Inseparable:

Room Acoustics and Sound Systems for the Worship Space

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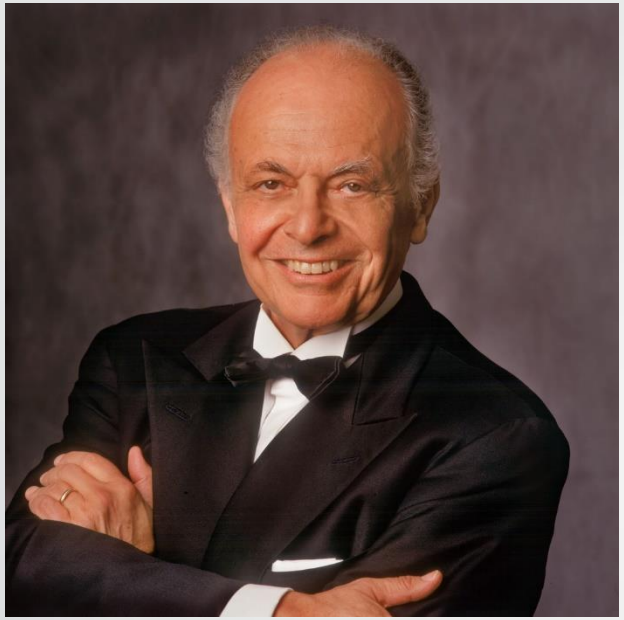


Maestro Lorin Maazel

Keynote Speaker, 106th AES Convention May 8, 1999

Everywhere in the universe there is light, almost nowhere is there sound, just silence. How privileged we are to be working with so rare and precious a material, how honored we must feel to help shape the language of the very soul of mankind.

I salute you, fellow movers and shakers of sound. Long may we prosper!

Next to the Word of God, music deserves the highest praise.

The gift of language combined with the gift of song was given to man that he should proclaim the Word of God through Music.

Martin Luther

Keynote Speaker – Reformation
circa 1517

WHY ARE WE HERE TODAY?

- We want to make our worship environment the best it can be…

For Spoken Word

For Music

For the Benefit of the Congregation
(and to the Glory of God, of Course!)

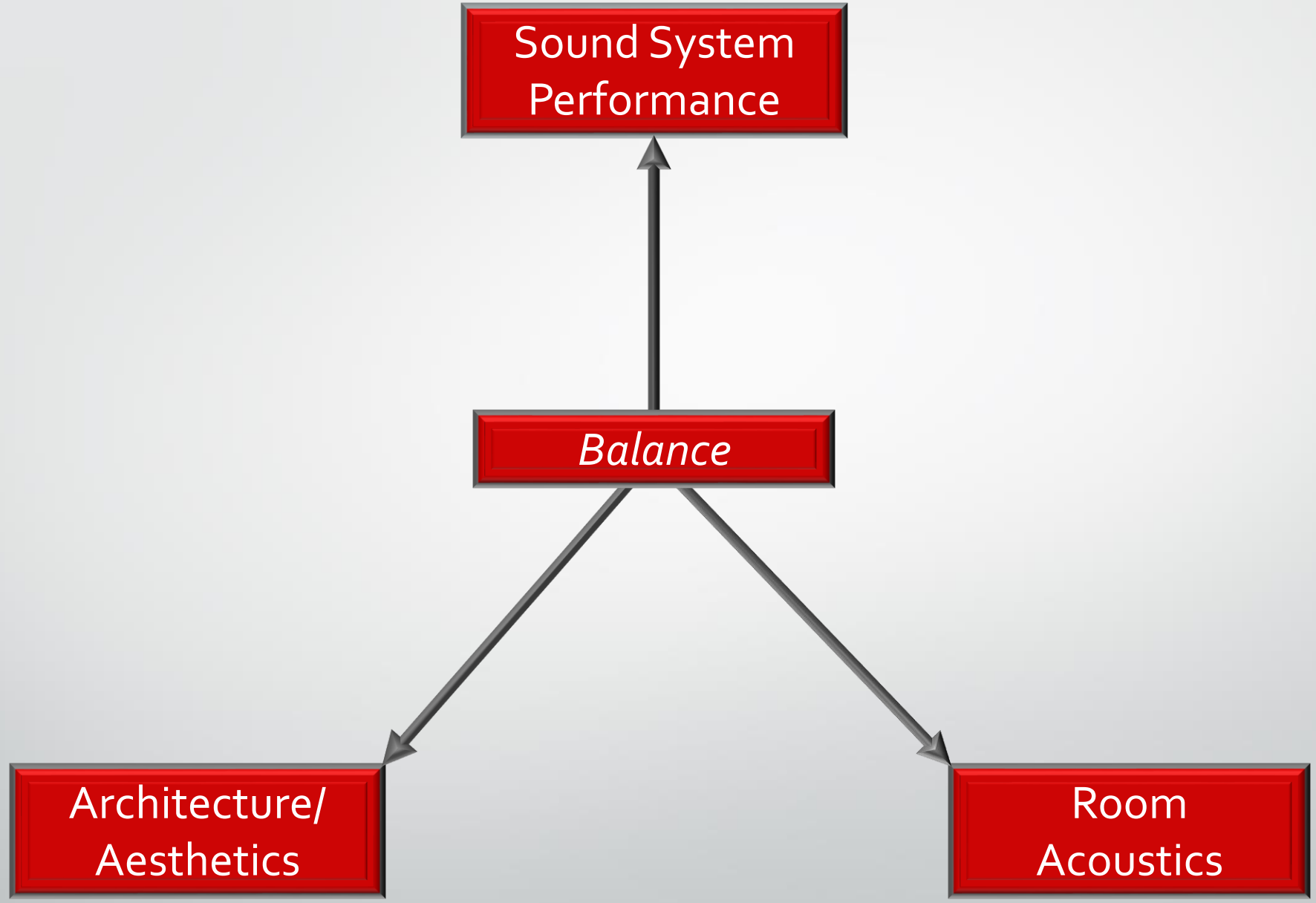
Without Interruption or Distraction from *NOISE*

Aunt Tilly comes to church – the new or newly renovated church. The space looks great…bright, spacious, majestic. The organ sounds fantastic…big, full, *really reverberant*.

What about the spoken word (and song text for that matter)? If Aunt Tilly can't hear clearly, the majestic looking space and outstanding organ sound just do not matter.

We're going to look at *science* and *application*…

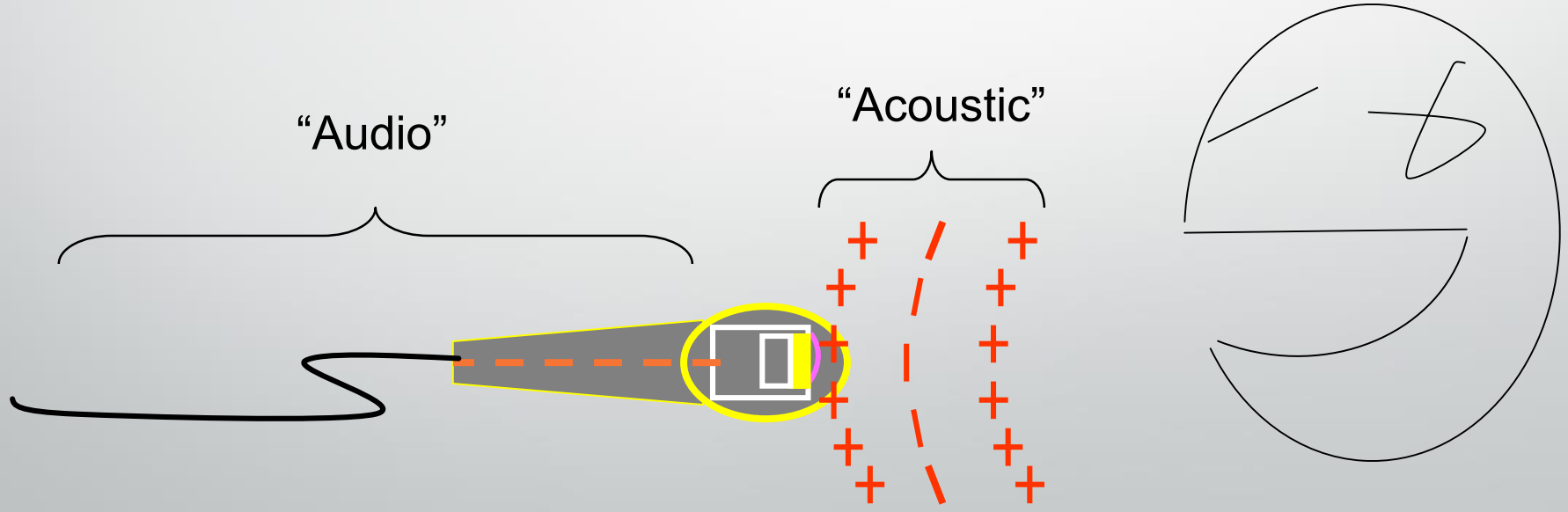
- Basic sound design
  - The sound field
  - Use the right type of loudspeaker and the right type of microphone, both applied properly
- Room acoustics
  - Reverberation is not the enemy, it's how sound is allowed to reflect
  - Absorb, diffuse, reflect, transmit
  - Room size does not matter
- Architecture
  - Wall shapes
  - Ceilings
  - *Making all this tech stuff blend in!*


Sound System Performance
Balance
Architecture/ Aesthetics
Room Acoustics

The Science of Sound

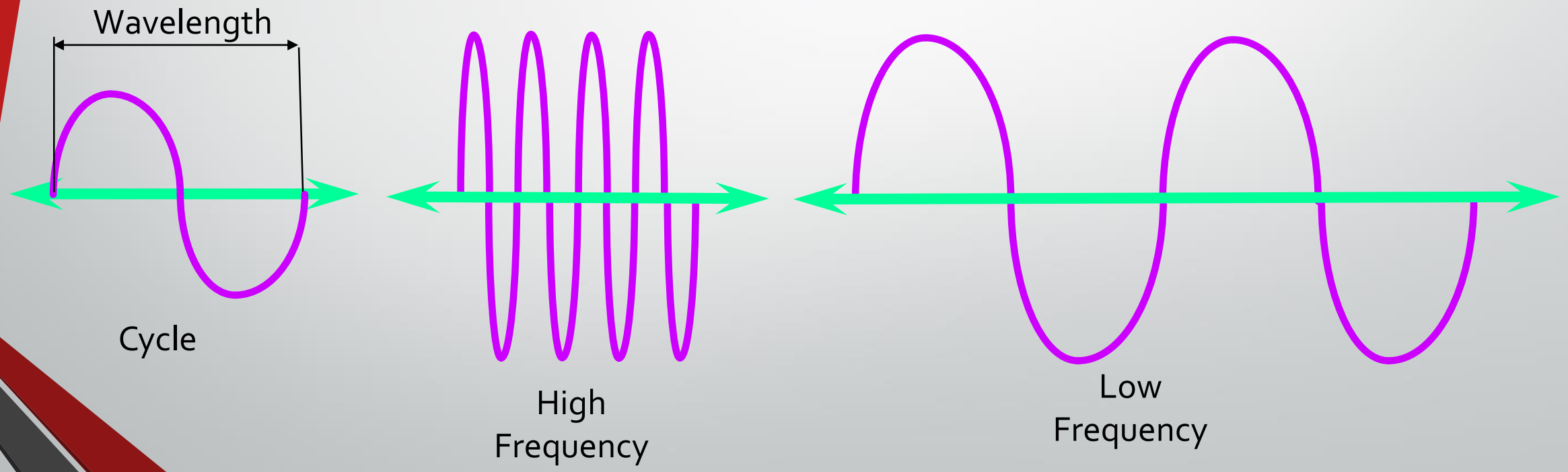
Sound Waves

- Pressure zones
  - *Very small* disturbances in atmospheric pressure.
  - that travel away from the source at the *speed of sound* (~1,130 ft/sec)



Hertz (HZ)

- **Hertz:** One sound wave "cycle".
- **Wavelength:** The length of one Hertz, or cycle
- **Frequency:** Number of cycles per second, or pitch.



