Accurate sound reproduction from two loudspeakers in a living room

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LINKWITZ LAB

Claim #1

Playback of a recording
over two loudspeakers
can only create an auditory illusion of
the original event

Confusing cues must be minimized to strengthen the illusion of “being there”

Confirmed confusing cues from the loudspeakers

- On-axis frequency response variations
- Resonance / stored energy
- Non-linear distortion
- Cabinet edge diffraction

Confirmed confusing cues from the room

- Modes / Resonances
- Reflections
  - Left-right symmetry
  - Delayed vs. direct sound
  - Spectral content
  - Decay rate

Questionable cues from loudspeakers and room

- Off-axis frequency response
- Floor reflection

Claim #2
To minimize confusing cues from loudspeakers and room requires:

- Symmetry of reflections rel. to direct sounds
- Delay of reflections >6 ms
- Spectrum of reflections = direct sound

Spectrum of reflections = direct sound requires:

Frequency-independent polar response

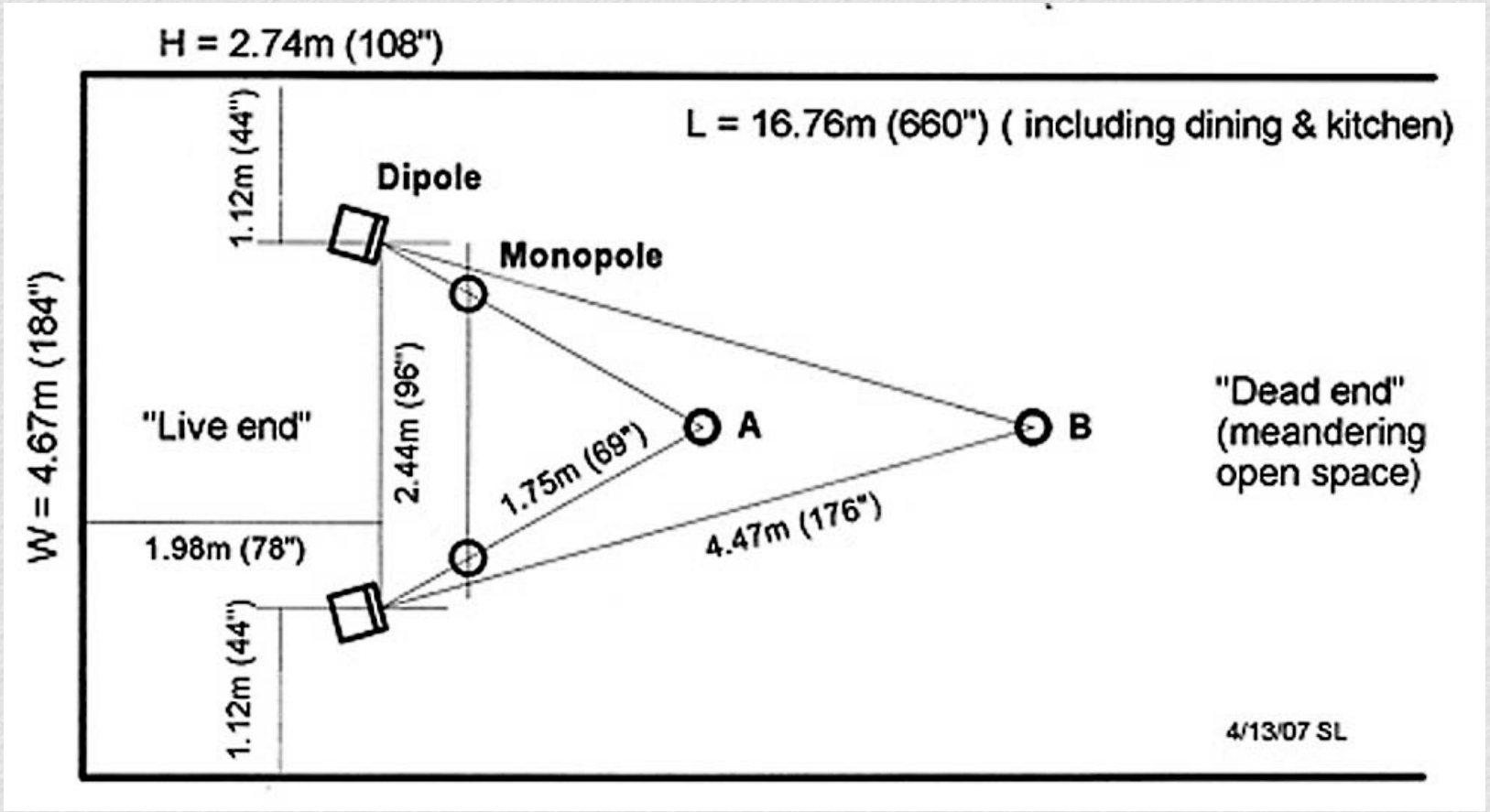
- Omni-directional
- Bi-directional, dipolar
- Cardioid loudspeaker

Frequency-independent room surface attenuation/diffusion

Symmetry and delay of reflections requires rooms with:

- Symmetrical loudspeaker-listener setup
- Loudspeakers >1 m from large surfaces

Room-Loudspeaker-Listener layout



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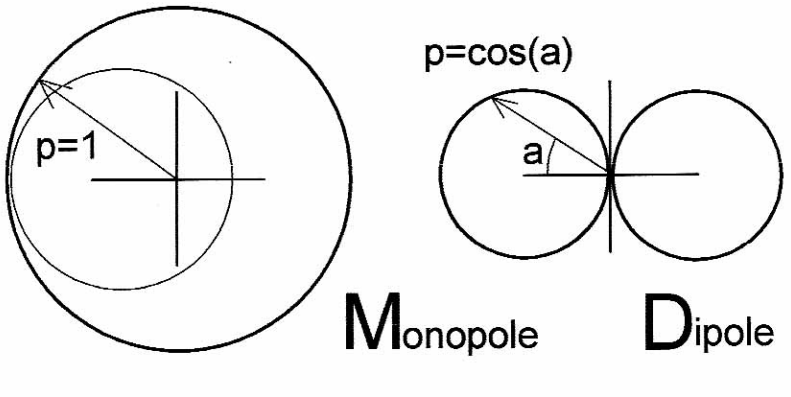
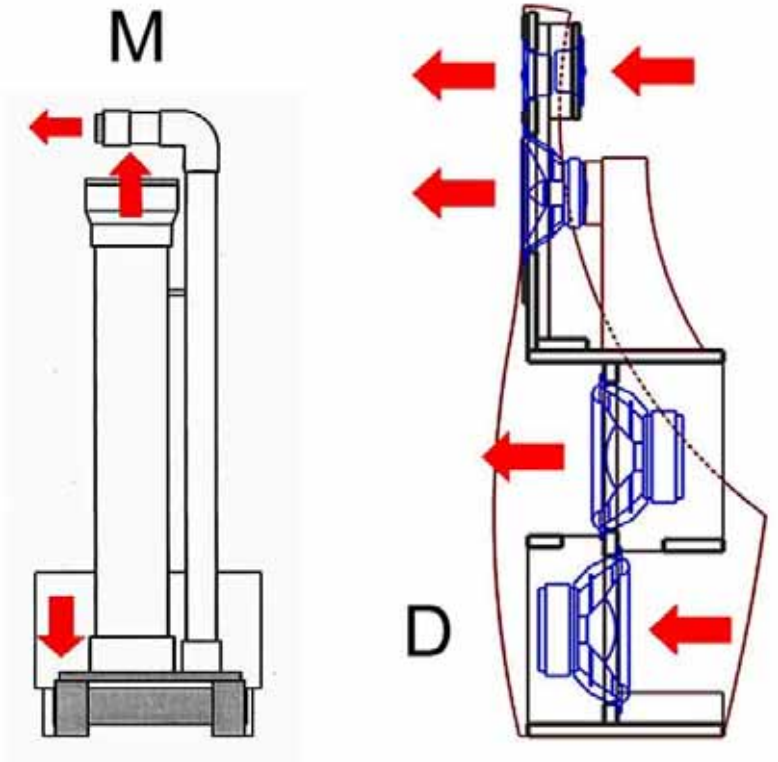
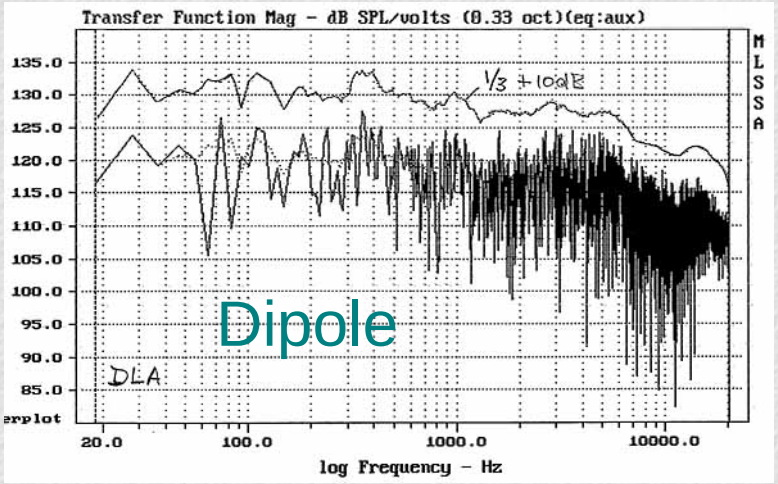
Two types of loudspeakers



