



Project Studio Design

Solutions for better sounding rooms

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Housekeeping

- **Please turn off cell phones**
- **We have lots to cover!**
- **Please keep questions on track**

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Introduction

- **We WILL talk about the design of project studios**
- **We will NOT talk about performance spaces**
- **We will talk about multichannel rooms**
- **How many of you do film post-production?**

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Topics Covered

- **Introduction**
- **Designing the room**
- **Specifying the Gear**
- **Placing the Gear**
- **Wiring it up**
- **Calibration**
- **Planning**

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Project Studio Statistics

- **350,000 project studios worldwide**
- **93% of A titles go through project studio at some phase of production**
- **In homes, in studios, in post-production facilities**
- **Translation to the outside world at issue!**

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2 Types of rooms

- **Sound Production (Tracking room)**
 - **Acoustic design of room contributes to the character of the recorded sound**
- **Sound Reproduction (Control room)**
 - **Acoustic design of room provides a neutral environment to audition pre-recorded sound**
 - **Let's talk about this !**

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Design References?!

- **Listening rooms at home**
 - What are they like?
 - IEC Room
 - Statistical average of consumer listening rooms
- **Cars**
 - What are they like?
- **iPod ?**

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The End User Reference **High performance listening rooms**



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The End User Reference

High performance listening rooms



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The End User Reference

High performance listening rooms



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The End User Reference

High performance listening rooms



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A Reference

- **A standard of quality: Film studio screening rooms**
- **Documented Standards**
 - ISO 2969X
 - SMPTE 202M



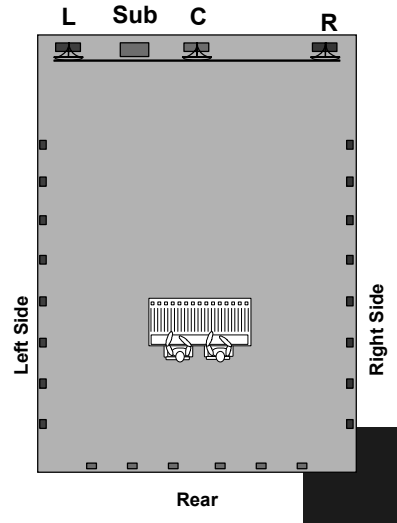
Stag Theatre, Skywalker Ranch

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Layout of a post production dubbing stage:

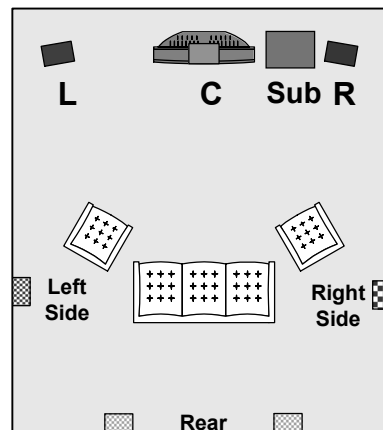
- 3 Screen speakers
 - Left
 - Center
 - Right
- 3 Surround arrays
 - Left Side
 - Right Side
 - Rear
- Subwoofers
- All seats face screen
- Good sightlines
- Screen size is 0.93x seating distance (50°)



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Layout of a Home Theater:

- 3 Screen speakers
 - Left
 - Center
 - Right
- 3 Surround channels
 - Left Side
 - Right Side
 - Rear
- Subwoofers
- All seats face screen
- Good sightlines
- Screen size is 0.55 of seating distance (30°) [0.71 for HDTV]



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Designing the Room

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Designing the Room

- **Acoustic character**
- **Optical Environment**
- **Aesthetics**

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Designing the Room

The Sound

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Designing The Room The Sound – The basics

- The right shape
- Good sound isolation
- No background noise
- No rattles
- No distractions

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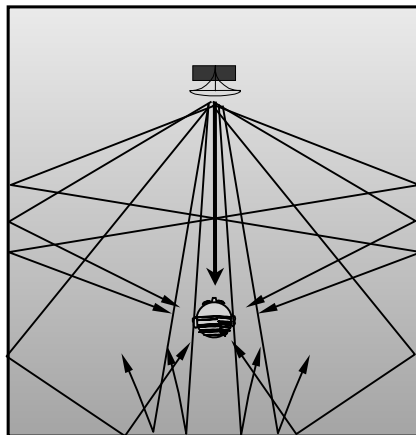


Shaping the Room

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Reflections in a Rectangular Room

- Reflections are evenly distributed

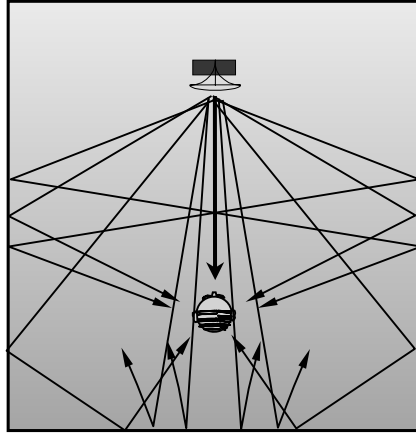


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Reflections in a Rectangular Room

- Reflections are evenly distributed

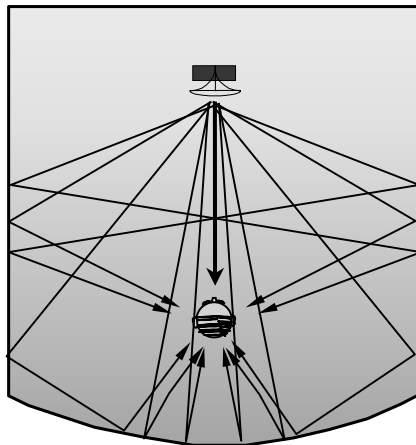


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Reflections in a Room with Concave Wall

- Reflections are focused to listening position

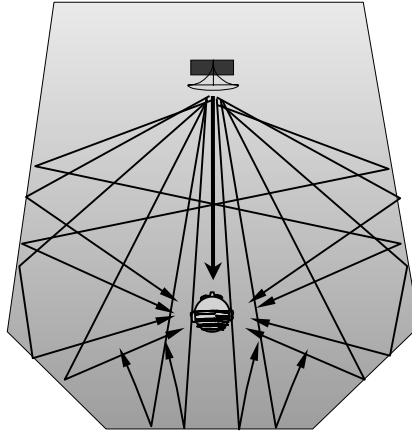


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Reflections in a Non Rectangular Room

- Reflections are still there
- Some are stronger
- Harder to predict

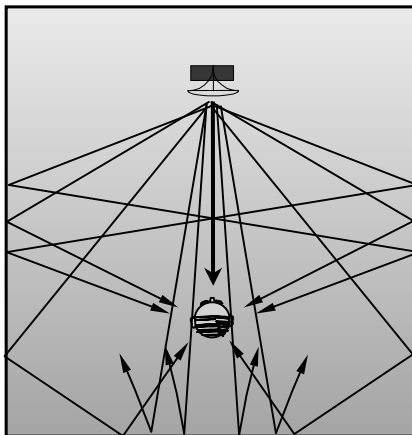


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Reflections in a Rectangular Room

- Reflections are evenly distributed



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Shaping the Room

- **Stick to rectangular rooms!**
- **Other shapes can work, but are difficult to predict and control**
- **Squares – Not great**
- **Circles, Ovals – Oh, Trouble!**
- **Bay Windows – More trouble!**

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Shaping the Room

- **Other Factors:**
 - **Room orientation (Width or Length)**
 - **Capacity**
 - **Seating type**
 - **Finish grade**

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Shaping the Room

- **Room orientation**
 - Favor the length direction
 - Not too long and narrow!
 - Around 1.3 : 1 works well
 - Several obstacles
 - Fireplace
 - Windows
 - Doors
 - Etc.

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Acoustics

The Design Process

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Acoustics

- **Why talk about acoustics?**
- **Acoustics are audible!**
- **Contribute to over 50% of quality**
- **Acoustics are fixable**

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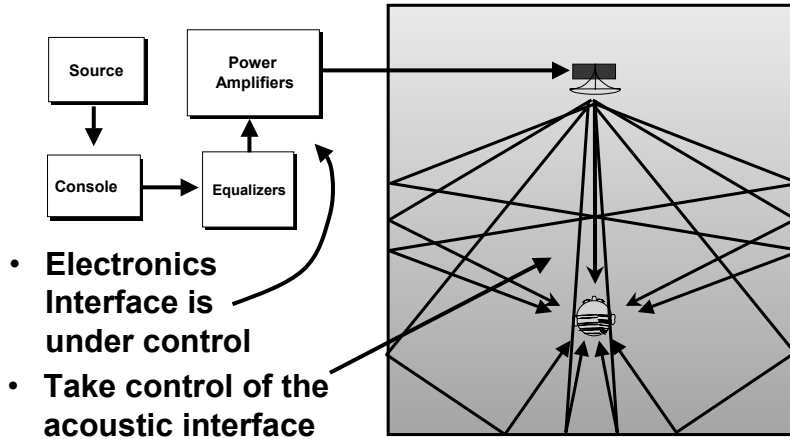
What's Acoustics?

- **It's about the speaker/room/listener interface**
- **It's what separates "Major" studios from "Project" studios**

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The Acoustic Interface



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Warning !

**Room acoustics will
mess you up !**

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The Acoustical Engineering Process 12 Steps

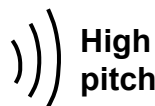
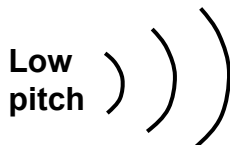
- | | |
|------------------------------|-----------------------------------|
| 1. Dimension the room | 7. Determine diffusion area |
| 2. Sound isolation | 8. Treat echoes |
| 3. Noise control | 9. Place listener |
| 4. Vibration control | 10. Place sound system |
| 5. Model decay time | 11. Determine treatment locations |
| 6. Determine absorption area | 12. Tune it all |

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... But First a Bit of Theory

- Sound is
 - Vibrating air
 - Changing pressure
 - Perceived by our ear-brain
 - Frequency of pressure changes determines pitch

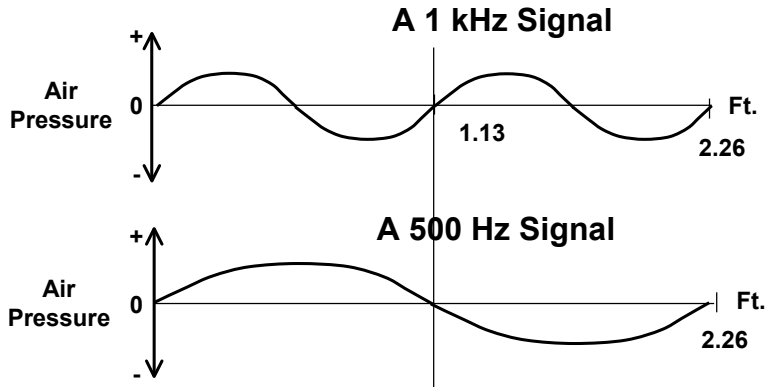


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Acoustic Wavelength

Sound Propagates at 1.13ft/msec



$$\text{Wavelength} = \frac{1130}{\text{Freq}}$$

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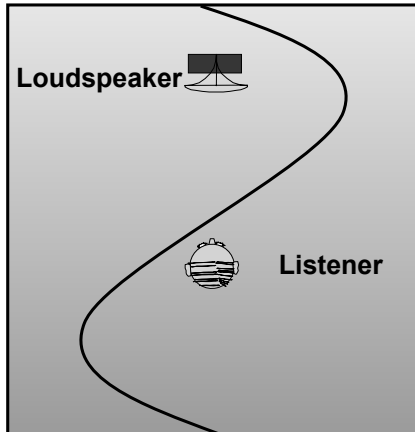


Room Dimensioning

Standing Waves

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Standing Waves a.k.a. Room Modes



- Standing waves happen when room dimension is equal to sound wavelength
- Also at 0.5, 1.5, 2, 2.5, 3, etc. times wavelength

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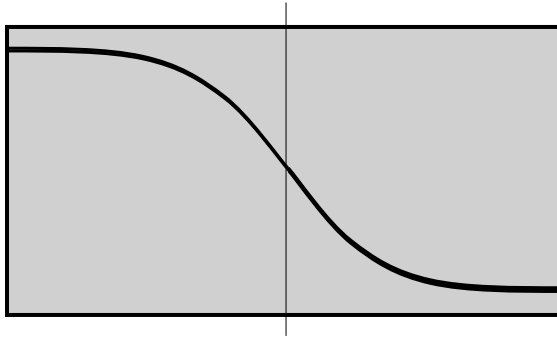
Standing Waves

- Standing waves cause
 - Resonances
 - Uneven frequency response
 - Poor bass impact
 - Different bass at each seat
 - Common problems are in the 30 Hz to 150 Hz range

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A Resonant Frequency

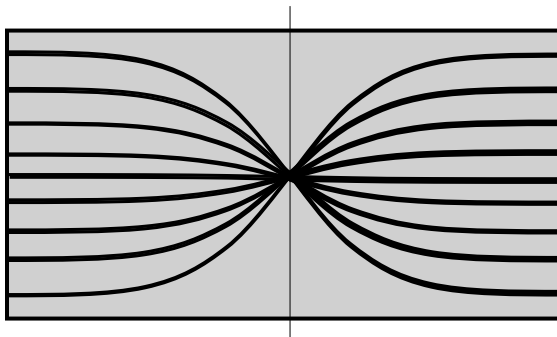


- After reflection, signal nulls overlap

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A Resonant Frequency

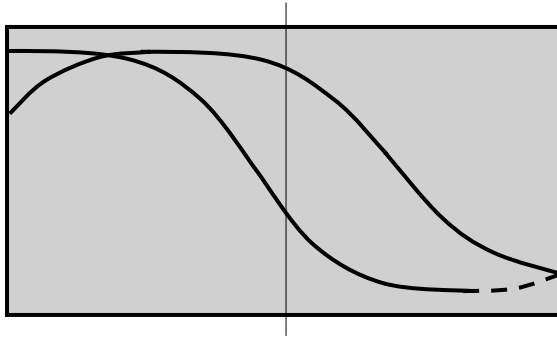


- After reflection, signal nulls overlap

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A Non-Resonant Frequency

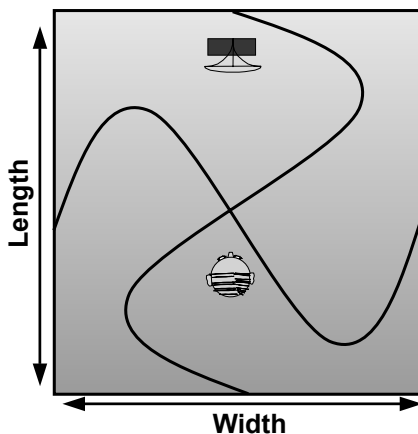


- No null overlaps
- No reflection gain

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Standing Waves

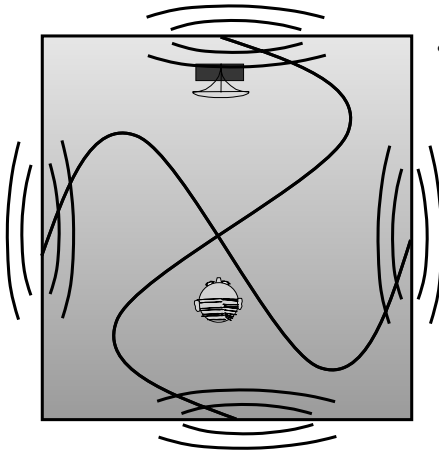


- All rooms will have some standing waves
- Resonance frequencies are set by room dimensions
- Overlaps in resonance frequencies =
Even more trouble
- Resonance overlaps depend on ratios in room dimensions
Length/Width/Height

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Standing Waves



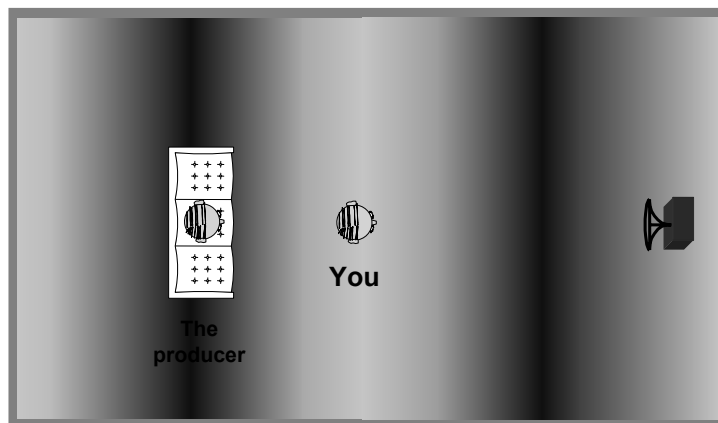
- Intensity of resonance depends on wall stiffness

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Standing Waves

A Second Harmonic Length Axial Standing Wave



Loud

Quiet

Loud

Quiet

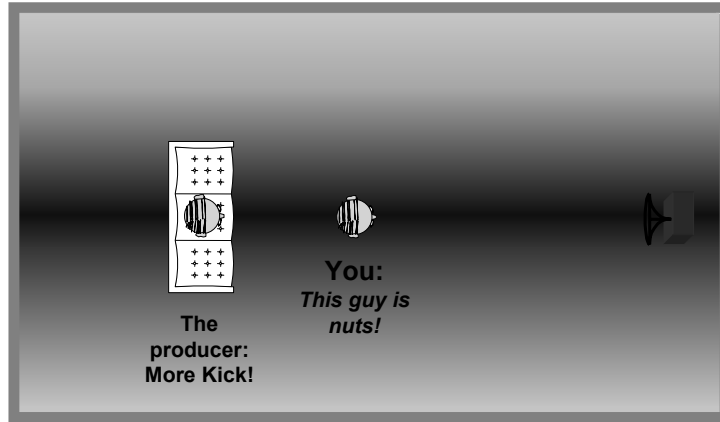
Loud

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Standing Waves – What to Avoid

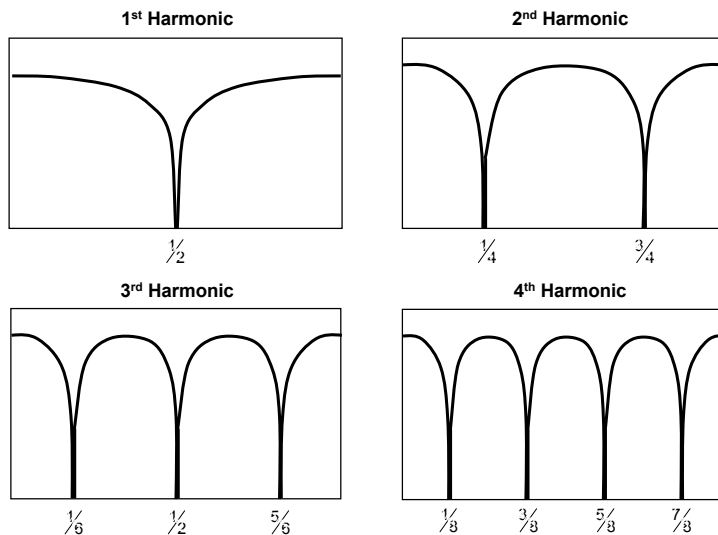
Frequency overlaps = double whammy!



