
# Project Studio Design

## Solutions for better sounding rooms



# Housekeeping

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



# 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?



# Topics Covered

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

## 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!



## 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 !

## Design References?!

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



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

# The End User Reference
## High performance listening rooms



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



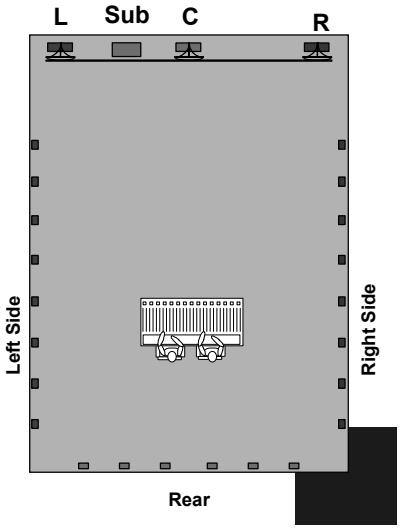
# A Reference

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

Stag Theatre, Skywalker Ranch

# Layout of a post production dubbing stage:

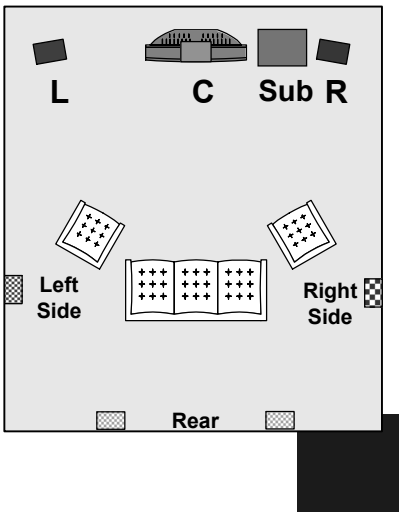
- 3 Screen speakers
  - Left
  - Center
  - Right
- 3 Surround arrays
  - Left Side
  - Right Side
  - Rear
- Subwoofers
- All seats face screen
- Good sightlines
- Screen size is 0.93x seating distance (50º)






# Layout of a Home Theater:

- 3 Screen speakers
- 3 Surround channels
- Subwoofers
- All seats face screen
- Good sightlines
- Screen size is 0.55 of seating distance (30º) [0.71 for HDTV]




# Designing the Room



## Designing the Room

- Acoustic character
- Optical Environment
- Aesthetics



# Designing the Room

## The Sound



## Designing The Room
## The Sound – The basics

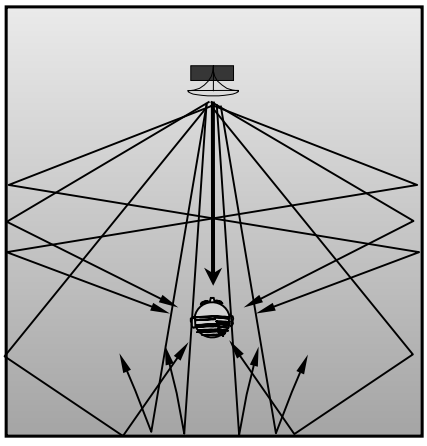
- The right shape
- Good sound isolation
- No background noise
- No rattles
- No distractions

# Shaping the Room



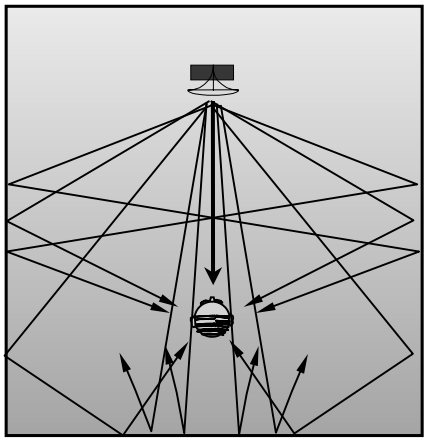
## Reflections in a Rectangular Room

- Reflections are evenly distributed



# Reflections in a Rectangular Room

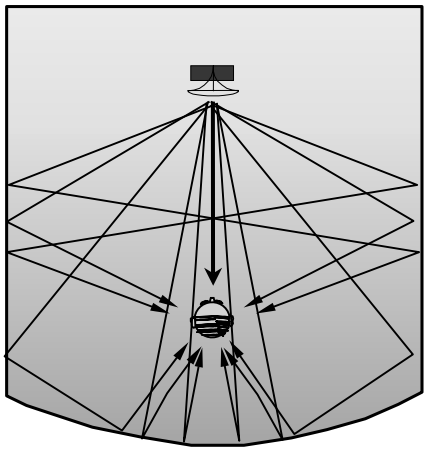
- Reflections are evenly distributed





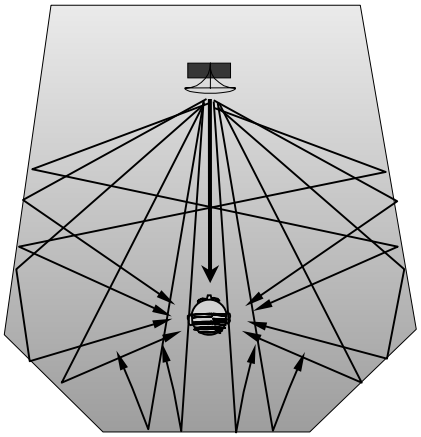
# Reflections in a Room with Concave Wall

