The Science of Surround

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Contents: Theory

- What does “Acoustics” mean?
- The acoustics of recording
- The psychoacoustics of panning
- The acoustics of playback rooms

Contents: Practice

- Practical rules for recording
  - the difficulties with main microphones
  - the reverberation radius again!
  - Multi-microphone leakage
  - what to do with the center channel
    - with decorrelated sources
    - with vocals or soloists
  - microphone technique in the rear
  - Surround placement and panning

What does “Acoustics” mean?

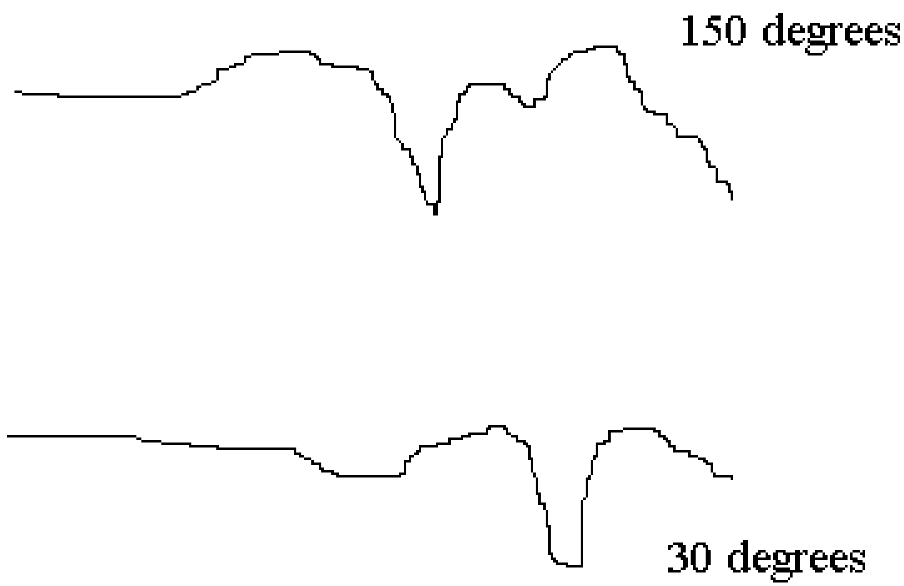
- Acoustics is PERCEPTION - in the brain!
  - Sound reflections alter or provide: clarity, distance and envelopment
- The acoustics of recording
  - Capturing clarity
    - The reverberation radius
  - Capturing sound distance
    - Early (<50ms) lateral reflections
  - Capturing envelopment
    - Decorrelated reverberation

The Psychoacoustics of Panning

– panning is not possible from front to rear

– Head Related Transfer Functions (HRTFs)

  • are too different to allow panning.



– demo

Front-back localization is frequency dependent

- Low Frequencies (LF) are not discriminated front/back without head movement
- demo

The acoustics of playback rooms

- Frequency response
- Envelopment
  - the importance of independent rear channels
  - the importance of low frequency decorrelation
- Externalization
  - the importance of low frequency phase

Perception of Reflected Sound

- depends on the type of sound
  - continuous vs syllabic (demo)
- and the time delay and amplitude of reflections.
- For speech and most music there are three time regions:
  - early (20-50ms) provides distance
  - middle (50-150ms) => distance + confusion
  - late (150ms +) creates reverberance and envelopment

Early Reflected Energy (15 to 50ms)

- Early energy is perceived as a property of the source
- Early Lateral reflections add a sense of distance, removing the “close-miked” sound (demo)
- Early Medial reflections add loudness, can alter timbre (demo)
- The ratio of direct energy to early energy is perceived, not the absolute level of the reflections (demo)

Mid-time Reflected Energy (50 to 150ms)

- Mid-time energy can contribute to both distance and loudness for continuous music
- For articulated music or speech mid-time energy reduces intelligibility
- Single reflections or a tight group of reflections are particularly disturbing in this time range (demo)
- Lateral reflections are more disturbing than medial reflections (demo)

Late Reflected Energy (150ms on…)

- Late-arriving energy is perceived separately from the foreground sound.
- the absolute level of the late energy is perceived, not the direct to reverberant ratio.
  - Thus the louder you play, the more reverberant it sounds! (demo)

Late Reflected Energy in Music

- spatially diffused (especially lateral) late energy creates envelopment
  - stage house reverberation doesn’t count because it’s medial
- envelopment is the holy grail of concert hall and opera acoustics
- for symphonic music the reverberant level at 300ms or more is particularly important due to masking by adjacent notes.

So, for “most” music

- acoustic perception depends on the strength of the reflections.
  - for early energy this means the direct to reverberant ratio.
  - for late energy it is the absolute loudness that matters.
- acoustic perception depends strongly on the time delay and directional characteristics of the reflected sound

For Recording: Know the Hall acoustics!

- Most halls are characterized by
  – the Reverberation Radius, (RR)
  – and the Reverberation Time (RT)
- The Reverberation Time is easy to measure or guess
- The Reverberation Radius is usually smaller than your first guess!

Reverberation Radius (Hall Radius)

– reverberation radius is the distance from a source where the direct sound and the reflected sound are equal

– reverberation radius depends on the hall volume and the reverberation time

– RT is prop. to V/S (=.163*V/S) where V is the volume and S is the total absorption.

– Reverberant energy is prop. to 1/S

– Direct energy prop to 1/D^2. So….

Setting Reverberant = Direct:

$$RT/V = 1/RR^2$$

$$RR^2 \propto V/RT \Rightarrow RR \propto \sqrt{V/RT}$$

To Estimate RR, compare volumes

- RT varies only a little in typical venues
  - sqrt of RT varies only about a factor of 1.4
- Volumes vary over an enormous range
- to estimate RR, estimate V/RT, and compare to a known hall.

Example: Boston Symphony

- Dimensions are about 85’x170’x60’ ~ 900,000ft^3
- RT is about 1.8s V/RT ~ 480,000
- RR is about 20’ (measured)

Picture - San Diego Symphony

Example: Recital Hall

- Dimensions about 35’x25’x70’ ~ 62,000ft^3
- RT is 1.5s
- V/RT ~ 40,000
- V/RT is 12 times less than Boston Symphony
- RR is thus ~ 20/sqrt(12) = 5.7ft

Evulon Hall, Eindhoven

Performing Arts Center, Concord

Example: Typical Recording Space

- Dimensions 17’x23’x9.5’
- RT is ~ 0.5sec
- V/RT ~ 7500
- V/RT is 64 times smaller than Boston Symphony
- RR is thus ~ 20/sqrt(64) = 2.5’

These Examples Assume NO Stage house!