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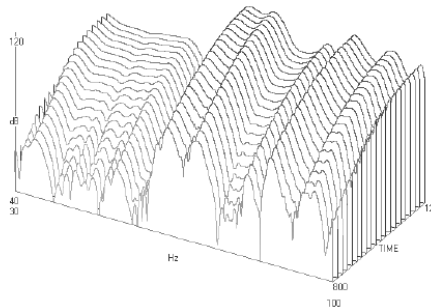


Standing Waves Pressure Representation for 1st, 2nd, 3rd, 4th Harmonics



Standing Waves

Modal decay



- Example of room modal decay plot
- Long decay
- Most audible effect of room modes

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Ways to Deal With Standing Waves (Room Modes Can Never Be Eliminated)

- Change one or more dimensions
 - Minimizes resonance pile-ups
 - Aim for even modal distribution (>5% difference)
- Move subwoofer location
 - Drive mode out-of-phase to reduce relative amplitude
- Use bass absorption or absorptive walls
- Move seating location
 - Moves the listener out of peaks and dips
- Equalize

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Ways to Deal With Standing Waves (Room Modes Can Never Be Eliminated)

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 - Minimizes resonance pile-ups
 - Aim for even modal distribution (>5% difference)

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Standing Waves Resonance Frequencies

Equation:

$$F = n1130/2D \text{ (in ft)}$$

$$F = n345/2D \text{ (in m)}$$

Where F is frequency

n is the harmonic

D is the distance between walls

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Solutions to Standing Waves Room Dimensions

- Determine room dimensions
- Determine modes ($F = n \cdot 1130 / 2d$)
- Find resonance overlaps

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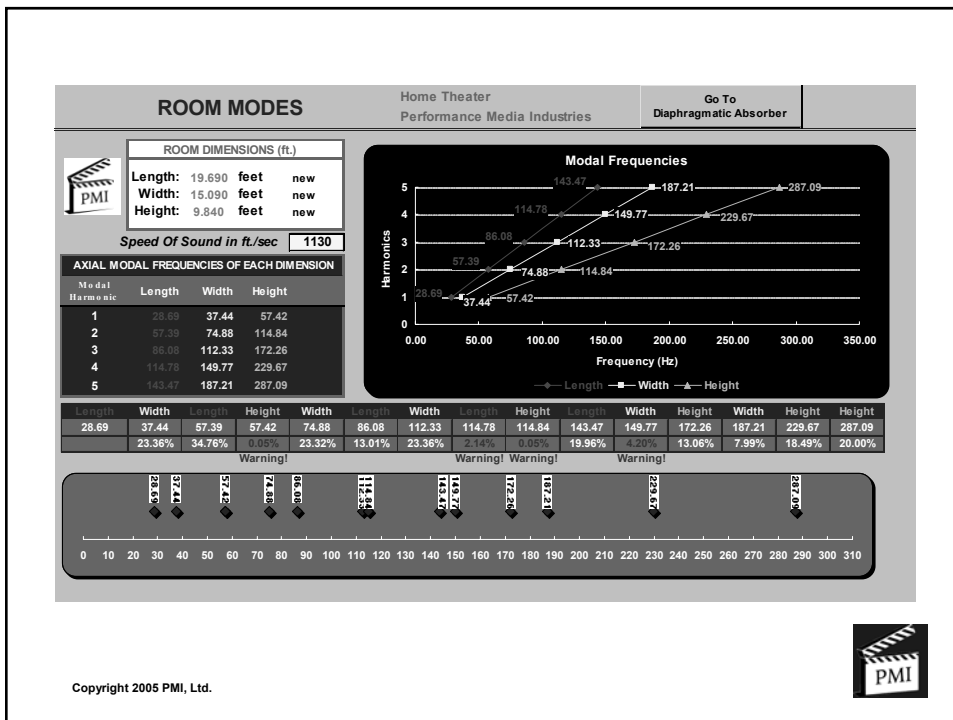


Solutions to Standing Waves Room Dimensions (continued)

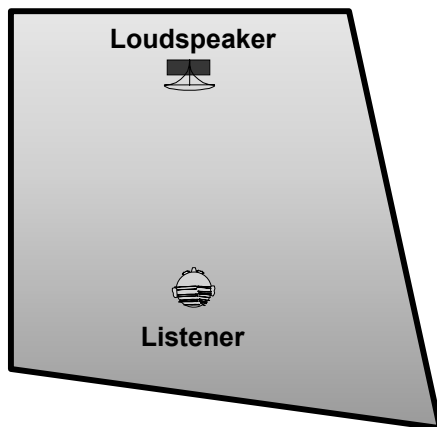
- Calculation programs
 - RPG Room Optimizer
 - CARA
 - THX Room Mode Calc
 - Ultimate AV online
 - PMI modeling program

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Solutions to Standing Waves Room Shapes



- Complicates Acoustic modeling and computations
- Doesn't get rid of standing waves or reflections
- Not recommended

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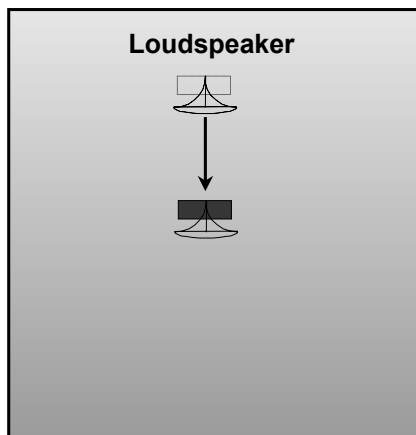
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- **Move subwoofer location**
 - Drive mode out-of-phase to reduce relative amplitude

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Solutions to Standing Waves Subwoofer and Speaker Placement



- Driving room standing waves in cancellation areas can improve response
- We'll talk about this later

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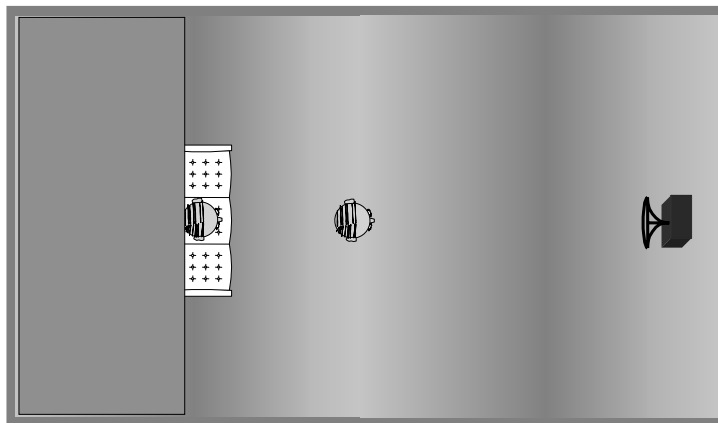
Ways to Deal With Standing Waves (Room Modes Can Never Be Eliminated)

- **Change one or more dimensions**
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- **Move subwoofer location**
 - Drive mode out-of-phase to reduce relative amplitude
- **Use bass absorption**

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Standing Waves **Absorb at least $\frac{1}{4}$ wavelength !**



Loud

Quiet

Loud

Quiet

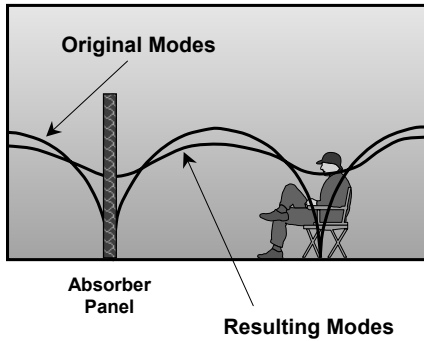
Loud

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Solutions to Standing Waves

Absorption at Standing Wave Null



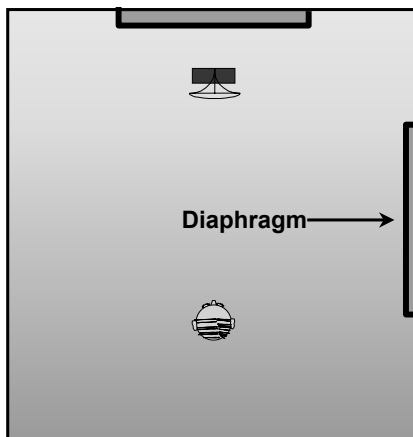
- Place absorber panel at null (high velocity, low pressure area)

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Solutions to Standing Waves

Diaphragmatic Absorption

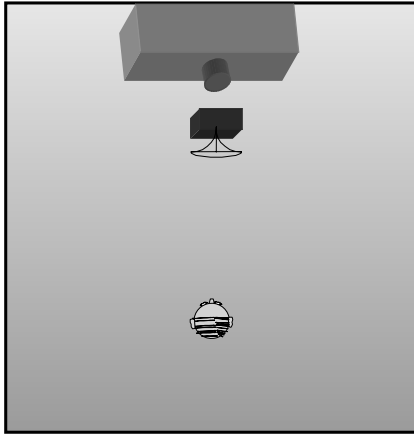


- Absorber units are resonating material tuned to problem frequencies
- Absorber box is filled with “fuzz”
- Works up to 150Hz
- Design of bass absorber is complex
- Unreliable!

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Solutions to Standing Waves Helmholtz Absorption



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- Helmholtz units are tuned to problem frequency
- Absorber box is filled with fuzz
- Works down to 80Hz
- Design of Helmholtz absorber is complex
- Not very efficient

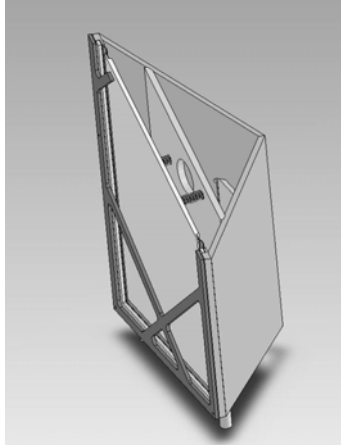


Solutions to Standing Waves CineTrap Absorption



- Combination
Pistonic diaphragm
and Helmholtz
absorber
- F_0 determined by
Mass – Spring – Air
- Reliable and
predictable

Solutions to Standing Waves CineTrap Absorption



- Triple ported enclosure
- Front panel suspended on springs
- Mineral wool inside cavity to widen resonance
- Port at bottom of cabinet

Solutions to Standing Waves CineTrap Absorption



- Main port at bottom
- Second chamber resonating port on bottom of cabinet
- Port extends up to middle of cabinet
- Optimized by PAM (Whise / Huon Labs)

Solutions to Standing Waves The SpringTrap

- Two fundamental equations
- Ported resonant enclosure:
 - $F = (c/2\pi)(A/L'V)^{1/2}$
- Spring loaded panel resonance:
 - $F = (1/2\pi)(k/m)^{1/2}$
- Paper presented at AES 114th Convention, Amsterdam, March 2003
- Patent Pending

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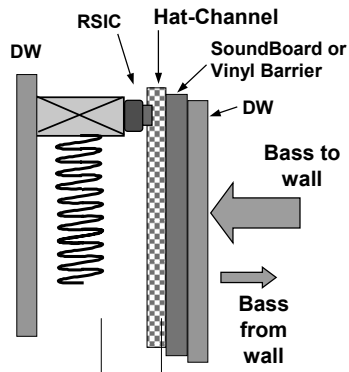
Ways to Deal With Standing Waves (Room Modes Can Never Be Eliminated)

- Change one or more dimensions
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- Move subwoofer location
 - Drive mode out-of-phase to reduce relative amplitude
- Use bass absorption or absorptive walls

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Solutions to Standing Waves Resilient Walls



Wall with PAC RSCI-1 Isolators

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- Resilient walls don't reflect bass well
- Sound energy is absorbed by the PAC RSIC rubber isolator
- Add Soundboard or Loaded Vinyl to spread the resonance frequency
- You get isolation too!

Solutions to Standing Waves Resilient Walls PAC RSIC1



RSIC-1

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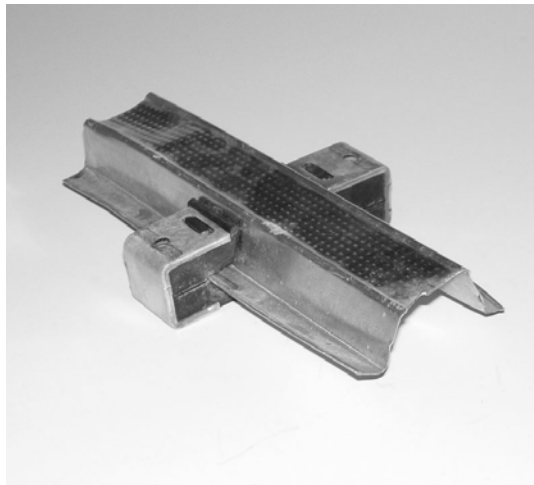
Solutions to Standing Waves Resilient Walls - Isomax



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Solutions to Standing Waves Resilient Walls - Isomax



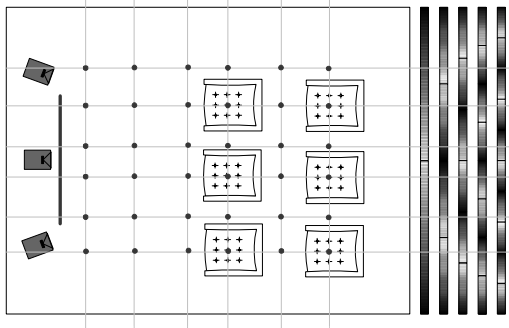
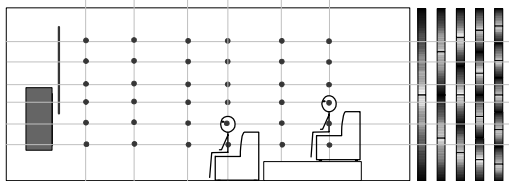
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Ways to Deal With Standing Waves **(Room Modes Can Never Be Eliminated)**

- **Change one or more dimensions**
 - Minimizes resonance pile-ups
 - Aim for even modal distribution (>5% difference)
- **Move subwoofer location**
 - Drive mode out-of-phase to reduce relative amplitude
- **Use bass absorption or absorptive walls**
- **Move seating location**
 - Moves the listener out of peaks and dips

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Solutions to Standing Waves

Seating Placement

**Stay away from
peaks or dips**

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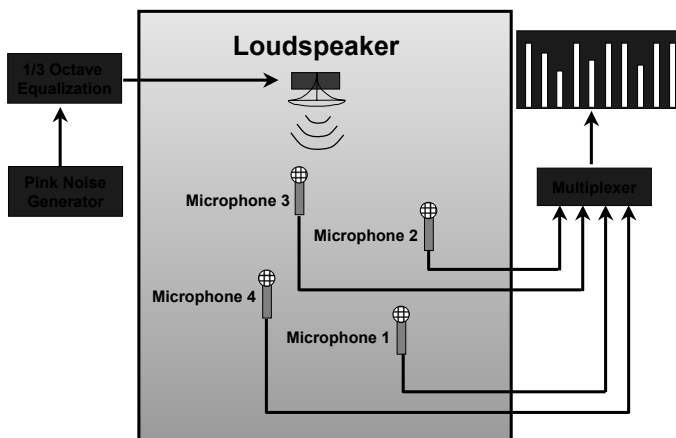
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- **Change one or more dimensions**
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 - Aim for even modal distribution (>5% difference)
- **Move subwoofer location**
 - Drive mode out-of-phase to reduce relative amplitude
- **Use bass absorption or absorptive walls**
- **Move seating location**
 - Moves the listener out of peaks and dips
- **Equalize**

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Solutions to Standing Waves Equalization



- Analysis should be spatially and temporally averaged
- Use Gold Line DSP30 Analyzer, or equivalent

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Designing the Room

Sound Isolation

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Sound Isolation

- **Good sound isolation means:**
 - use the room anytime!
 - No interference: lose none of the sound subtlety
 - Privacy

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Sound Isolation

- **Demonstration: Action movie**
- **In room** (Chap 14)
- **Adjacent room: standard construction – STC38** (Chap 16)
- **Adjacent room: better construction – STC60** (Chap 18)
- **Adjacent room: best construction – STC75** (Chap 20)

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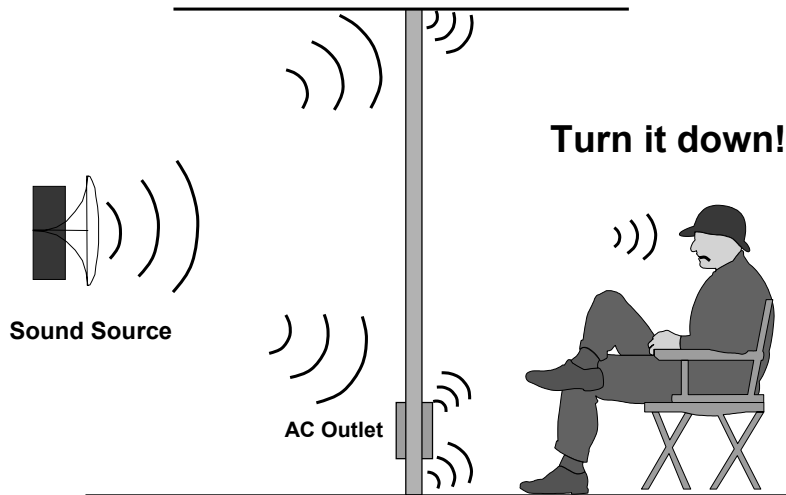
Sound Isolation – 2 processes

- **Sound leakage**
 - Isolate doors, windows, and plumbing
 - Isolate, seal and caulk all leakage paths
- **Mechanical Transmission**
 - Special wall structures
 - Floating floor
 - Floating ceiling

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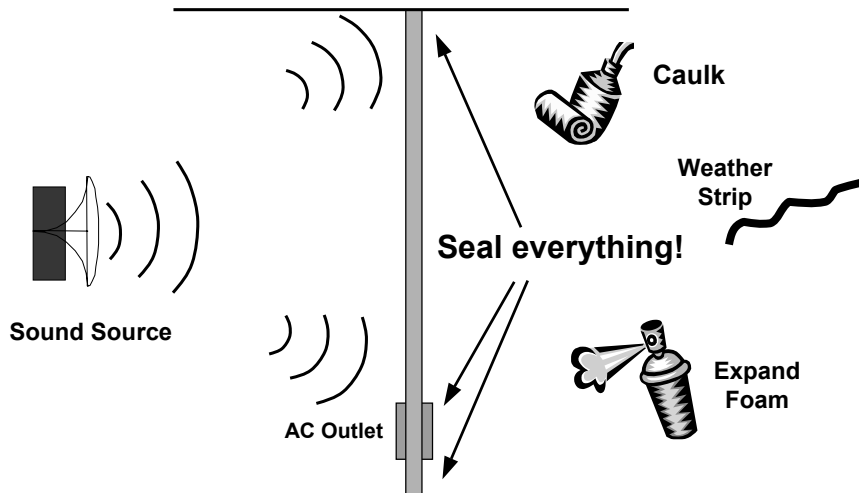