- Reflections are focused to listening position



# Reflections in a Non Rectangular Room

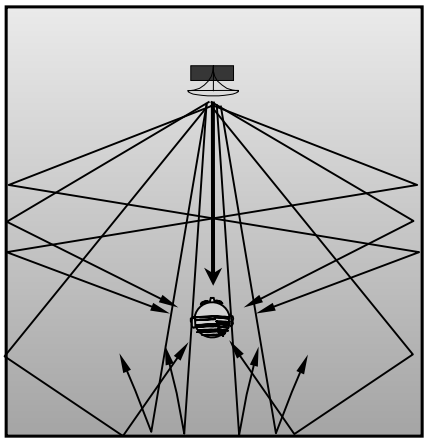
- Reflections are still there
- Some are stronger
- Harder to predict





# Reflections in a Rectangular Room

- Reflections are evenly distributed



## 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!




## Shaping the Room

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

## 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.



# Acoustics

## The Design Process

# Acoustics

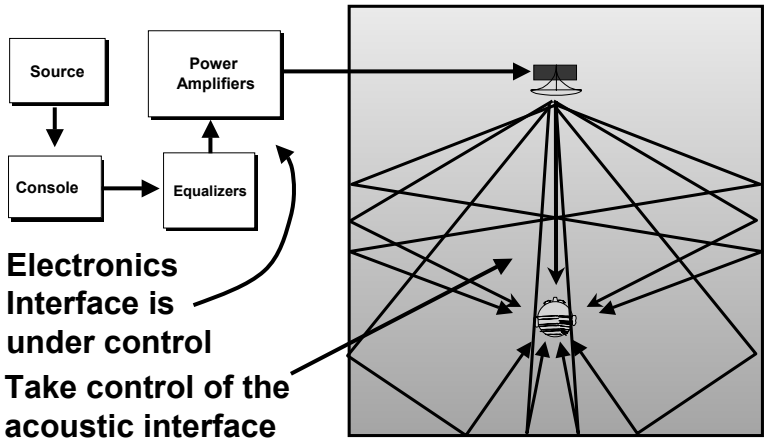
- Why talk about acoustics?
- Acoustics are audible!
- Contribute to over 50% of quality
- Acoustics are fixable



# What's Acoustics?

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

# The Acoustic Interface




- Electronics Interface is under control
- Take control of the acoustic interface



# Warning !

**Room acoustics will mess you up !**

## The Acoustical Engineering Process 12 Steps

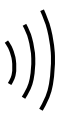
1. Dimension the room
2. Sound isolation
3. Noise control
4. Vibration control
5. Model decay time
6. Determine absorption area
7. Determine diffusion area
8. Treat echoes
9. Place listener
10. Place sound system
11. Determine treatment locations
12. Tune it all



## … But First a Bit of Theory

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

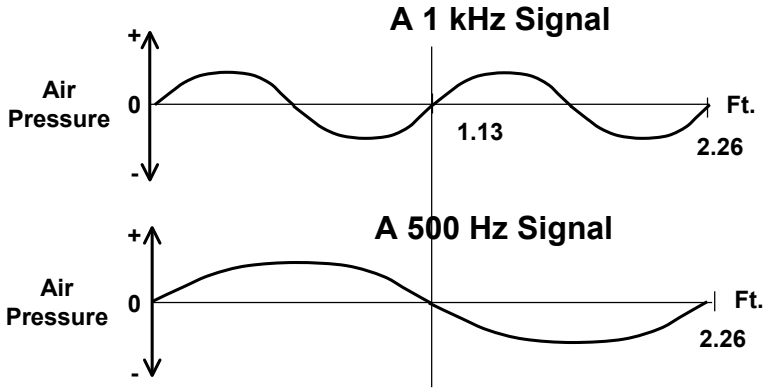
Low pitch



High pitch

# Acoustic Wavelength

**Sound Propagates at 1.13ft/msec**



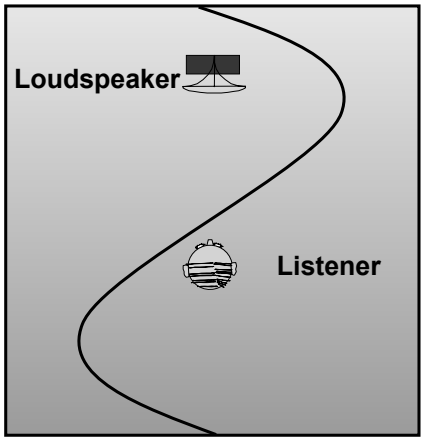

$$\text{Wavelength} = \frac{1130}{\text{Freq}}$$



# Room Dimensioning

## Standing Waves

# Standing Waves
## a.k.a. Room Modes



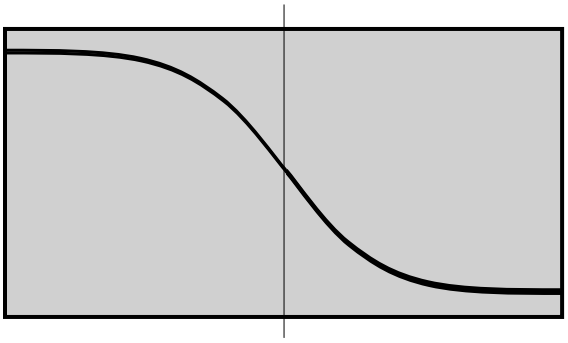

- Standing waves happen when room dimension is equal to sound wavelength
- Also at 0.5, 1.5, 2, 2.5, 3, etc. times wavelength