- Typical concert stage house Dimensions are 40x25x30
- Stage house RT ~ 1.1 seconds
- V/RT ~ 27,000
- RR ~ 5' EVEN WHEN THE HALL IS LARGE!

Minneapolis Symphony Hall

NEVER place a microphone beyond the Reverberation Radius!

- Omni microphones must be well within RR.
- Cardioid microphone can increase your reach to approximately the RR.
- At this distance the direct/reverberant ratio with a cardioid is 4.6dB!!
- In a small hall the reverberation is concentrated at short time delays. Exceeding the RR results in muddyness.

Keeping the mike within the RR prohibits most single position techniques

- Single position microphone techniques (Binaural, ORTF, Soundfield) are possible only in large halls or with small groups.
- In small halls balance and clarity are almost always impossible to achieve with a single microphone position.
  - Unless the group is smaller than the RR.

Simple rules of good recording

- Adapt the recording technique to match the reverberation radius.
- Don't place a microphone beyond the RR from a significant sound source.
- Small spaces require close miking and artificial reverberation.
- Large spaces have large RR and long RT at the same time.
  - But they are rare and often noisy!

Be sure the reverberation is decorrelated!

- Many simple microphone techniques fail this criterion
- ORTF is correlated - particularly at low frequencies
- semi-coincident hypercardioids are OK
- MS technique with cardioid front microphone is OK

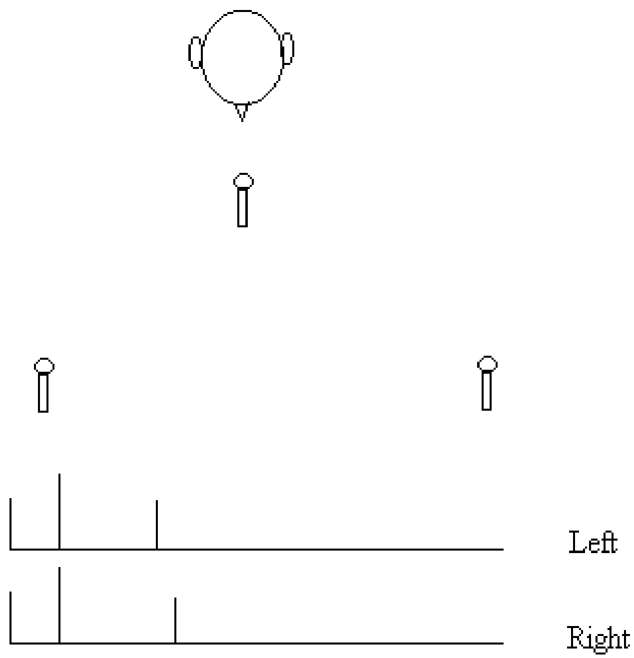
Acoustics in Recording

- Reflected energy has TWO desirable perceptions
  - early (lateral) energy contributes distance
  - late (lateral) energy contributes warmth, envelopment, and musical support.
- These two perceptions must be SEPERATELY optimized.
- And the middle energy should be avoided

Distance is created by lateral reflections

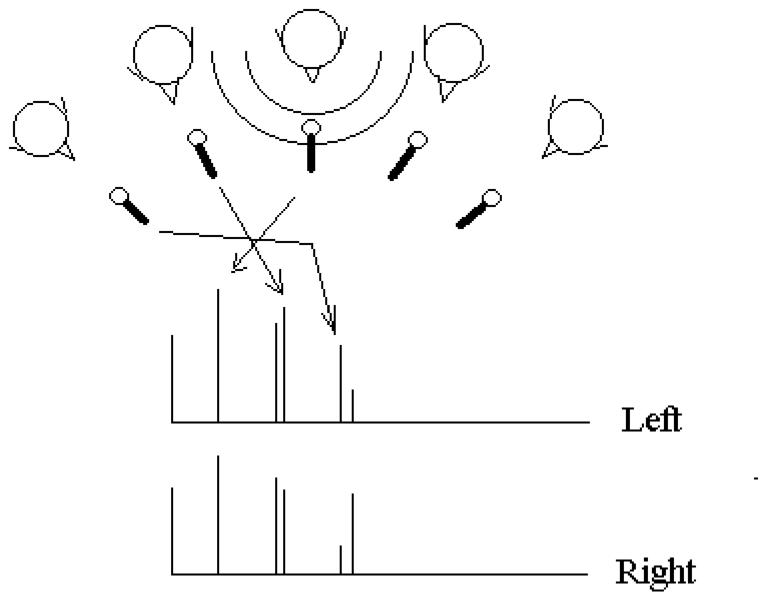
- Desirable early reflections are often provided by leakage between microphones.
- Frontal flanking omnis are a frequent source of desirable early energy.
- The optimal level for the sum of all early reflections is ~ -6dB relative to direct sound.
- The reflections must have different delays in the right and the left. (Think uncentered mikes)
- In Surround - early reflections should come from all channels except the center.

Distance Example: two-channel early reflections through flanking omnis



The flanking mikes must be not centered in order to add different left and right delays. Note if we delay the "accent" mike we spoil the effect!

Distance confusion: Multi-miking with a single active performer



– leakage provides early reflections, but standard panning make the reflections monaural.
– Stereo microphones can help - the leakage is separated left and right.

Common main microphone techniques are too monaural for reverberation.

- ORTF technique with cardioid microphones gives only about 10dB left/right separation.
- Reverberation (diffuse field pickup) has substantial correlation.
- M/S technique with forward facing omni microphone is similar.
- Replacing the cardioids with hypercardioids is a big improvement

Binaural techniques work well with low frequency width expansion.

- Unfortunately there is too much phantom center to work well with 5 channel surround.
- Shuffler circuits are not commonly included in mixing desks.

Envelopment is provided by Late (>160ms) reflections

- The amount of late energy can be controlled by mixing microphones placed at some distance in the hall.
- too much distance causes a disconnect between early and late reverb.
- Backwards facing cardioids solve this problem by emphasizing the later reverberation.