Airborne Sound Leaks



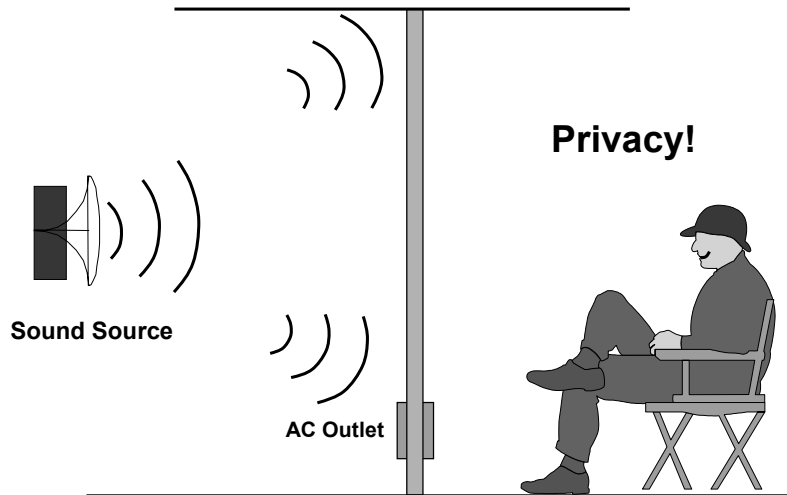
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Preventing Leaks



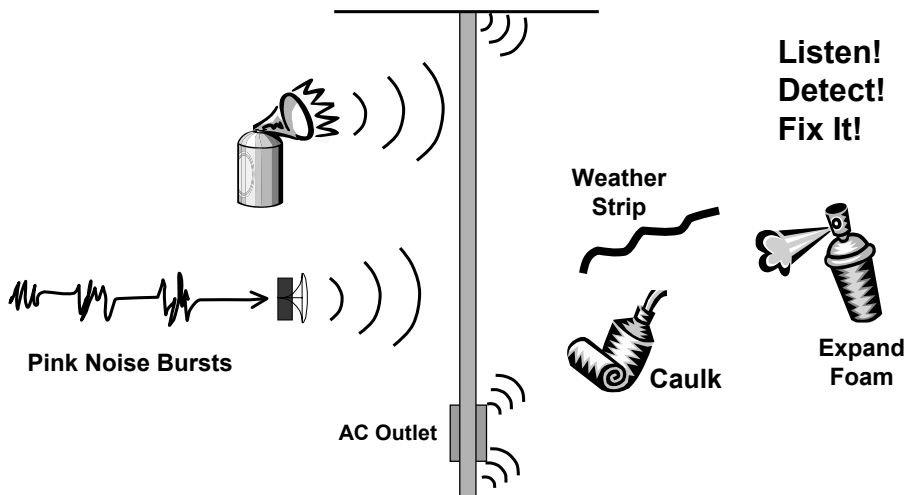
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No Leaks



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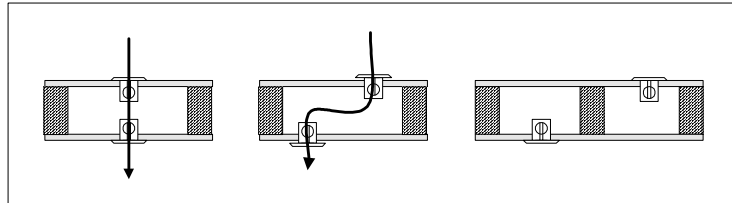
Noise Transmission Detection



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Isolate Flanking Paths

AC outlets



Full Flanking

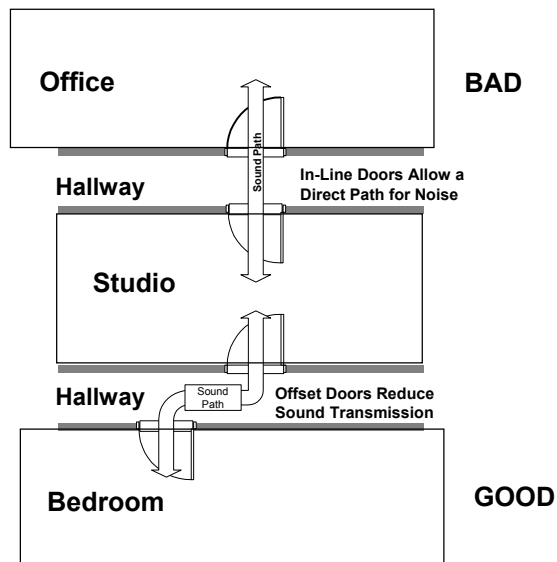
Offset

Offset and Isolated

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Isolate Flanking Paths



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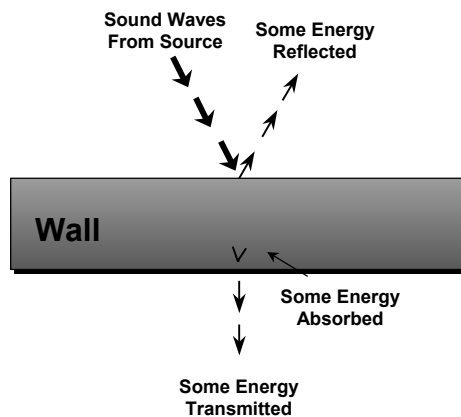


Isolation Solutions

Wall Construction

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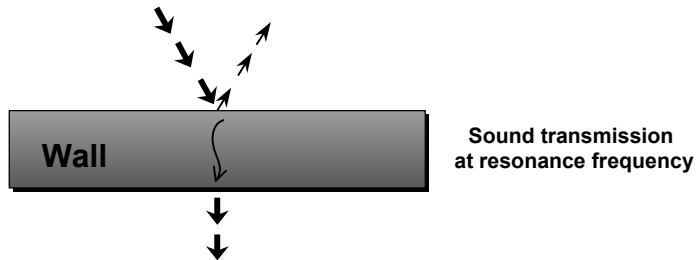
The Mechanism of Sound Transmission



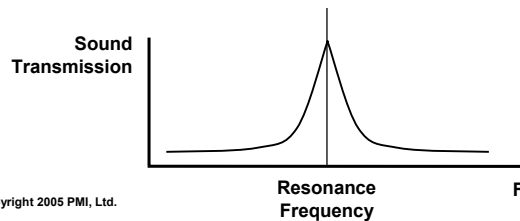
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Wall Construction Resonance



- All wall surfaces have a resonant frequency where they transmit lots of energy

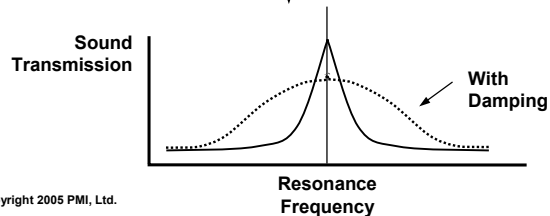
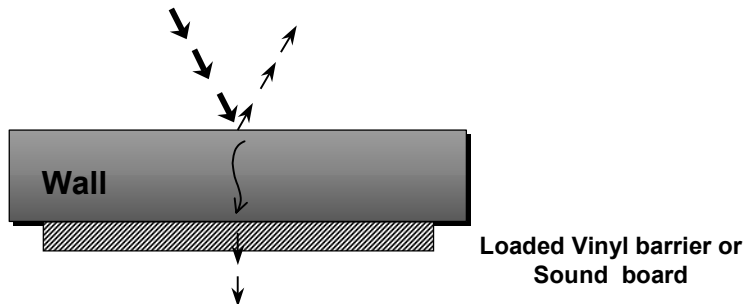


$\frac{1}{2}$ " Drywall
Example



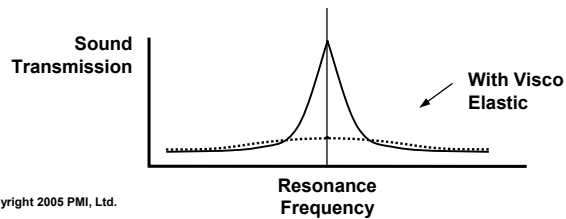
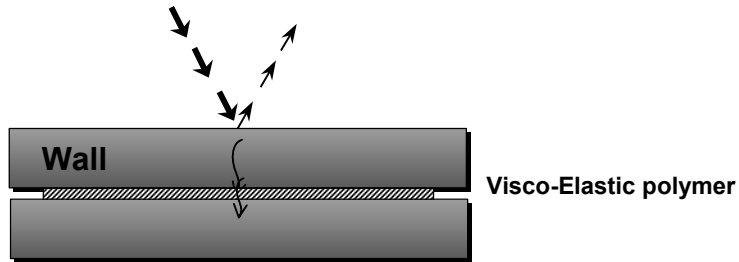
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Wall Construction Damped Resonance



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Wall Construction Constrained Layer Damping



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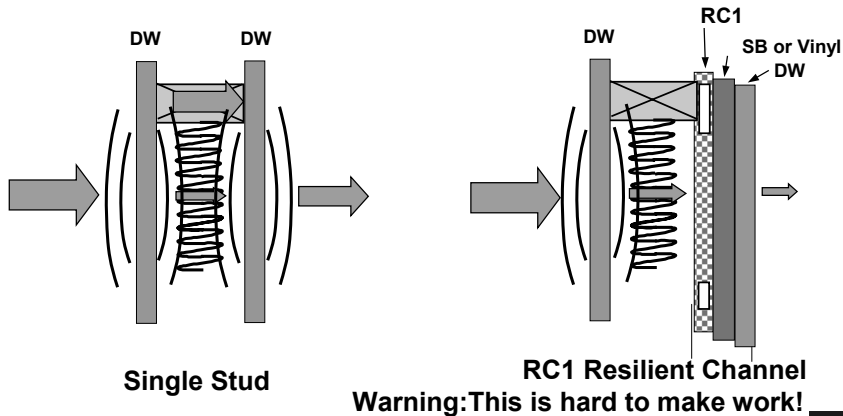
Isolation Strategies

- More Mass
- Damp resonance
- Decouple
- Larger airgap

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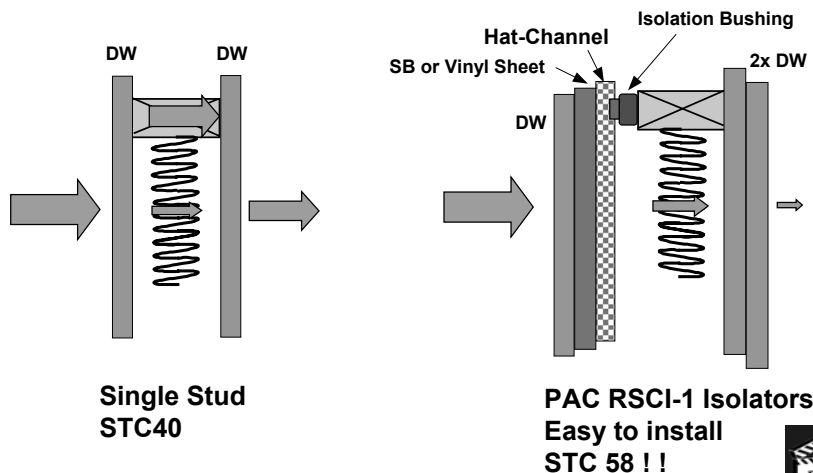
Sound Isolation Strategies Wall Construction - Decoupling



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Sound Isolation Strategies Decoupling – A better solution

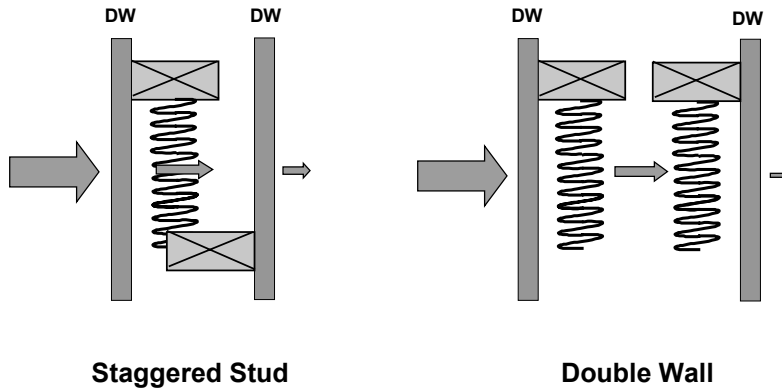


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Sound Isolation Strategies

Wall Construction - Decoupling

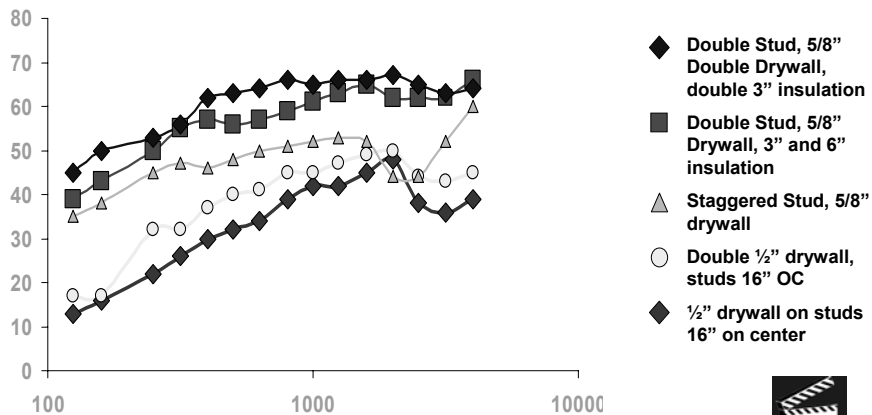


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Studwall Isolation

Noise Transmission Coefficients

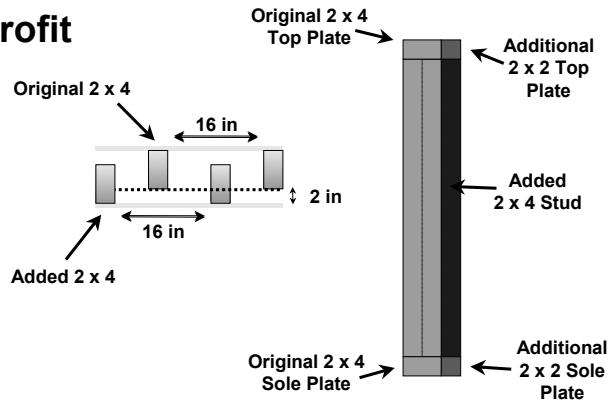


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Staggered Stud Construction

Retrofit

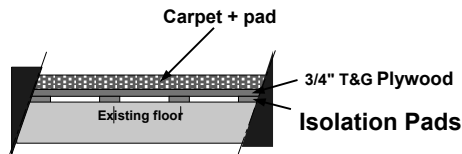


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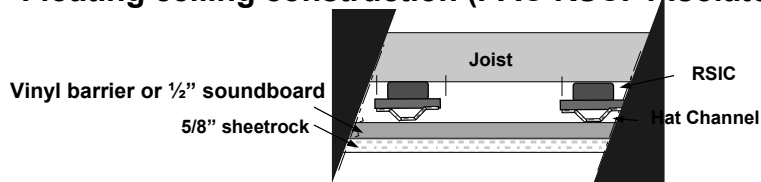


Isolating the ceiling and floor

– Floating floor construction



– Floating ceiling construction (PAC RSCI-1 Isolators)



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Background Noise

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Background Noise

- **Interferes with loudness perception**
- **Masks low level signals and detail**
- **Transient noise is distracting**

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Background Noise

- **Demonstration: Speech**
 - **No background noise** (Chap 4)
 - **Low background noise: NC20** (Chap 6)
 - **Medium background noise: NC30** (Chap 8)
 - **High background noise: NC40** (Chap 10)
 - **Stupid High Noise: NC50** (Chap 12)

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Sources of Background Noise

- **Local sources**
 - HVAC
 - Plumbing
 - Fans
 - Pumps/Compressors
 - Washer/Dryers
 - Garage door openers
 - Projectors

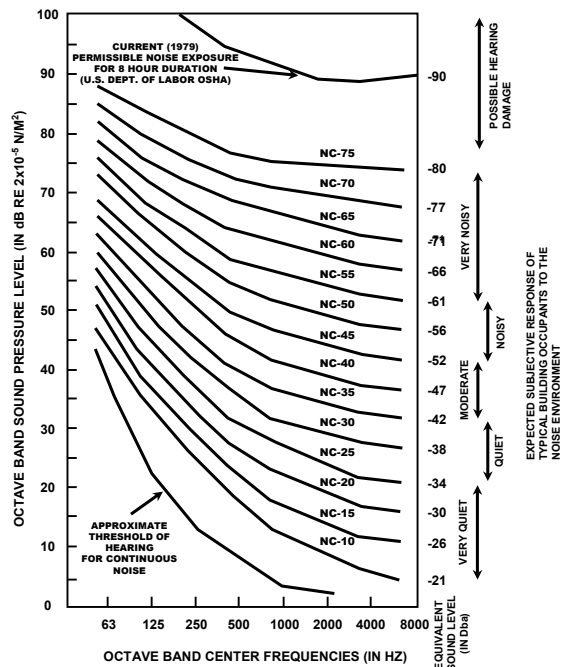
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Sources of Background Noise

- External sources
 - Traffic
 - Airplanes
 - Wind
 - Neighbors

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Noise Criteria Curves (NC)

Targets:

NC25 for basic room

NC15 for High End room



Measuring Background Noise

- Use spectrum analyzer
- Use a low noise microphone
- Take a time and space average
- Use NC weighting
- Plug your ears, wait, unplug and listen
 - Use Earplugs, or fingers

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Solutions to Background Noise

- Large air ducts for lower air velocity
- Longer ducts with several turns
- Plenum silencers
- Lined ductwork
- “Whistle Free” air grilles
- Isolate motors on suspension or move
- Completely seal windows, doors, etc.

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Background Noise Summary

- **Background noise degrades dynamic range, detail clarity, and intelligibility**
- **Noise can be detected with test instruments or earplugs and ears**
- **Treatments include seals, better walls, slower air, quieter air handlers, etc.**

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Designing the Room

Vibration Control and Rattles

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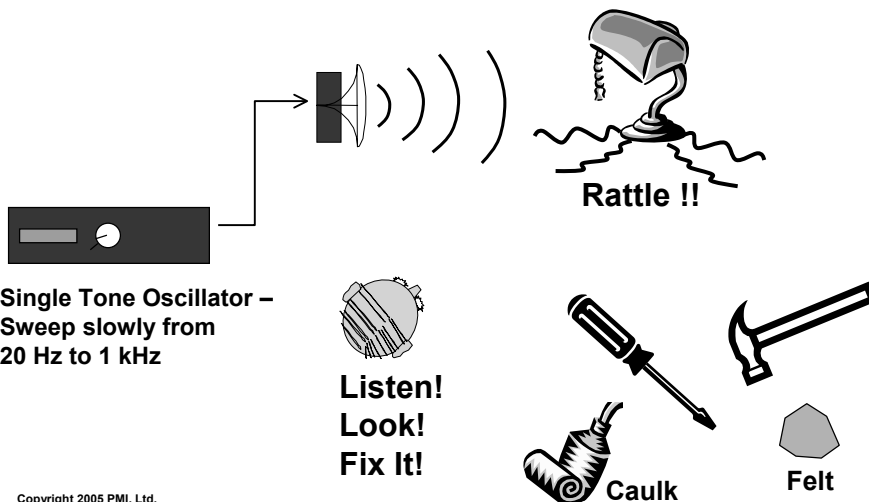
Rattles

- Very prominent for low frequency signals
- These are usually caused by acoustical or mechanical coupling with loose fixtures, lights, furniture, and doors.
- Rattles can sound like speaker or amplifier distortion, and their localization can be distracting.