WAVELENGTH

FREQUENCY	WAVELENGTH
10,000 Hz	0.113 ft (1.4 in.)
2,000 Hz	0.57 ft. (6 in.)
1,000 Hz	1.13 ft. (14 in.)
500 Hz	2.26 ft. (27 in.)
100 Hz	11.3 ft.
20 Hz	56.5 ft.

- **Wavelength:** The length of one Hertz, or cycle.
- The longer the wavelength, the more difficult it is to control where that sound is going, and the more we are in danger of losing speech intelligibility.

Hertz (HZ)

- **20 Hz:** Low end of sound audible to humans
- **30 - 80 Hz:** Subwoofer (boom-boom) sounds
- **150 Hz:** Low end of male voice – speech
- **440 Hz:** 'A' above Middle 'C' on piano
- **1000 Hz (1KHz):** 'C' two octaves above Middle 'C'; above the high end of soprano voice (music)
- **2-4KHz:** Percussive sounds of voice – consonants: 'K', 'T'
- **4186 Hz:** Top end of piano keyboard
- **6000 Hz:** Sibilance – 'S'

The Decibel (dB)

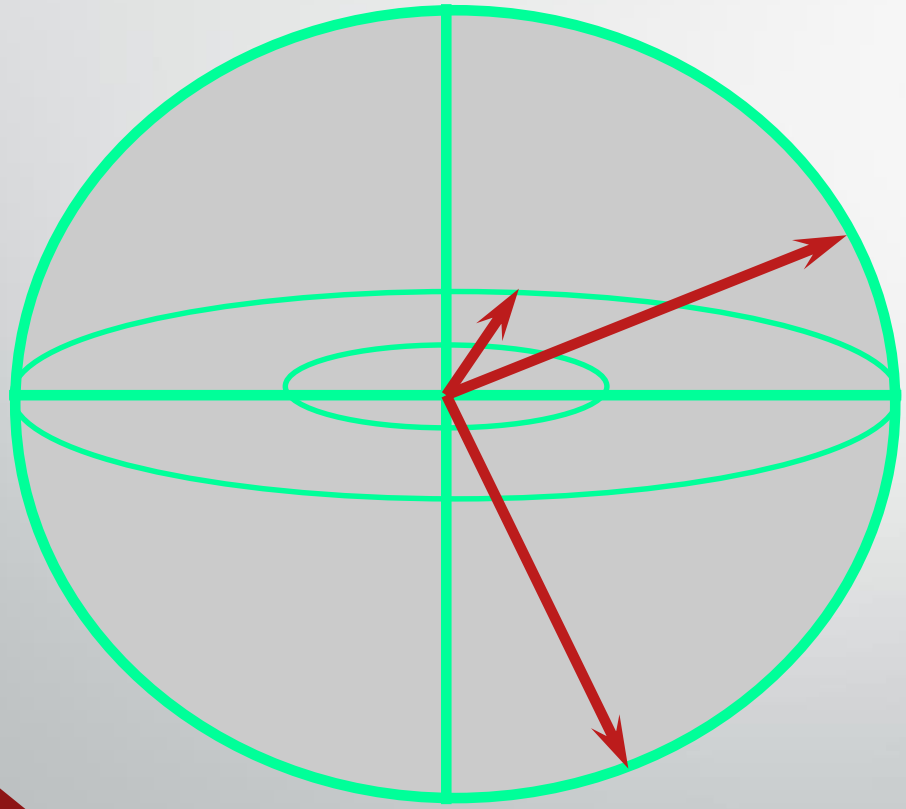
- dB is a unit-less quantity…it is a ratio or comparison

0 dB	Threshold of hearing
60-65dB	Normal conversation
75 dB	Shouting
95-100 dB	Some musical instruments; loud home stereo
110dB	Sports stadium noise; Bar band sound system
115-120 dB	World-class touring rock n roll concert; pain
130dB	Permanent loss of hearing

Perceived Loudness

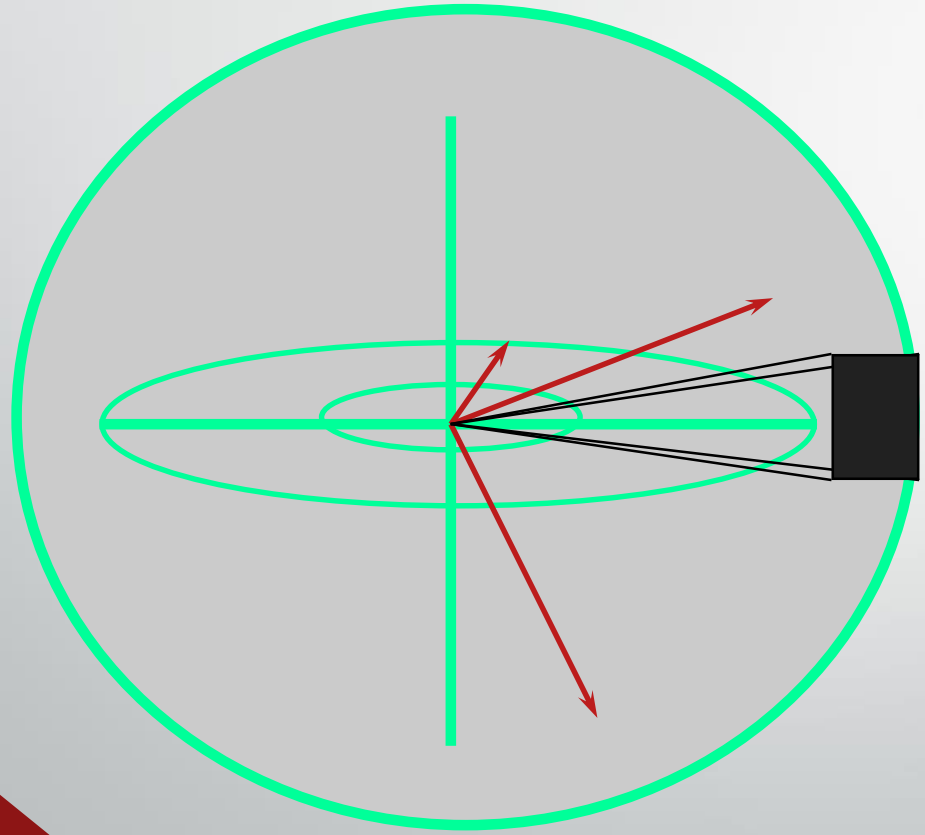
- To most people, SPL changes of 3 dB or less are usually indiscernible:

The Sound Field



- Sound waves propagate spherically, or omnidirectionally.

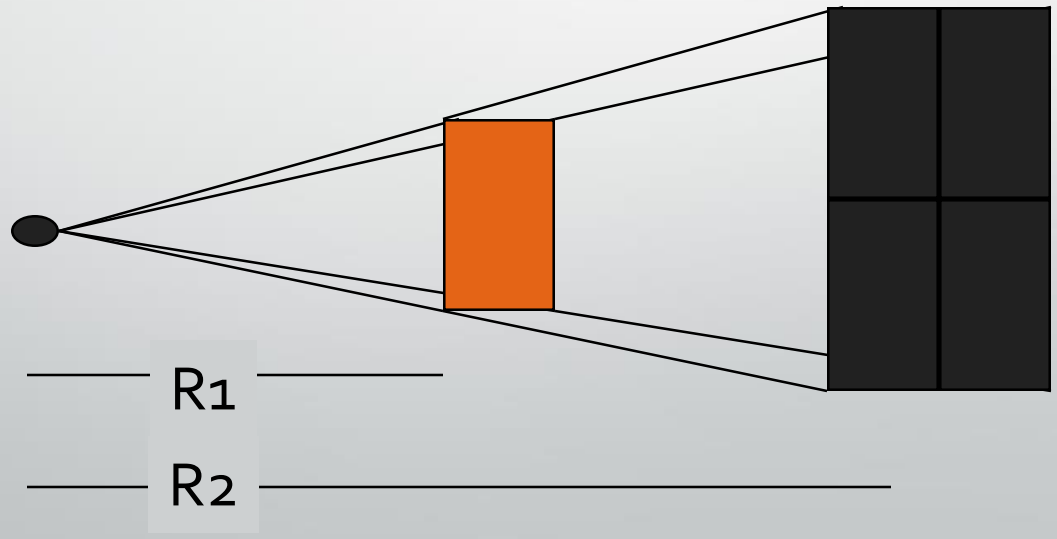
Wave Expansion



- As the distance from the sound source increases, the area covered by the sound wave increases.

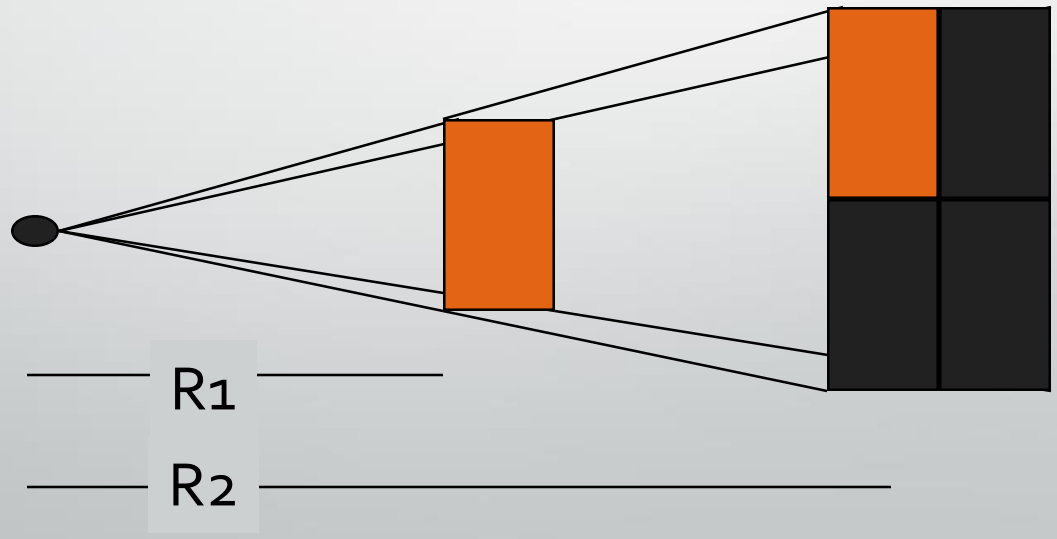
Wave Expansion

- Doubling the radius quadruples the surface area.



