K., Komiyama, S. and Hamasaki, K. (**2002**). “The minimum number of loudspeakers and its arrangement for reproducing the spatial impression of diffuse sound field”, 113th Convention, Audio Eng. Soc., Preprint 5674.

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 15

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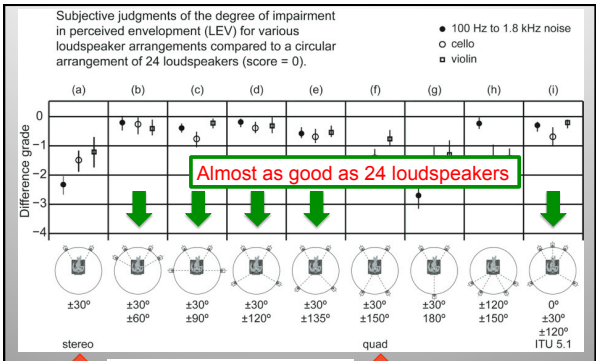

Stereo and front/back symmetry are not effective

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 15

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How many channels and where?

- Two significant investigations:

2. An objective comparison of Frequency-dependent IACC in four halls, compared to FIACC measured in multichannel reproductions of those spaces.

Muraoka, T., Nakazato, T. (**2007**). “Examination of multichannel sound field recomposition utilizing frequency dependent interaural cross correlation (FIACC)”, J. Audio Eng. Soc., **55**, pp. 236-256.

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 15

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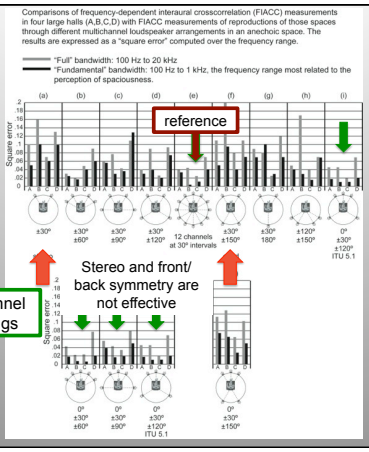

A center channel improves things

Toole, *Sound Reproduction*, Focal Press 2008, Chapter 15

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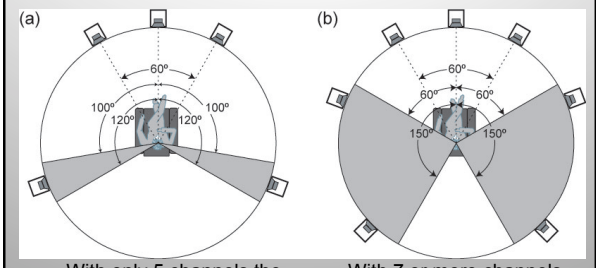
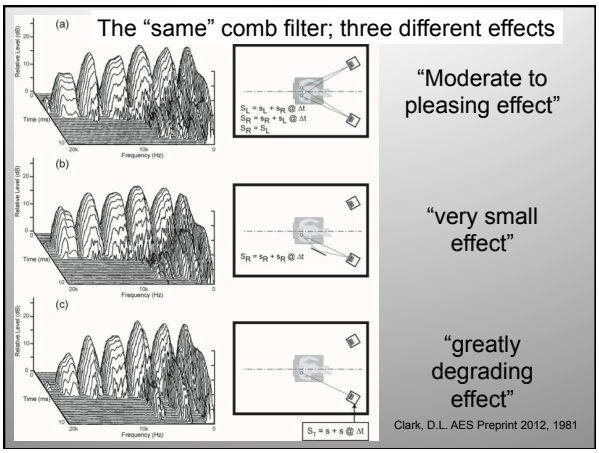
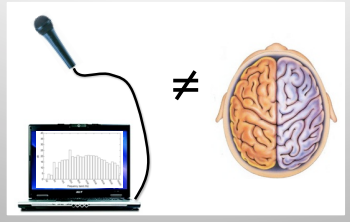
The ITU-R BS.775-2 recommendations:



With only 5 channels the side channels must be slightly behind the listener to allow for “flyovers” in movies.