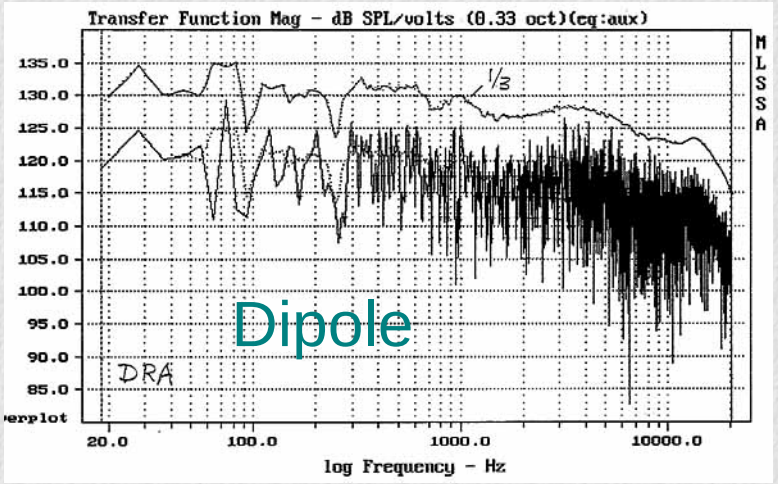


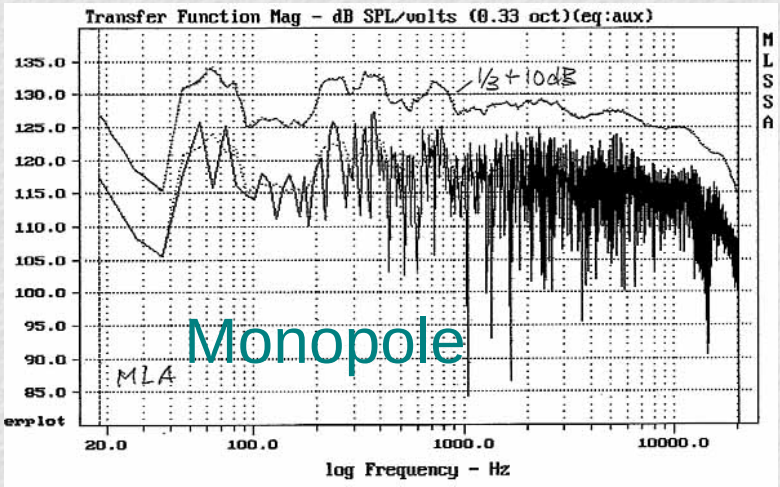
Room response at A

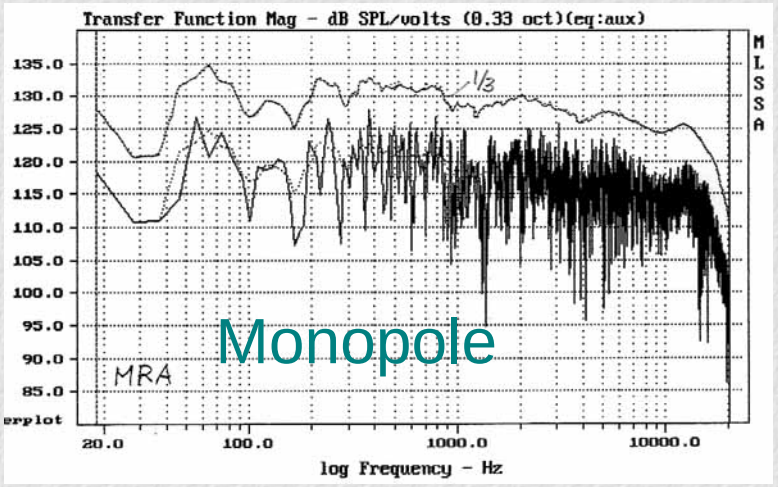
Left speaker



Right speaker

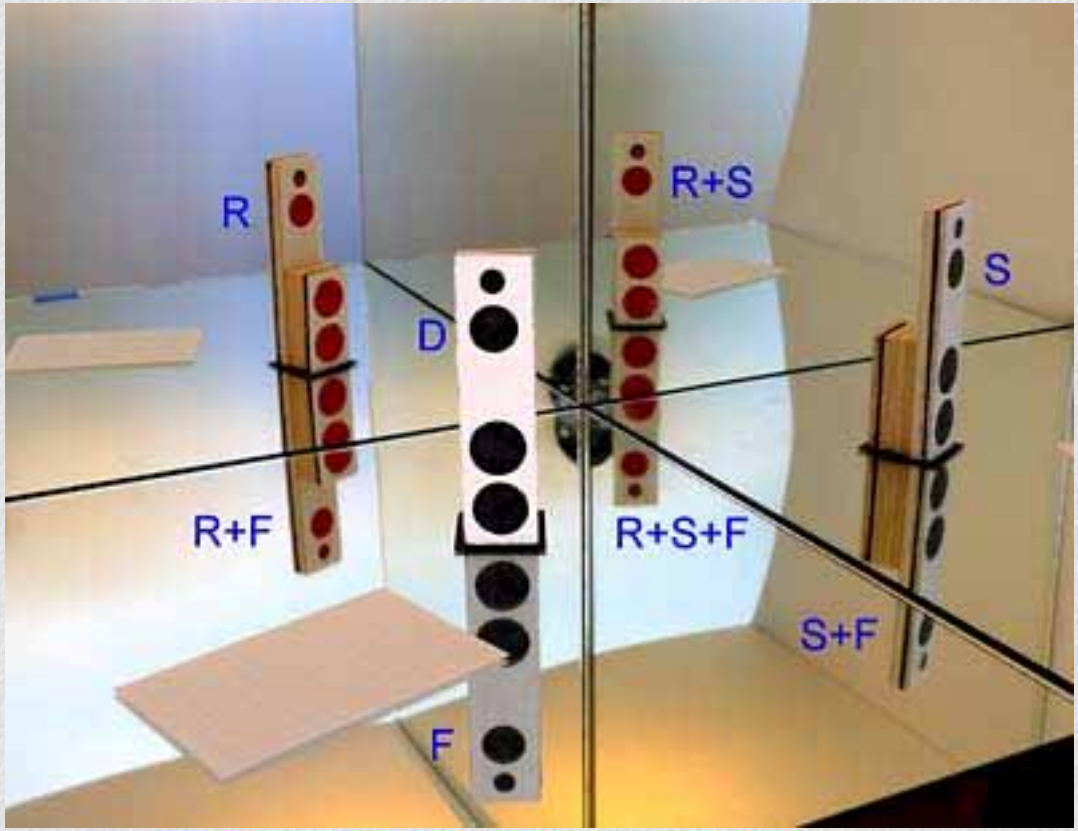


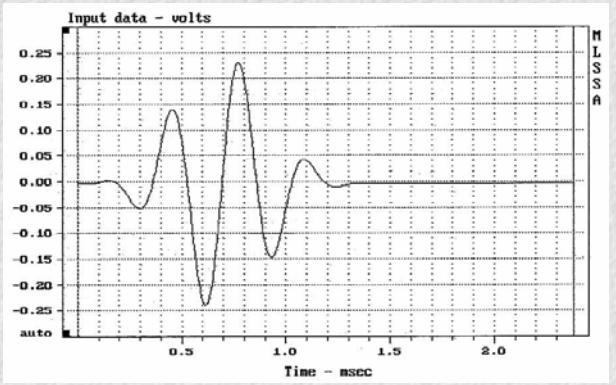


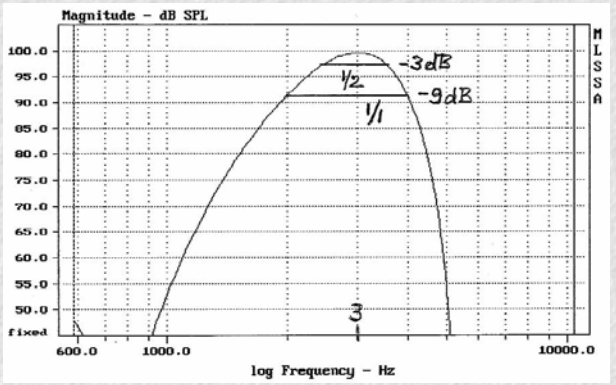


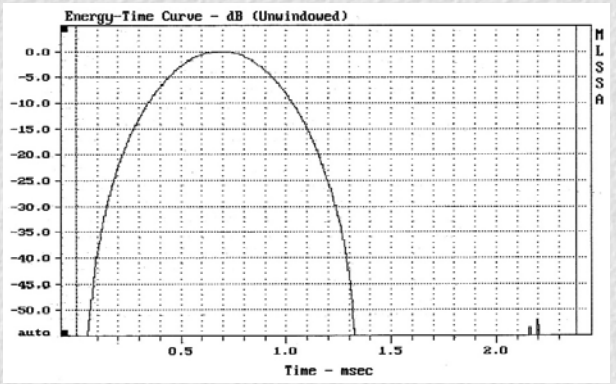
from 200 ms impulse response time record