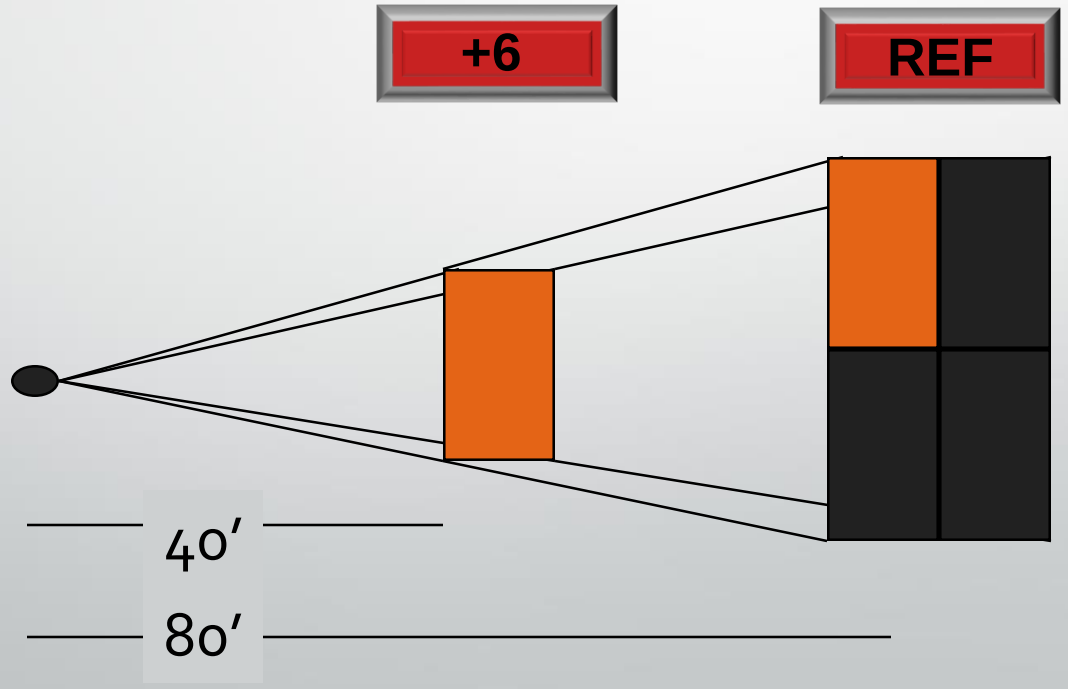
Wave Expansion

- If you quadruple the surface area, the energy decreases to one fourth.

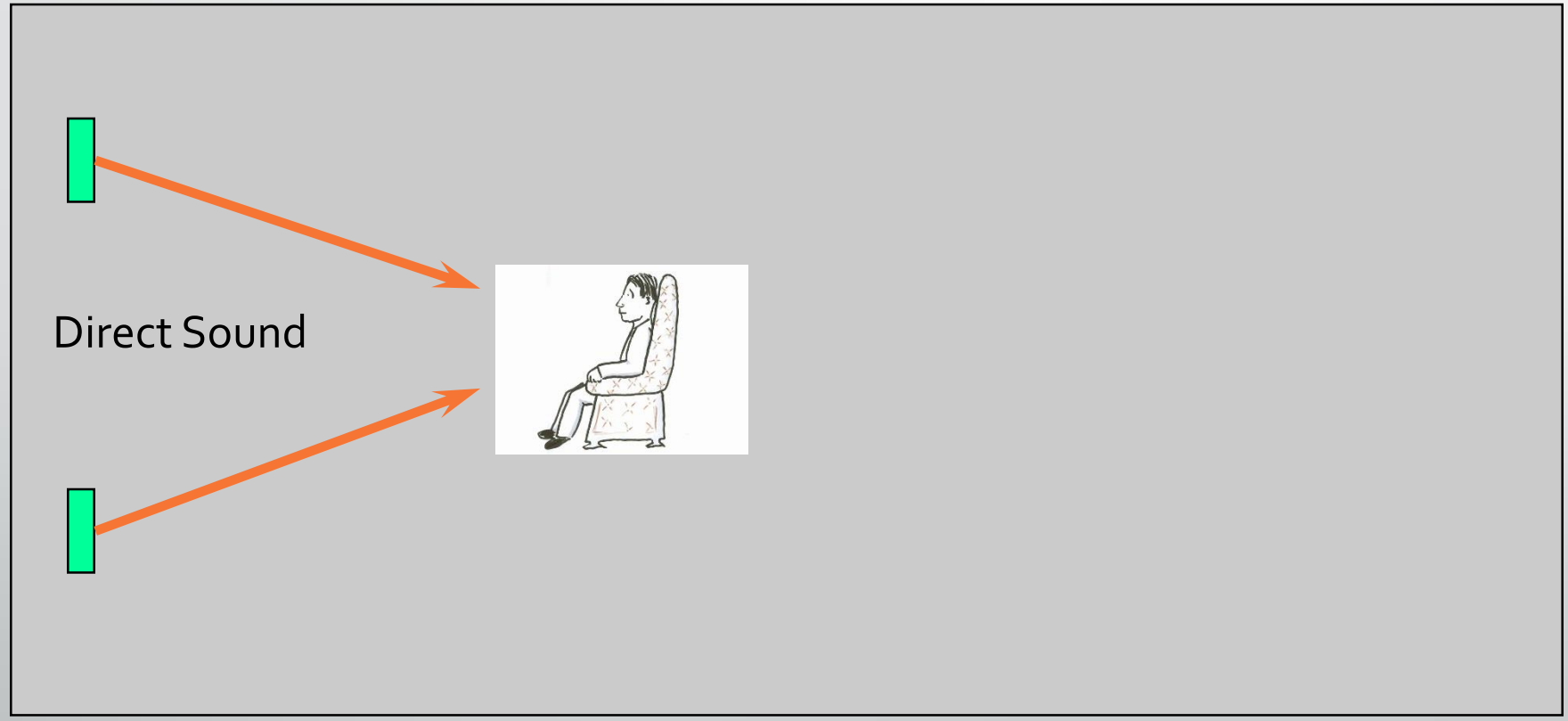


Wave Expansion

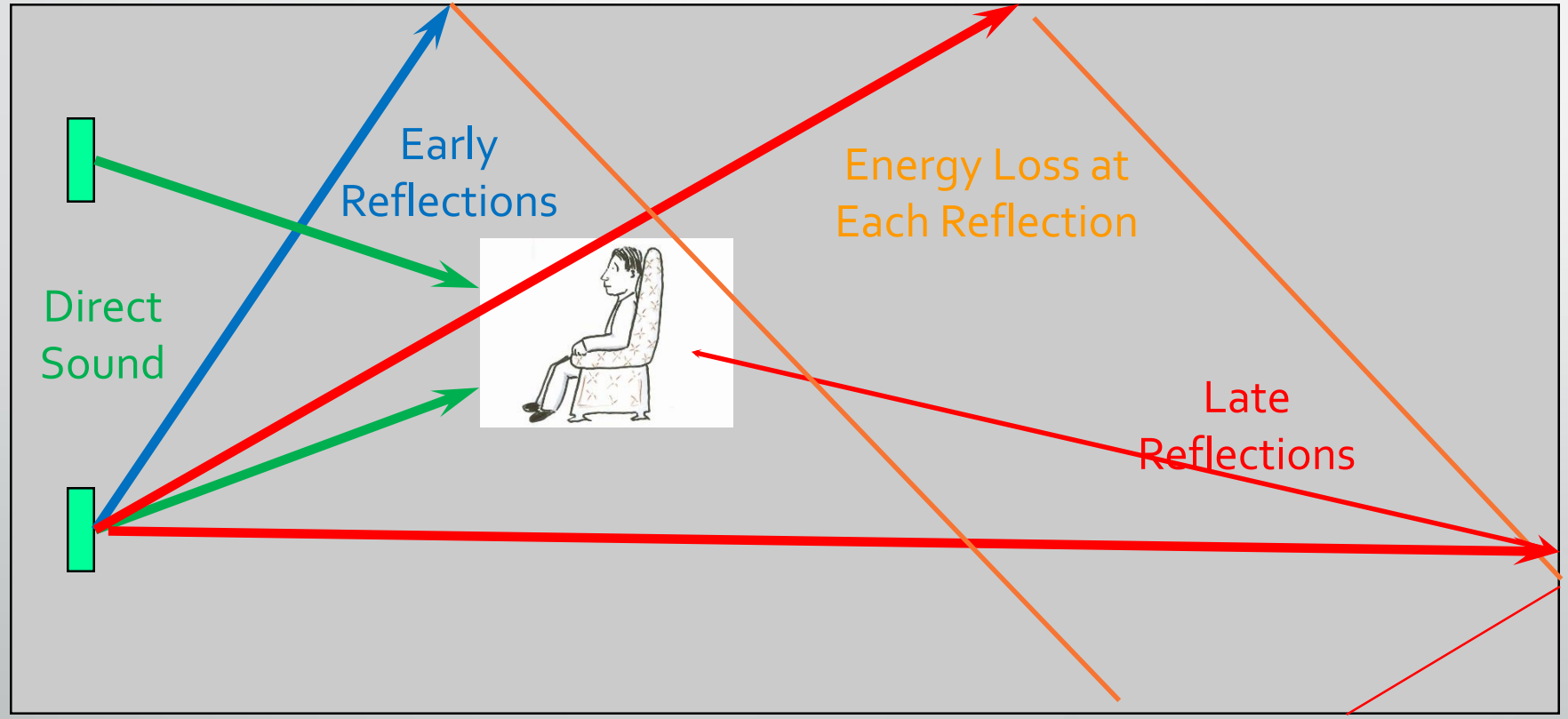
- Here the sound intensity will drop by 6 dB
- This is the principle of "Inverse Square Law"



