Accurate sound reproduction from two loudspeakers in a living room

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Measurement & listening room
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

H = 2.74m (108")
L = 16.76m (660") (including dining & kitchen)

W = 4.67m (184")
1.12m (44")
1.98m (78")
1.12m (44")

"Live end"
Dipole
Monopole

2.44m (96")
1.75m (69")
4.47m (176")

"Dead end"
(meandering open space)

A
B

4/13/07 SL
Two types of loudspeakers

Monopole

Dipole

\[ p = \cos(a) \]
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

Driver size/\lambda

\text{Xmax}

\text{Sealed Box}

\text{d}<\lambda/4

105\text{dB SPL}

1\text{m, free-space, } 4\pi
Dipole loudspeaker design issues

Baffle size/\lambda

X_{\text{max}}
Building a cardioid loudspeaker

1 - Summation of coincident omni source and dipole source
C = 1/2 + 1/2 cos(α)

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/m³

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