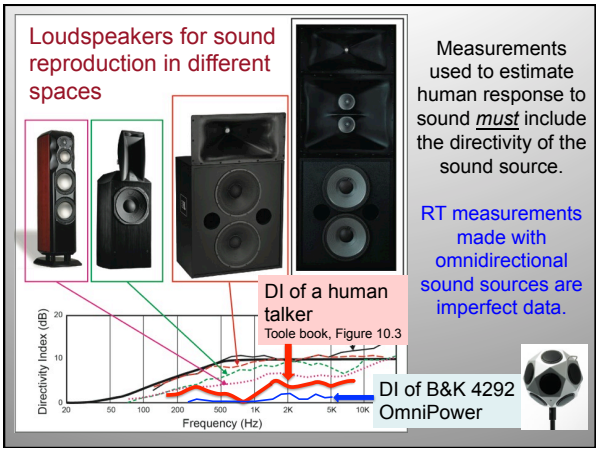
With 7 or more channels rear loudspeakers provide “flyovers” leaving side channels to be located to enhance LEV.





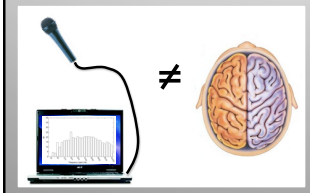
We need to have good psychoacoustical data to allow us to interpret technical measurements.

188



Obviously the nature of the sound source matters, but what about the receptor?

Tests show that RT measurements with a dummy head are close to those made with an omnidirectional microphone. Is this reassuring?



No. What is missing is the directionally discriminating, temporally and spectrally analytical, cognitively adaptive brain between the binaural microphones! ☺

190

Because most of the sound we hear is reflected . . .

. . . It seems logical that all surfaces and acoustical devices on them should be spectrum-neutral above the transition frequency.

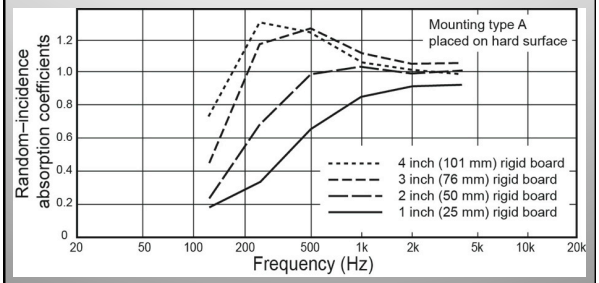
If so, based on commonly available information, in “small” rooms:

- Absorbers should be at least 3 inches deep.
- Engineered diffusers should be at least 8 inches deep.

Let us look at absorbers.

191

“Resistive” absorbers: thickness matters.



Toole, *Sound Reproduction*, Focal Press 2008, Chapter 21

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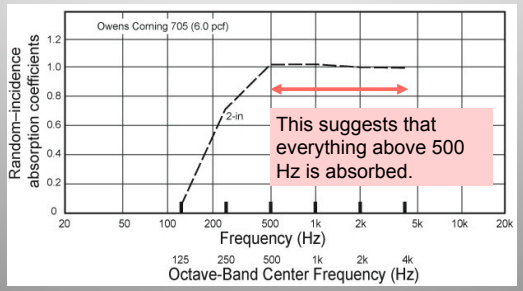
2-inch (50 mm) rigid fiberglass board



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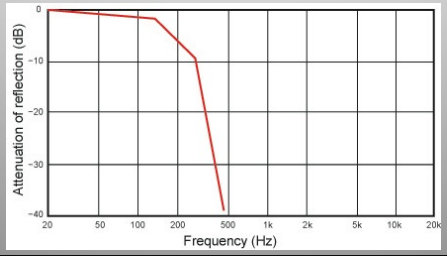
A simple reinterpretation of these data, looking at the attenuation of sound reflected from such a surface.



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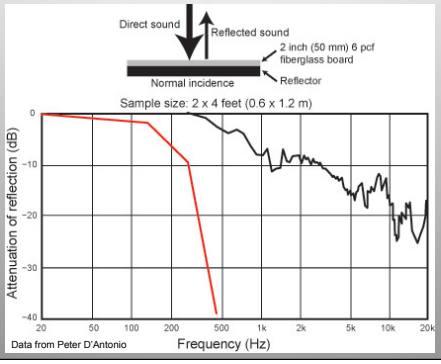
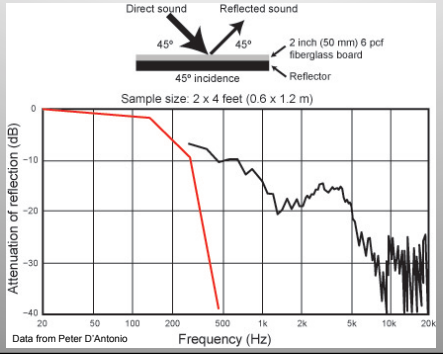
The angle of incidence matters: 0°