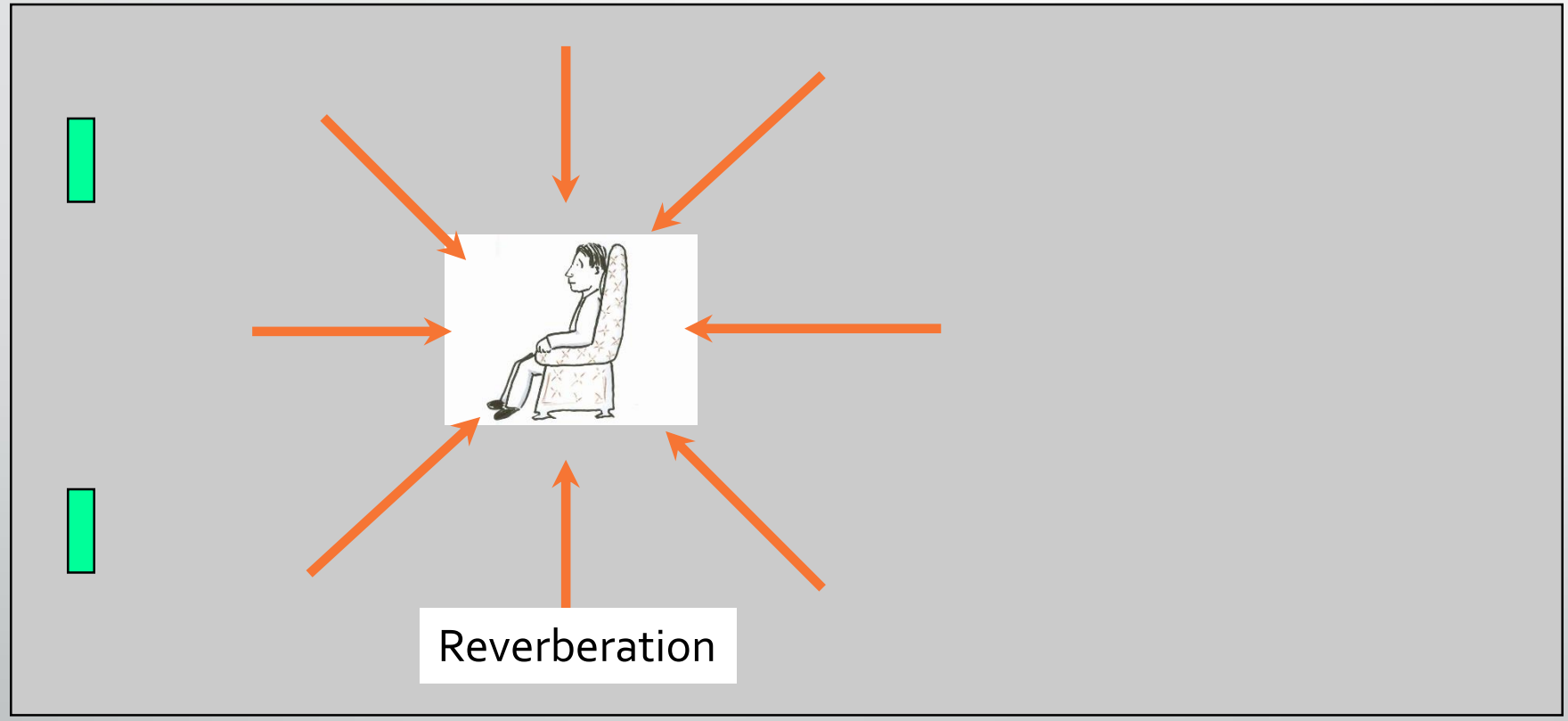
Indoor Sound Field



Direct & Reflected Sound

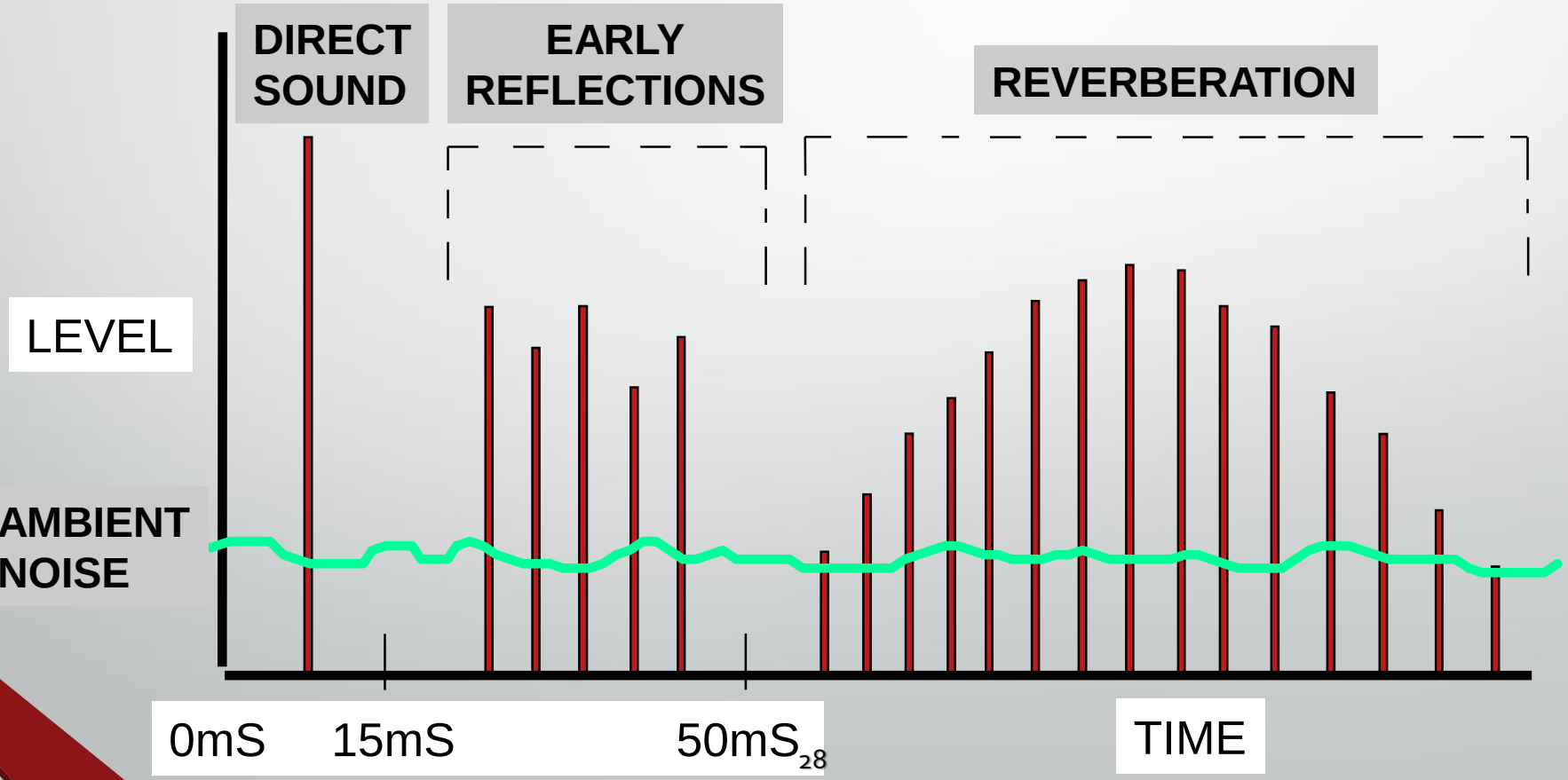


Direct & Reflected Sound



Sound Field vs. Time

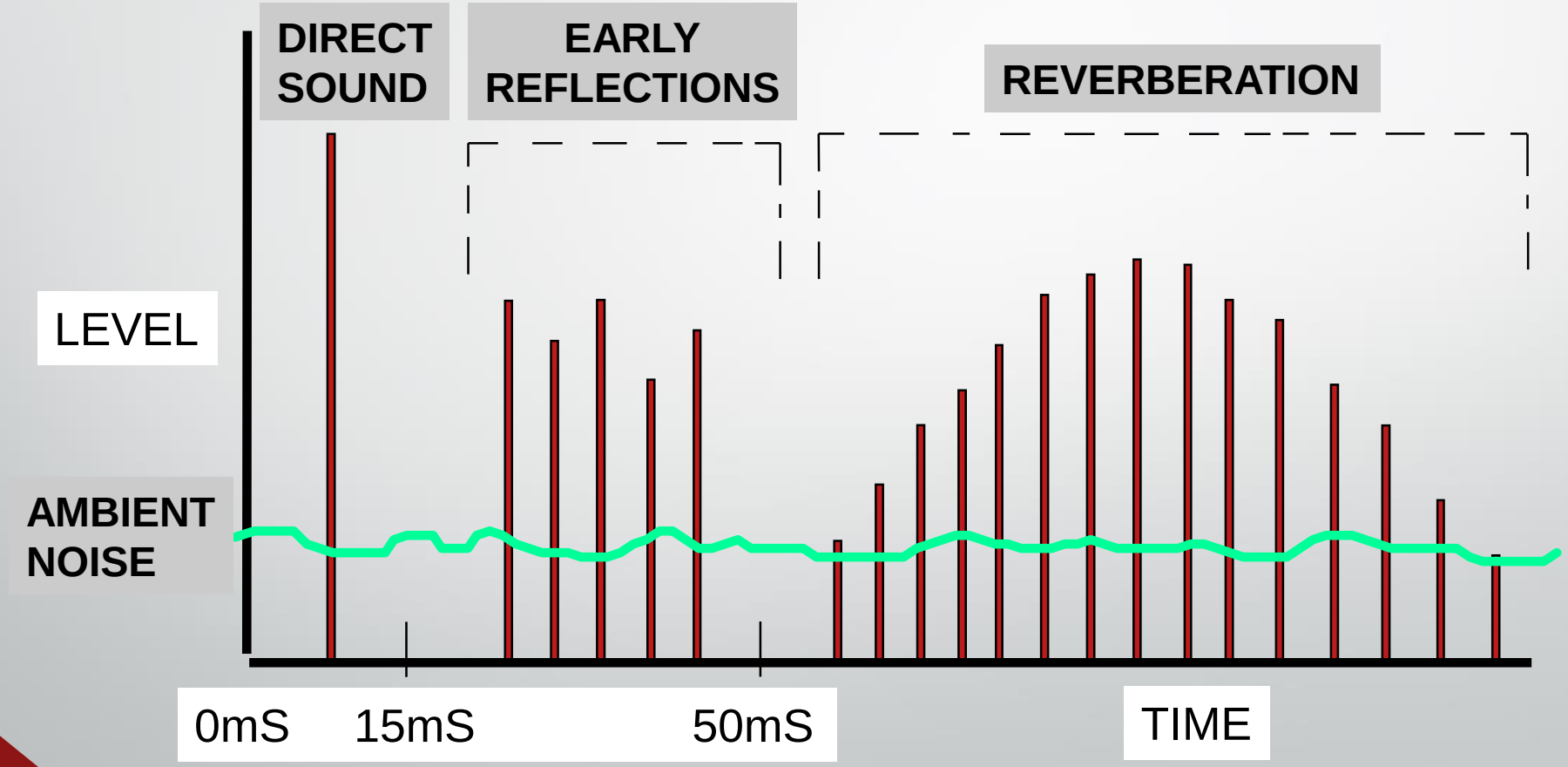
!!EACH PART OF THE SOUND FIELD AFFECTS INTELLIGIBILITY!!



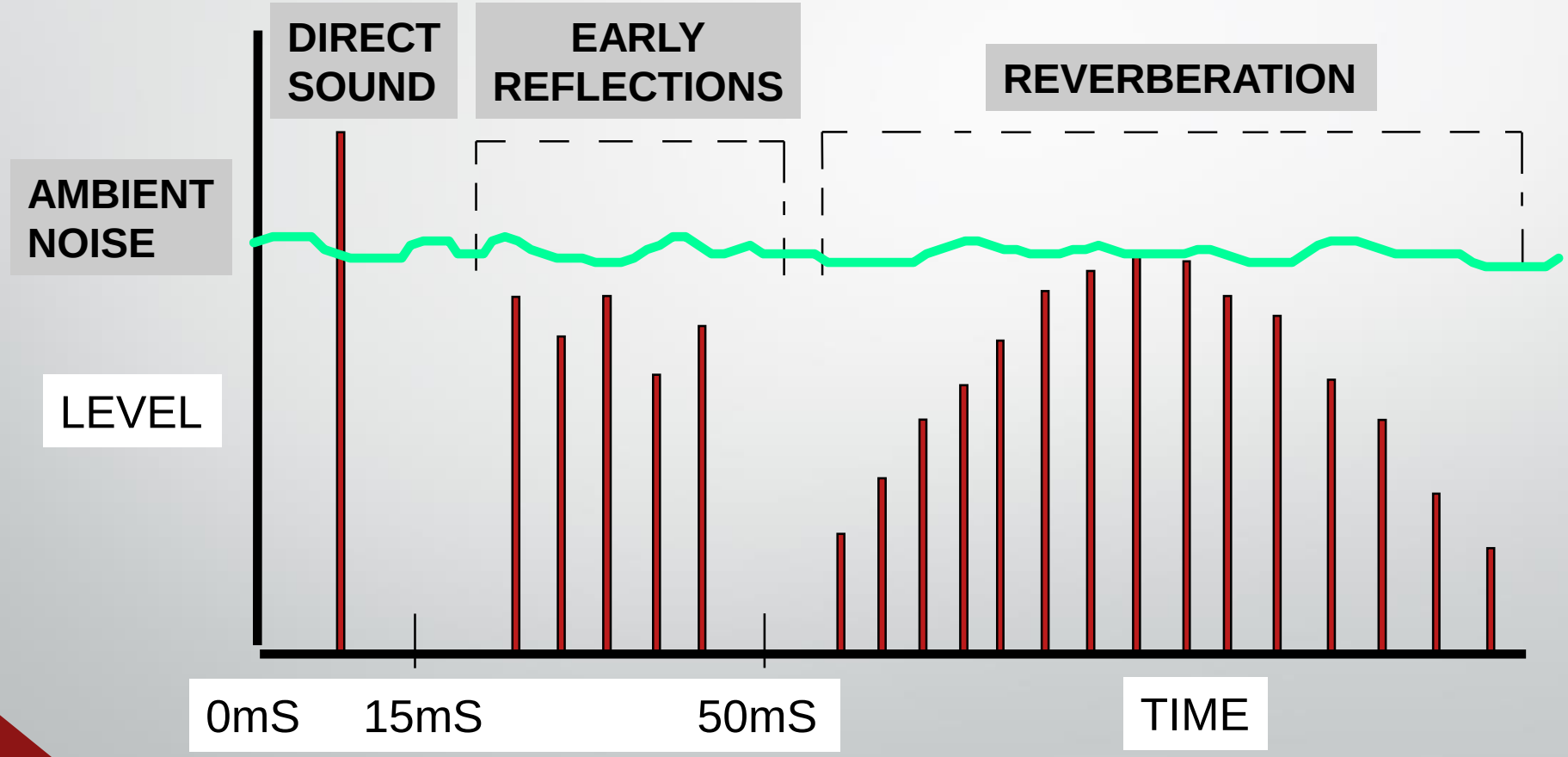
Intelligibility

- Six factors affect intelligibility:
  - Acoustic signal to noise ratio
  - Delayed high-level reflections
  - Distance to source
  - Excessive reverberation
  - Loudspeaker system design
  - Misequalization