# 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

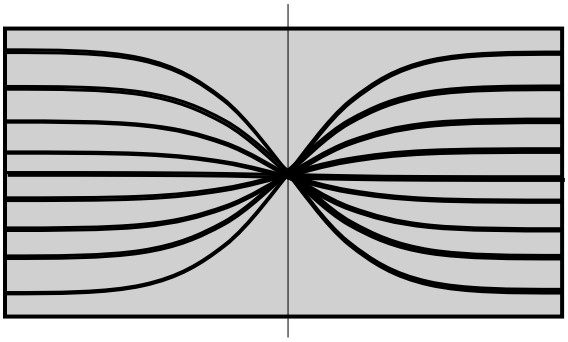
# A Resonant Frequency



- After reflection, signal nulls overlap

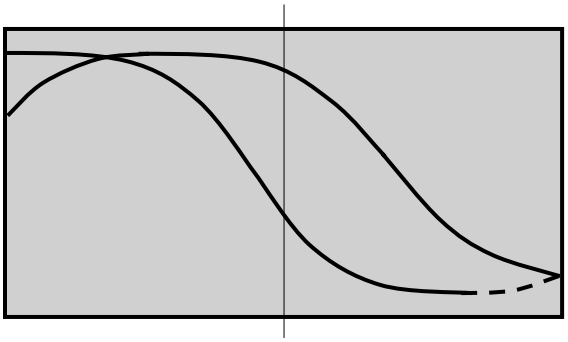


# A Resonant Frequency



- After reflection, signal nulls overlap

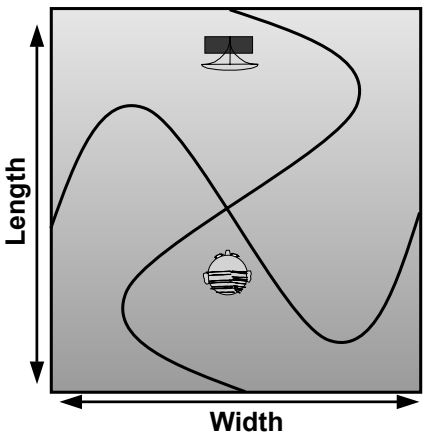
# A Non-Resonant Frequency



- No null overlaps
- No reflection gain

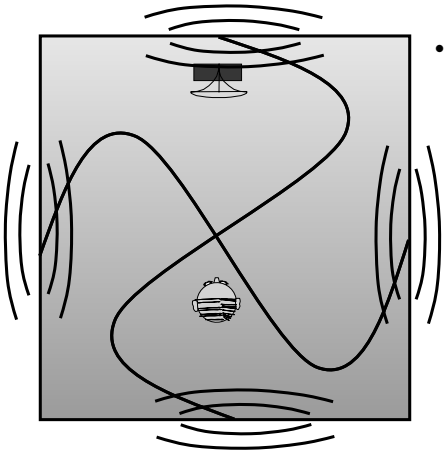


# Standing Waves




- 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*

# Standing Waves

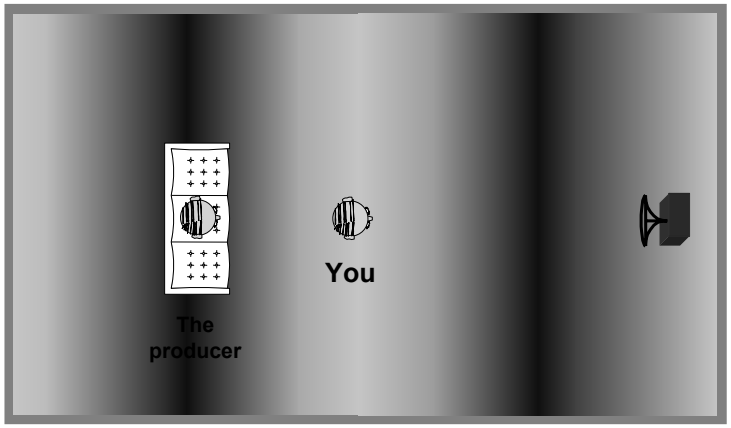


- Intensity of resonance depends on wall stiffness



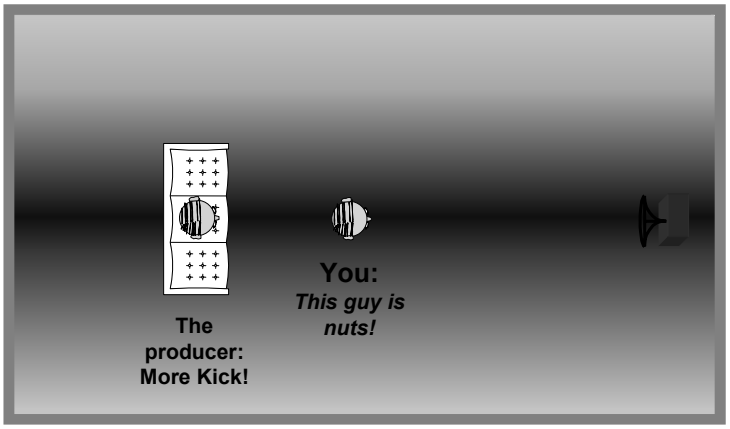
# Standing Waves

## A Second Harmonic Length Axial Standing Wave



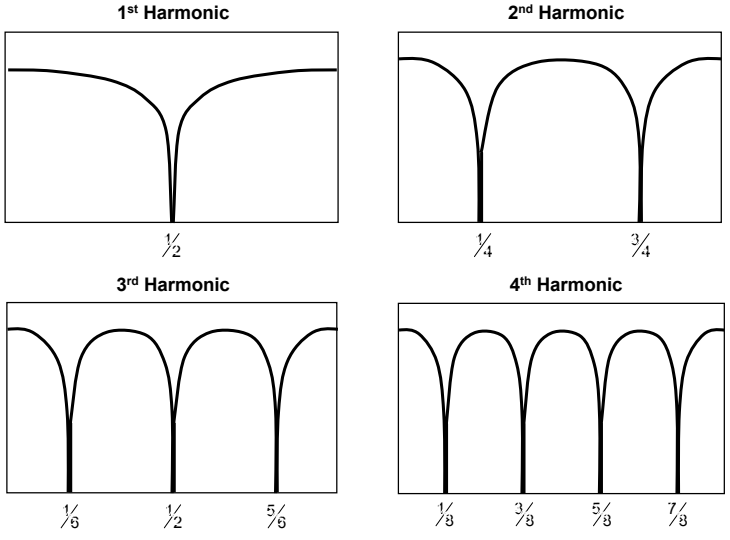
# Standing Waves – What to Avoid

## Frequency overlaps = double whammy!

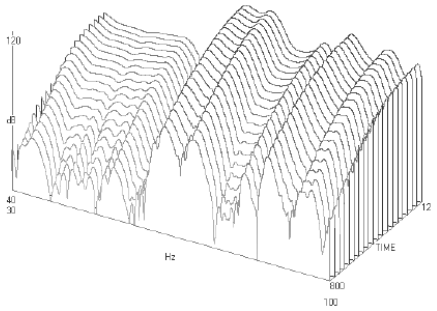