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Rattle Detection



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Rattles (continued)

- **Method: use slow varying frequency sweep**
- **Check**
 - Furniture
 - Glass Surfaces
 - Track Lights
 - Hung Pictures
 - Walls and Doors
 - Fixtures
 - HVAC Ducts and Vents
 - Ventilation System

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Solutions to Rattles

- **De-couple loudspeakers from room surfaces**
- **Add elastic mass to surfaces**
- **Tighten loose fixtures**
- **Isolate fixtures with**
 - Rubber Pads
 - Caulk
 - Insulation

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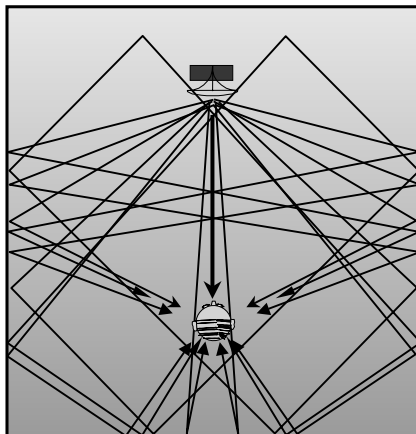


Designing the Room

Reflection Decay Time (aka Reverberation)

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Reverberation



- Reverberation is the result of multiple reflections
- Decay time and spectrum have to be just right

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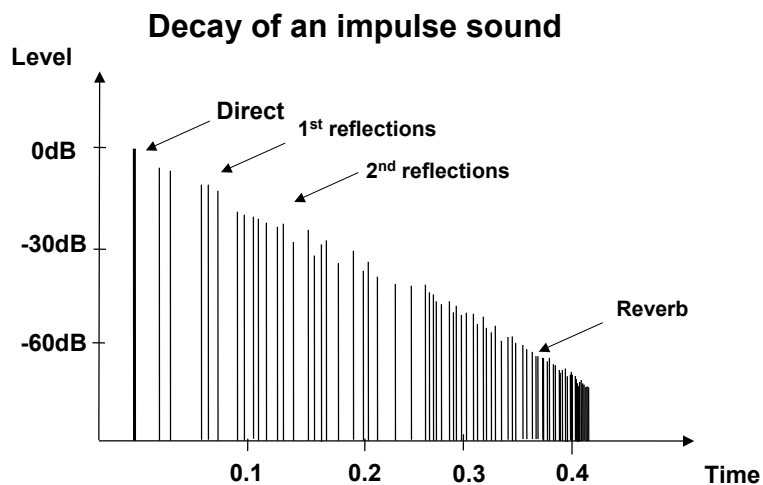
Reverberation

- When the sound has bounced around the room several times
- No net direction or time cues remain
- Small room reflections die out before complete reverberation is achieved
- We call it reflection decay time

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Decay Time



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Decay Guidelines

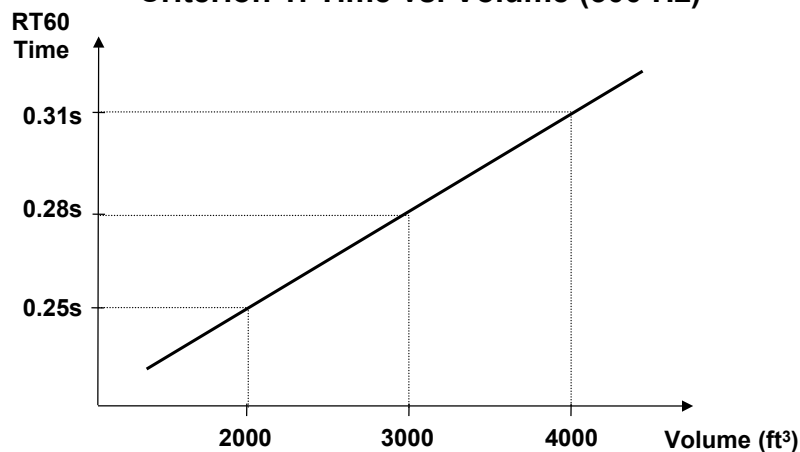
- Decay time should be .2 to .4 seconds
- Research shows that most people like the same range of decay time
- $T_m = 0.3 (V/3532)^{1/3} \pm 15\%$ where V =room volume in ft^3
- $T_m = 0.3 (V/100)^{1/3} \pm 15\%$ where V = room volume in m^3
- Handy rule of thumb for project studios, look for ~25% absorptive wall area

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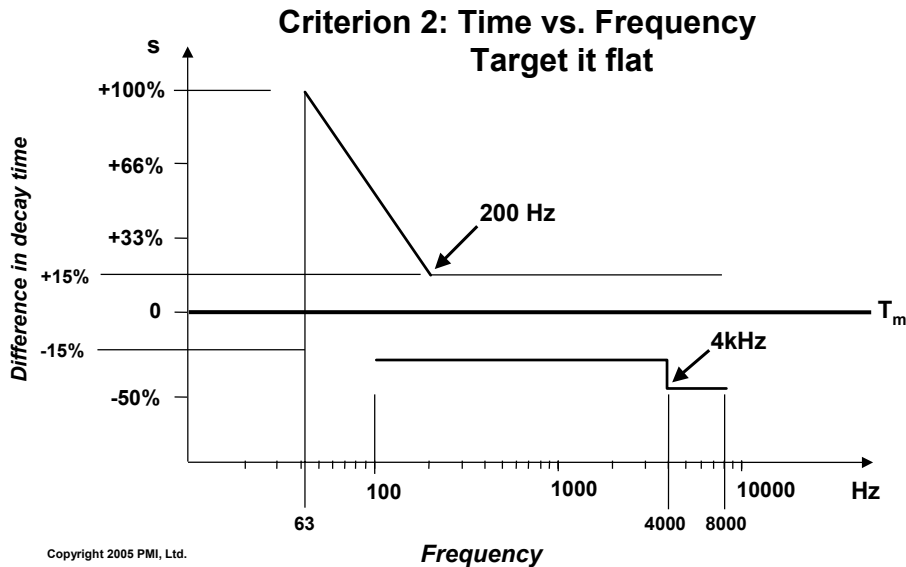
Decay Time

Criterion 1: Time vs. Volume (500 Hz)



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Tolerance Limits for Decay Time



Decay Time Getting it right

- Use the right amount of “frictional” absorption for the mids and highs
- Use the right amount of perforated panel bass absorption
- Calculate the amount with the Sabine, Eyring or Arau- Puchades equations
 - Know the absorption coefficient of materials
 - Be prepared to do lots of math

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Decay Time Getting it right

- The Sabine equation: Good but old

$$RT60 = \frac{0.049V}{S_{total}a}$$

V is volume
S is absorption surface area
a is absorption coefficient

- The Eyring equation: Better and more recent

$$RT60 = \frac{0.049V}{-S \ln(1-A)}$$

V is volume
S is total room surface area
A is area-weighted averaged absorption coefficient

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Decay Time Getting it right

- The Arau- Puchades equation: Best and latest

$$RT60 = \left[\frac{0.161V}{-S \ln(1-\bar{\alpha}_x)} \right]^{x/s} \times \left[\frac{0.161V}{-S \ln(1-\bar{\alpha}_y)} \right]^{y/s} \times \left[\frac{0.161V}{-S \ln(1-\bar{\alpha}_z)} \right]^{z/s}$$

V is volume
S is total room surface area
 α is area-weighted averaged absorption coefficient for each wall
x is area of Left +Right walls
y is area of Front + Rear walls
z is area of Floor + Ceiling

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Decay Time Getting it right

- **Rule of thumb: cover 25% of walls with absorption**
 - Also treat ceiling first reflection
- **Spread absorption materials around the room surfaces**
- **Also use diffusion to smooth out decay**
- **Diffusion enhances absorption effectiveness**

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Designing the Room

Sound Reflection Control

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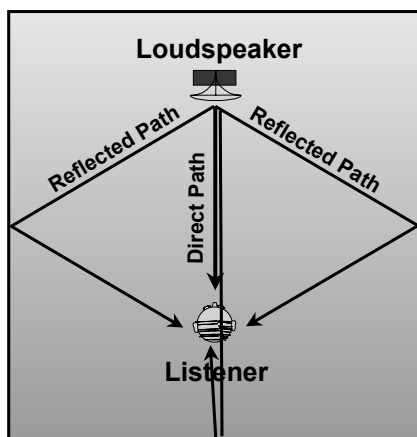
Reflections = Distortion



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Room Reflections



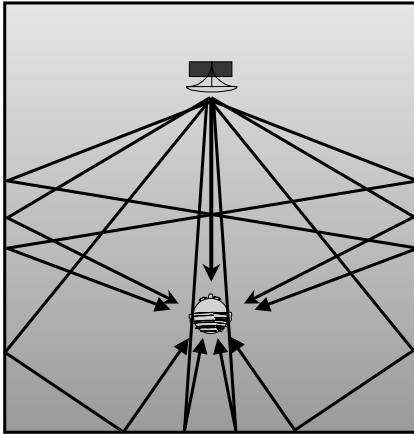
- Reflections cause
 - Blurring of image
 - Spectral imbalance by comb filtering

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Room Reflections

Did you Know?!



- At main seat you listen to as much reflected sound as direct!
- Need to get more direct sound

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Designing the Room

Sound Reflection Control

Absorption

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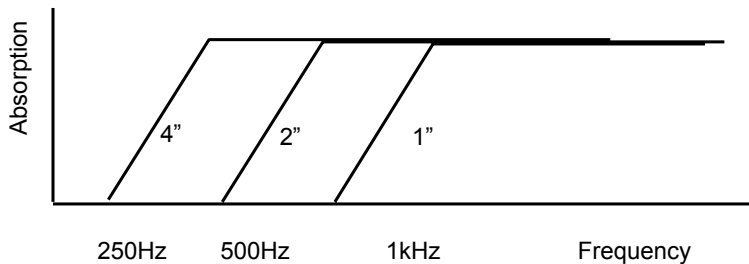


- 

Acoustical Treatments

Absorption Thickness

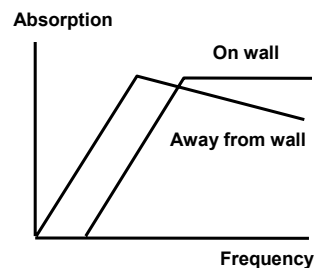
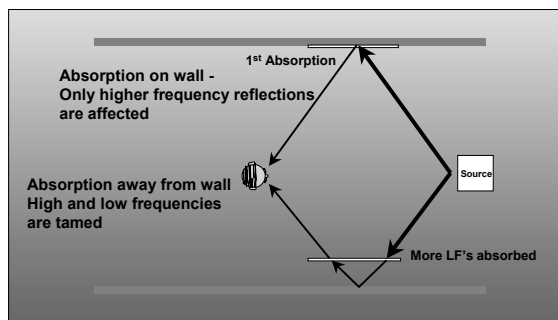
- 1" Panels work down to 1kHz (not enough)
- 2" Panels work down to 500Hz (better)
- 4" Panels work down to 250Hz (best)



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"Floating" an Absorption Panel



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Acoustical Treatments

Notes on Absorption

- **Don't "over absorb"**
 - Dead rooms sound odd
 - Target reflection decay time: 0.3s
 - 25% coverage of wall surface

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Acoustical Treatments

Notes on Draperies

- **Draperies are uneven acoustical absorbers**
- **Performance affected by fabric weight, pleat number, distance from boundary**
- **At least 3" air gap**
- **Velour mass 32 ounces per lineal yard**
- **100% fullness**

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Reflection issues

Control room surfaces

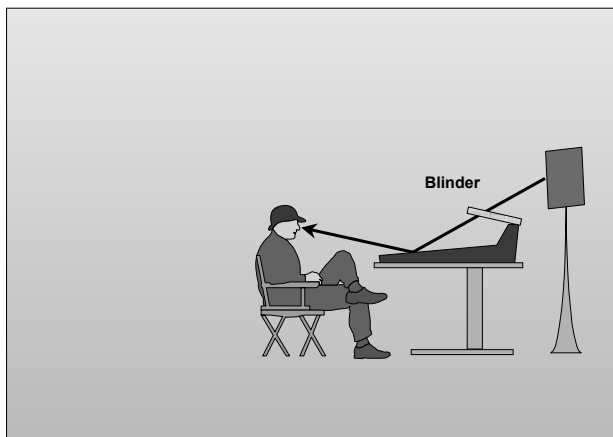
- Work surfaces are large reflectors
- Work stations are reflectors
- Video displays are reflectors
- Place them all carefully
- Put “acoustic blinders” over work station

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Reflection issues

Control room surfaces



- Place speakers on stands
- Use an acoustic blinder to cut out the reflection

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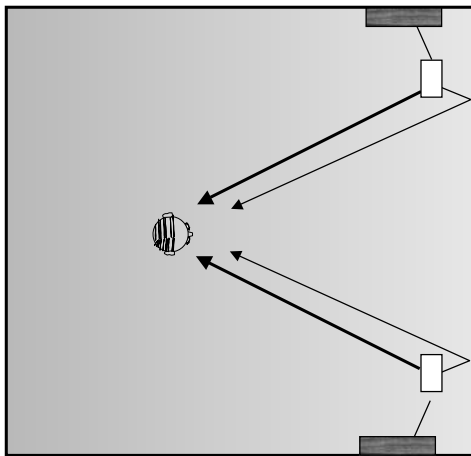
Low Frequency Reflection Control Strategies

- First reduce peak/dip errors through proper placement
- “Resistive” Absorbers too thick
- Use Helmholtz and Diaphragm methods

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Bass Absorption



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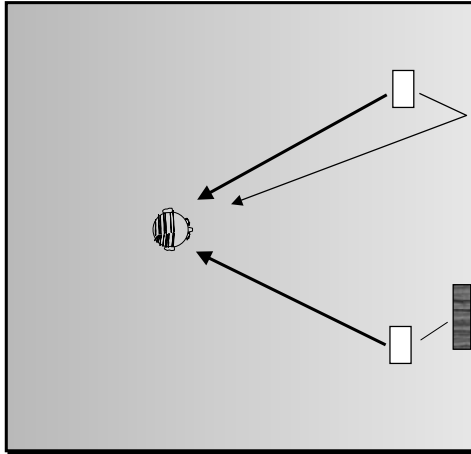
- Use Perforated wood surface on box
- Tuning equation:

$$f_0 = 200 \sqrt{\frac{p}{(d)(t)}}$$

f_0 is frequency
p is perforation percentage
t is hole length
d is air space depth



Bass Absorption on the front wall



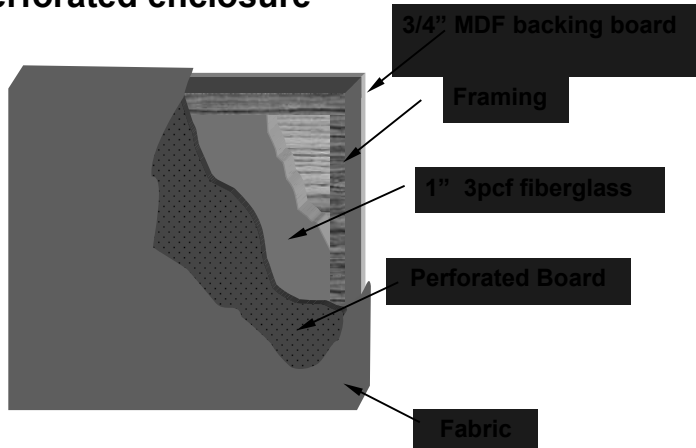
- Use Bass absorber to kill front wall reflection

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A Bass Absorber

Perforated enclosure



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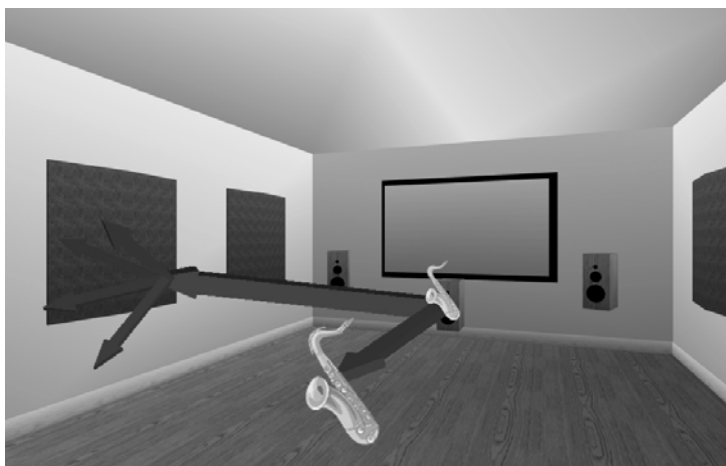


Designing the Room

Sound Reflection Control Diffusion

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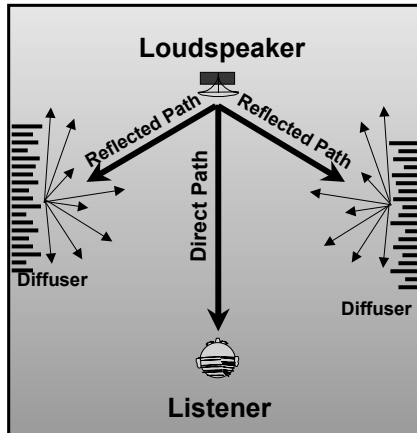
Solutions to Room Reflections Diffusion



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Solutions to Room Reflections Diffusion



- Diffusive materials
 - Purpose-built panels
 - Bookcase

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Acoustical Treatments Diffusion

- Need enough diffusion surface to “smooth out” the soundfield
- Balance diffusion and absorption
- Keep some liveness to the room
- Mix diffusion in with absorption
- It’s the stuff that high-end studios are made of

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Acoustical Treatments

Diffusion types

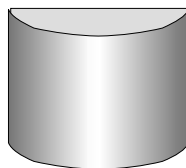
- 2D diffusion redistributes incident sound to a plane
 - Use along front portion of side walls to diffuse front speakers
- 3D diffusion redistributes sound to a hemisphere
 - Use it towards the rear of room for surround speakers

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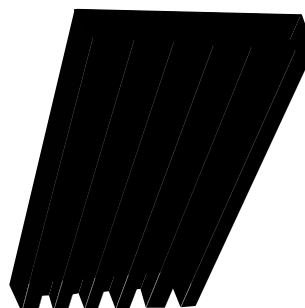


Acoustical Treatments

Diffusion – 2D Diffusers



Cylindrical



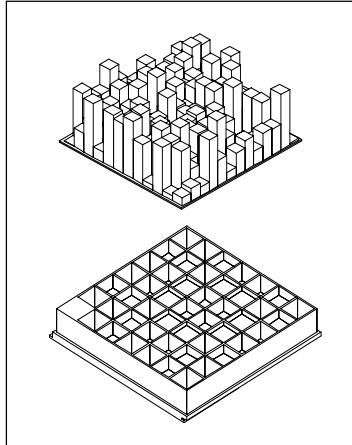
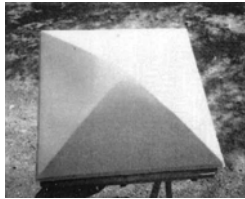
Slotted