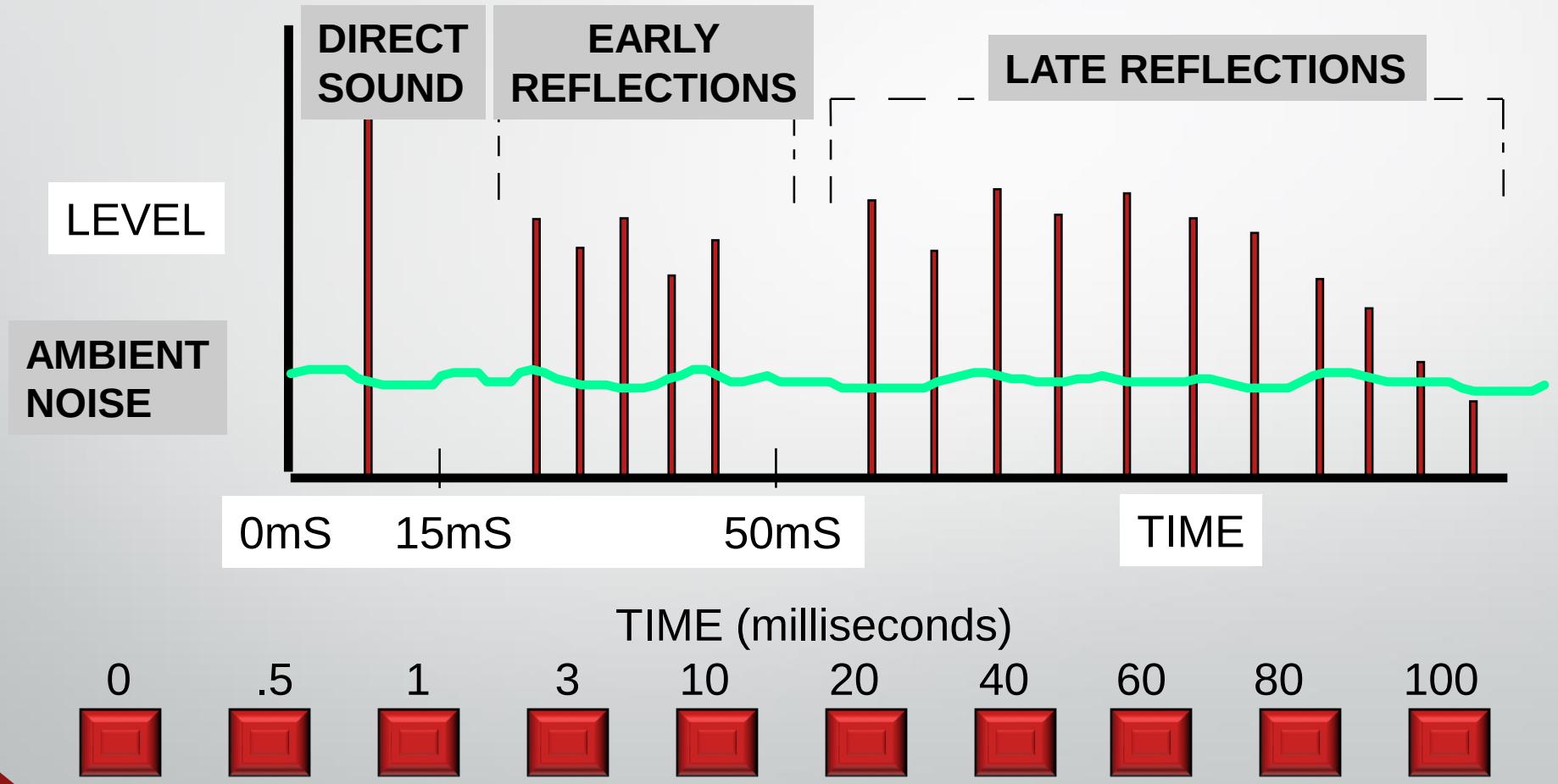
Acoustic Signal to Noise Ratio



Acoustic Signal to Noise Ratio



Delayed Reflections



Distance to Source

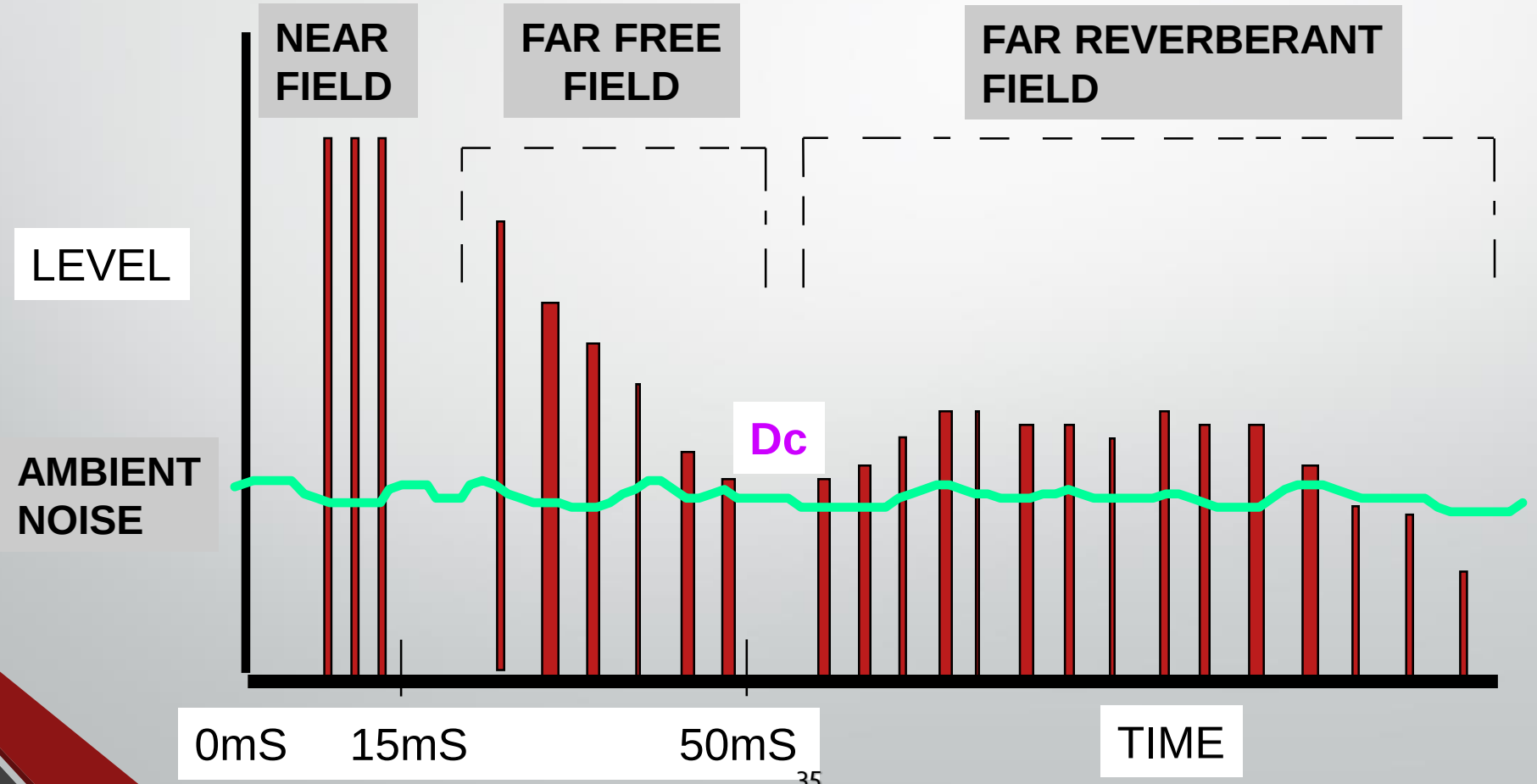
- The farther away you are, the more the SPL drops (Inverse Square Law)
- The farther away you are, the lower the S/N ratio
- The farther away you are, the more the reverberant field interferes

Excessive Reverberation

- RT-60: The time it takes for a sound to drop by 60dB from its loudest point
- Reasonable reverberation adds to the appreciation of music
- Too much reverberation is degrading to speech intelligibility
- In highly reverberant fields, ***critical distance*** is "critical".

Critical Distance

- The point at which the level of the direct sound is equal to the reverberant noise in the room.



Critical Distance

- When you're beyond critical distance
  - Perception of the sound source is reduced or eliminated
  - Speech cannot be understood
  - Music is no longer appreciated
  - Loss of intelligibility can be measured

Critical Distance

TALKER	ED/DR	x Dc	%ALCONS
MALE FEMALE	4.5 dB	.5Dc	5.6%
MALE FEMALE	0 dB	Dc	7.0%
MALE FEMALE	-11.4 dB	2Dc	20.5%

Increase Intelligibility

- Increase direct sound
  - Loudspeaker type and location
  - Point the loudspeakers at the people
  - The back of the loudspeaker should roughly face the acoustic source
- Decrease destructive reflections
  - Diffusive and absorptive surfaces in the right combination
  - Some early reflection is good for musical fullness and depth
- Decrease ambient noise level
  - HVAC systems
  - Pew cushions
- Ensure that 500 Hz - 5 kHz is kept as smooth as possible
  - Loudspeaker and microphone selection

The Science of Room Acoustics

Room Acoustics

- Volume: How much air space?
- Room size: Large or small, size does not matter
- Room shape: Fan, cruciform, shoebox
- Construction materials: Do they…
  - Absorb?
  - Reflect?
  - Diffuse?
  - Transmit?
- Location of elements: What difference does it make?
- Real World Examples

Size Does Not Matter – Small

Size Does Not Matter - Large

Rectangle

Shoe Box

In the Round

Fan

Room Acoustics

- Ambient Noise Levels
  - Remember the earlier graphic?
  - A grade-school science experiment with your hands and whispers
- Wall Shaping vs. Absorption
- Focusing Reflections--Diffusion
- Fan / Shoebox / Reverse Fan Auralizations
- Real World Examples