Room reflections and their measurement



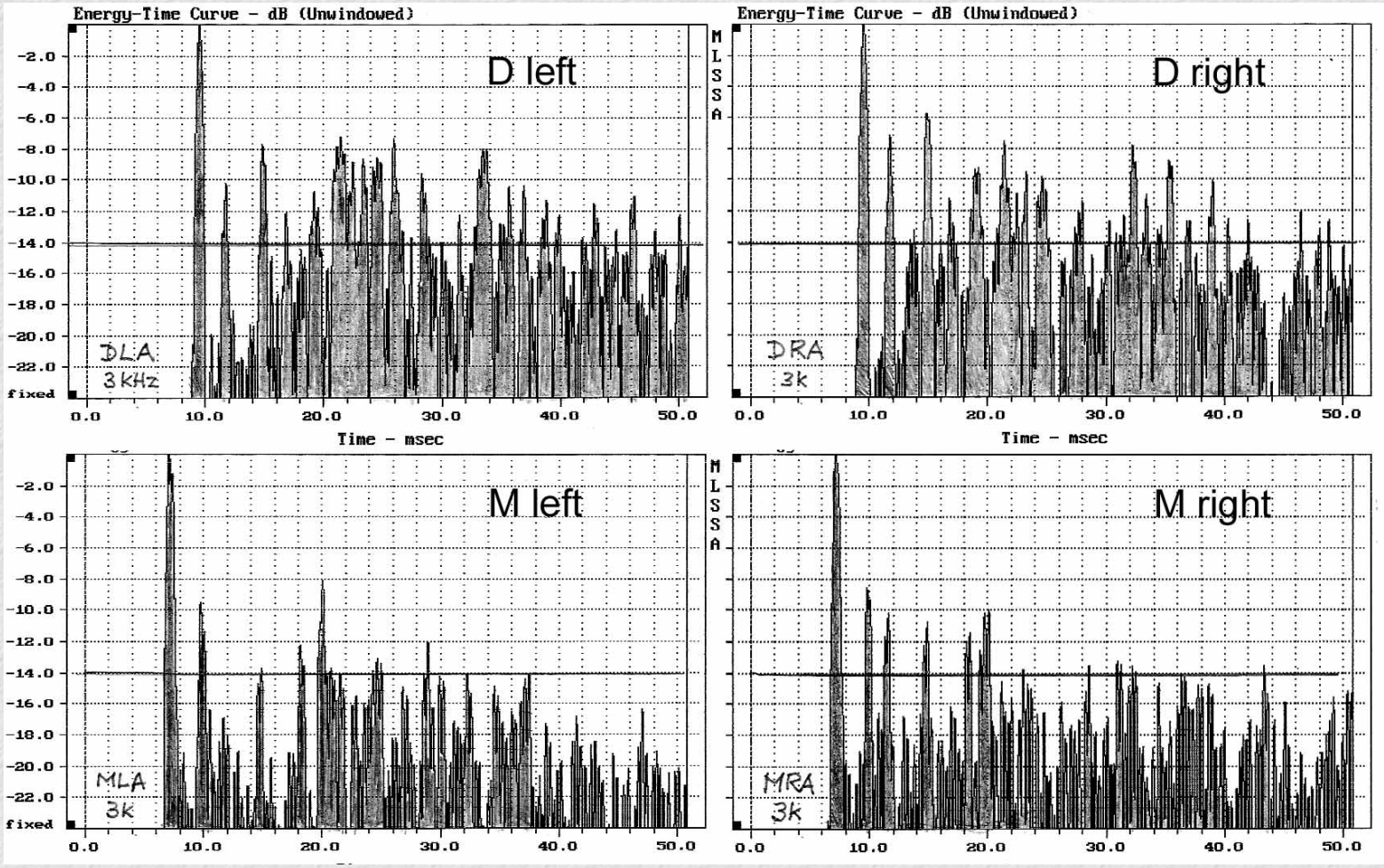




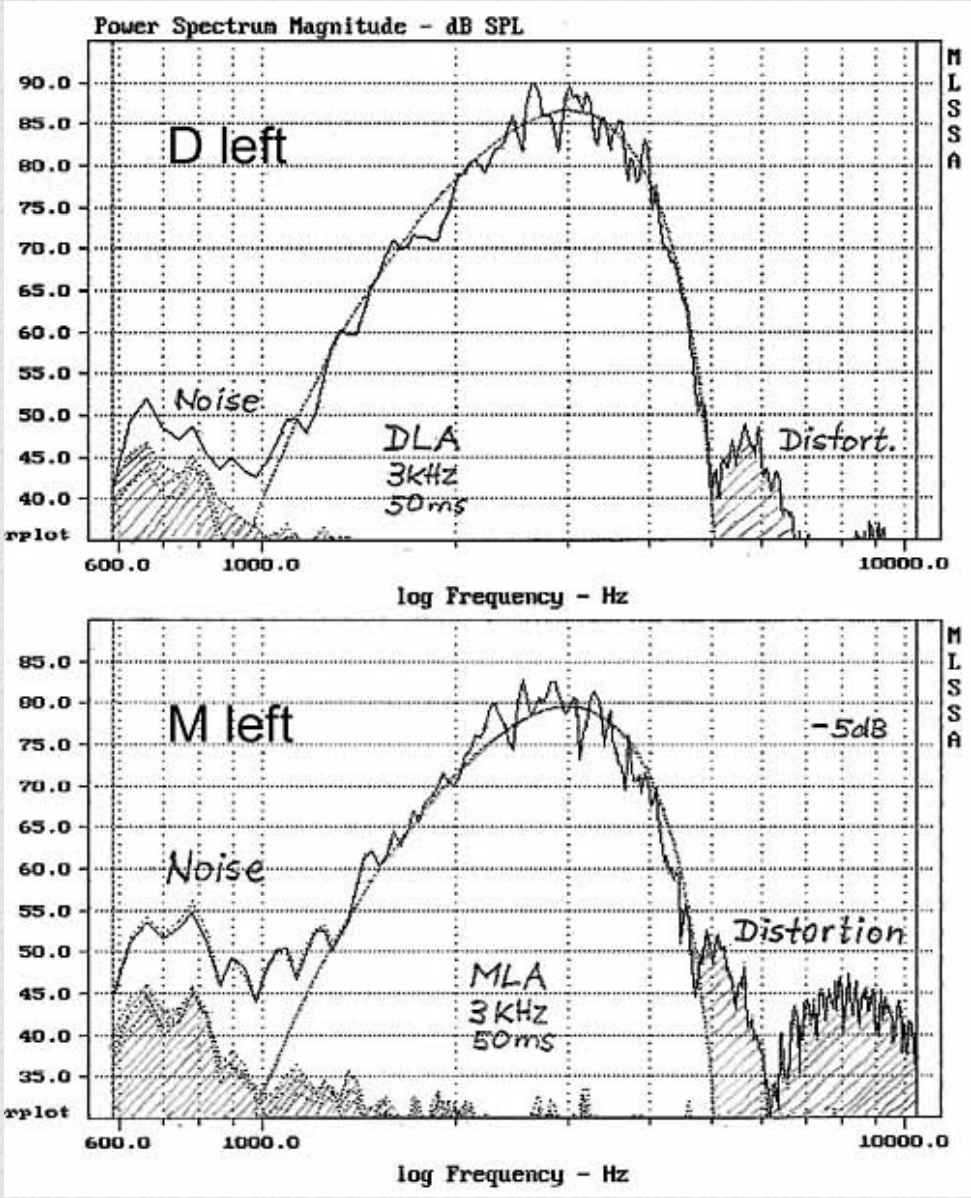


Tone burst test signal

3 kHz burst response at A during 50 ms



Power spectrum during 50 ms of 3 kHz burst



OBSERVATION

The dipolar and monopolar loudspeakers
sound almost identical in
spectral balance and clarity
despite their differences in measured
room response and burst response.

Phantom imaging is very similar, precise,
but with greater depth for the dipole.

Loudspeakers and room “disappear”

HOW IS THIS POSSIBLE?

Sound stream segregation & integration from onset, timbre, duration, loudness, direction, distance cues

Our perceptual "acoustic horizon" is variable and adapts by attention

"This is your brain on music", Levitin, 2006
"Spaces speak, are you listening?" Blesser & Salter, 2007
"Auditory scene analysis", Bregman, 1990