# Standing Waves Pressure Representation for 1st, 2nd, 3rd, 4th Harmonics



# Standing Waves
## Modal decay




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



# 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

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

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## Standing Waves Resonance Frequencies

**Equation:**

**F = n1130/2D (in ft)**
**F = n345/2D (in m)**

**Where F is frequency**
**n is the harmonic**
**D is the distance between walls**

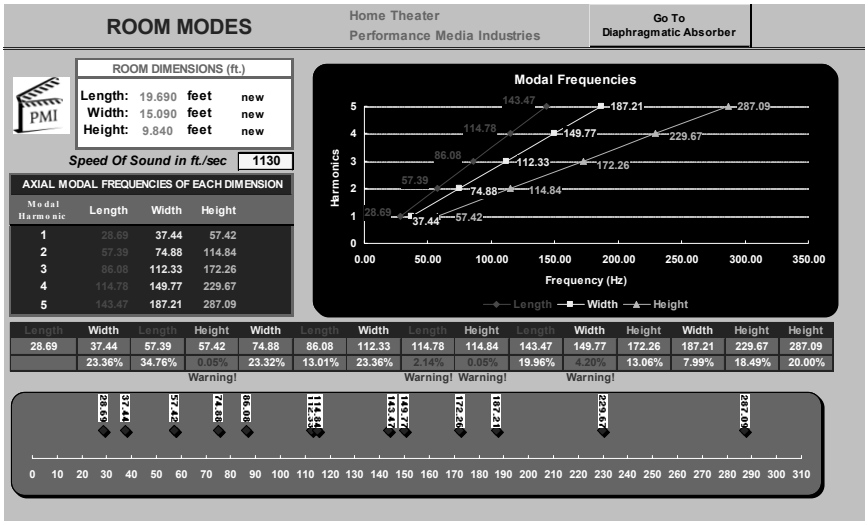
## Solutions to Standing Waves
### Room Dimensions

- Determine room dimensions
- Determine modes (F=n1130/2d)
- Find resonance overlaps



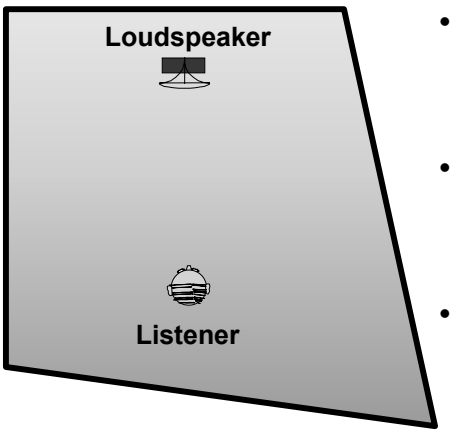
## Solutions to Standing Waves
### Room Dimensions (continued)