Building Materials: Reflective

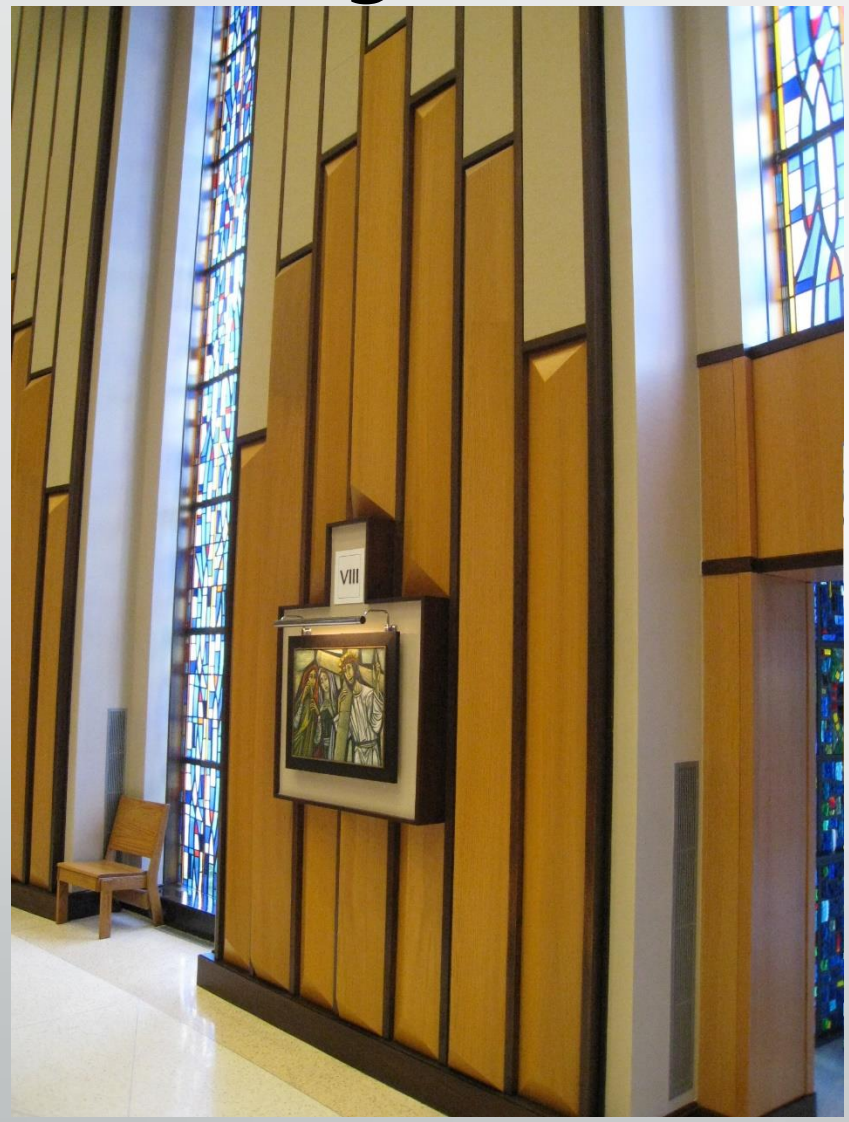
Building Materials: Reflective

Building Materials: Reflective

Building Materials: Absorptive

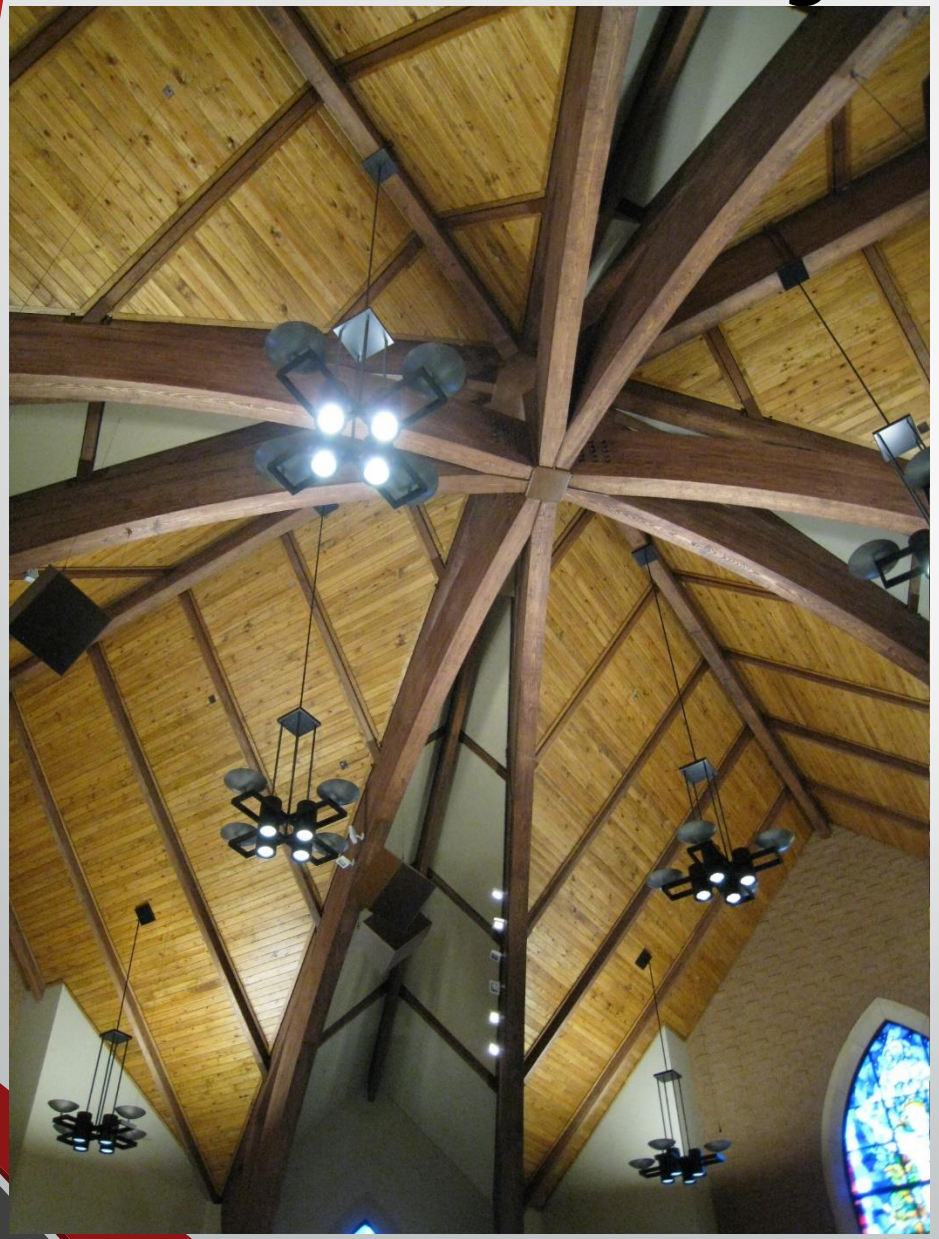
Building Materials : Absorptive

Building Materials: Absorptive & Diffusive

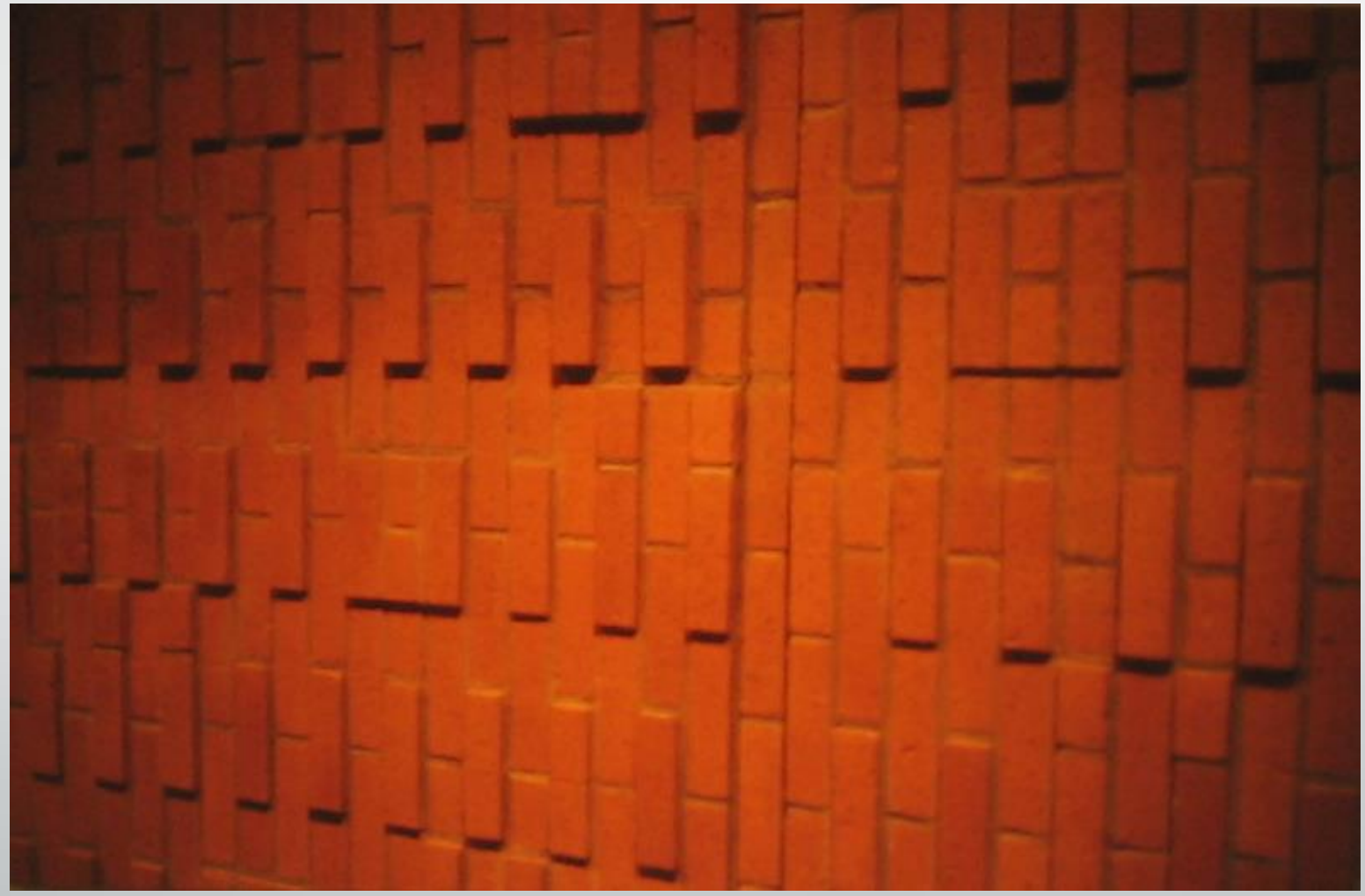


Building Materials: Diffusive

Building Materials: Diffusive

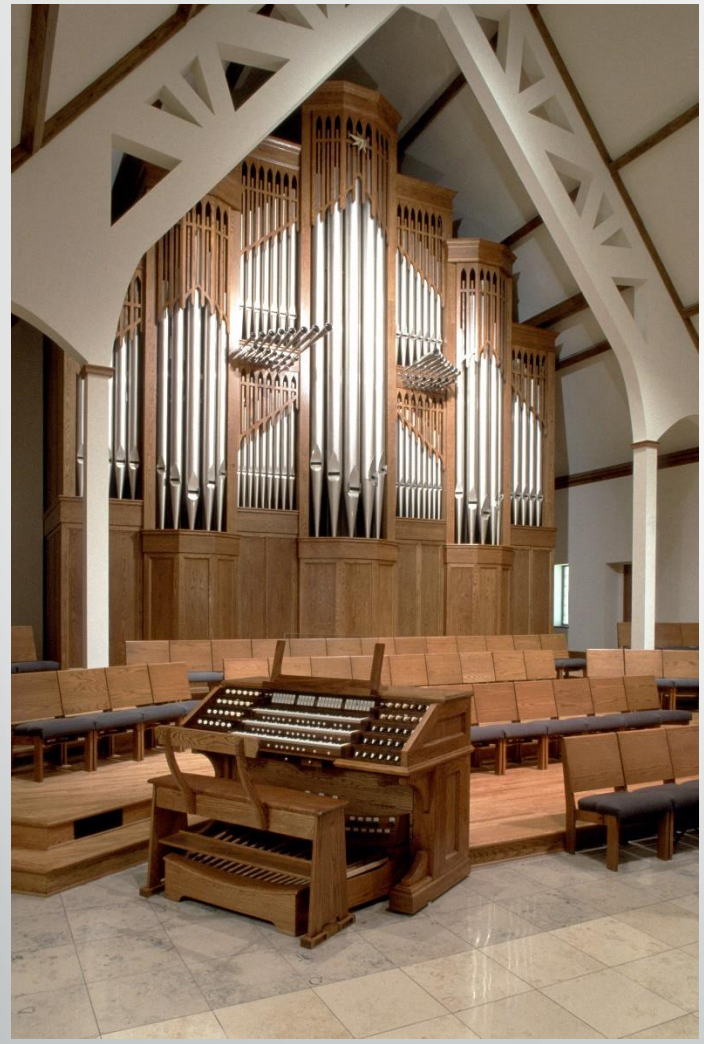


Brick & Mortar Diffusion