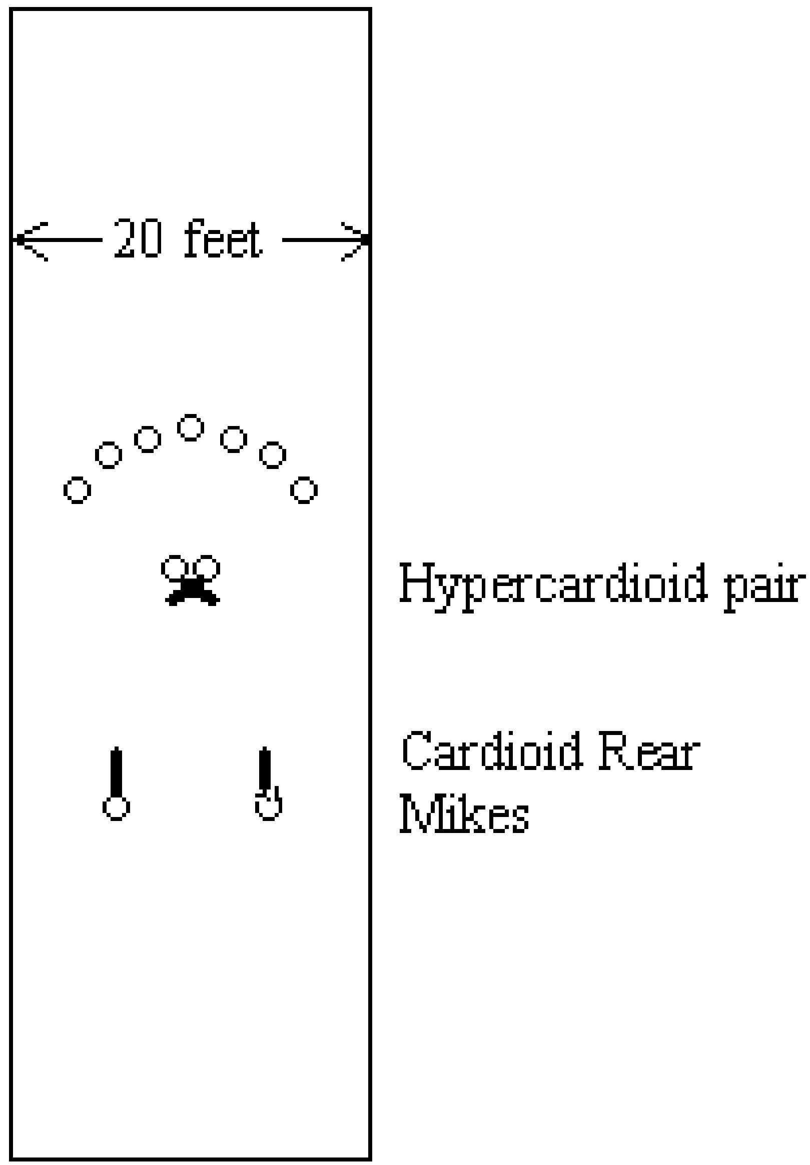
Simple technique (usually) doesn't hack it!

- It is almost never possible to achieve optimum source distance and optimum late reverberant level at the same time!
- DG has found rear-pointed cardioids useful for reverberation since Steve Fassett's suggestion in 1968.
- Proper sense of distance in the main image is created by careful control of leakage - or by DSP.

Rare exception - Lindsay chapel Boston

– long narrow Gothic space - works well with a small group
– side wall reflections are ~-6dB and ~17ms
– late reverberation is almost correct with a simple binaural technique
– still sounds more enveloping when backwards cardioids are added.