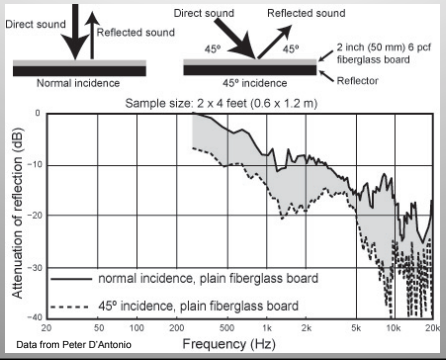
195

The angle of incidence matters: 45°



196

A substantial difference!



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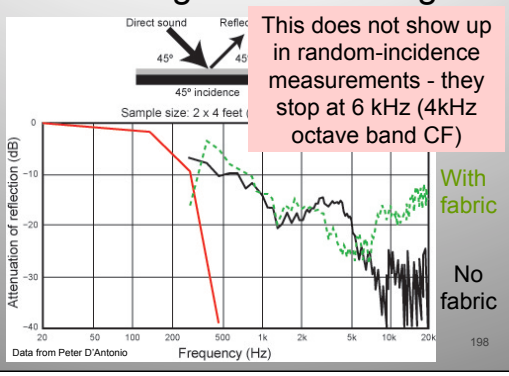
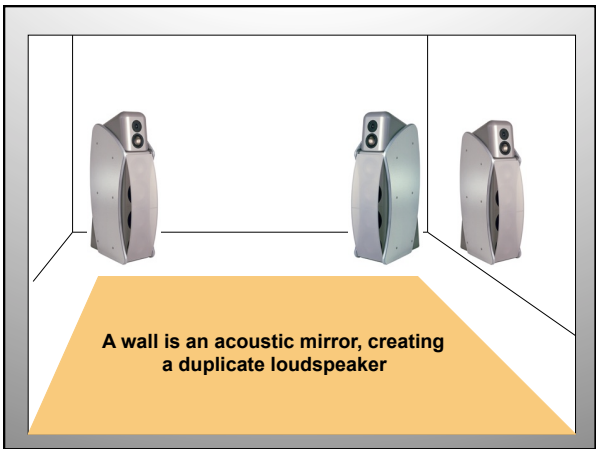
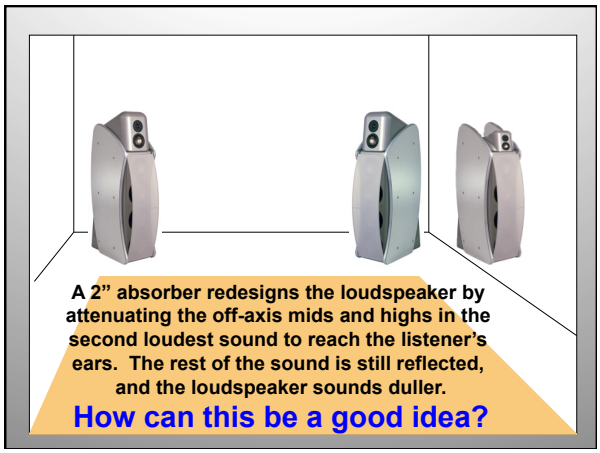
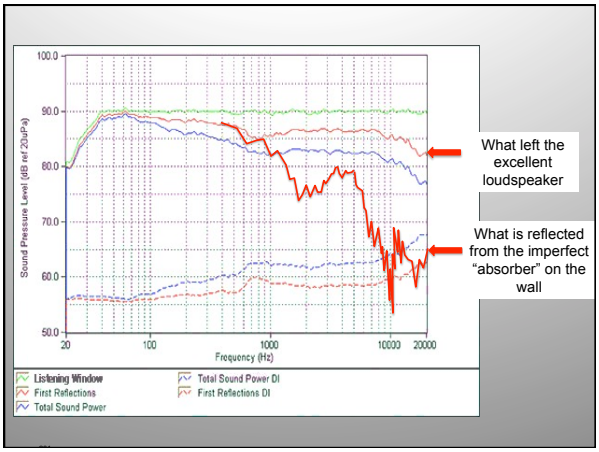
And adding fabric covering:

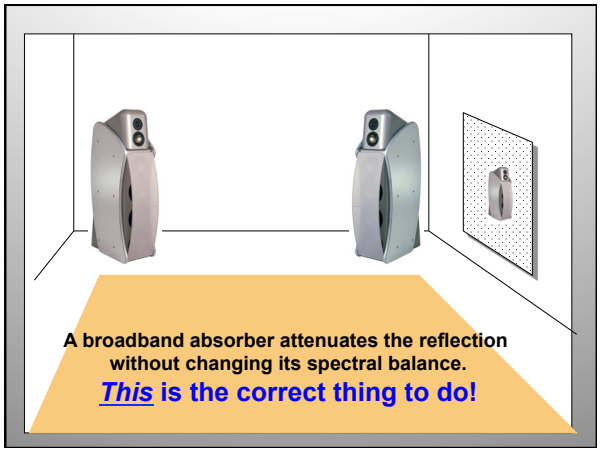


198









Audio/acoustics industry upgrade:

Find a way to give us some relevant acoustical measurements on the materials we use and for the frequency range over which they are used.

We do not live and listen in diffuse sound fields and we listen to sounds having bandwidths much in excess of speech – especially bass!

203

In all of the acoustical spaces that matter to the audio industry:

- Domestic listening rooms and home theaters.
- Recording control rooms for music.
- Dubbing stages for film sound.
- Cinemas.
- Dedicated live/amplified performance venues.

The sound fields are dominated by direct and early reflected sounds. These are not diffuse “Sabine” spaces.

Why then, do we persist in treating them as if they were? Another example: headphones.

204

Headphone “target” frequency responses have been disputed for decades

- A few have been inspired by free-field HRTFs
- More have employed diffuse-field integrations.
- Most have ignored both, and simply experiment to find something they think the public will buy.
- But recordings are made using loudspeakers in rooms, on the presumption that they will be listened to using loudspeakers in rooms. Should not headphones consider this fact.
- The following recent test addressed the issue.

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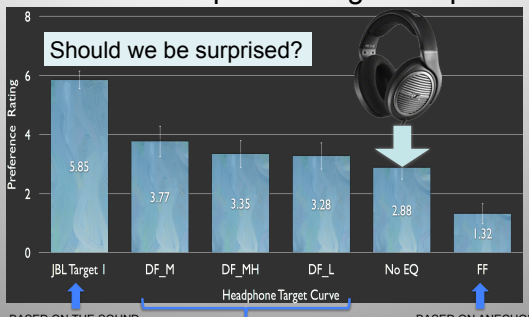
Preferred Headphone Target Response



BASED ON THE SOUND FIELD CREATED BY GOOD LOUDSPEAKERS IN A GOOD LISTENING ROOM

DIFFERENT VERSIONS OF A DIFFUSE FIELD TARGET

BASED ON ANECHOIC, FREE-FIELD LISTENING

Olive, et al., AES preprints 8867 & 8994, 2013

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In conclusion:

- If we ask them, listeners will tell us what they like. If the tests are unbiased, what listeners like is neutral, uncolored sound.
- These subjective preferences correlate well with data in accurate, comprehensive, high-resolution measurements of loudspeakers and headphones.
- The problem for consumers is that this kind of data is not widely available. This could change, but don’t hold your breath.

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In the meantime

- It is fortunate that humans are adaptable.
- Tunes, rhythms and lyrics survive bad sound quality. We get the musical “information” but an incomplete acoustical experience.
- The audio industry needs more scientific guidance, leading to more precise design objectives and more meaningful measurements. This is where we all live and listen – we deserve the best.
- Well reproduced audio art sends chills down the spine!

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Thank You!

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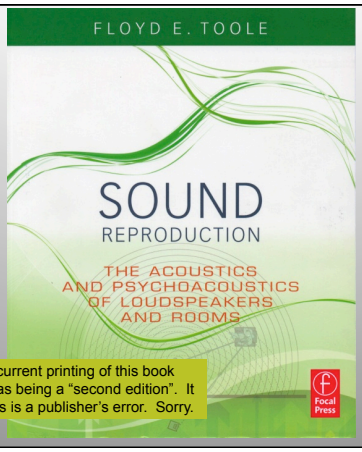

NOTE: the current printing of this book identifies it as being a “second edition”. It is NOT. This is a publisher’s error. Sorry.

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