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Acoustical Treatments

Diffusion - 3D Diffusers



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Acoustic Treatment

Manufacturers

- **StudioPanel**
- **RPG**
- **Acoustics First**
- **Kinetics Noise Control**
- **Auralex**
- **And many others!**

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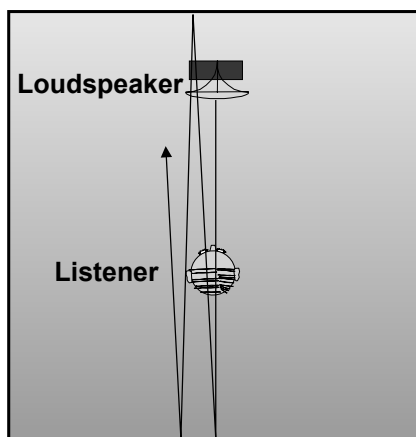




Slap Echoes

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Slap Echoes



- **Echoes are**
 - Repeated reflections between two parallel surfaces
- **Slap echoes cause**
 - Bright, “zingy” sound
 - Interference with acoustic character of sound
 - Timbral changes

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Slap Echoes Detection Methods

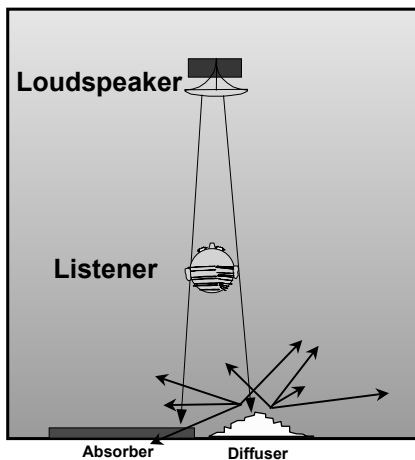


- Clap hands at various locations in room
- Listen for echo
- If possible, sit at primary seat and listen to a person clapping at various locations

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Solutions to Echoes Materials



- Absorptive
 - Fiberglass panels
 - Foam panels
 - Drapes
- Diffusive
 - Diffuser panels
 - Bookcases
 - Furniture

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Placing listeners

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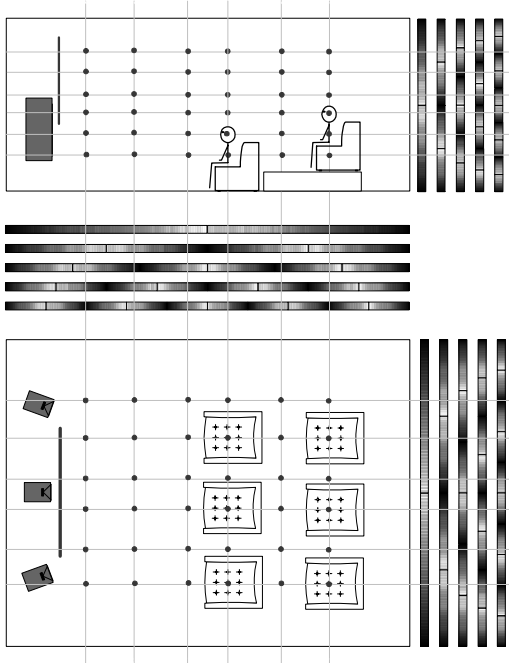
Seating Placement

- **Don't sit at Standing Wave Peaks or dips**

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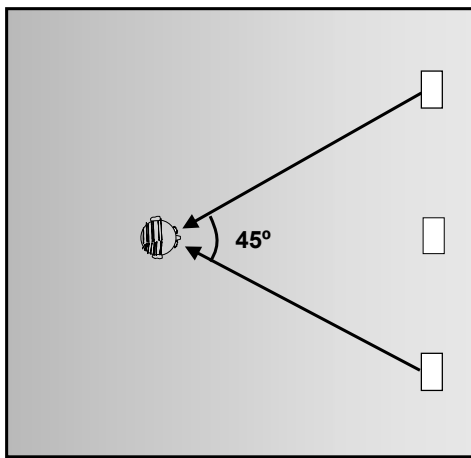


Solutions to Standing Waves Seating Placement



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Listener/Speaker placement



- Position Left and Right to form a 45 degree angle to seating area

- Balance between stereo phantom image and multichannel separation



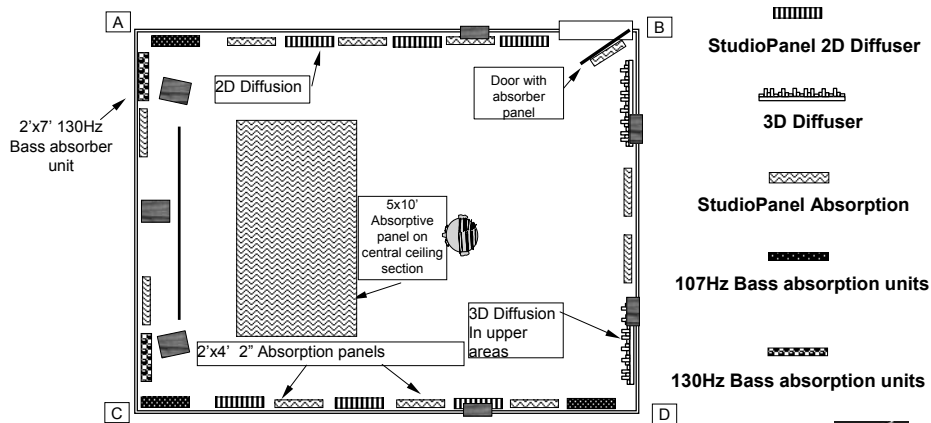
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Example Layout

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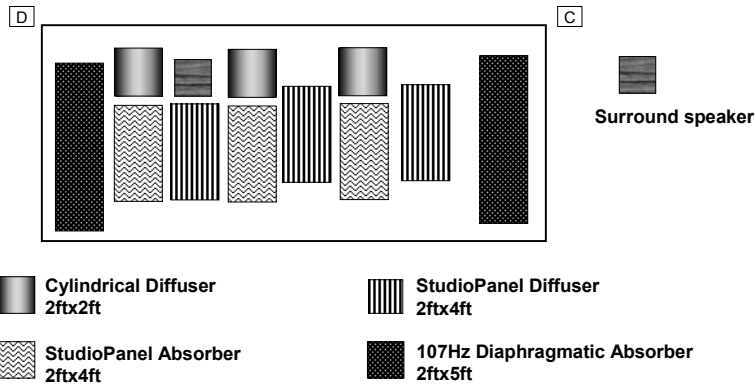
Example Treatment Layout



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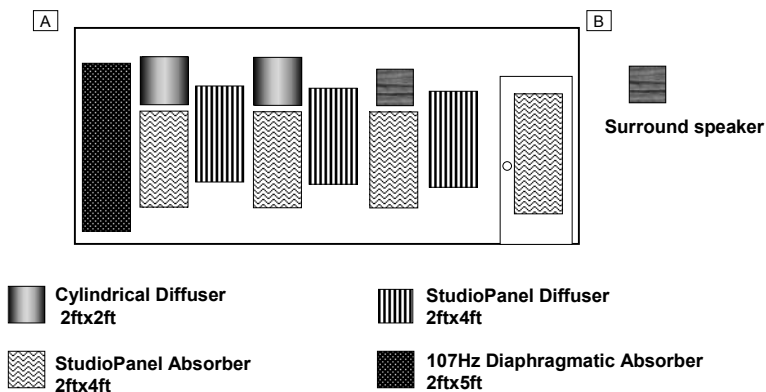
Example Treatment Layout Left Wall



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Example Treatment Layout Right Wall



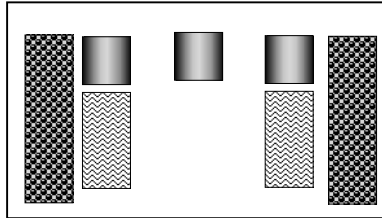
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Example Treatment Layout Front Wall

A

C



 Cylindrical Diffuser
2ftx2ft

 StudioPanel Absorber
2ftx4ft

 130Hz Diaphragmatic Absorber
2ftx5ft

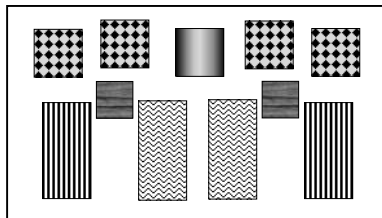


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Example Treatment Layout Rear Wall

A

C



Rear speaker

 Cylindrical Diffuser
2ftx2ft

 StudioPanel Absorber
2ftx4ft

 StudioPanel Diffuser
2ftx4ft

 3D Diffuser
2ftx2ft



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Designing the Room

The Picture

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Designing the Room **The Picture - Light Control**

- **Windows**
 - Use black out shades
 - The fewer the better
- **Doors**
 - Must be closed when system is in use
 - Must have good seal to prevent light leakage

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Designing the Room

Screen Light Reflection Control

- Light from screen will reflect on walls and ceiling
- Light-colored walls will wash out screen contrast – choose dark colors
- Make the room as dark as possible
 - Resolve the full difference between black and white

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Designing the Room Visual Environment

- **Make the room as neutral as possible**
- **Colors around the screen affect perception of picture**
- **Observe these examples :**















Designing the Room

The Picture - Light Control

- **Lighting types**
 - Ambient
 - Task
 - Artifact
- **3 Lighting Modes**
 - Entrance/Exit
 - Screening (No light on the screen)
 - Work



Designing the Room

Interior Design

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Designing the Room Interior Design Guidelines

- **Make the room an event**
- **Rely on interior designers**
- **Treatments are ugly; hide them!**
- **Be creative**

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Designing the Room

Interior Design Approaches

- **Visible treatments**
- **The stretched fabric approach**
- **Other looks**
 - Porous plaster
 - Perforated wood
 - Perforated metal

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Acoustic Treatment

Integration

- **Stretched fabric room**
 - Most flexible design approach
 - Designate 8" zone for acoustics and speakers
 - Integrate moldings
 - Use acoustically transparent fabric
 - For video use dark and neutral fabrics

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Acoustical Treatments

Acoustically Transparent Fabric

- Fabric should be transparent up to 6kHz for Treatments
- Fabric should be transparent up to 16kHz for speakers
- Measure and listen to Pink noise from speaker with and without the fabric

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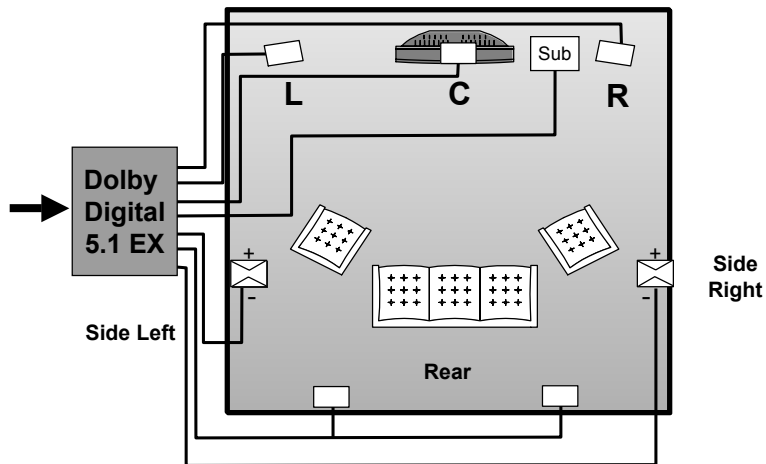
Specifying the Gear

The Audio System

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Dolby Digital 5.1 EX

"6.1" Channels



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Multichannel Sound

The roles of each channel

- **Center**
 - Focal point for soundfield
 - Melodic lines, vocals, bass, solos
 - Highest acoustic energy of all channels
- **Left / Right**
 - Phantom center sounds with soft focus
 - Further back in soundfield
 - Sounds panned laterally

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The roles of each channel

- **Sides and Rears**
 - Spatial definition (verb, delays, echoes)
 - Secondary instrumentation
 - Special effects

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The roles of each channel

- **LFE (Low Frequency Effects)**
 - Bass exceeding 0dBfs
 - Disappears in 2 channel downmix mode
 - Special effects for listeners with multichannel playback
 - Not usually needed in music !

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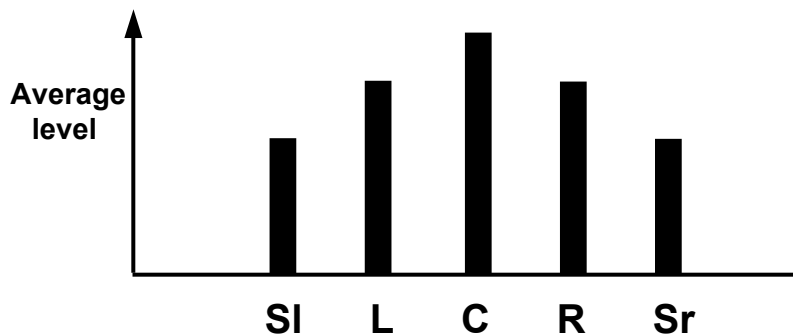
The roles of the Subwoofer output

- Low bass below cutoff of your main monitors
- Low bass that would overload your monitors
- Low bass distributed through multiple subs for cleaner, tighter bass
- Sum of L/C/R/SI/Sr+LFE

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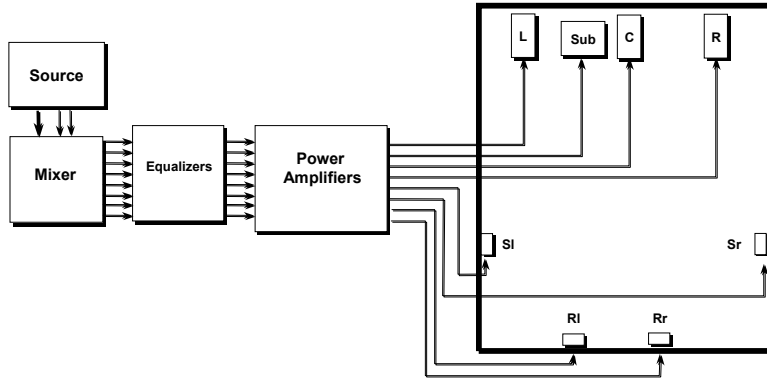
Roles of each channel **Distribution of sound energy**



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Studio Audio System Diagram



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Basic System Requirements

- Sources: Mics, Keyboards, etc
- Outboard gear
- Console / Controller
- Room Equalizer (highly recommended)
- Amplification
- Speakers

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What to look for in Sources Microphones

- **Good quality microphone**
- **Mic polar patterns**
 - Omni
 - Cardoid
 - Hypercardioid
 - Figure 8
- **Over what frequency range ?**
- **Warning: better mics pick up more room tone**

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What to look for in Sources Mic preamps

- **Many choices**
- **Vacuum tubes**
- **Noise floor**
- **Coloration**
- **Gain range**
 - 30dB to 50dB typical
 - Ribbon mics need 60dB

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What to look for in Sources Keyboards

- **Most all are unbalanced**
- **Use a balance converter**
 - **Passive transformer type**
 - **Active**

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What to look for in Sources Direct boxes

- **Not all equal**
- **Some saturate at high levels**
- **Choose better ones!**

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What to look for in Sources

Direct / Reamping converter

- For guitar re-amping use a good impedance matching converter box to avoid noise

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What to look for in controllers

- Bass management
- Calibration features
- Solo/Mute of multichannels
- Multichannel source selection
 - DAW
 - DVD player
 - Surround decoders
 - Gaming system

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What to look for in controllers

- **Metering**
- **Multichannel metering**
- **Remote control**

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Which DAW to use ?

- **You choose !!**

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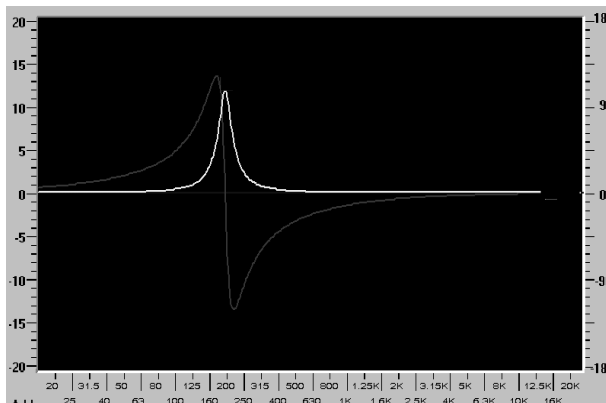
Minimum System Requirements

- Room Equalizer
 - Analog
 - Digital
 - Manual
 - Automated
- Either way you need one!

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Frequency Response Calibration Room + Equalizer Phase Response



- 12 dB peak error at 200 Hz (yellow line)
- Phase error (red line)
- Equal cut introduces inverse phase error
- Amplitude and phase are corrected!

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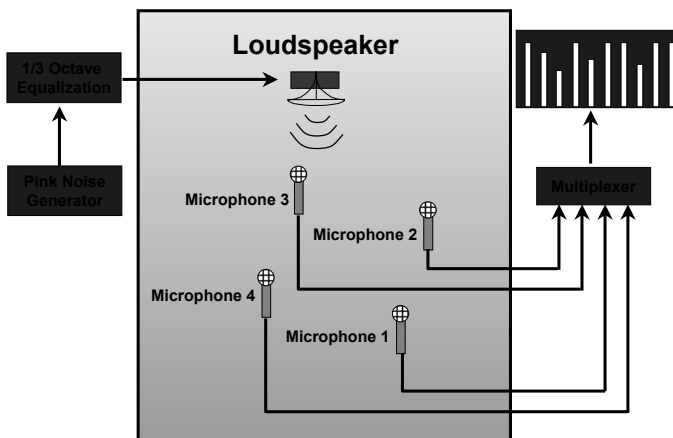
Equalization Requirements

- At least 1/3rd octave resolution from 80 to 1kHz for all main channels
- At least 1/12th Octave resolution from 20Hz to 80Hz for subwoofer
- Parametric is great
- Low noise
- Low distortion
- Ability to program presets recommended

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Analysis – the useful way



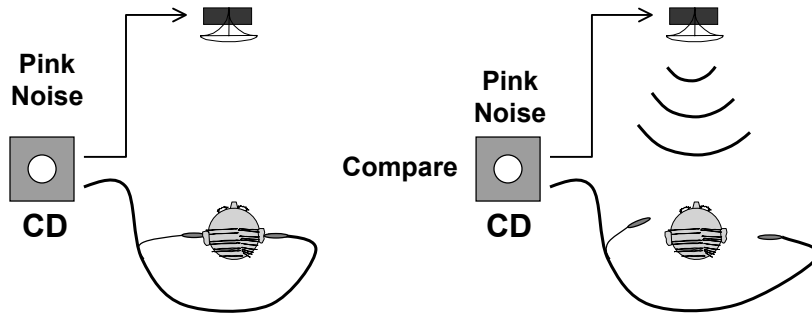
- Analysis should be spatially and temporally averaged
- Use Gold Line DSP30 Analyzer, or equivalent

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Quick Check of Overall Frequency Response

Using Etymotic ER-4S or ER-6 Earphones



Set earphone level to match speaker

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What to look for in Amplifiers

- **Power Rating**
 - Enough to get to 105dB per channel
 - Speaker sensitivity –6dB rule
- **Power at 4, 8, 16 ohms**
- **Protection circuitry**
- **Ability to play into low impedances?**
- **Reliability**
- **Fixed gain is easier**
- **Good sound!**

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Minimum System Requirements Front Speakers

- **Front Loudspeakers**
 - 3 identical speakers for LCRs
 - Appropriate directivity
 - Center **MUST** be the same make / model as L & R
 - All horizontal or all vertical
 - Exception: Home THX systems with dedicated matched horizontal center

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Minimum System Requirements Front Speakers

- 80 Hz to 20 kHz bandwidth
- 89 dB sensitivity
- 105 dB in-room SPL throughout the bandwidth

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Minimum System Requirements Front Speakers

- **Active Speakers – Several advantages**
 - More efficient
 - Better control over response
 - Built in protection

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What to look for in Speakers:

- Flat response in pass-band
- Uniform off-axis response
- Good dispersion (no “lobing”)
- Power handling
- Efficiency
- Bass Headroom
- Reliability
- Good sound!