Lindsay Chapel

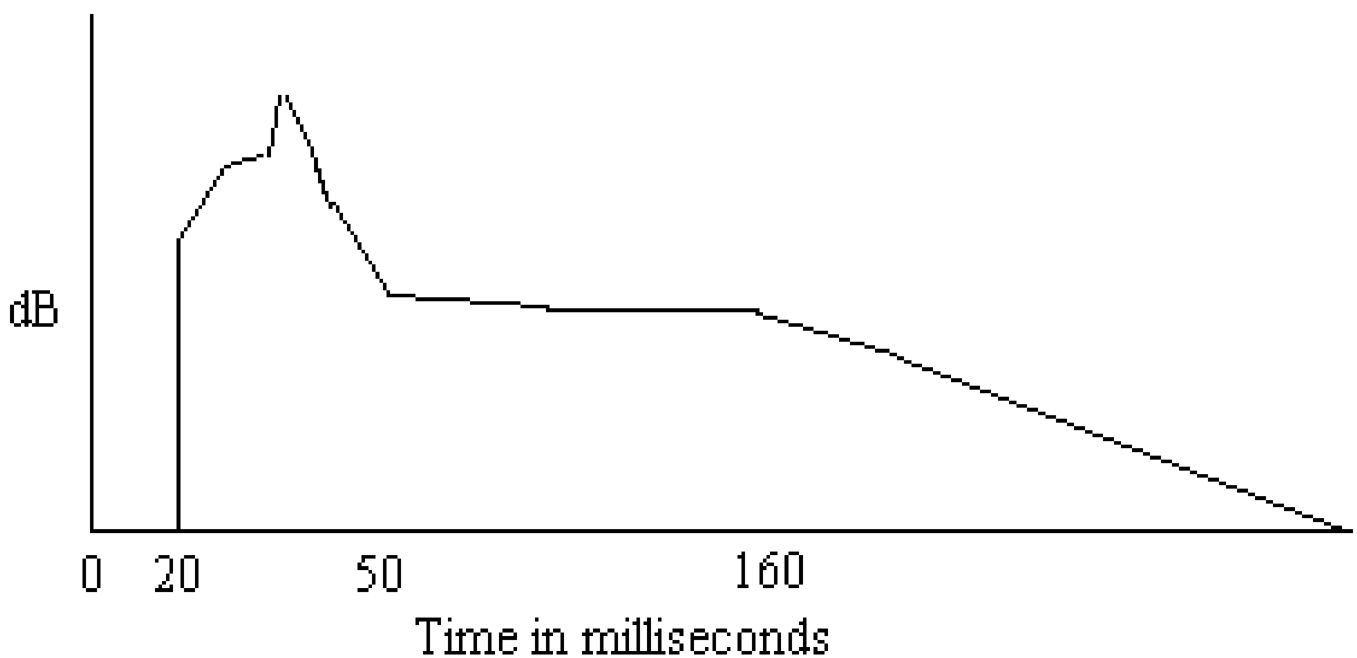


Solution - Use DSP

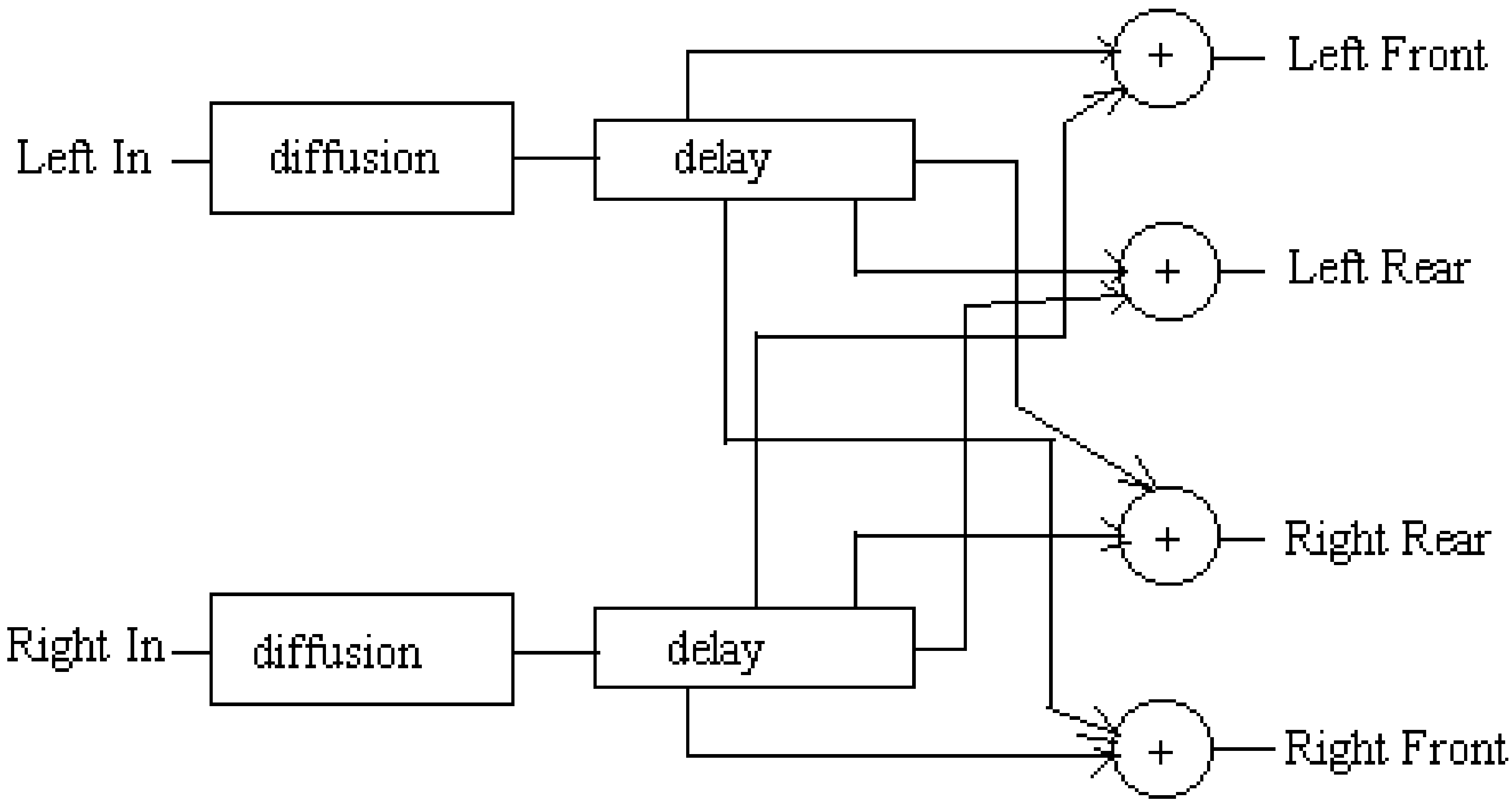
- The "Ambience" program will provide the missing "distance".
- The "Random Hall" program provides late reverberation and warmth.
- The engineer can concentrate on clarity and balance.

Ideal Energy Profile

- We need ~-6dB energy in the 15-50ms range
- flat energy profile to over 160ms independent in each channel



Four channel Ambience - Early Reflection Structure



– note NO early reflections in the center speaker

Recording in Surround

- Identify the goals of the recording:

- 1. Large listening area - no sweet spot!!
- 2. Use the center speaker - not Quad
- 3. High listener envelopment
- 4. Conductor’s perspective

If we honestly believe these goals, physics imposes CONSEQUENCES!!!

- First goal: Large listening area for direct sound
  - A single sound should be panned to at most two adjacent channels.
  - Separation between center and left and right fronts should be at least 6dB.
  - 6dB separation is difficult to achieved with microphones at a single point.

First goal: Large Listening Area for envelopment

- reverberant or background sounds should be decorrelated in all channels, particularly the front and rear
  - Thus minimal or no use of pans between the front and rear speakers.

2nd goal: True 5 channels, not Quad

- sounds from front center should come from the center loudspeaker
- leakage of center sounds into other speakers should be -6dBor less
- pans should go from left to center, and from center to right.
- With diffuse sources be sure the center is -4.5dB vs L&R

Phantom Center VS Hard Center for soloists

- "Ideally" panning should be left to center or right to center with no phantom.
- Some phantom center is tolerable in practice and may be desirable
- Lexicon Logic uses -6dB less in left and right than in the center, implying a phantom center 3dB less than the hard center.

Center Channel Technique

- Diffuse sources are easy
  - technique is non-critical when the center level is low
  - center microphone pairs can be panned left-center and right-center
    - total center energy can be less than left/right energy
- Centered Solos and Vocals must be stronger in the center than in left/right
  - left-center and right-center panning still works.