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






# Solutions to Standing Waves
## Room Shapes



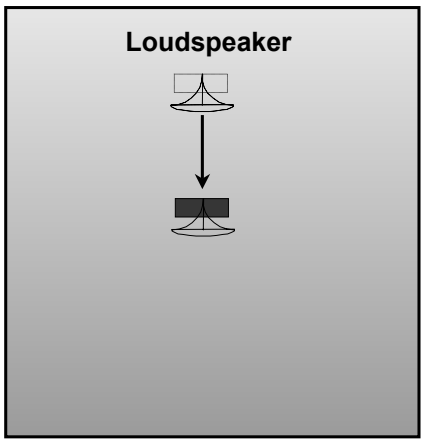

- Complicates Acoustic modeling and computations
- Doesn't get rid of standing waves or reflections
- Not recommended

## 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



## Solutions to Standing Waves Subwoofer and Speaker Placement




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

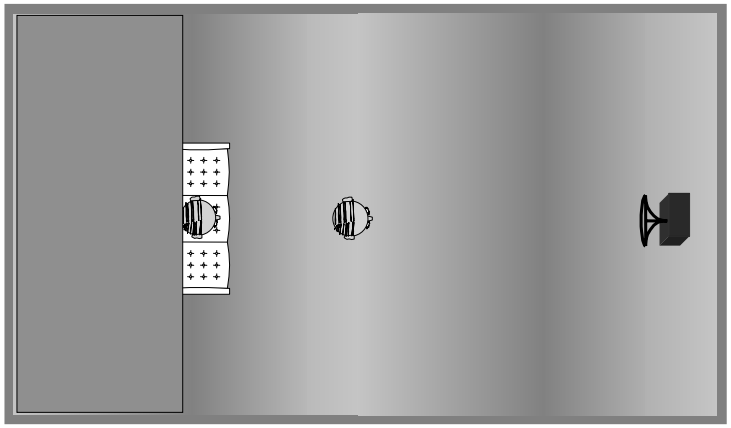
## Ways to Deal With Standing Waves (Room Modes Can Never Be Eliminated)

- 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



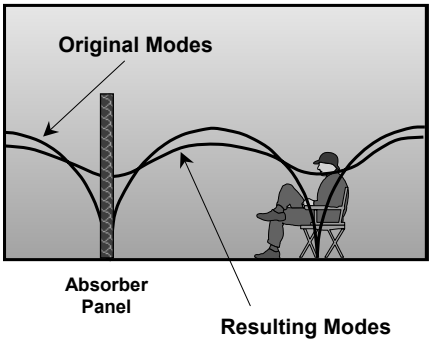
## Standing Waves

### Absorb at least ¼ wavelength !



Loud Quiet Loud Quiet Loud

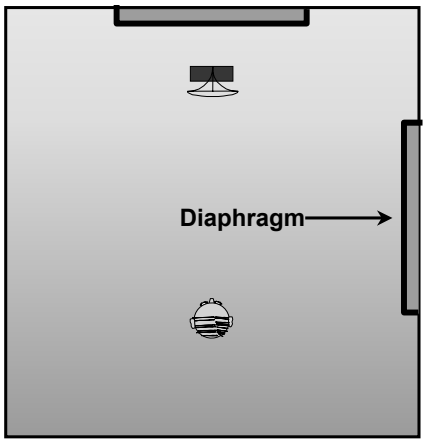
# Solutions to Standing Waves
## Absorption at Standing Wave Null




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

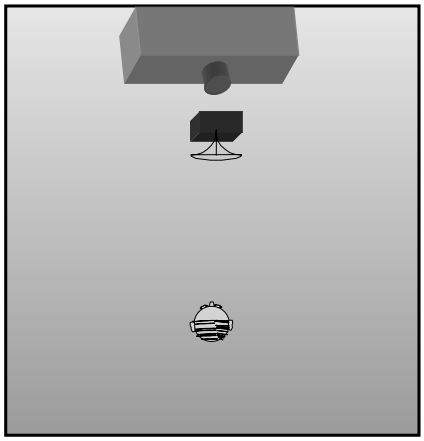


# Solutions to Standing Waves
## Diaphragmatic Absorption




- 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!