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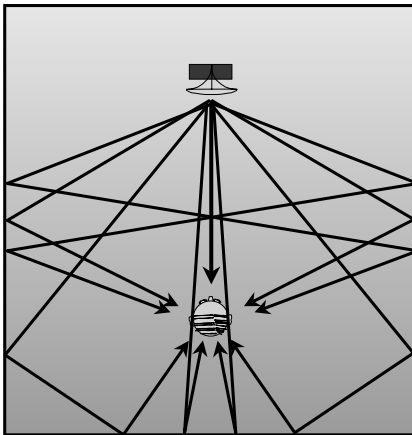
What's all this about directivity?

- It's one of the most important things
- You often hear more reflected sound in a room
- The sound returned from the room should match the direct sound

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Room Reflections: Did you Know?!



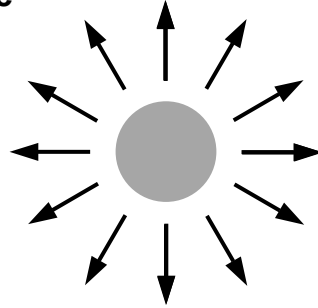
- At the listening position you listen to as much reflected sound as direct!
- The room plays an important part in the sound you hear
- Speaker directivity will affect reflected sounds

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What's all this about directivity?

- **An idealized speaker:**
 - The “pulsating sphere”
- **Flat axial response**
- **Radiates evenly in all directions**
- **Flat “sound power” response**

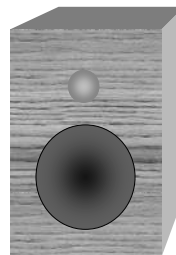


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What's all this about directivity?

- **A real speaker:**
 - Cones and domes
- **Flat axial response**
- **Radiation depends on frequency**
- **“Sound power” response tilted down**

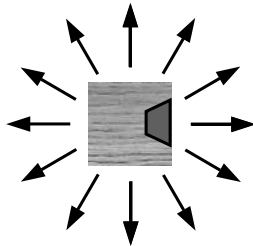


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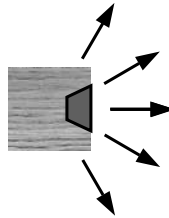


What's all this about directivity?

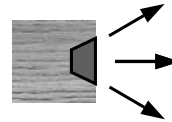
- **A real speaker: Variable dispersion**



Low Frequency
100Hz



Mid Frequency
1kHz



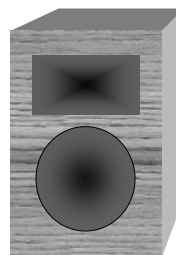
High Frequency
10kHz

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How to get directivity?

- **Some speakers have more focus than others**
- **Stacks of drivers**
- **Horns**
- **Ribbons**

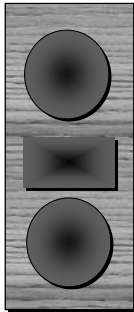


**The Obvious:
Two way with
Horn loaded
tweeter**

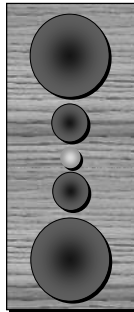
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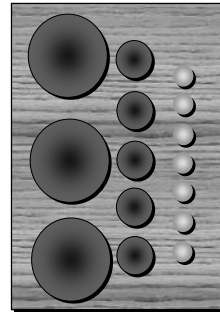
How to get directivity?



Less Obvious:
Pattern control to
lower frequencies



**Not Obvious: three
way tapered array.**
Pattern control to
lower frequencies



**Not Obvious: three
way line array.**
Pattern control to
lower frequencies

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What's all this about directivity?

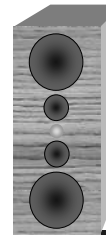
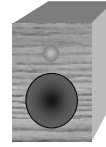
- **Match the directivity**
 - To the room
 - To the intended usage
- **Higher directivity**
 - Better clarity
 - Tighter imaging
- **Lower directivity**
 - Smoother quality
 - More envelopment

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What's all this about directivity?

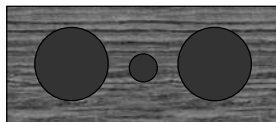
- The traditional 2 way speaker is the magic balance for 2 channel music: Good envelopment and sufficient directional cues at high frequencies
- 5.1 channel music and film may need more frontal directivity to avoid “cacophony”
- However, remember to match the speaker to the room !



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Center Speaker

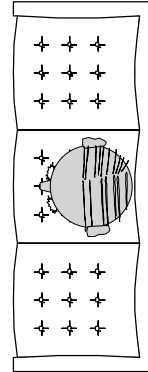
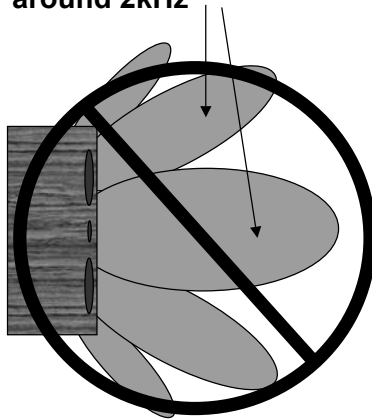
- Beware of this type of center speaker
- Sound should be identical throughout the listening area



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Center Speaker Dispersion No Lobing Allowed

Radiation pattern of traditional center speakers
around 2kHz

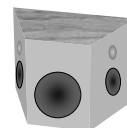
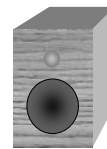


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What about directivity of Surrounds?

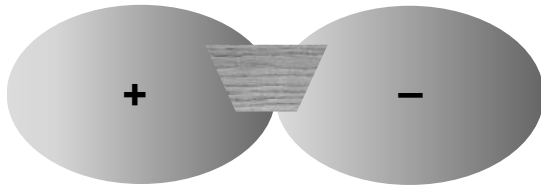
- The traditional 2 way speaker is OK – Sound dominated by reflections from 3kHz down
- 5.1 channel music and film may benefit from more envelopment to avoid distraction:
Dipoles and Bipoles



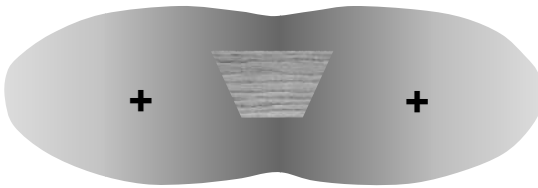
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What about directivity of Surrounds?



Dipole:
Deep null and lots
of envelopment



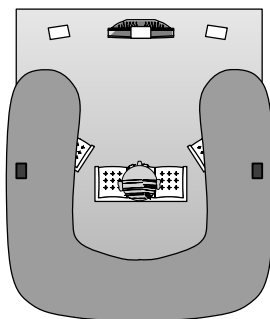
Bipole:
Broader waistline
More directionality

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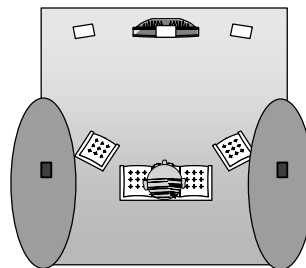


Surround Loudspeakers Home Theatre Surround Soundfield Effect

Dipole



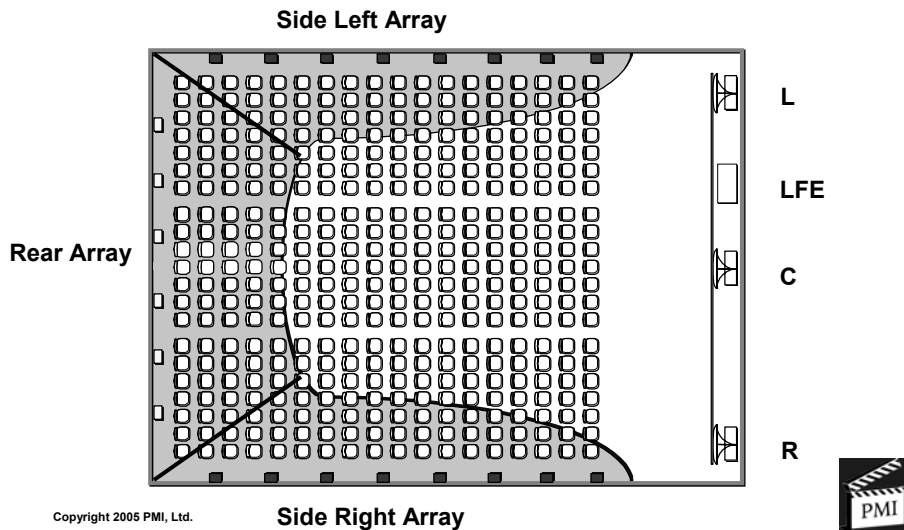
Direct



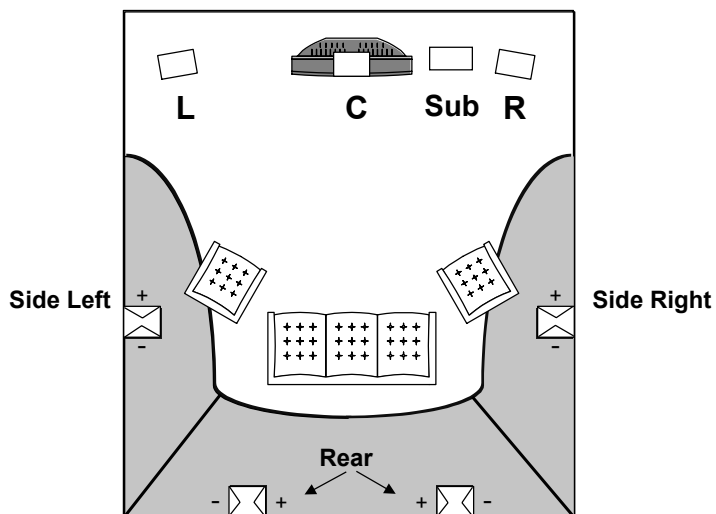
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Surround EX Soundfield in Cinemas



Surround EX for Home Theatres



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Minimum System Requirements

- **Side speakers**
 - Use dipole, bipole, or direct speakers
 - Balance envelopment and directionality
 - Flat sound power response
 - The issue of sound power response – equalize or choose the right speaker

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Minimum System Requirements

- **Rear speakers**
 - Use dipole, bipole, or direct speakers
 - Balance envelopment and directionality
 - Flat sound power response
 - The issue of sound power response – equalize or choose the right speaker
 - Watch for “Front-Back Reversal” potential

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What to look for in Subwoofers

- **Powered or passive?**
- **Frequency response – smooth down to 35Hz then 12dB/Oct roll-off → Flat to 20Hz in-room**
- **Limiting**
- **Crossover adjustments**
- **Unfortunately, placement will be at one or two pressure maxima (floor, side/front wall)**
- **Solution: Always use 2 or 4 subs placed so as to reduce resonances**

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Audio Gear Placement

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Gear Placement considerations

- **Keep noisy components away**
- **Be careful with noisy video projectors**
- **Heat dissipation**
- **Ergonomics**
- **Organization**
- **Interface cable maximum run lengths**
- **Electrical interference**

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Gear Placement considerations

- **Organization**
 - **How many rack spaces**
 - **Create spreadsheet list**
 - **I/O – think cable lengths (to Computer)**
 - **Patch bays**
 - **Usage types**
 - **Mic Preamps / outboard gear / etc.**
 - **Put most used gear in most accessible location**
 - **Maintain flexibility**

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Speaker Placement Several Considerations

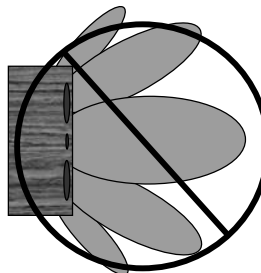
- “Nearfield” or “Farfield”
- Boundary reflections
- Standing waves
- Horizontal placement width
- Seated ear height
- Relationship to picture

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Front Speaker Placement General Guidelines

- Keep away from corners and floors
- Provide for equal acoustical environment across front
- Do not place speakers horizontally unless properly designed for it



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Speaker Placement Summary

- **Position of speakers affect their sound**
- **Find best position through:**
 - Computer modeling
 - Measuring in-room with analyzer
 - Listening
- **Aim speakers appropriately**
 - Fronts towards the listening area
 - Surround towards the room

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Boundary Effects Loudspeaker/ Room Interactions

- **Reflection issues at low frequencies are called “boundary effects”**
- **Peaks and dips in bass/mid frequencies depend on speaker location**
- **Low frequencies are hard to absorb**
- **In multi-channel systems, each speaker may have a different boundary interaction**

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Boundary Effects

Goals

- Smoothest frequency response across the listening area
- Good tonal match between front speakers
- Articulation
- Speech clarity

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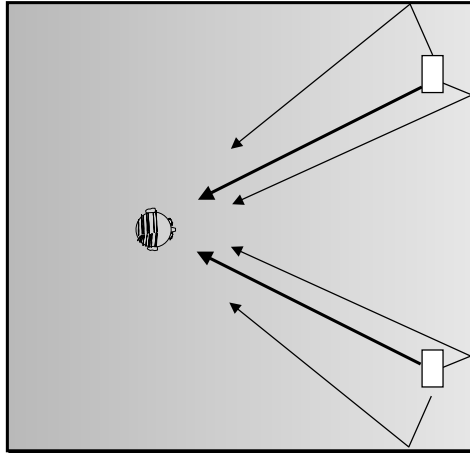
Boundary Effects

- | | |
|---|--|
| <ul style="list-style-type: none">• Evaluation<ul style="list-style-type: none">– Computer predictions<ul style="list-style-type: none">• CARA• RPG Room optimizer– Use circulating pink noise and listen for timbral variations– Use pink noise and RTA to measure spectral variations | <ul style="list-style-type: none">• Correction<ul style="list-style-type: none">– Avoid multiple equal boundary distances– Change speaker position– Match boundary conditions for the front speakers– Flush mount speakers– Use low frequency absorption– Equalize |
|---|--|

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Front Speaker Placement Unequal Boundaries

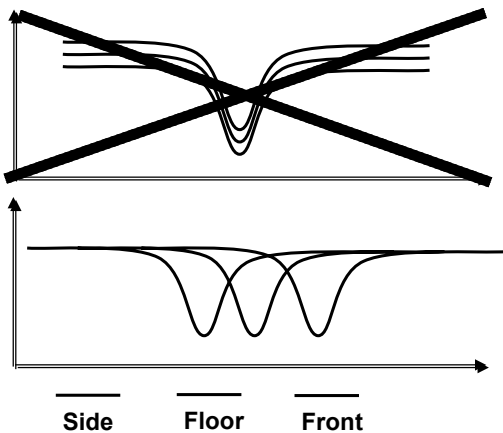


Unequal
Reflected
Path Lengths

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Front Speaker Placement

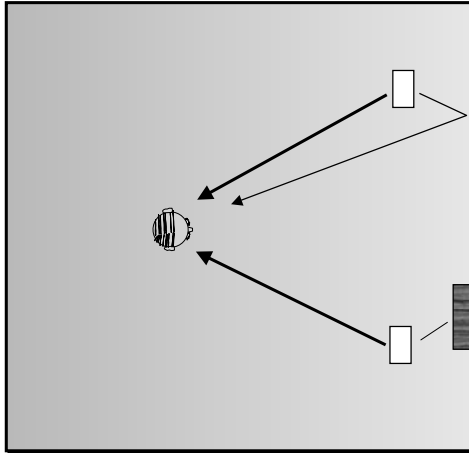


- Aim for unequal reflection path lengths for floor / side / front wall
- Distribute peak-dip frequencies

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Bass Absorption on the front wall

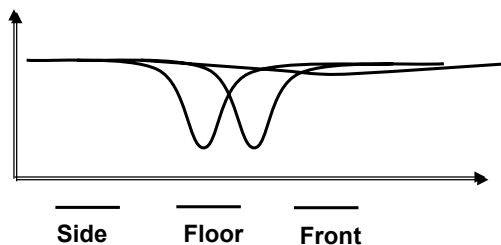


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- Use Bass absorber to kill front wall reflection

Solutions to LF Reflections Bass Absorption



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- With Bass absorber, front wall response is smoother
- The remaining error can be equalized
- Can also use Bass absorbers on front wall

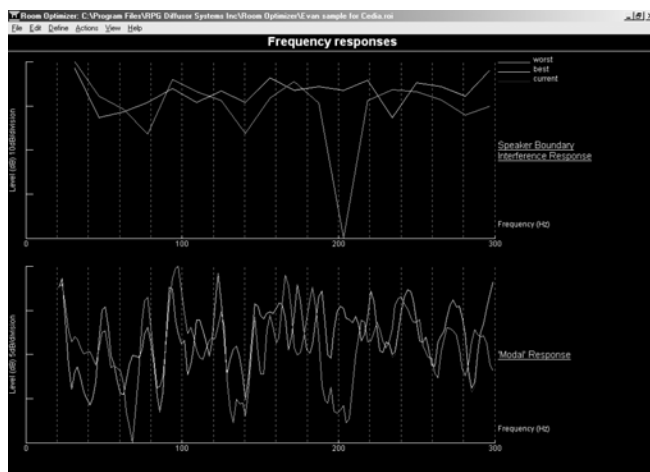
Front Speaker Placement

- Use planning and modeling for best boundary conditions
 - RPG room optimizer
 - CARA

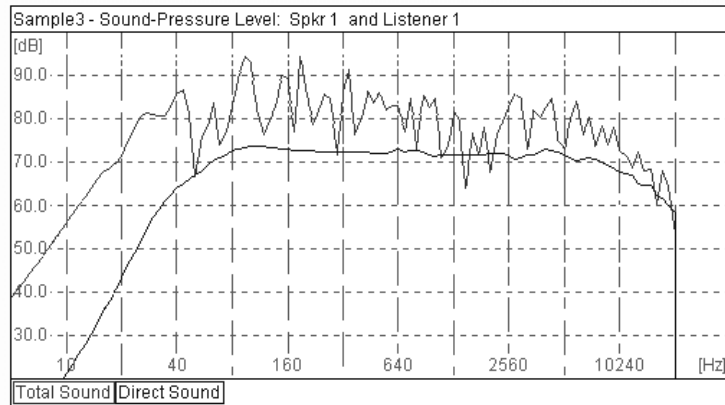
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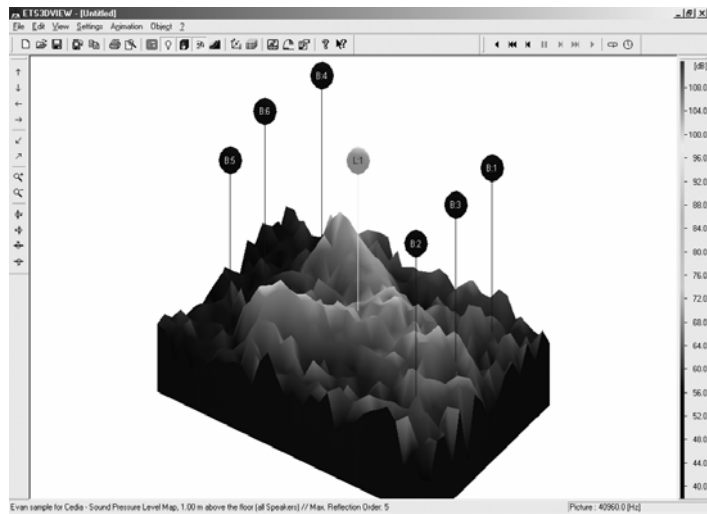
Modeling Software RPG Room Optimizer