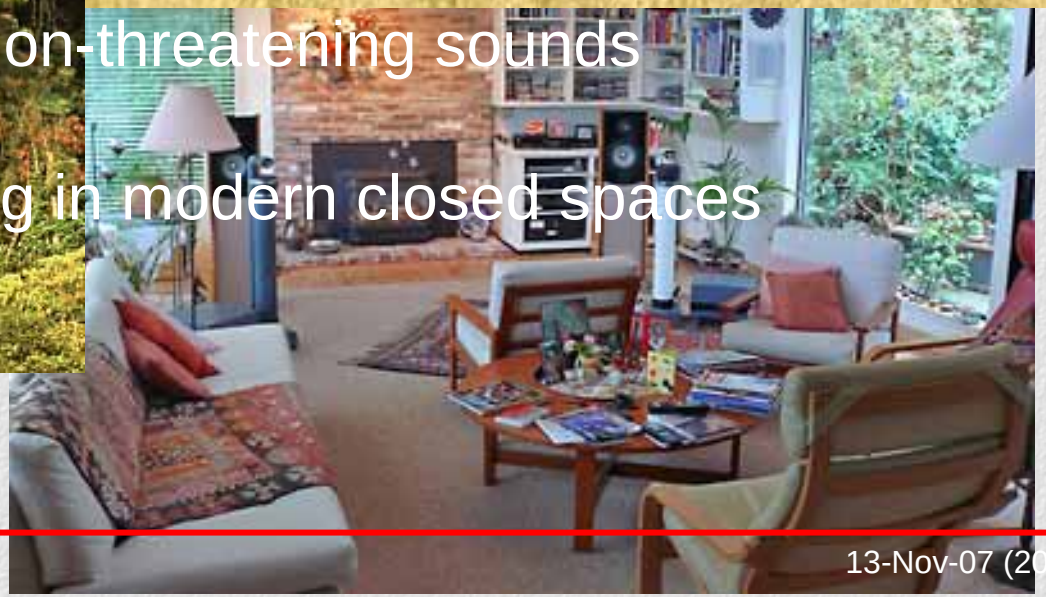
EVOLUTION OF SPATIAL HEARING

Adaptation to the different acoustic properties of forest and savanna

Survival by attention to cues for direction and distance of a threat

Ignoring stationary, non-threatening sounds

Adaptation to listening in modern closed spaces



THE PRECEDENCE EFFECT IN A ROOM

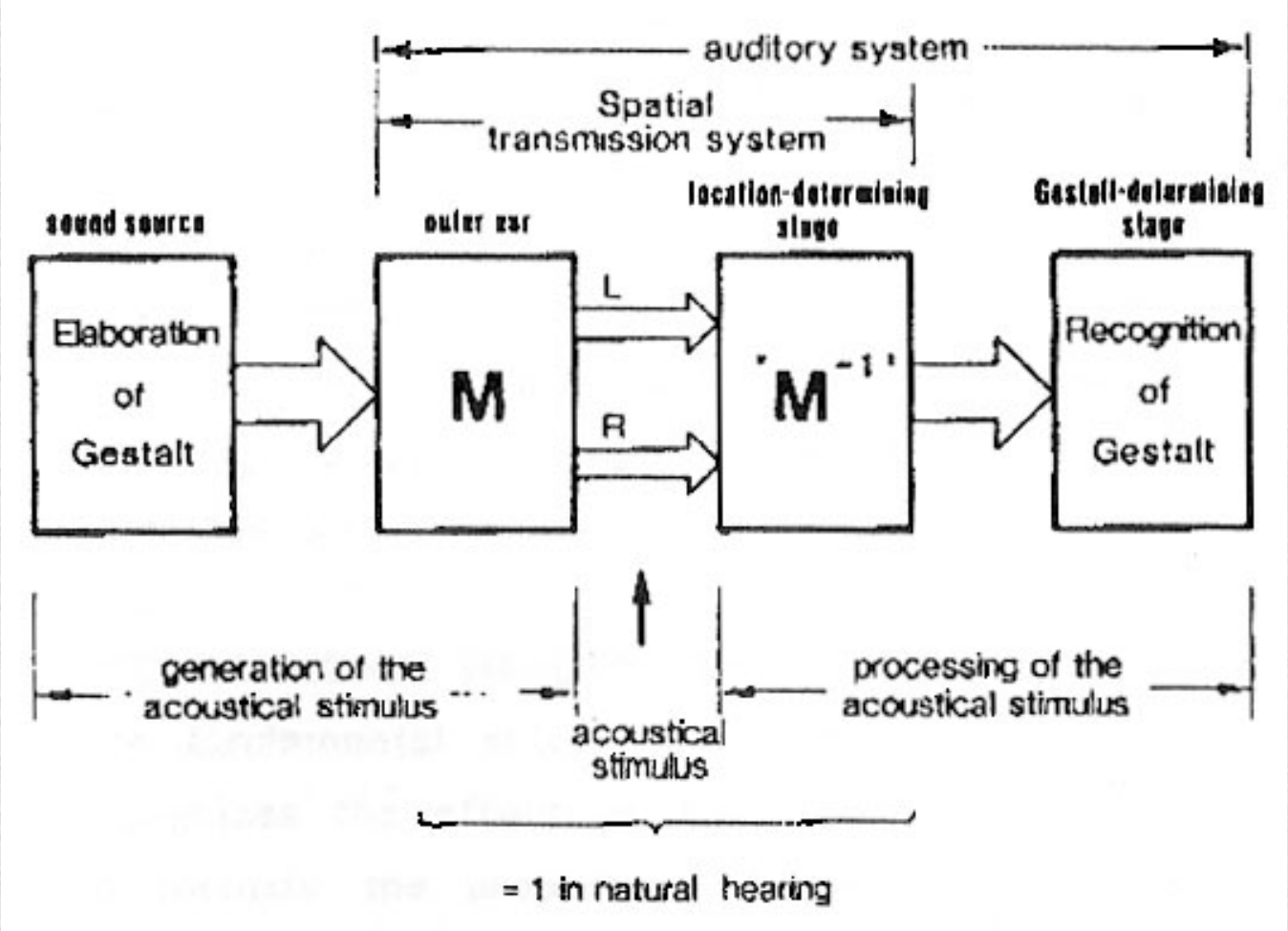
Localization
Direct and reflected sound are heard as a single entity from the location of the direct sound.

The Haas effect
Integration of a direct sound with a delayed sound adding loudness

De-reverberation
We are not normally much aware of reverberated sound even when its energy is larger than that of the direct sound