# Solutions to Standing Waves Helmholtz Absorption



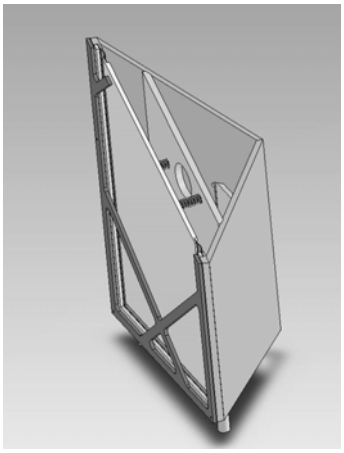
- Helmholtz units are tuned to problem frequency
- Absorber box is filled with fuzz
- Works down to 80Hz
- Design of Helmholtz absorber is complex
- Not very efficient



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




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

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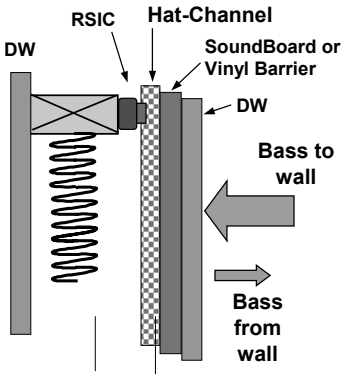
- Move subwoofer location
  - Drive mode out-of-phase to reduce relative amplitude
- Use bass absorption or absorptive walls



# Solutions to Standing Waves
# Resilient Walls

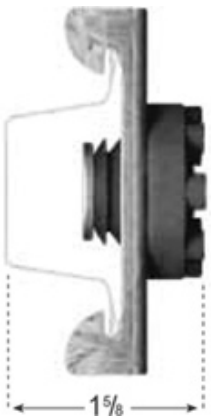



Wall with PAC RSCI-1 Isolators

- 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

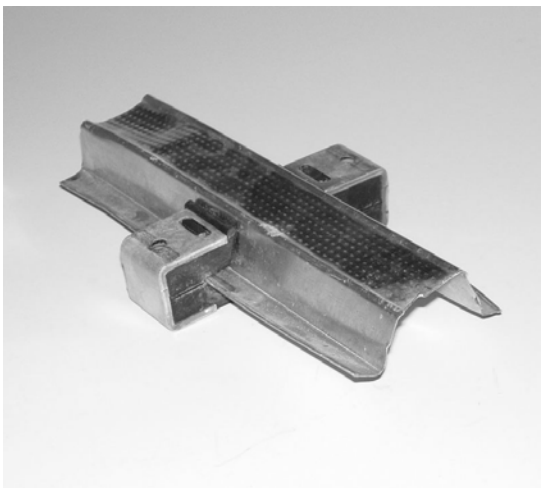



RSIC-1

# Solutions to Standing Waves
## Resilient Walls - Isomax



# Solutions to Standing Waves
## Resilient Walls - Isomax



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

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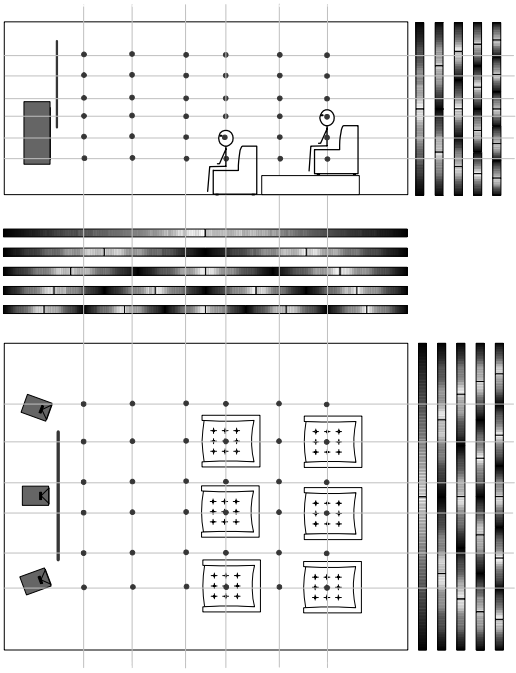
- Use bass absorption or absorptive walls
- Move seating location
  - Moves the listener out of peaks and dips





# Solutions to Standing Waves

## Seating Placement

**Stay away from peaks or dips**

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

- Change one or more dimensions
  - Minimizes resonance pile-ups
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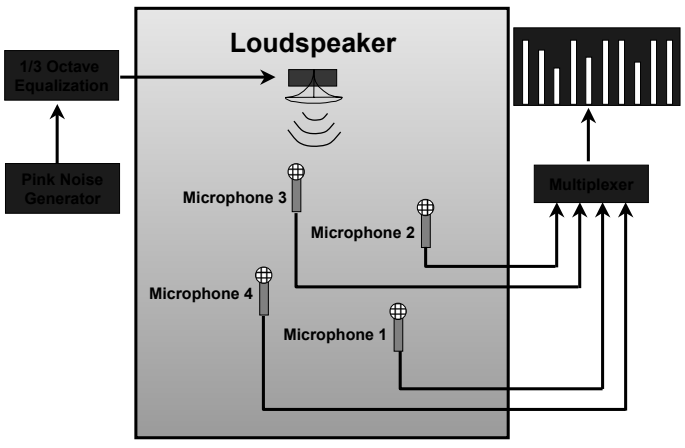
- Move seating location
  - Moves the listener out of peaks and dips
- Equalize