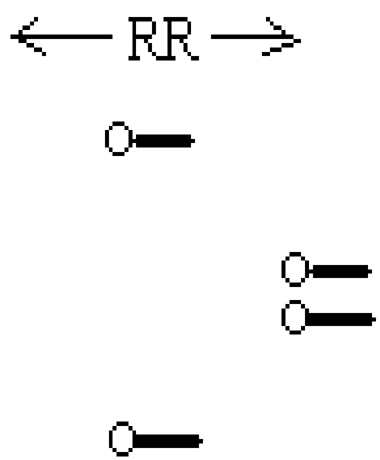
Advantages recording with four front channels

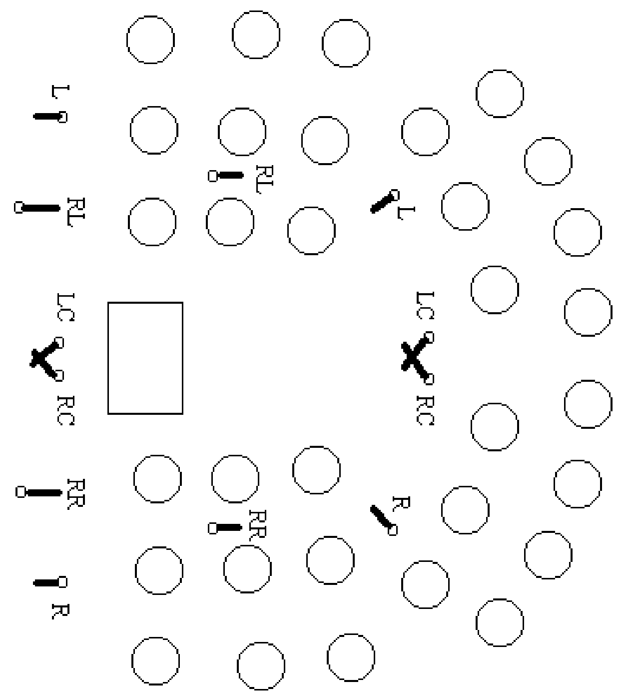
- Recording with four front channels allows later adjustment of the phantom center/hard center ratio.
- Mixer channels come in pairs.
- Four front loudspeakers perform better than three, at least for classical music.

3rd goal: Recording High Listener Envelopment

- The left/right directions should be uncorrelated - particularly in the rear, and particularly for reverberation
- Low frequency reverberation should be reproduced in stereo.
- In practice rear microphones should be separated by the reverb radius (critical distance).

Rear Microphone separation





- Close microphones are correlated - even if they look random on a phase meter.
- Rear mikes should be separated by more than the reverberation radius.

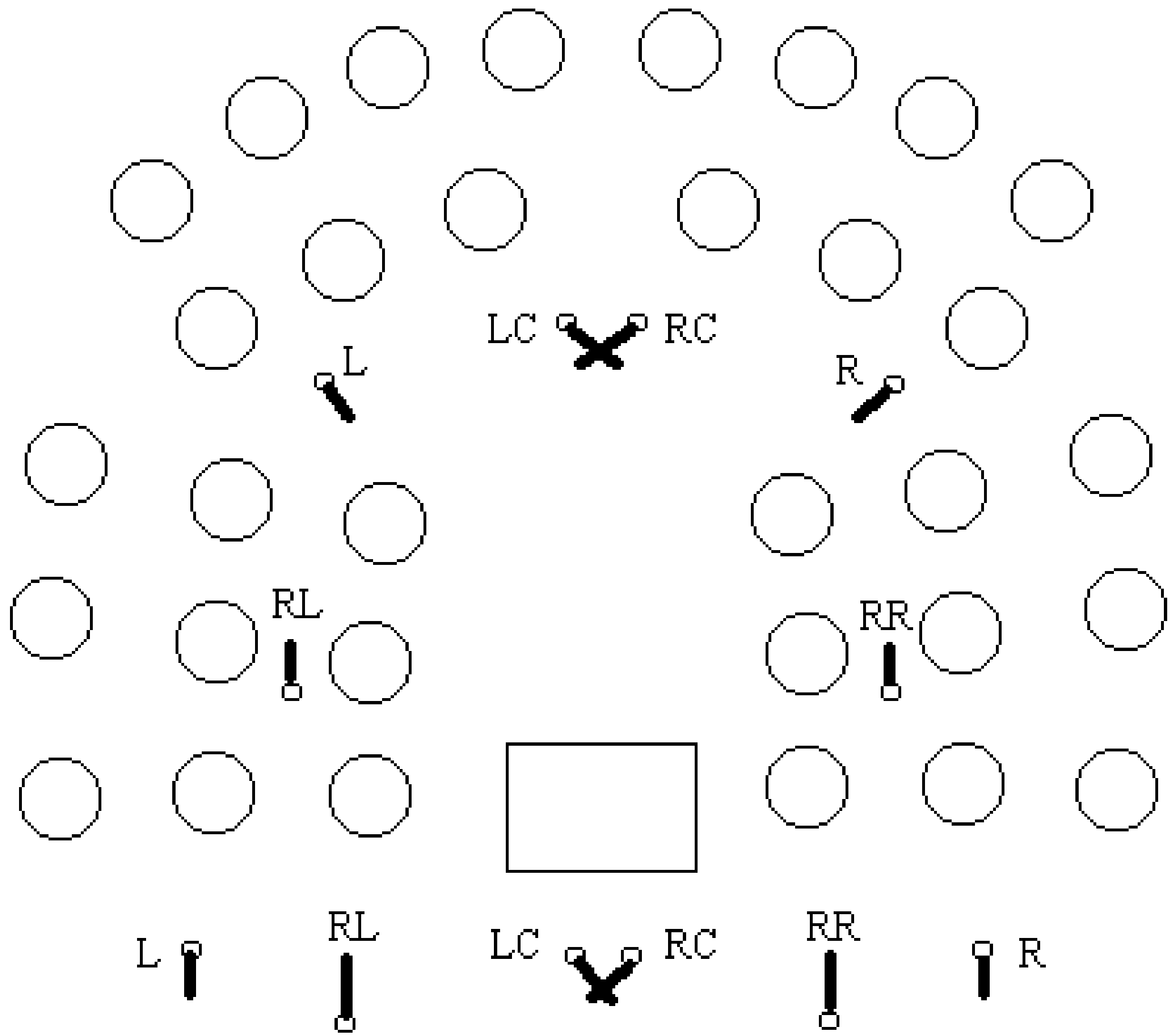
Rear microphone frequency response

- Rear channels supply low-frequency decorrelated reverberation.
- Delayed high frequencies can be distracting from the rear
- A ~6dB boost below 400Hz can improve both clarity and envelopment
- This technique is used in LARES installations in opera houses. (Also by Lexicon Logic and Teldec Berlin.)