Location…Location…Location

Location…Location…Location



One More Location…

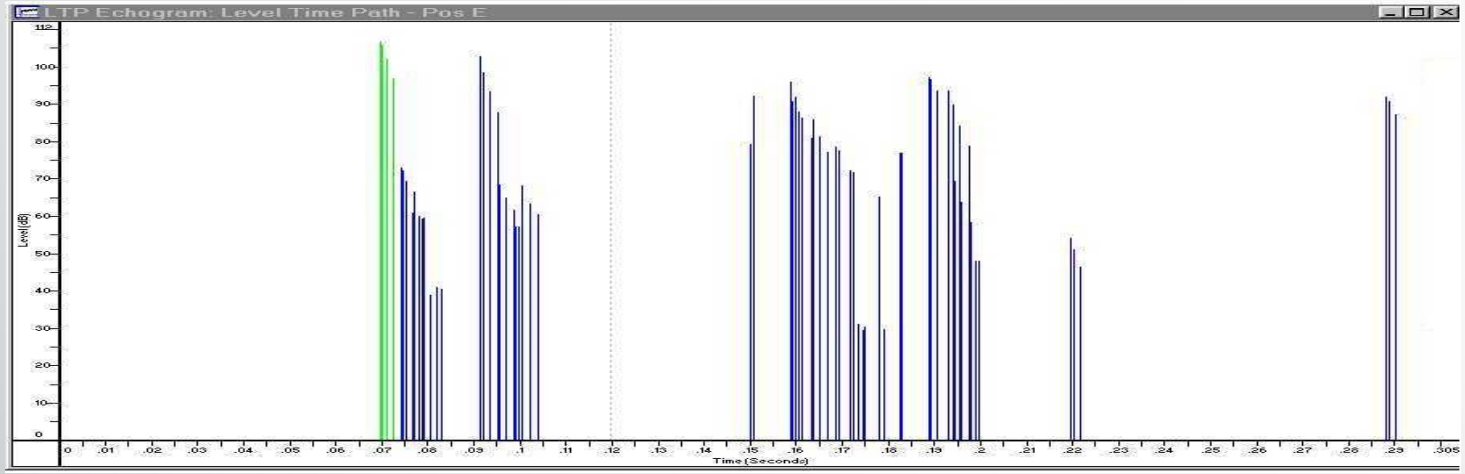
Application

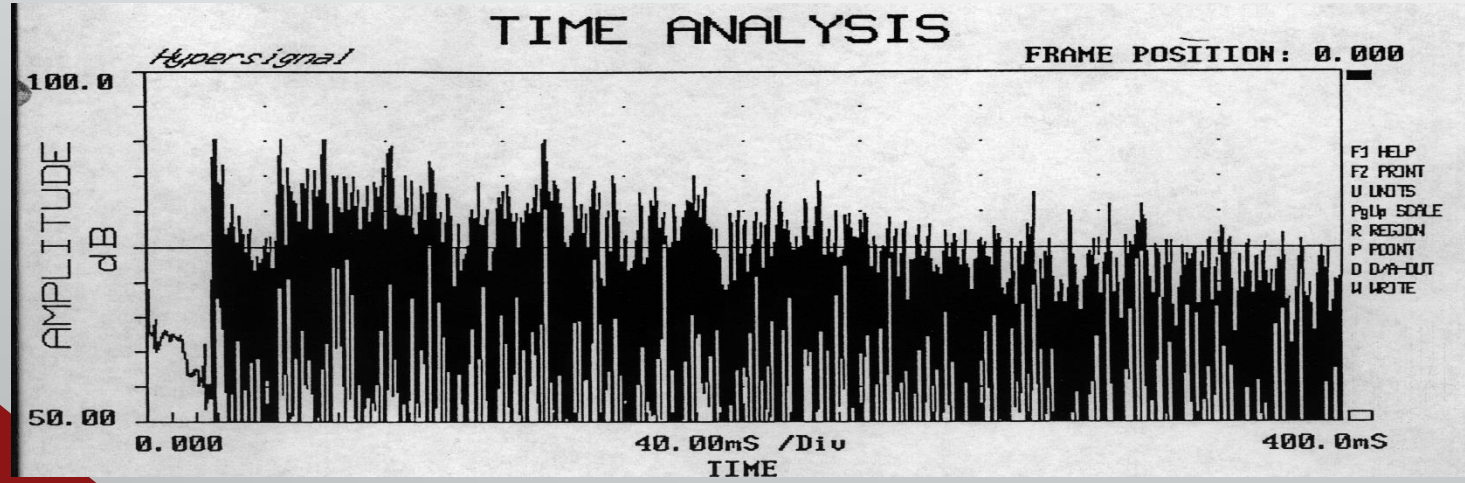
The Church of St. Anydenom

Before

Auralization

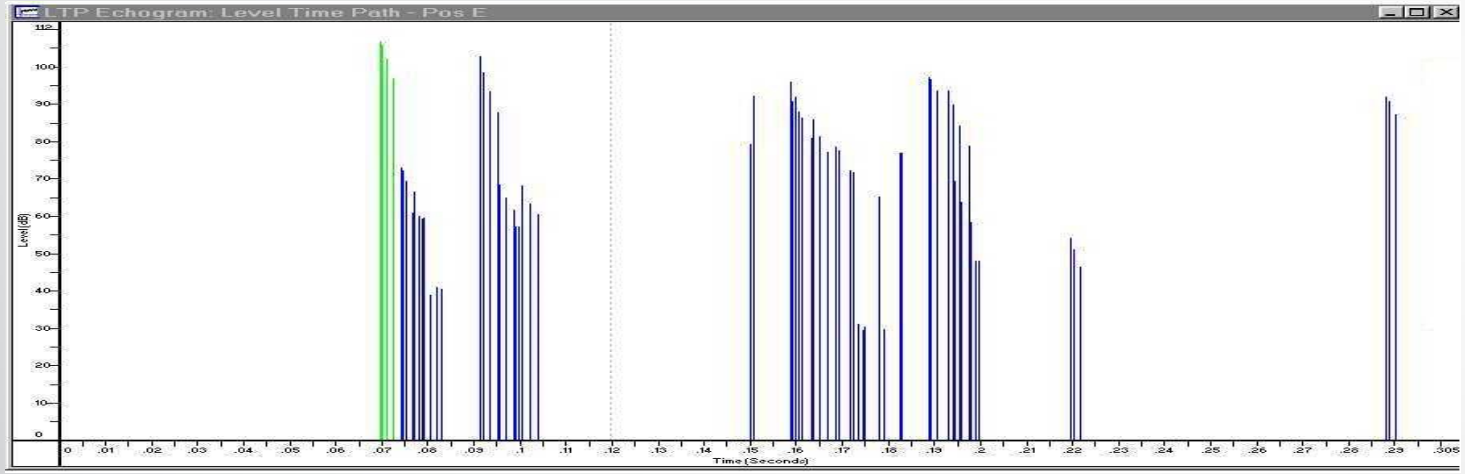
Recording





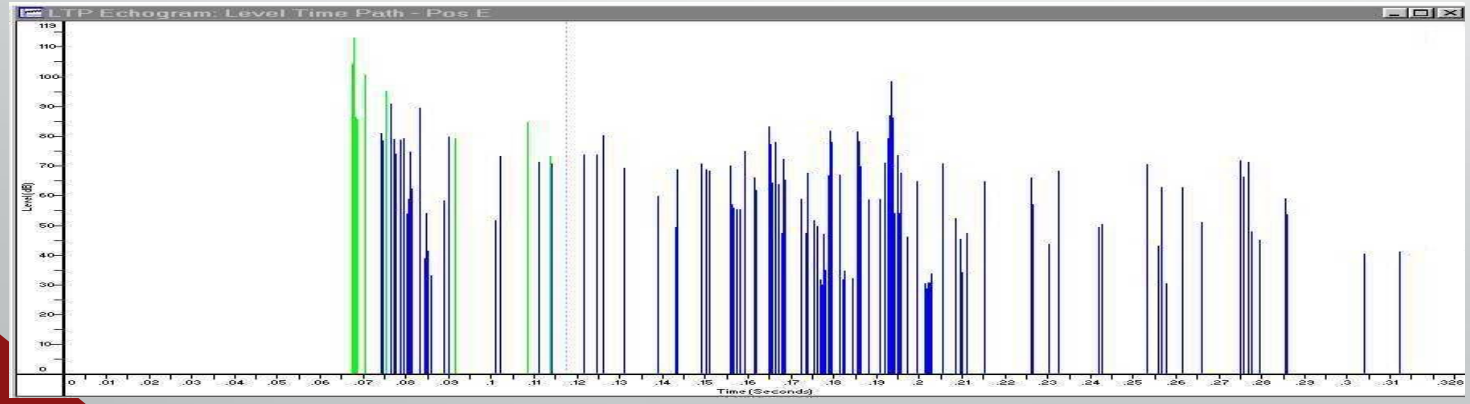
- Hard reflections, early and later in time, smear clarity
- Long reverberation time degrades clarity and musical definition
- What's the fix?