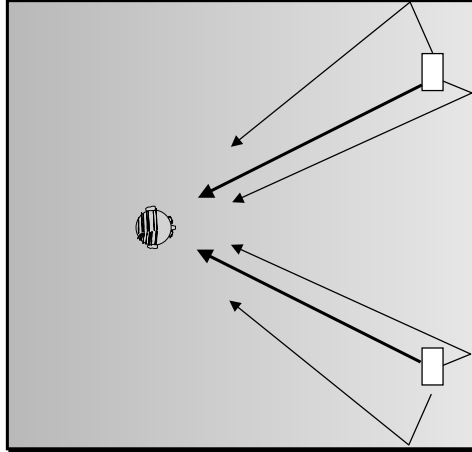
Modeling Software CARA



Modeling Software CARA



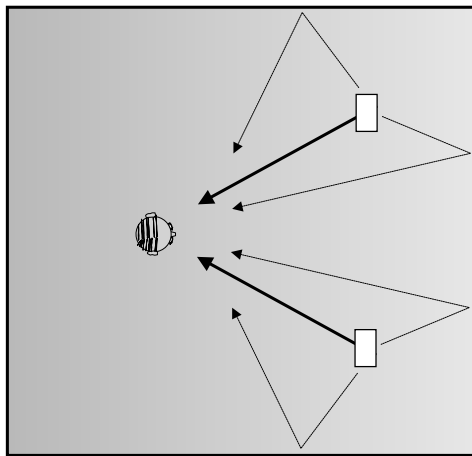
Front Speaker Placement



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Front Speaker Placement Reducing boundary effects



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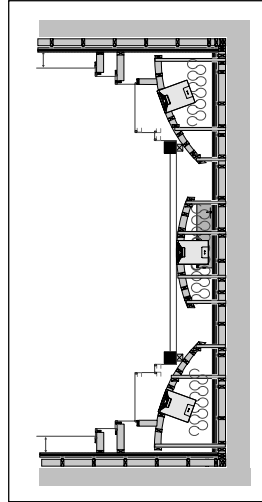


- Move speakers away from walls
- Reduces reflection effects
- Robs you away from precious real estate

Front Speaker Placement

Another strategy: Baffle mounting

- Removes reflections from front wall
- Cleaner bass response
- More bass headroom
- Bass boost needs EQ
- Baffle is best convex-shaped
- Covered with absorption
- Preserves real estate



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Front Speaker Placement

Baffle mounting example



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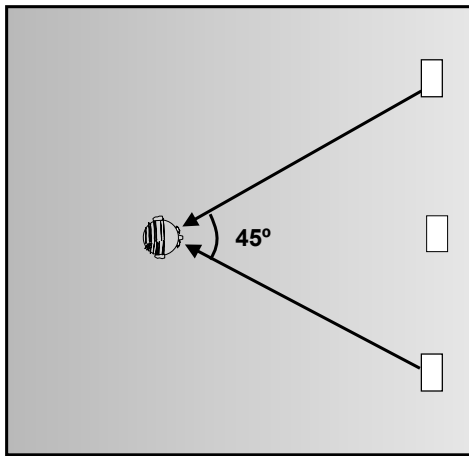
Front Speaker Placement Guidelines Vertical Plane

- Place at seated ear height
- Place at mid-height of screen
- Keep Difference Center / Left-Right < 10°
- Remember to:
 - Eliminate a standing wave
 - Reduce reflections and boundary effects

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Front Speaker Placement Guidelines Horizontal Plane



•Position Left and Right to form a 45 degree angle to seating area

•Balance between stereo phantom image and multichannel separation

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Front Speaker Placement Guidelines Horizontal Plane

- L/R form a 45 degree angle to seating area
- Ensure adequate phantom image
- Ensure proper coverage (aim speakers)
- Avoid any nearby obstructions (workstations, displays, etc.)
- Remember to:
 - Eliminate a standing wave
 - Reduce reflections and boundary effects

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Front Speaker Placement Guidelines “Nearfield” or “Farfield”

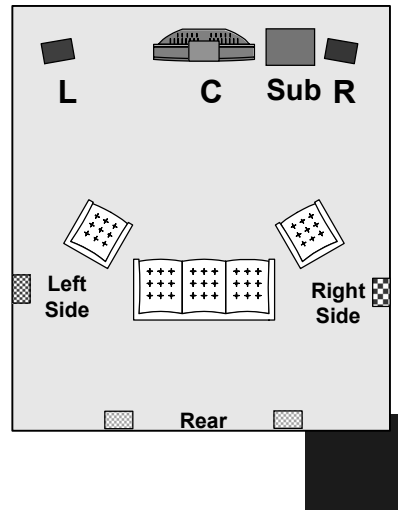
- Speakers don’t know what field they’re in
- Consumers sit in “midfield”
 - Transition area between direct and reverberant energy [F. Toole, 2005 AES119]
 - Typically 12 feet

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Layout of a typical Home Theater:

- 12 feet from front speakers
- Side surrounds on side wall firing in
- Rears on rear wall



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Front Speaker Placement Guidelines “Nearfield” or “Farfield”

- Speakers don’t know what field they’re in
- Consumers sit in “midfield”
 - Transition area between direct and reverberant energy [F. Toole, 2005 AES119]
 - Typically 12 feet
- Why not sit in “midfield”?
 - Sit at 8 to 12 feet
 - Don’t nitpick the small stuff; focus on the whole picture!

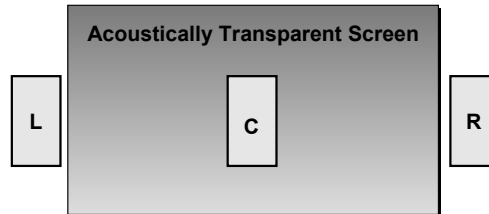
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Front Speaker Placement

The Best Solution for post work

- Use acoustically transparent screen whenever possible



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Front Loudspeaker Aiming

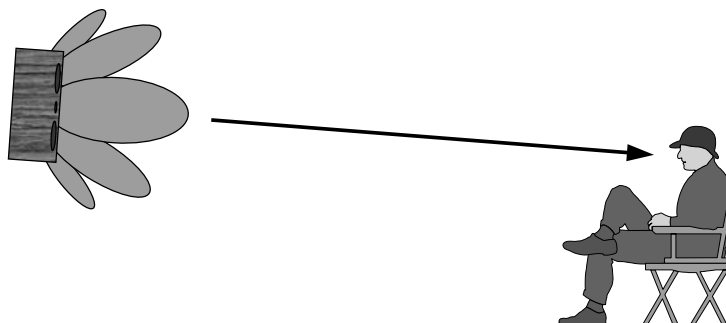
- Aim speakers towards the listening area
 - Vertical Plane – “Toe In”
 - Horizontal Plane – Aim up or down

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Front Speaker Coverage Lobing Problems

- Radiation pattern of “DiAppolito” speakers around 2kHz
- Aim them!



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Subwoofer Placement

- Use planning and modeling
- Esthetics vs. Acoustics
- Use in mono
- Eliminate a room resonance

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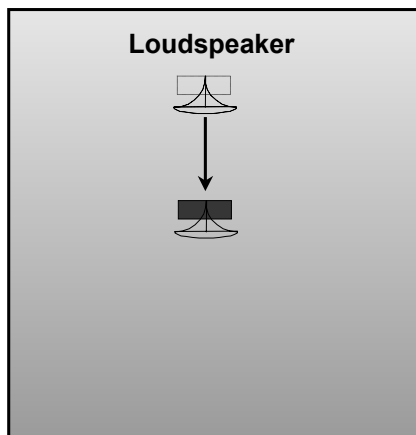
Subwoofer Placement

- Multiple subwoofers can be better
- Move seats if needed
- Use bass absorbers if needed
- Measure frequency response
- Listen to single tone sweep

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Subwoofer Placement



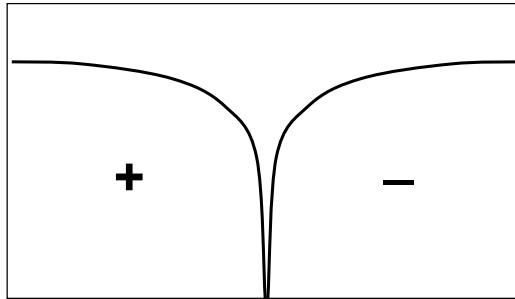
- Driving room standing waves in cancellation areas can improve response

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Standing Waves Pressure Polarity

1st Harmonic



$1/2$

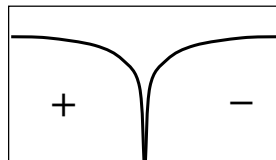
- The acoustic polarity changes around the null

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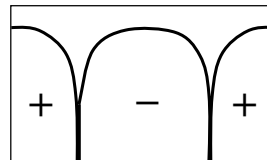
Standing Waves Pressure Polarities

1st Harmonic



$1/2$

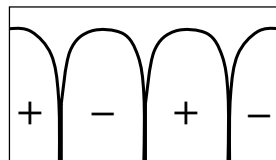
2nd Harmonic



$1/4$

$3/4$

3rd Harmonic

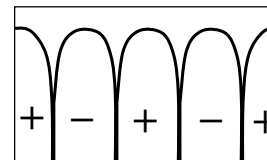


$1/6$

$1/2$

$5/6$

4th Harmonic



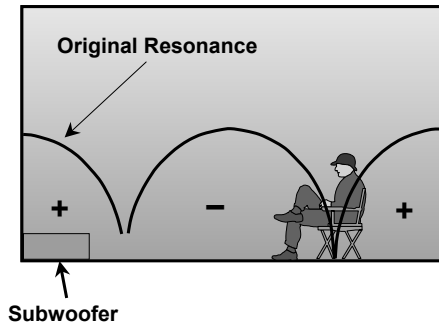
$1/8$

$3/8$

$5/8$

$7/8$

Subwoofer Placement Driving Standing Waves

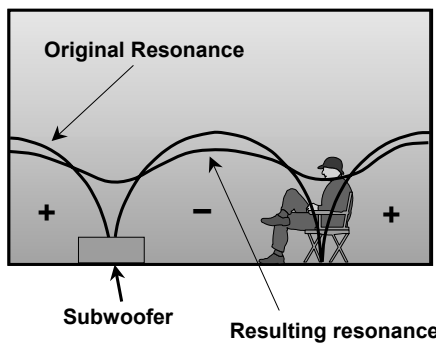


- The subwoofer drives the 2nd order standing wave resonance

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Subwoofer Placement Reducing Standing Waves



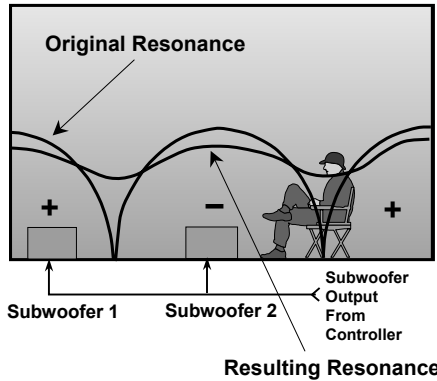
- Move subwoofer to null
- The subwoofer drives the + and - areas equally, resulting in reduction of resonance

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Subwoofer Placement

Reducing Standing Waves (continued)



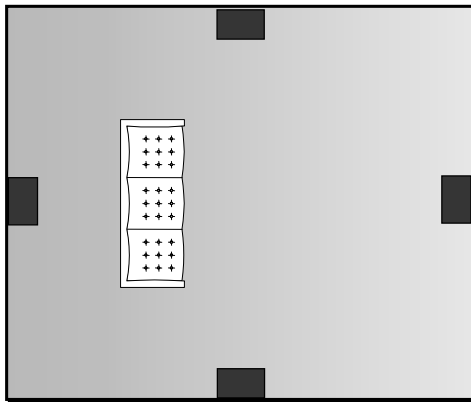
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- Improving a 2nd order standing wave
 - Connect the 2 subwoofers together as “in-phase”
 - The 2 subwoofers drive the + and - areas equally, resulting in reduction of resonance
 - Experiment a lot



Subwoofer Placement

Reducing Standing Waves - A good solution



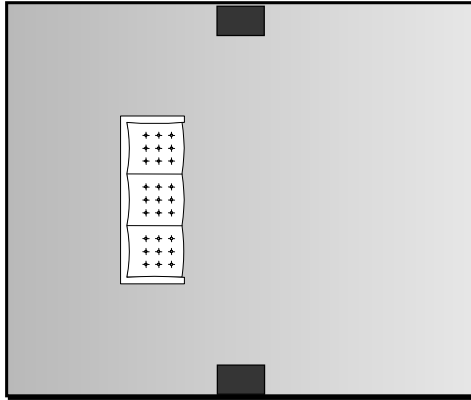
- 4 subwoofers
- They can be small and hidden
- It's the latest research findings
- Todd Welti et al.

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Subwoofer Placement

Another good solution



- 2 subwoofers
- More SPL
- More standing waves

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Side Speaker Placement

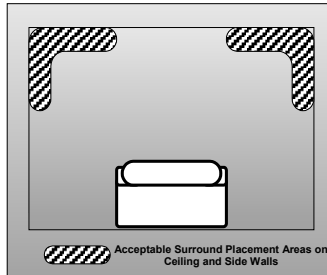
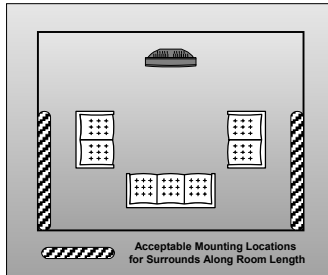
- Use Planning and Modeling
- To the sides or slightly behind listeners
- 24" (60 cm) above seated ear height
- Ensure adequate coverage

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Side Speaker Placement Dipole Speakers Guidelines

- Place on sidewalls or ceiling with null towards listeners
- Place high in room for best reflections (about 2 meters)
- Dipoles can get lost in large reverberant rooms

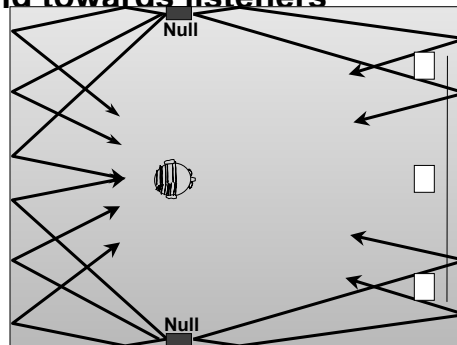


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Dipole Side Speaker Typical Position

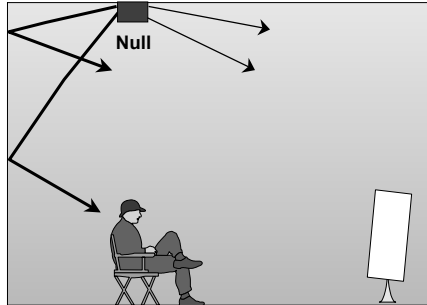
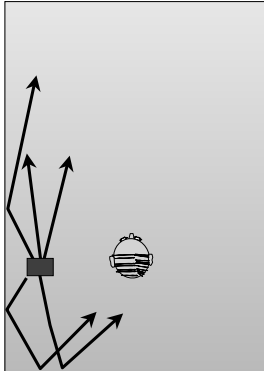
- Place on side walls or ceiling, with null pointing towards listeners



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Dipole Side Speaker Placement Ceiling Placement

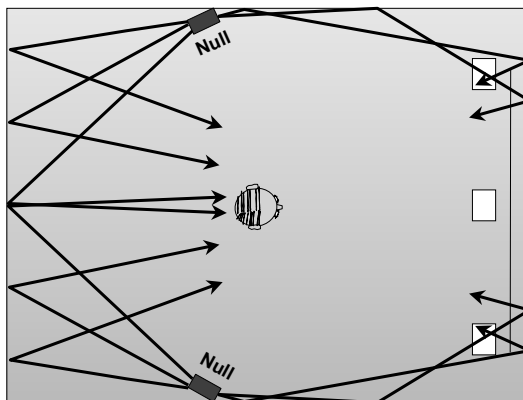


- Aim null at listening position
- Good alternative to sidewall placement
- Good for aesthetics

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Dipole Side Speaker Placement For Mid-Room Seating Position

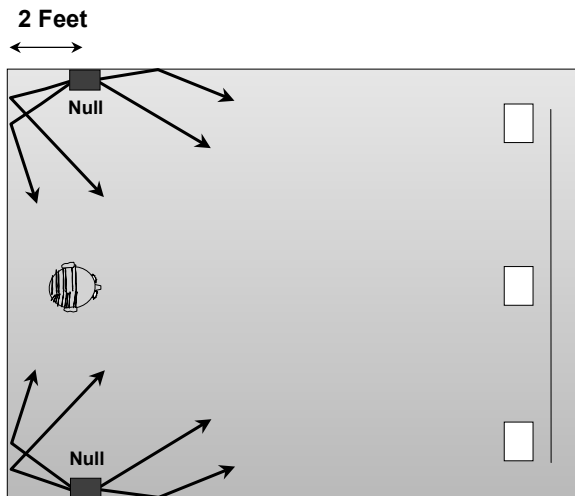


- Make rear wall the first reflection to ensure surround effect
- Aim null at listening position

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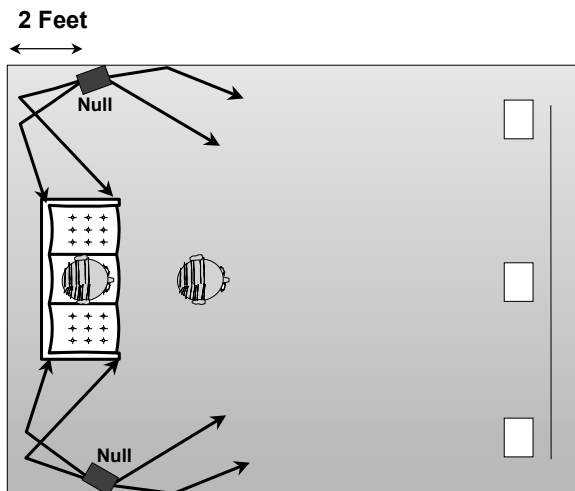
Dipole Side Speaker Placement Seat on Back Wall