# Solutions to Standing Waves Equalization




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

# Designing the Room

## Sound Isolation



## Sound Isolation

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

# Sound Isolation

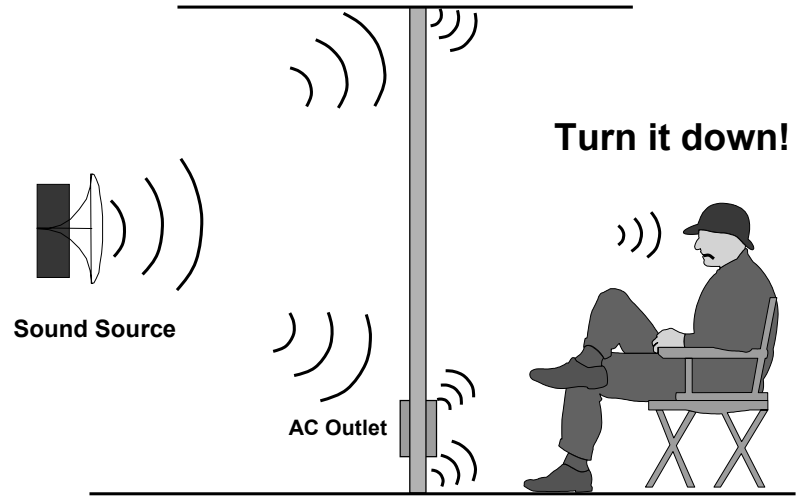
- Demonstration: Action movie
- In room (Chap 14)
- Adjacent room: standard construction – STC38 (Chap 16)
- Adjacent room: better construction – STC60 (Chap 18)
- Adjacent room: best construction – STC75 (Chap 20)



# Sound Isolation – 2 processes

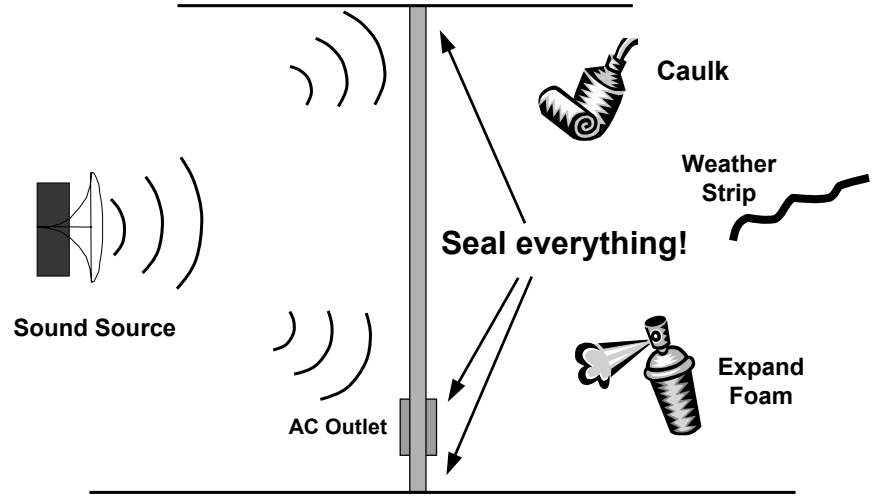
- Sound leakage
  - Isolate doors, windows, and plumbing
  - Isolate, seal and caulk all leakage paths
- Mechanical Transmission
  - Special wall structures
  - Floating floor
  - Floating ceiling