William M. Hartmann, 1997

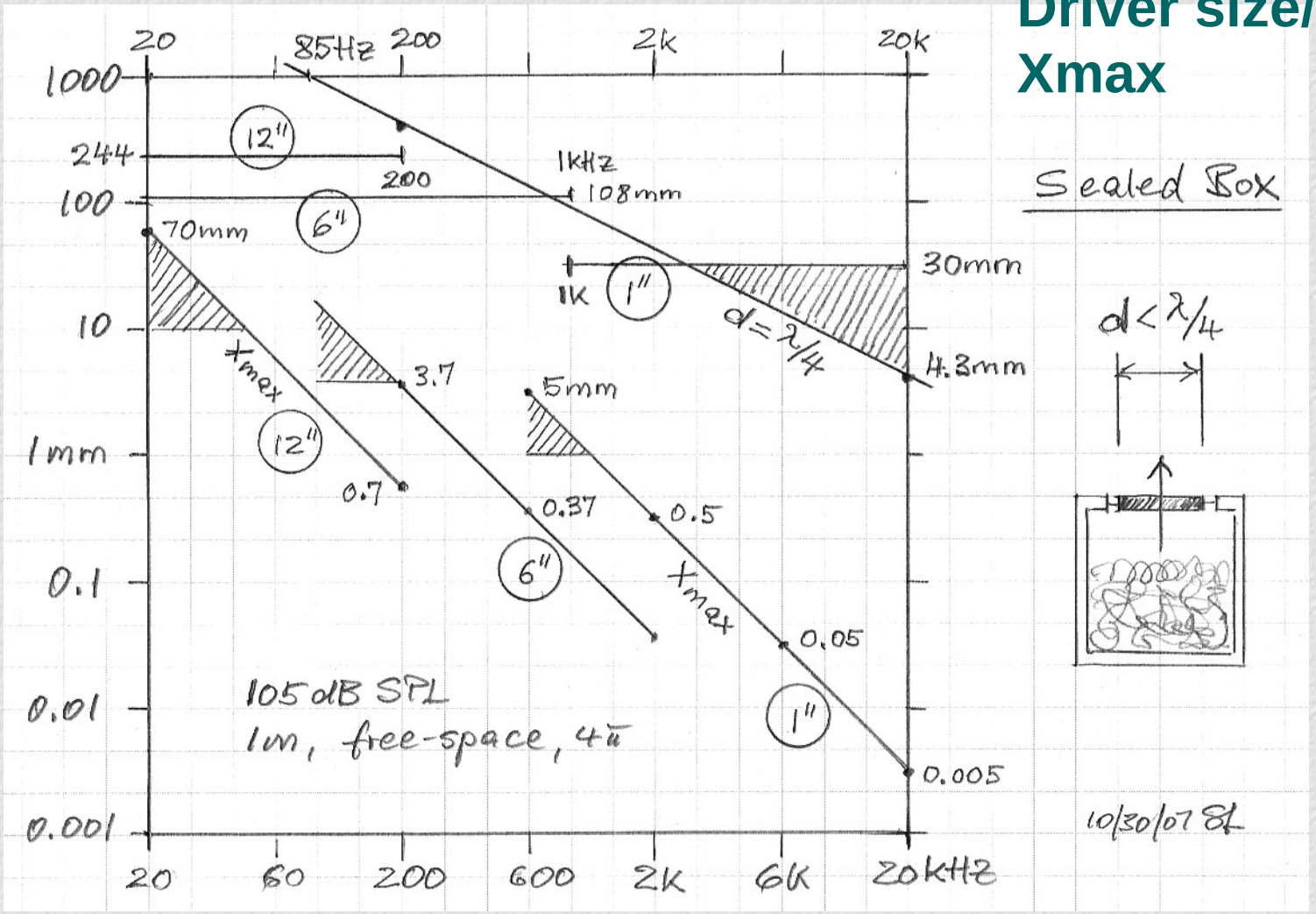
Guenther Theile's Association Model



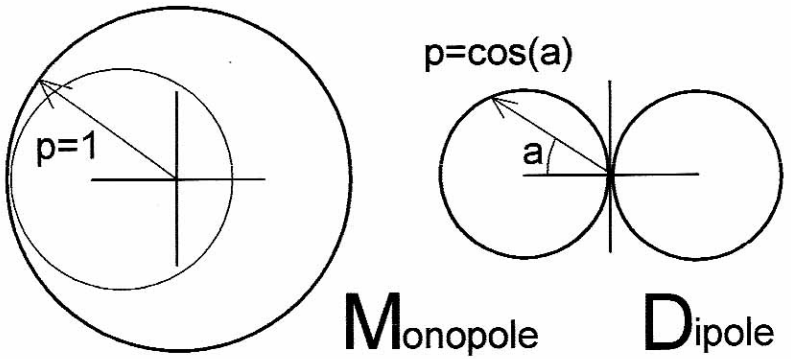
Perception of Reproduced Sound 1987

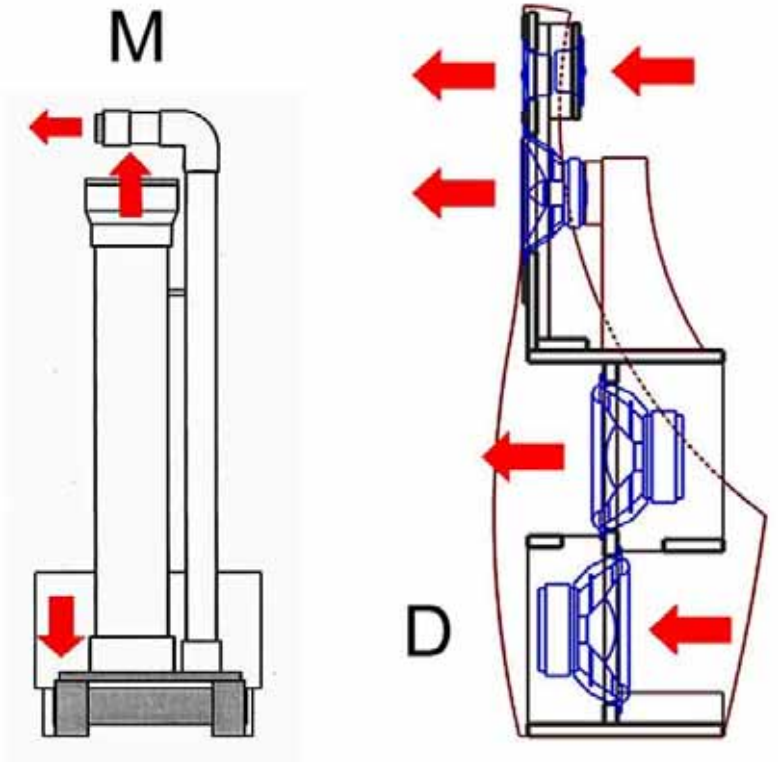

Two-channel playback in a normal living space can provide an experience that is fully satisfying. Loudspeakers and room disappear and the illusion of listening into a different space takes over.

Omni-directional loudspeaker design issues



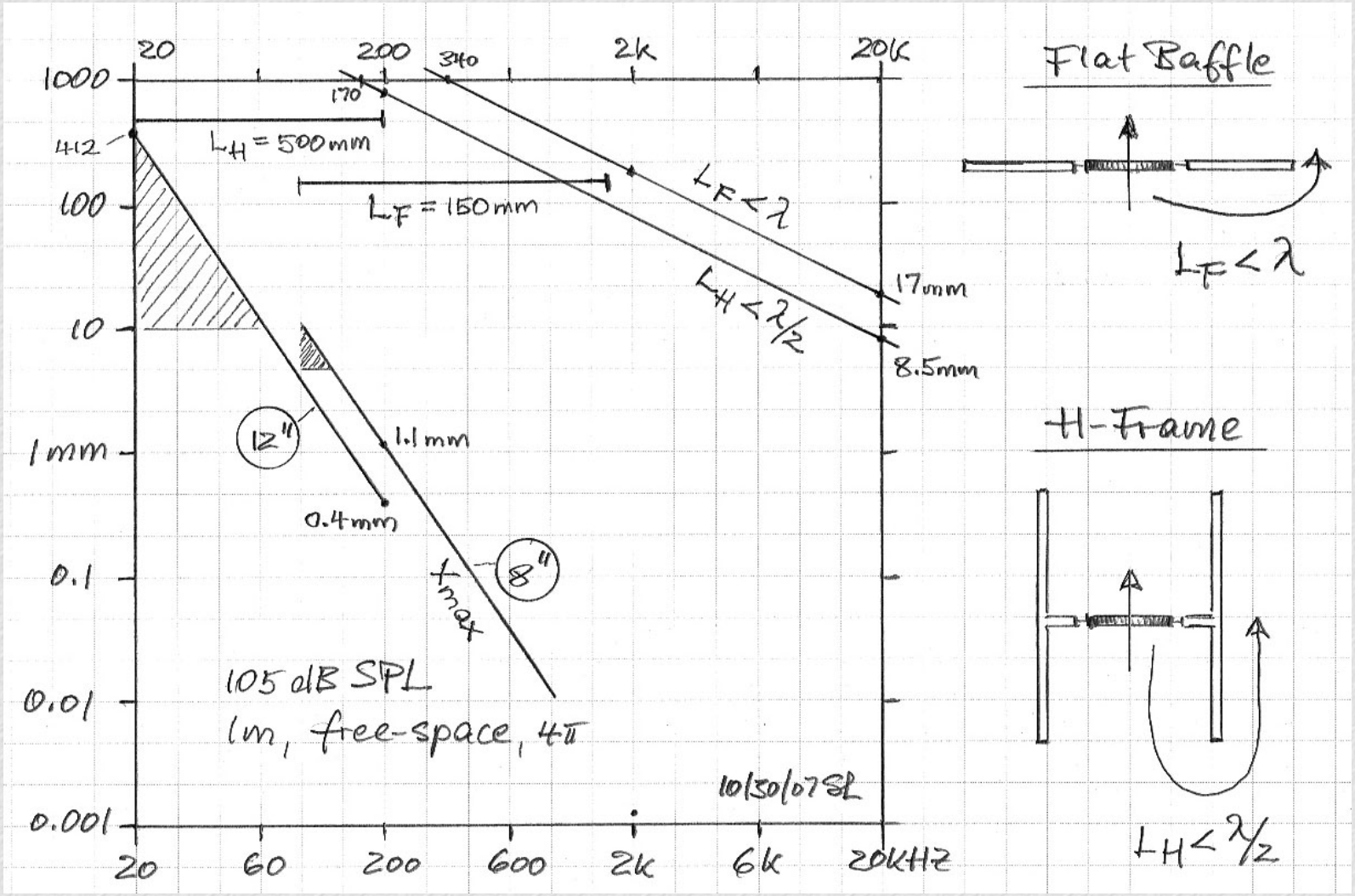
Monopole - Dipole





Dipole loudspeaker design issues

Baffle size/λ
Xmax



Building a cardioid loudspeaker

1 - Summation of coincident omni source and dipole source