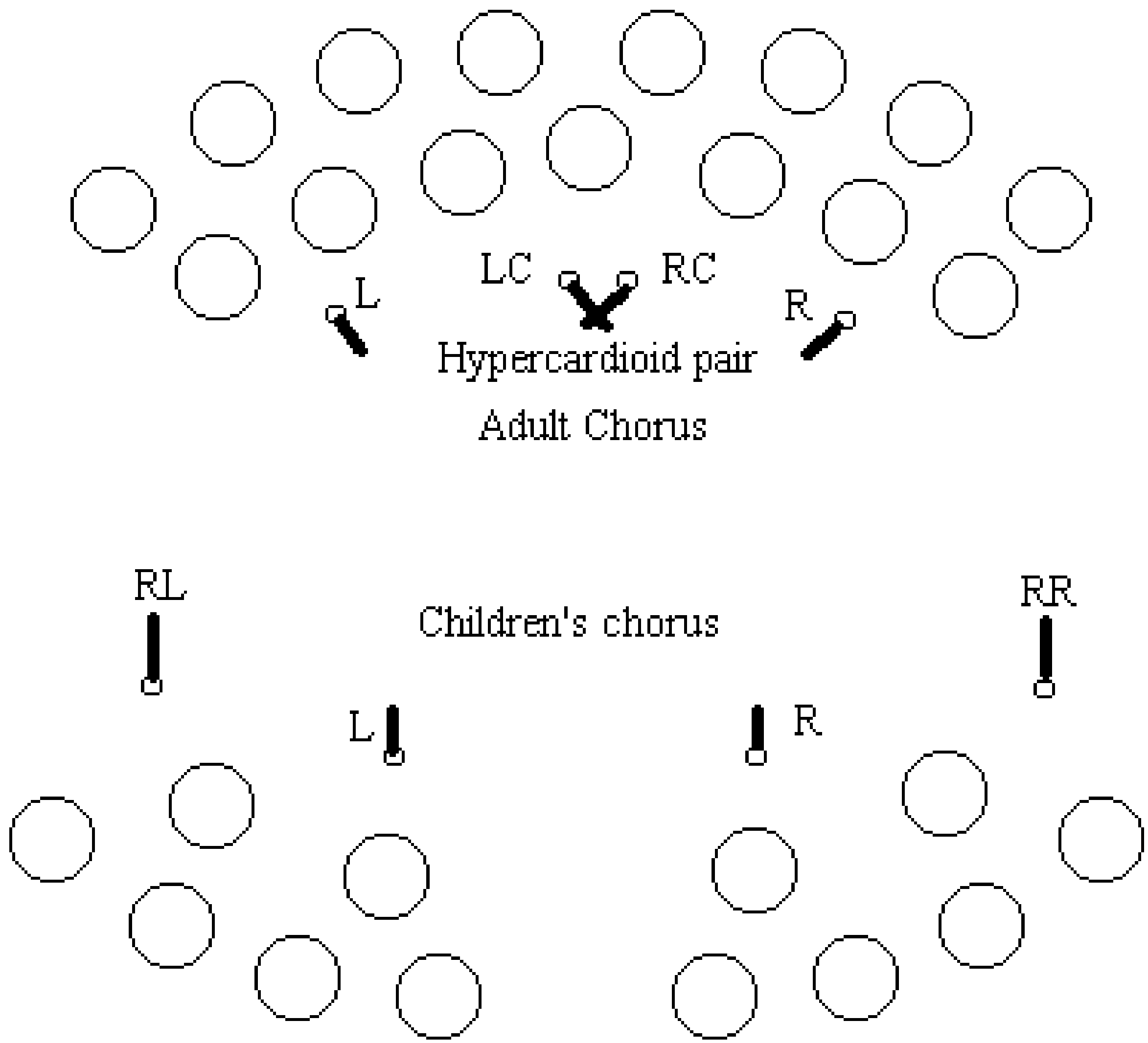
4th goal: Conductors Perspective

- Can be controversial - but give it a try!
- Separate microphone channels can be used to pick up the front rows of orchestra EXCLUSIVELY
- These mikes can be mixed preferentially to the rear channels to create the conductors perspective.
- Please don't use panning to achieve the same result

Example - Orchestra and Chorus



Example - Two Choruses



Repeat the four goals

- 1. Large listening area - no sweet spot!!
  2. Use the center speaker - not Quad
  3. High listener envelopment
  4. Conductor's perspective

Envelopment and the design of Logic decoders

- recent research into the acoustics of small rooms shows a standard stereo pair of speakers is NOT the optimum method of coupling two recorded channels to a room.
- A description of this work is too lengthy for this workshop. We can summarize the conclusions.

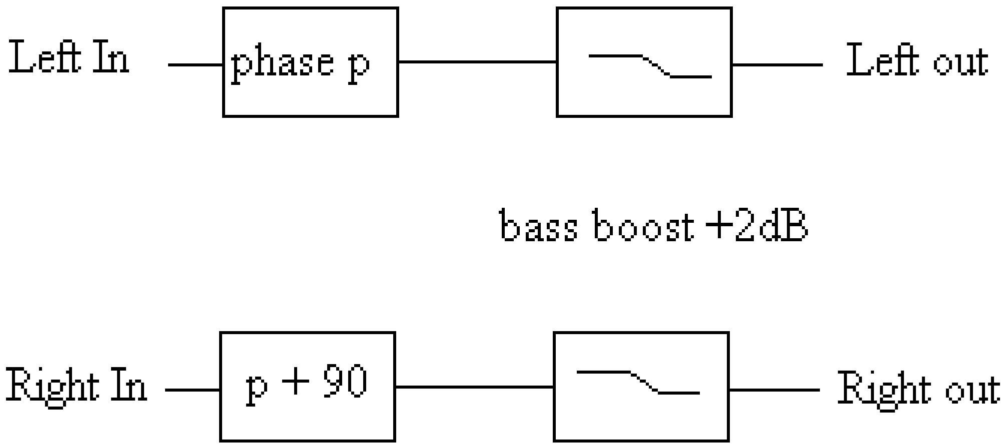
Conclusions on Envelopment

- Two or more independent drivers are essential for music reproduction in small listening rooms.
- Recordings must include decorrelated reverberation.
- Two drivers in the front will not produce envelopment where lateral room modes are weak.
- A standard stereo pair can generate envelopment at HF even in an anechoic space.
- A single LF driver in a small room does NOT create envelopment with music signals.
- LF drivers work better when placed at the side.

Conclusions on Externalization

- AITD (a measure of externalization) is low when two drivers are in phase.
- AITD improves with a phase shift of ~90 degrees between LF drivers.
- There is a 3dB loss in total pressure with the 90 degree shift
  - and some change in the pressure distribution
- drivers at the side of the listener are preferred
- Asymmetric lateral room modes can be manipulated to give envelopment at LF in some rooms, by increasing the width at low frequencies.