Comparison: Computer model



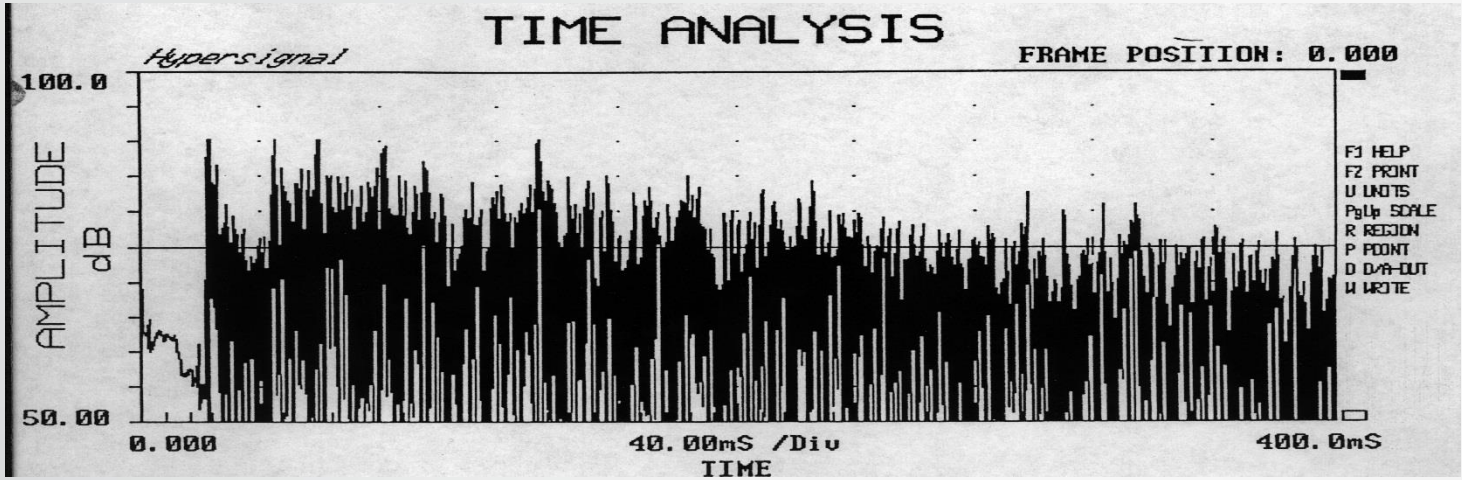
Before

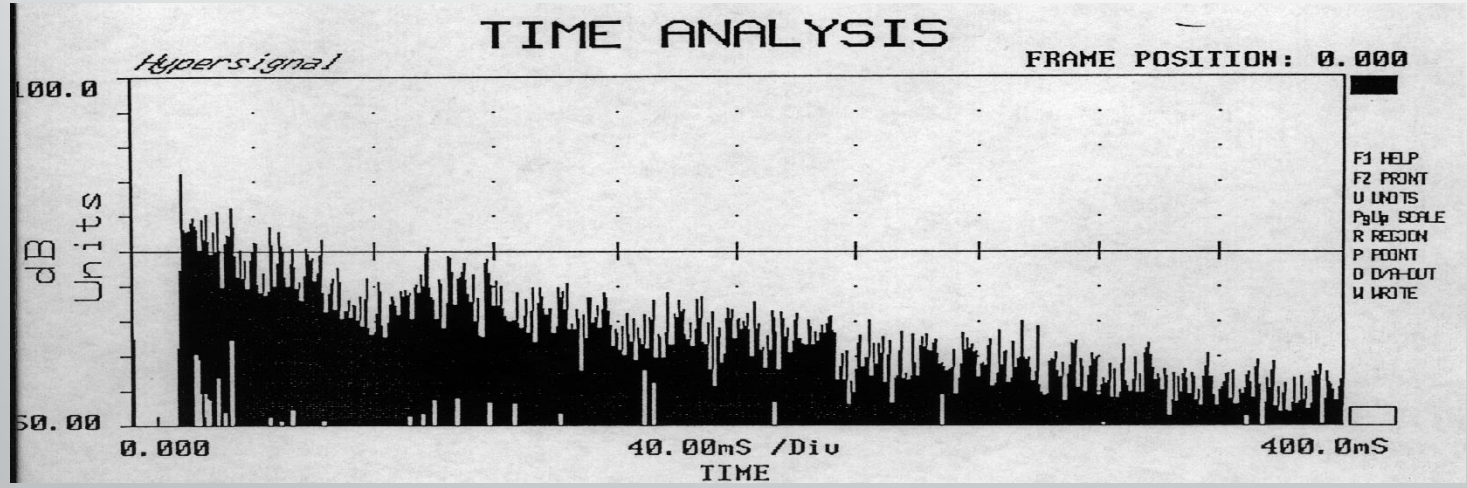
- Diffusion helps "fill in the gaps"
- A little absorption cleans up the long reflection



After

Comparison: Real world measurement





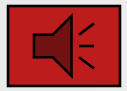
Before

- We went from sound that goes on, and on, and on…
- To a very nice smooth decay
- Reverberant, full sound with clarity

After

Comparison : Audio recordings

Auralization



Before

After

Recording

Before

After

Reverberation is not always the enemy!

Late reflections and loudspeaker placement

Achieving great sound in the worship space

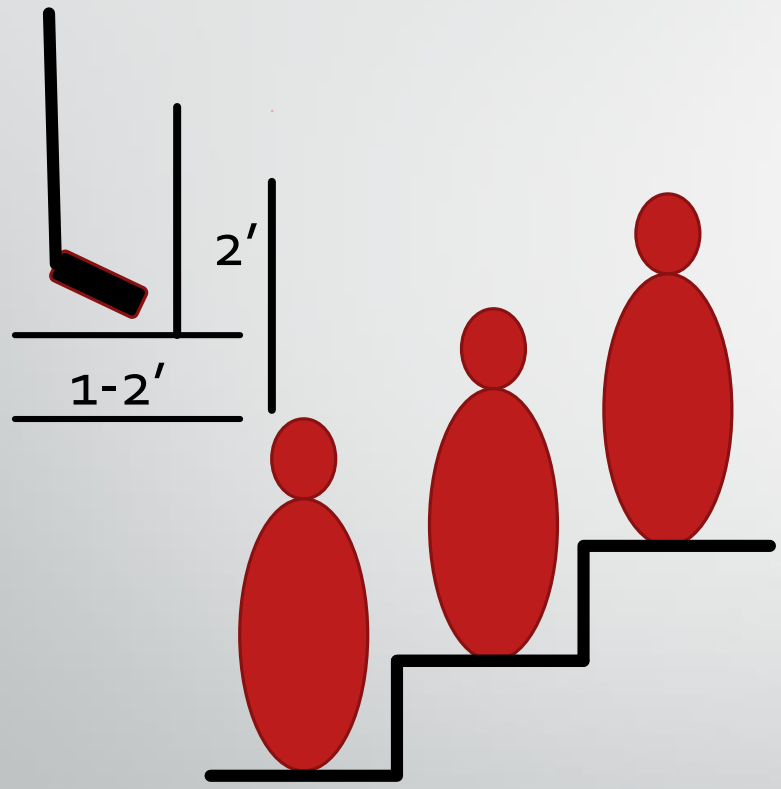
- Tone projection: solid ceiling surface helps sound travel across room naturally
- Develop lively space *with control*
- Use and create wall shapes to create sound "splash" as opposed to sound "slap"
- Use absorption where necessary
  - Pew cushions – seat bench only
  - Carpet and/or wall panels in strategic locations
- Don't ask for cathedral-like 4-second reverberation times in a 200-seat nave! The room won't support it!

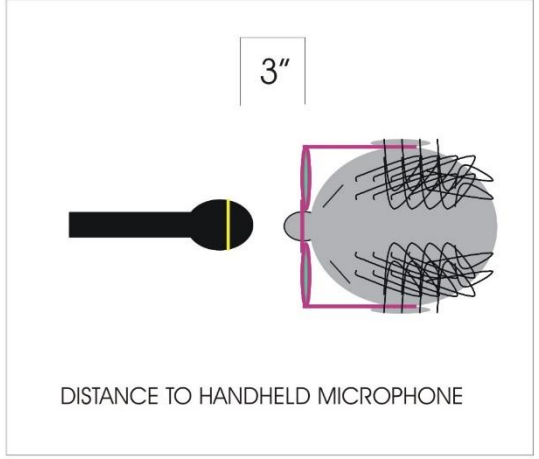
Achieving great sound in the worship space

- Use the right type of loudspeaker, the right type of microphones, applied properly
- Lapel vs. earworn microphones
- Column-arrays vs. traditional horn-loaded loudspeakers

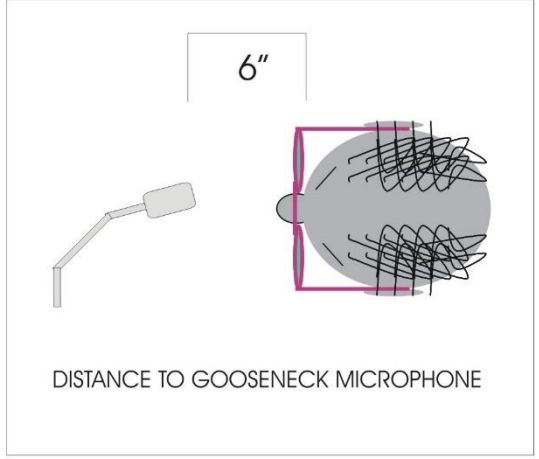
- All loudspeakers are not created equal when talking about sound quality, and so must be chosen for the application
- The same can be said for microphones
- You will usually get what you pay for in both cases

Microphones

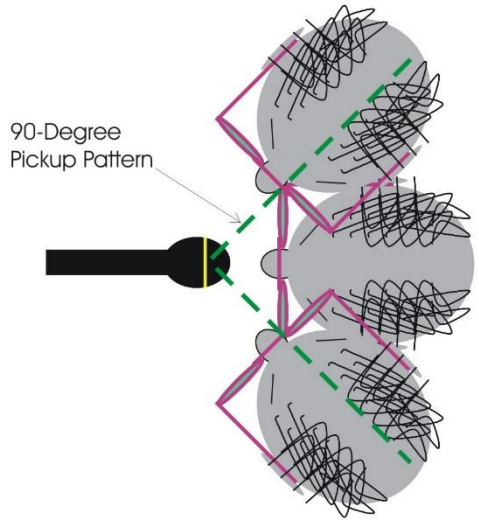




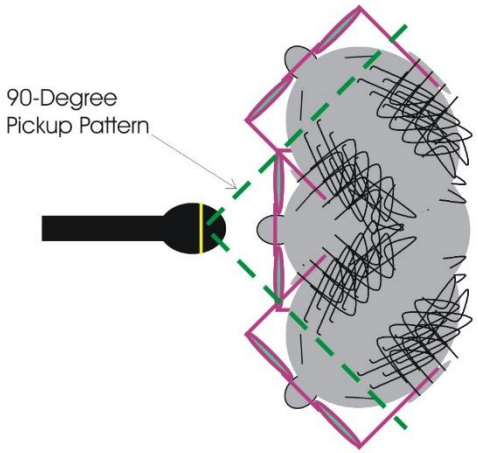
DISTANCE TO HANDHELD MICROPHONE



DISTANCE TO GOOSENECK MICROPHONE



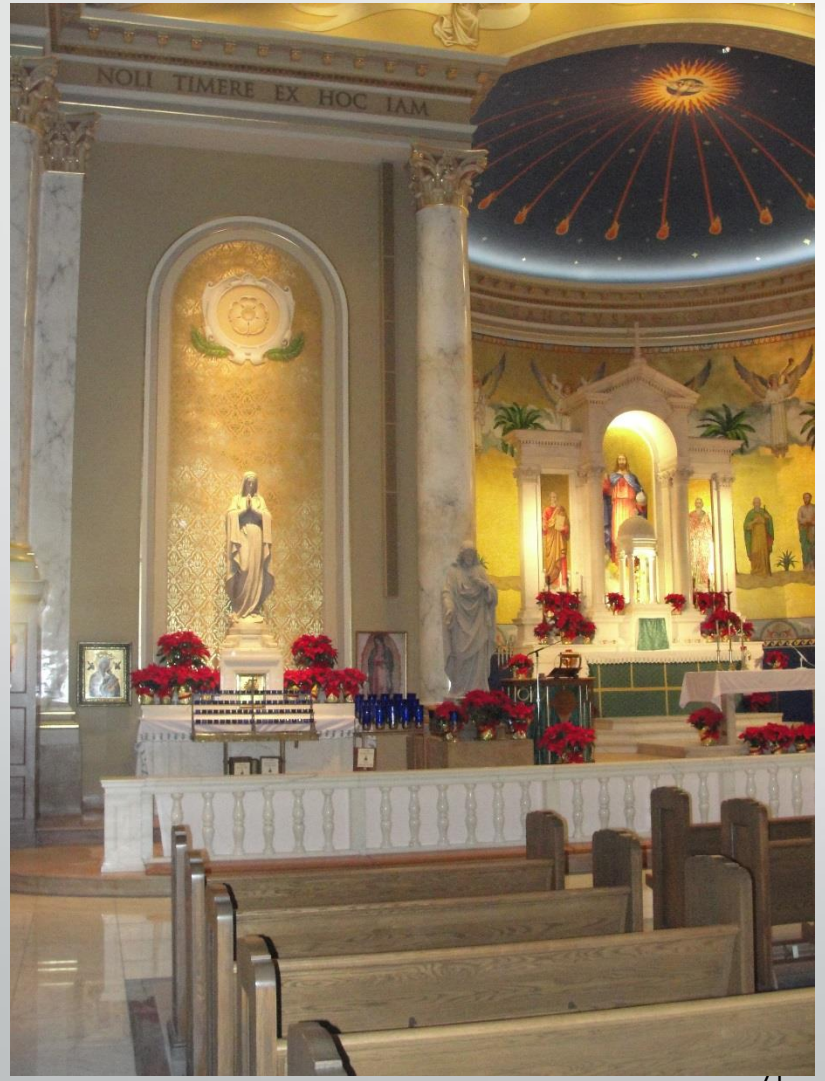
DO!
Always face the microphone!



DO NOT!
Never turn away from the microphone!

DISTANCE RELATIONSHIP TO MICROPHONE
- APPLIES TO GOOSENECK MICROPHONES AS WELL! -

Loudspeakers



Loudspeakers

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For Spoken Word

For Music

For the Benefit of the Congregation
(and to the Glory of God, of Course!)

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