$C = 1/2 + 1/2 \cos(\alpha)$

2 - Gradient loudspeaker
Summation of two spaced omni sources,
one delayed electrically by T = d/c

3 - Resistance box
Rear wave delayed by acoustic RC lowpass filter
$T = 2/RC = d/c$ with $R = 411\ Ns/m^3$

Benefits?

Claim #2

Polar response - Spectrum of reflections

Loudspeaker placement - Delay of reflections

and current practices

- Loudspeaker construction
- Loudspeaker setup
- Room treatment materials
- Room equalization methods
- Recording techniques

Two-channel Stereo vs. Surround sound

What am I missing?

- Complete Envelopment

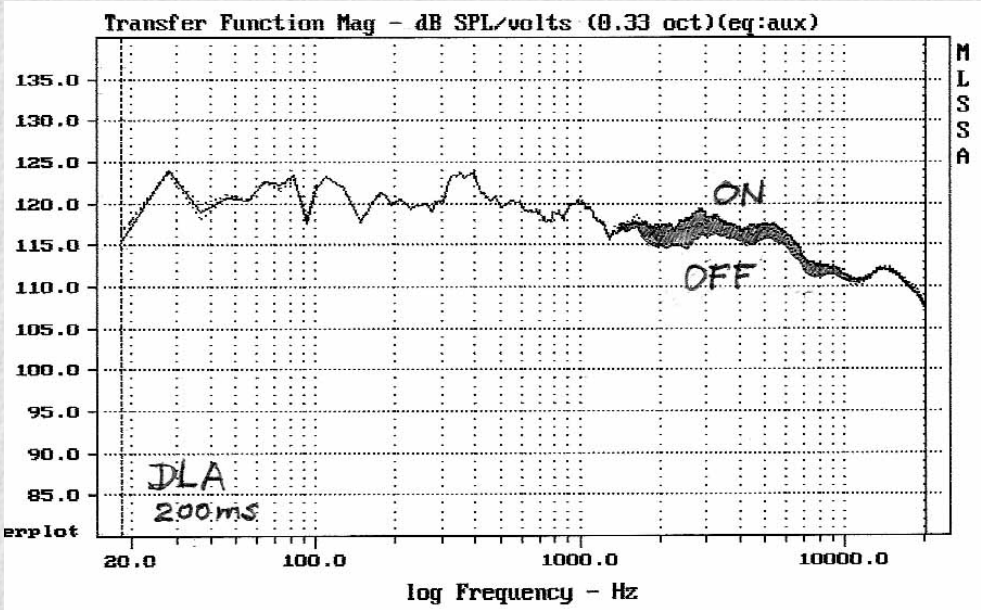
What am I gaining?