Application:



- both phase shift and a slight bass boost is applied

Externalization and Env. can be enhanced by matrix decoders

- Lexicon Logic decoders are designed to maintain left-right decorrelation
- side and rear channels are maximally decorrelated whenever the front/back steering is +-22 degrees
  - side and rear speakers supply maximal envelopment under most conditions
- front speakers are always decorrelated when the sound is toward the rear
- low frequencies are NOT reproduced by the center loudspeaker - and are in stereo.

Design of Lexicon Logic at low frequencies

- Low frequencies from the center are directed to either the front or the side speakers, or both
- separate 90 degree phase filters are applied to the front and the sides.
- In a 7 channel version the rear speakers are also phase shifted
- front/back balance is dynamically adjusted by shelving filters, so the LF stays at full level from the sides.

Design of Logic 7 at high frequencies

- in “music” mode center material is split between the center loudspeaker and the front left and right.
  - Typically the center is a maximum of 6dB stronger than the left and right during vocals.
  - Special applications can use a maximum difference of 3dB
  - center power ratio is preserved
- in “film” mode center material is directed strongly to the center loudspeaker and is removed from left and right front

HRTF technology in five channel surround

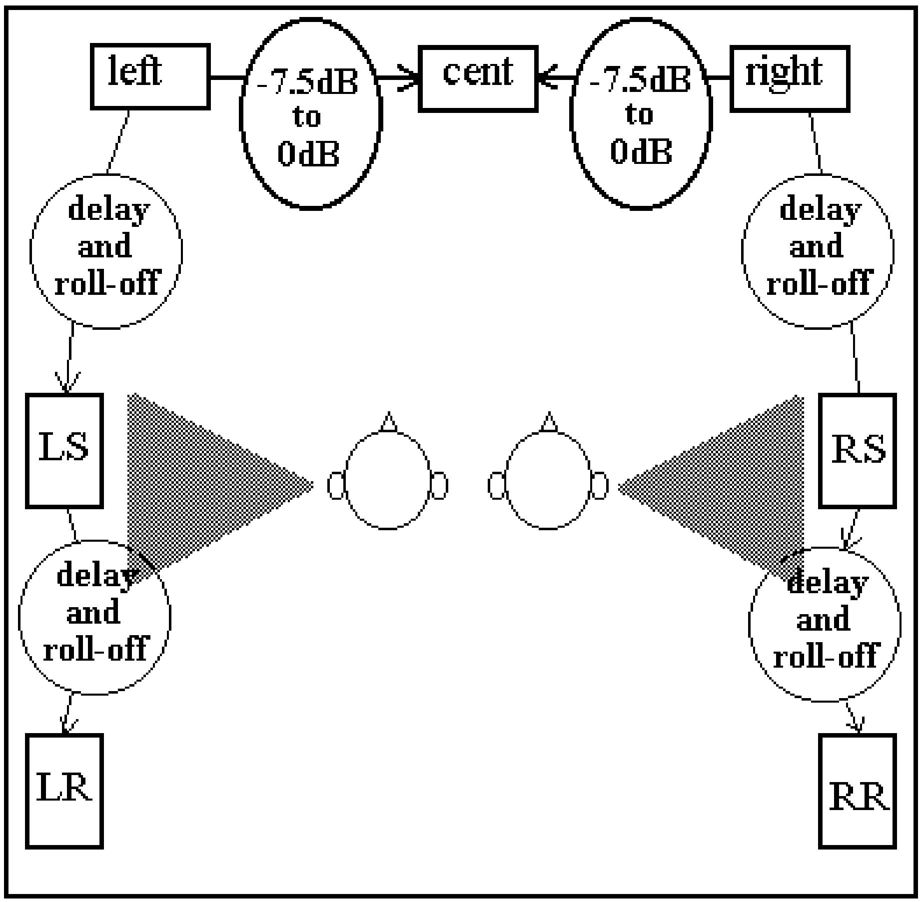
- Two surround speakers are optimally at the sides for LF and at 150 degrees at HF
- HRTF technology can be used to
  - give the side speakers the psychological impact of rear speakers,
  - and decrease the front/back ratio. (Morimoto)

Lexicon Music Logic - a logical alternative

- recording for matrix encoding
- record/encode/playback examples

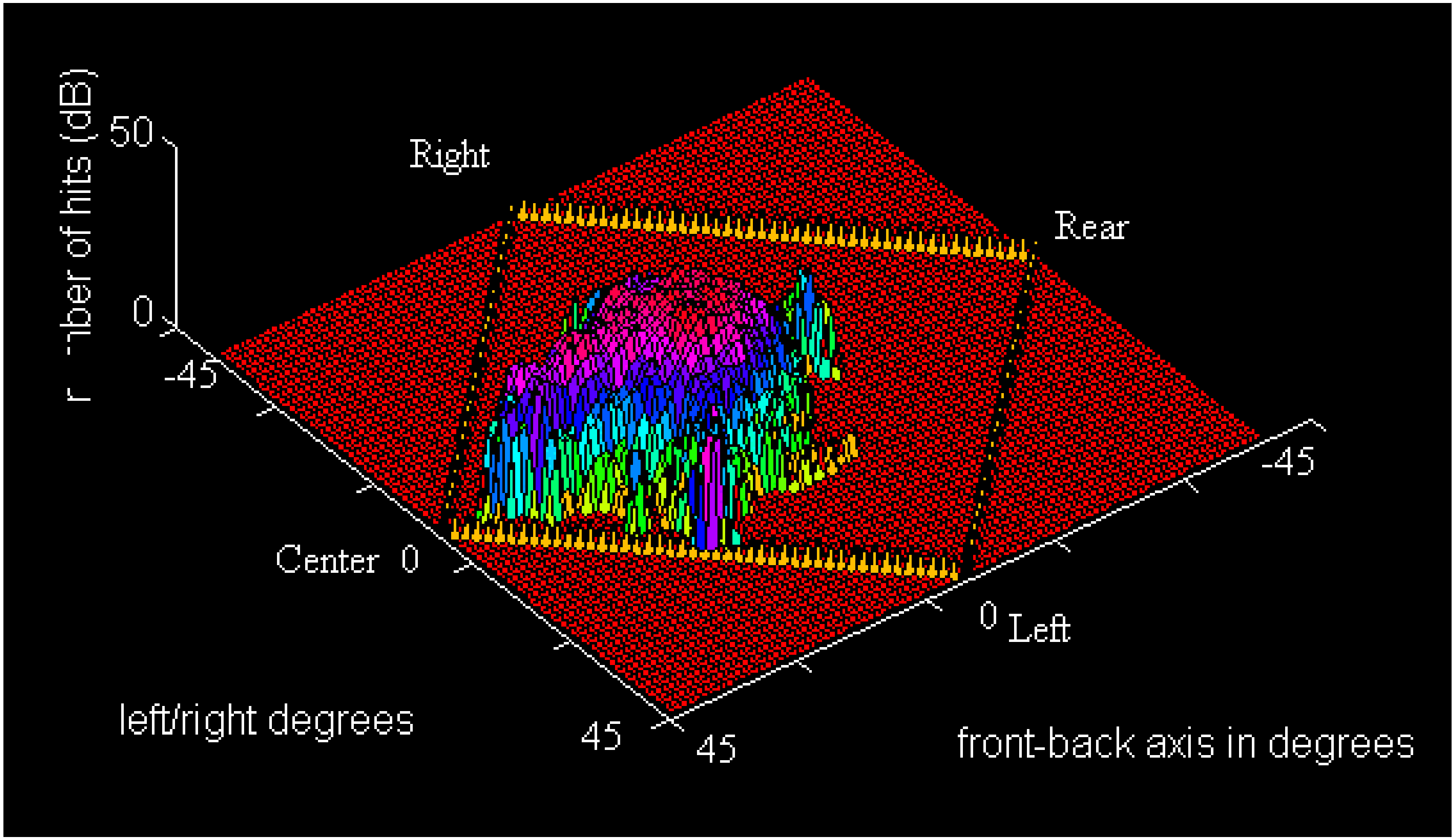
Stereo Bass drivers - theory and examples