- Place on side walls or ceiling, 2 feet (60cm) from rear wall
- Aim null at listening position if needed



Dipole Side Speaker Placement Room with Multiple Rows - 1

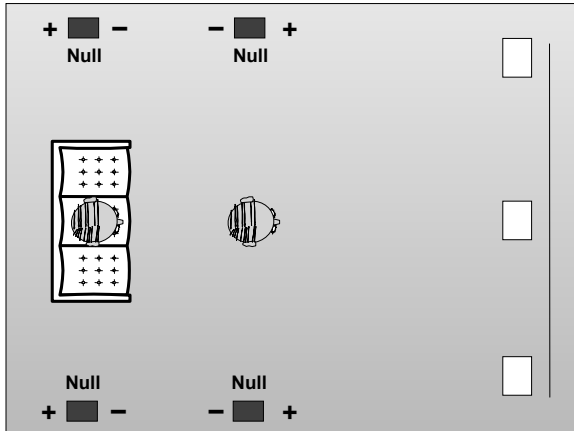


- Aim null for most even coverage



Dipole Side Speaker Placement Room with Multiple Rows - 2

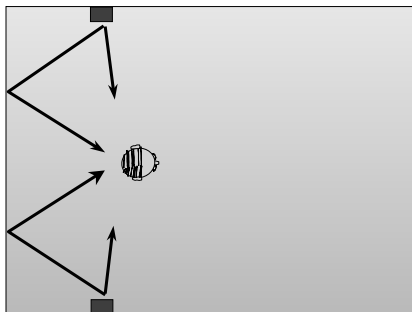
2 Feet



- Invert polarity of rear pair
- Adjust position for even coverage



Side Speaker Placement Direct Radiating Speakers

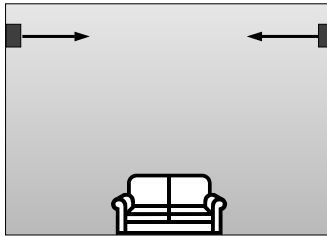
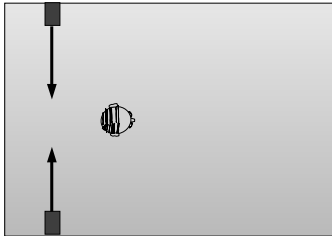


- Place on side walls
- Slightly behind listener area
- Place high in room (about 6 feet)
- Avoid placing close to listeners

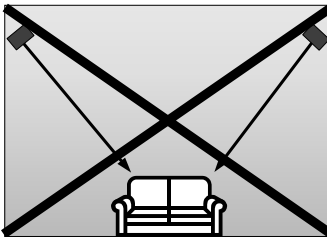
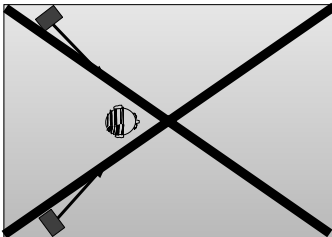
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Direct Surround Speakers Placement and Aiming



- Aim across room



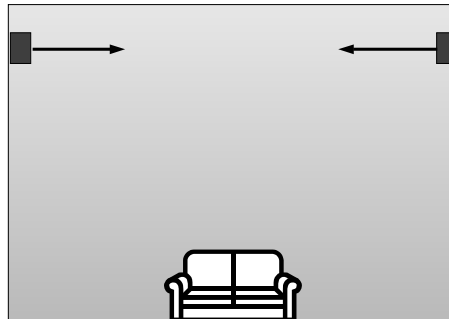
- Don't aim toward listener

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Direct Surround Speaker Placement Seat on Back Wall

1 Foot
↔

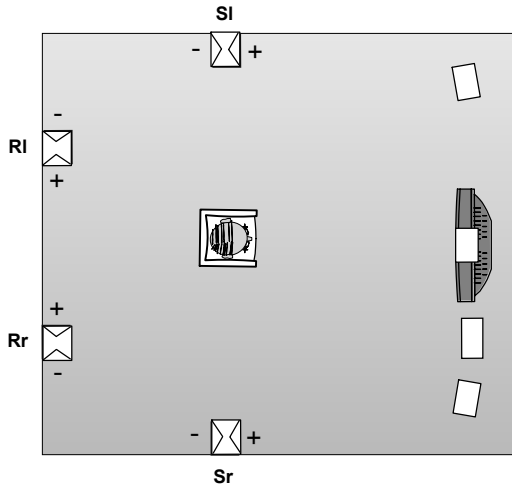


- Aim across room

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Dipolar Rear Speaker Placement for Surround EX

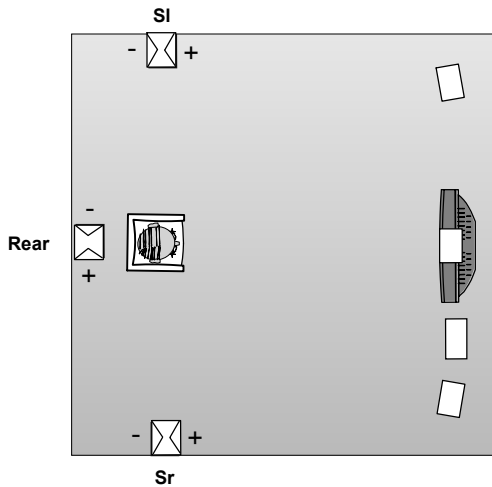


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- Place rear speakers at 2 meter (6 feet) height
- Place at 150° from front center

Dipolar Rear Speaker Placement for Surround EX

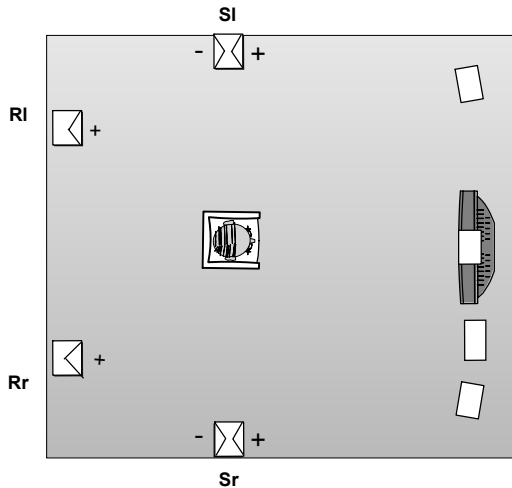


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- Place rear speakers at 2 meter (6 feet) height
- Good solution for small couches

Direct Rear Speaker Placement for Surround EX



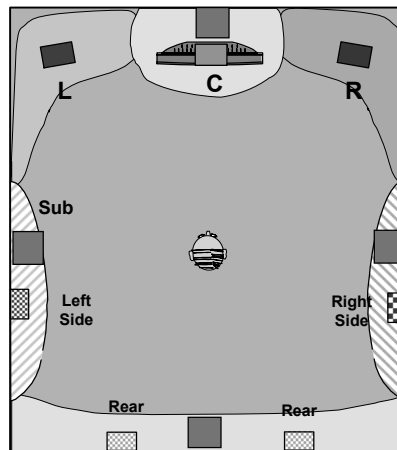
- Place rear speakers at 2 meter (6 feet) height
- Place at 150° from front center
- Watch for Psycho-Acoustic inversion
 - Try asymmetrical placement

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Speaker Placement The “Magic Layout”

- Front speakers placed for best interaction with the room (measure them with an analyzer)
- L/R form a 45 degree triangle
- C at same height as L/R
- LCR arc is unnecessary (set delay time for each spkr in the monitoring control / equalizer)
- Side speakers to sides of listeners
- Rear speakers behind listeners



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An example room studio.jory.org



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An example room studio.jory.org



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An example room **studio.jory.org**



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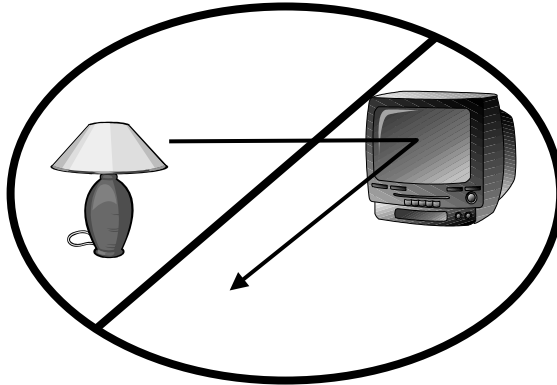


Video Gear Placement

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Video Component Placement

- No direct light onto the screen

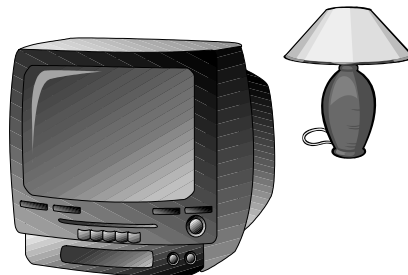


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Video Component Placement

- If possible provide low level neutral light behind the screen



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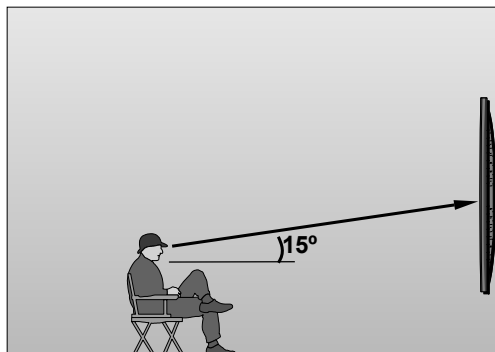
Screen placement guidelines

- Vertical viewing angle to middle of screen $<15^\circ$

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Screen height

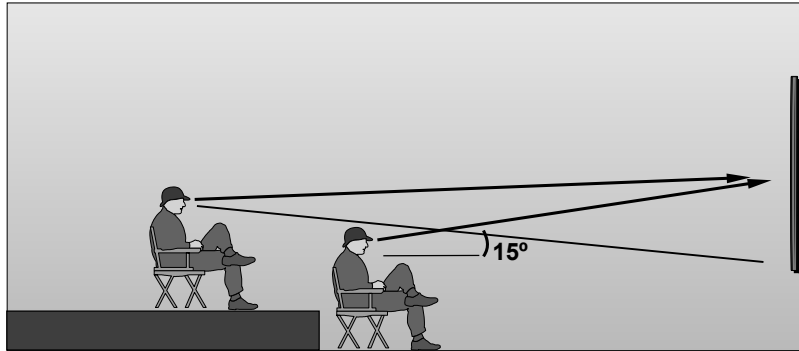


Comfort Angle limit:
 15°

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Screen height - Sight Lines



—— Clear sight line



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Wiring it all up

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Wiring Considerations

- **Use decent quality cable**
- **Learn how to solder**
- **Make up wiring list**
- **Total up wire length for each type**
- **Create parts list**
 - **Wire**
 - **Connectors**
- **Patch bay layout**

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Wiring Considerations

- **Power distribution**
- **Don't run with audio lines**
- **Grounding**
 - **Go back to same outlet**
 - **Star ground**
 - **Measure ground voltage differences**

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Wiring – Color coding

- **Patch bay coding**
 - Sound Generating devises
 - Mic preamps
 - Recording / Playback devices
 - Encoders
 - Decoders
 - Monitors
 - Tie Lines
 - Mults
 - Misc.

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Tuning it All

Analysis and equalization

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Electrical Level Calibration

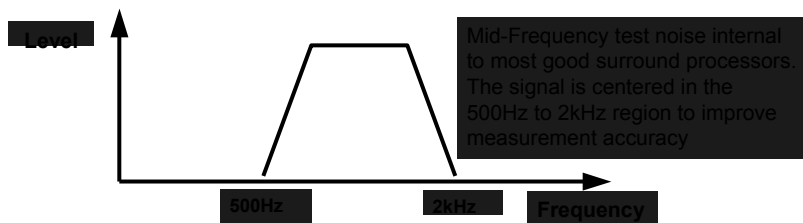
- Digital reference level: -20dBfs
- => 20dB Headroom
- Electrical levels: 0 VU = +4dBm = 1.23V
- Verify and adjust levels throughout
- Calibrate the outputs first
 - 1kHz @ -20dBfs => +4dBm
- Calibrate inputs next
 - Take calibrated output and feed to input
 - Set input gain for -20dBfs at meters

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Level Calibration of DAW

- Acoustic: Use midband pink noise signals at +4dBm output
 - reference disk or internal test tones
 - For music, calibrate for 85dB
 - For film, calibrate surrounds to 82dB



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Level Calibration

External multichannel source

- **Electrical:**
 - Use $-10/+4$ dB balanced adapter with gain controls
- **Acoustic: Use test DVD with midband pink noise**
 - Calibrate for 85dB across all channels

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Level Calibration

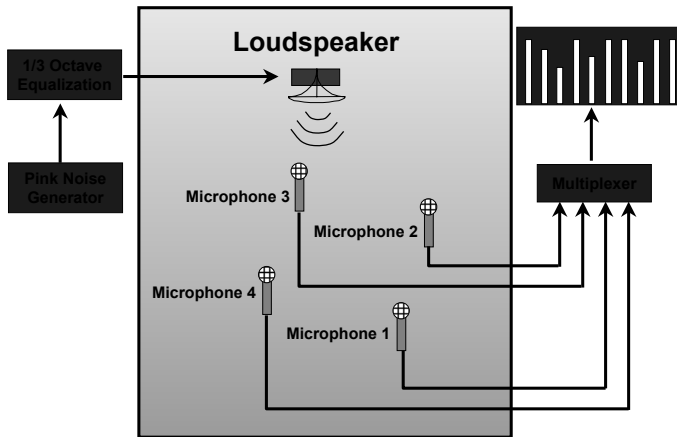
Time synchronization

- **Compensate for differences in speaker distance**
- **Set delays for nearest speakers**
- **Sound propagates at 1ft/ms**

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Analysis – the useful way

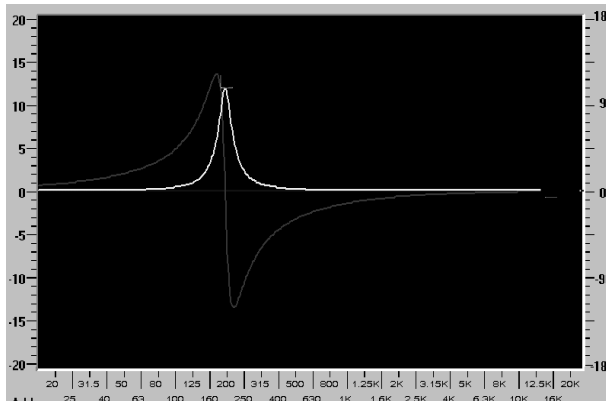


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- Analysis should be spatially and temporally averaged
- Use Gold Line DSP30 Analyzer, or equivalent



Frequency Response Calibration Room + Equalizer Phase Response



- 12 dB peak error at 200 Hz (yellow line)
- Phase error (red line)
- Equal cut introduces inverse phase error
- Amplitude and phase are corrected!

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Equalization Requirements

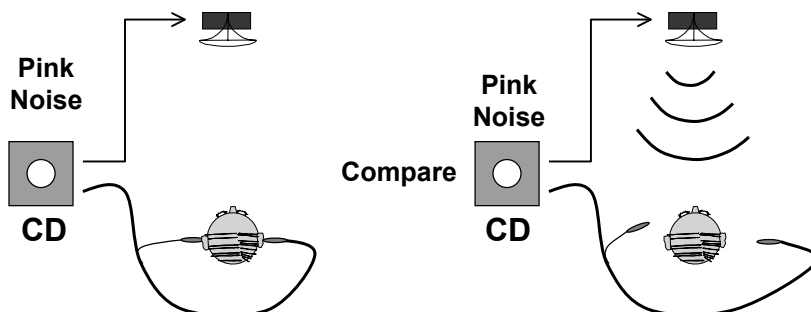
- **Pink noise source**
 - 20 Hz–20 kHz, switchable to each channel before the crossover (5.1 Audio Toolkit)
- **Real time analyzer**
 - 20 second time averaging
 - The ability to average 4 or more readings from mic multiplexing
 - 1/12 octave resolution in low frequencies

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Quick Check of Overall Frequency Response

Using Etymotic ER-4S or ER-6 Earphones



Set earphone level to match speaker

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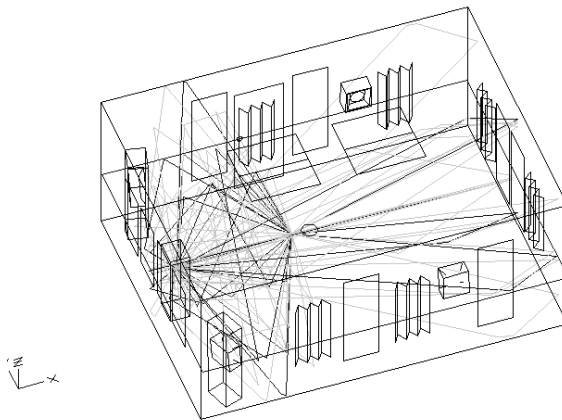




Tools

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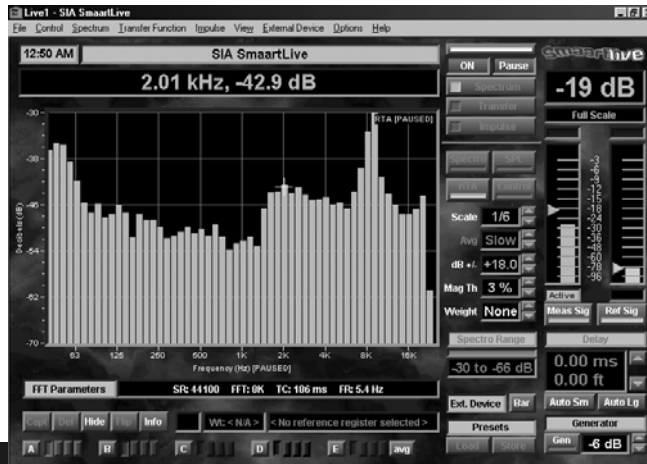
Ulysses Ray Tracing



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SMAART Live



Gold Line DSP30

- RTA
- 1/3, 1/6, 1/12th Octave
- Averaging
- NC
- RT60
- Integrated solution



TEF 25

- RTA
- TDS
- MLSSA
- Log sweeps
- Phase measurements
- Many more

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Planning

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Planning is key

- Mission statement
- Goals
- Macro to Micro
- Time schedules
- Budgets
- Parts lists
- Wire lists
- Expect it to all cost more than planned

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Good Reading Materials

- Acoustics and Psychoacoustics, Howard, David M., Angus, James, Focal Press, 1996, ISBN 0 240 51482 9
- Audio Engineering Handbook, Benson, K. Blair ed. McGraw-Hill Book Company, 1988
- Building a Recording Studio, Cooper, Jeff, Synergy Group, Inc., Los Angeles. To order call 1-800-468-4322
- The Master Handbook of Acoustics, Everest, F. Alton, TAB Books, Division of McGraw-Hill Inc., Blue Ridge Summit, PA. To order call 1-800-468-4322
- Project Studios, P. Newell, Focal Press, ISBN 0 240 51573 0
- Room Acoustics, Kuttruff, Heinrich, Applied Science Publishers 1973/1991

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Conclusion

- Project studio design is very complex
- Pay attention to all details for a good system
- I hope you enjoyed the presentation
- Thanks,

Anthony Grimani

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