- Believability
- Satisfaction
- Simplicity

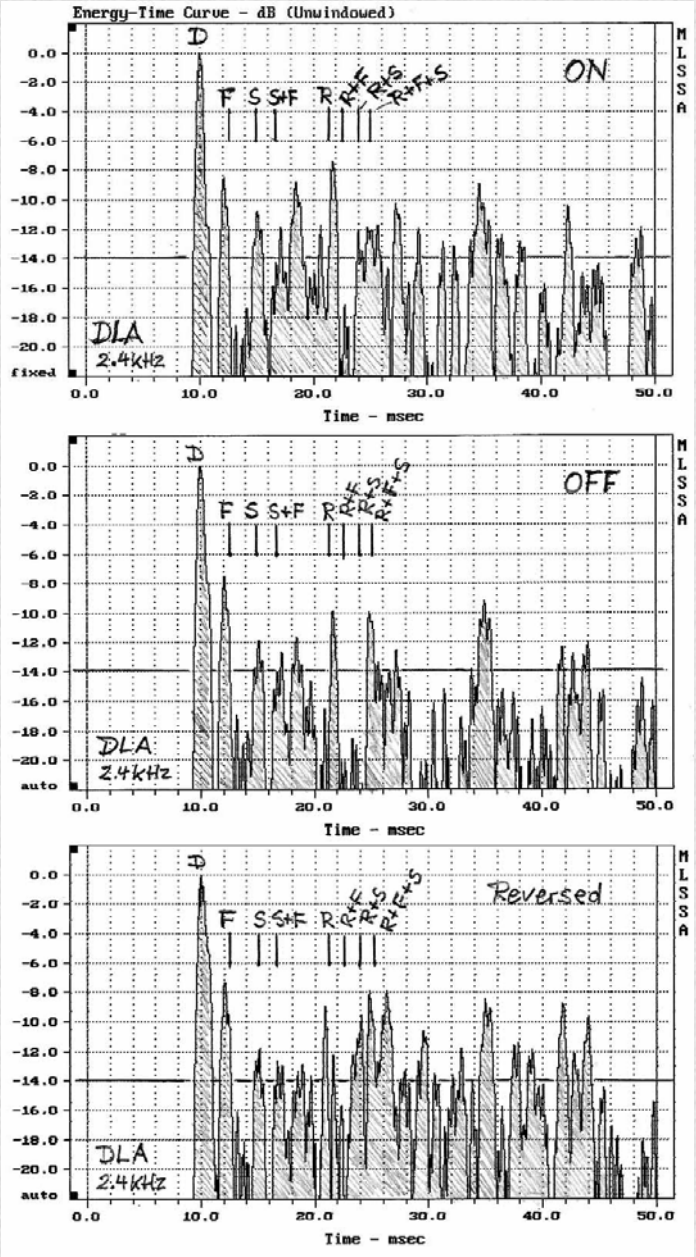
Thank you for your attention

Questions?