Logic 7 Decoders - Default



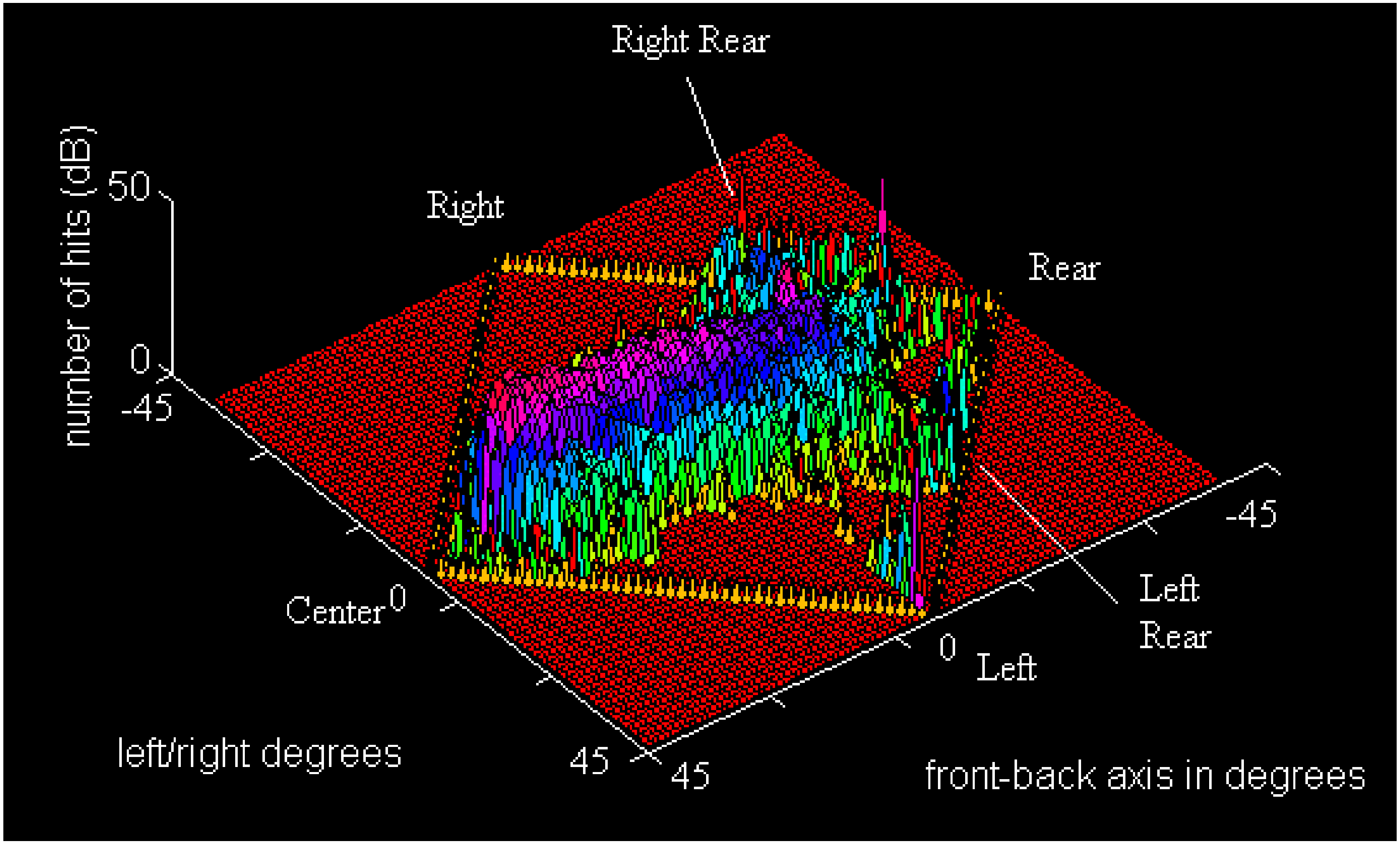
- **Precise control of center channel loudness yields excellent stereo imaging.**
- **Stereo balance is preserved.**
- **Two or four rear channels with high left/right separation, decorrelation, and minimal delay**

A Histogram of a typical stereo piece (first 30 seconds of Jennifer Warnes)



•**Note the bulk of the power is not steered (uncorrelated), but it moves from the middle to the front**

A Histogram of an encoded 5-channel piece (first 30 seconds of Boyz II Men)



•**Note the extensive use of the rear directions. Here we need full stereo width in the front and in the rear!**

Further Conclusions

- Standard stereo is not an optimal system for reproducing music in rooms.
- A five channel system is nearly always superior to two, but only if the side speakers are independent.
- A seven channel system - with an additional pair at +-150 degrees - yields further improvements in listening area and HF envelopment.
- Envelopment is enhanced if the side speakers have response to 40Hz.