Rear tweeter contribution to dipole loudspeaker D

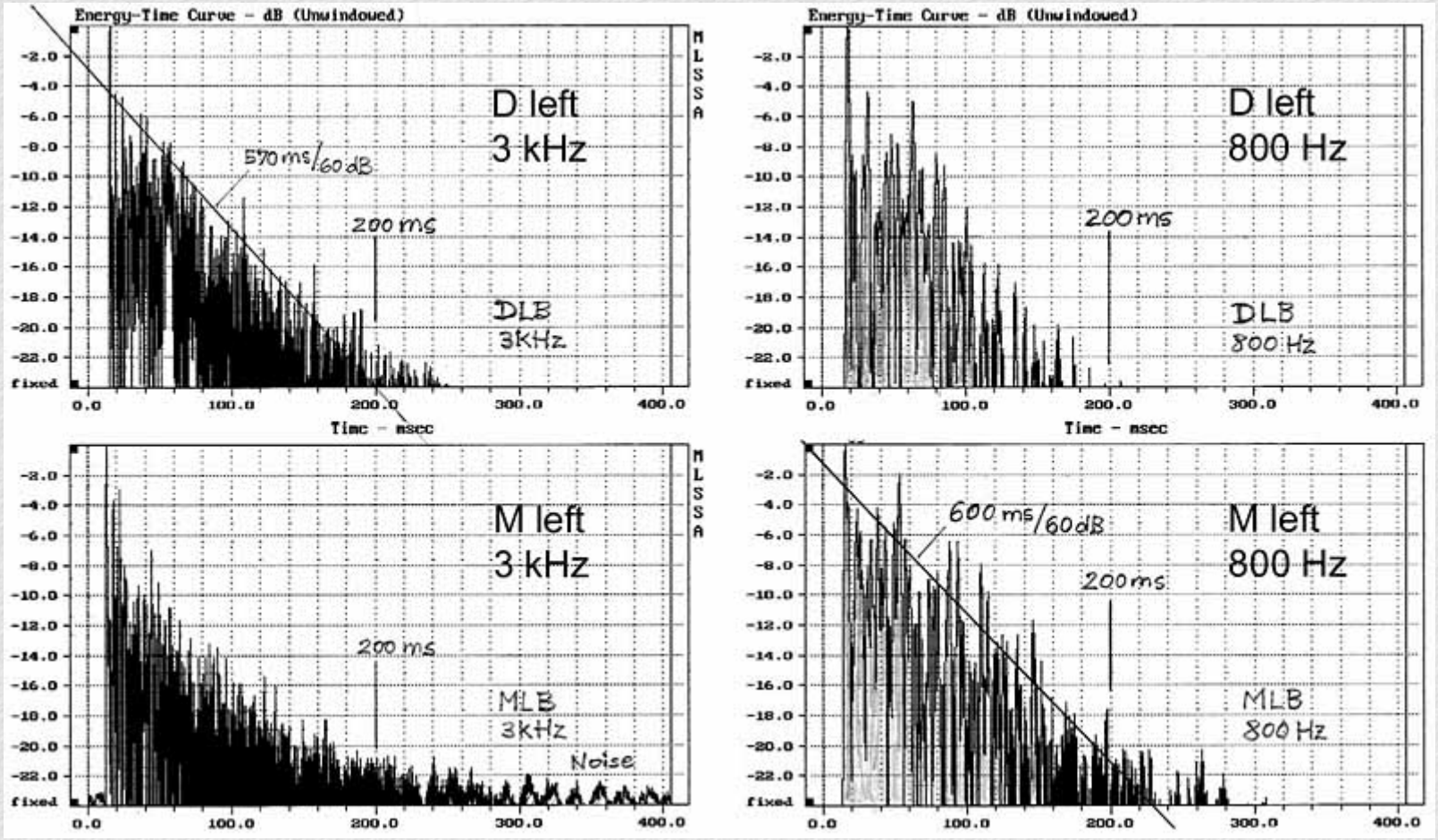


Frequency response

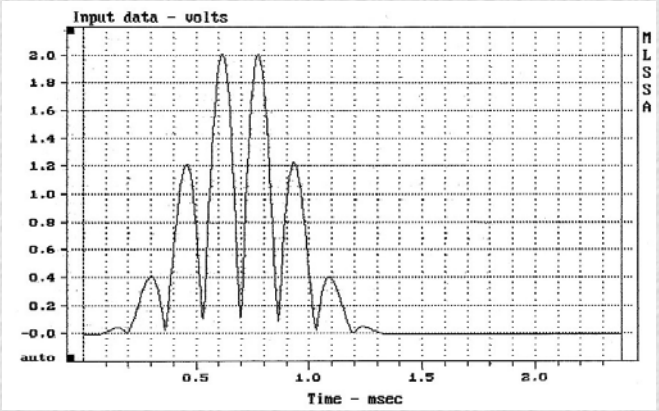


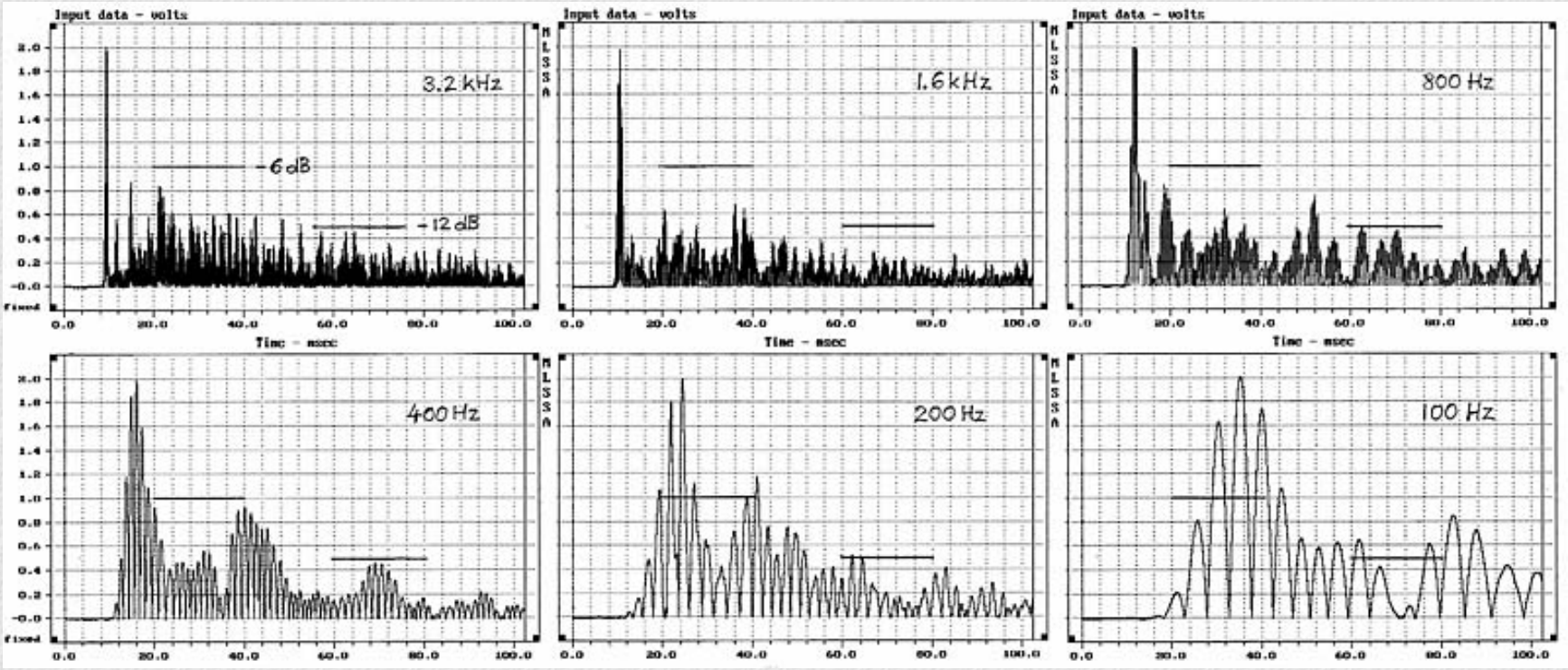
Reflections

3 kHz burst response at B during 400 ms



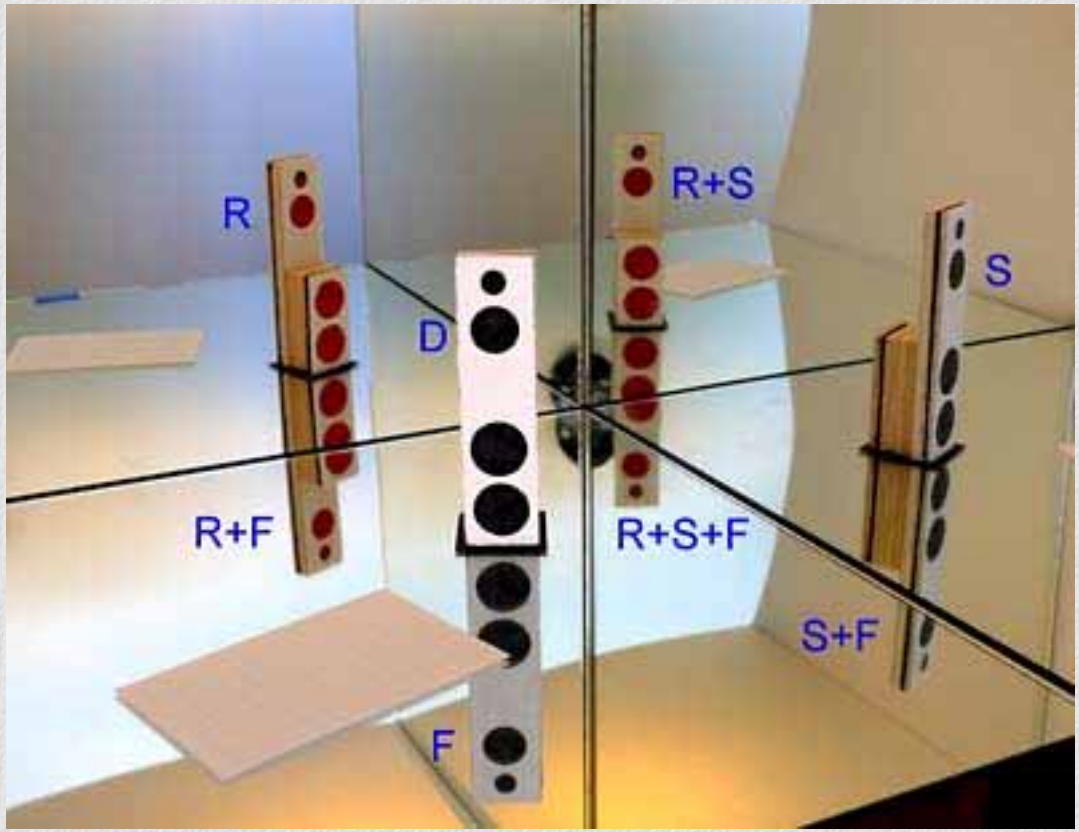
Rectified burst response of D at location A for different frequencies during 100 ms





HYPOTHESIS

Confusing cues from the room
are minimized if the reflections are:



(1)
Left-right
symmetrical

(2)
Delayed >6 ms

(3)
Attenuated copies
of the direct sound
in spectral content

Impediments to creating a realistic impression of an acoustic event

- Inadequate polar response of typical box loudspeaker designs
- Insufficient dynamic range of the loudspeakers
- Loudspeaker placement too close and non-symmetrical to the room walls
- Room treatment with absorbers and diffusers which change the spectral content of reflections
- Electronic room equalization above bass frequencies
- Recordings with too many microphones and in separated spaces