# Airborne Sound Leaks

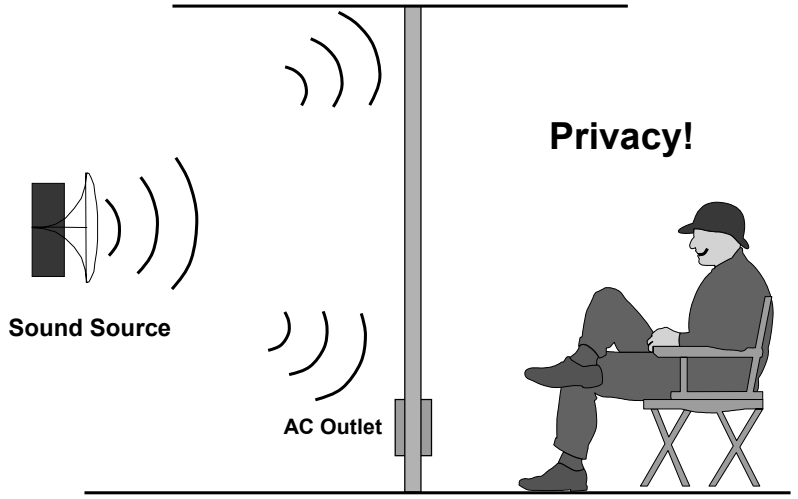





# Preventing Leaks

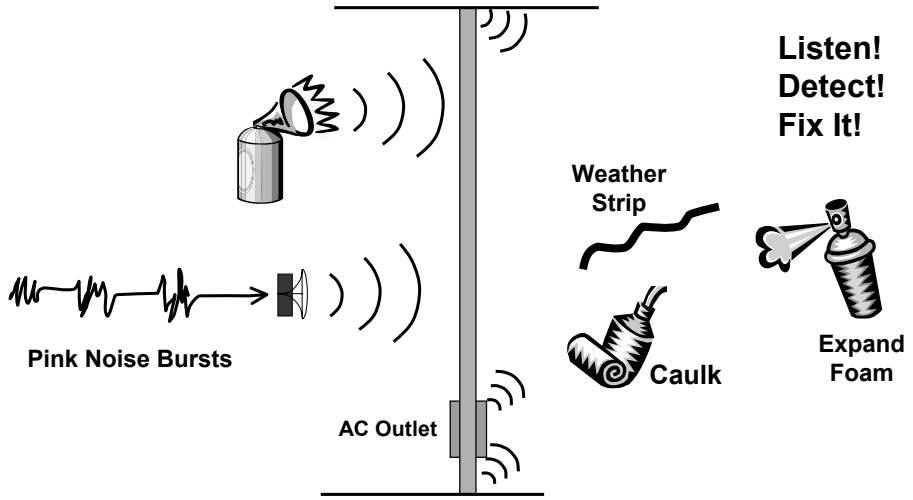


# No Leaks



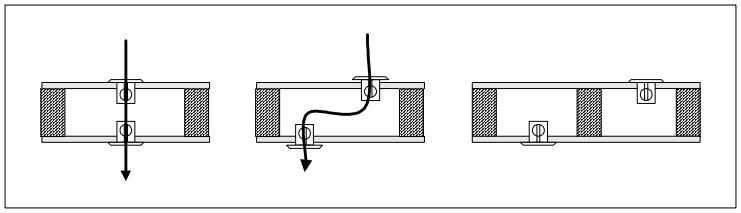



# Noise Transmission Detection



# Isolate Flanking Paths

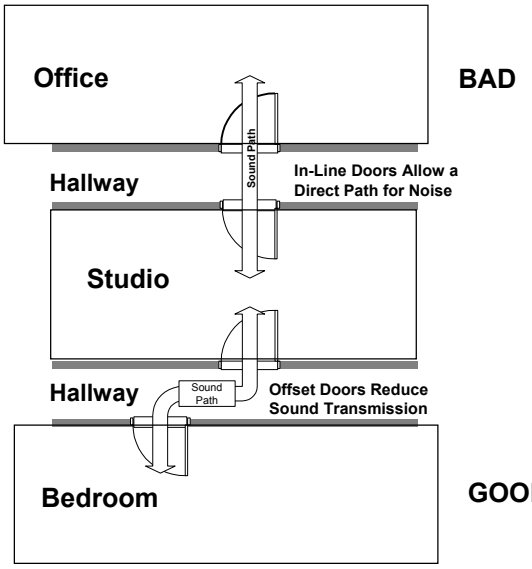
**AC outlets**



**Full Flanking** **Offset** **Offset and Isolated**



# Isolate Flanking Paths

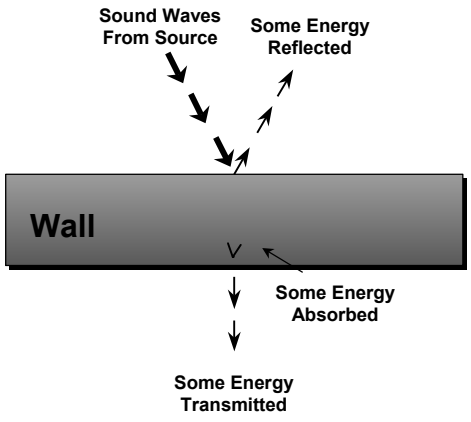


# Isolation Solutions

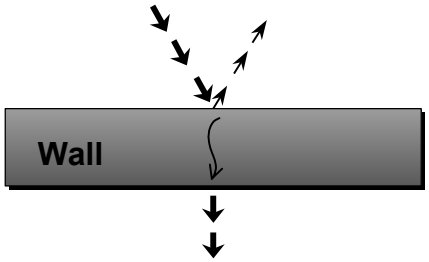
## Wall Construction



## The Mechanism of Sound Transmission

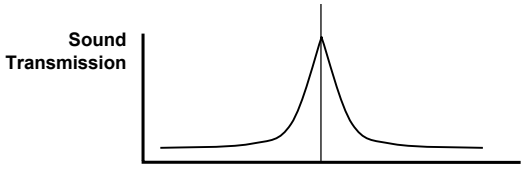


# Wall Construction Resonance




Sound transmission at resonance frequency

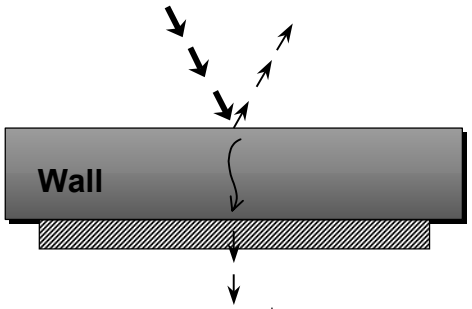
- All wall surfaces have a resonant frequency where they transmit lots of energy



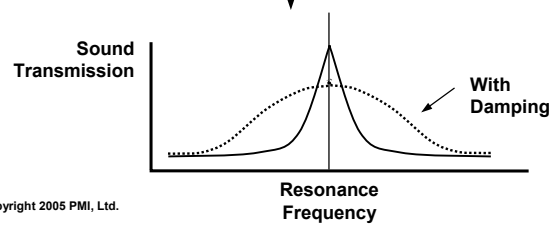

½" Drywall Example



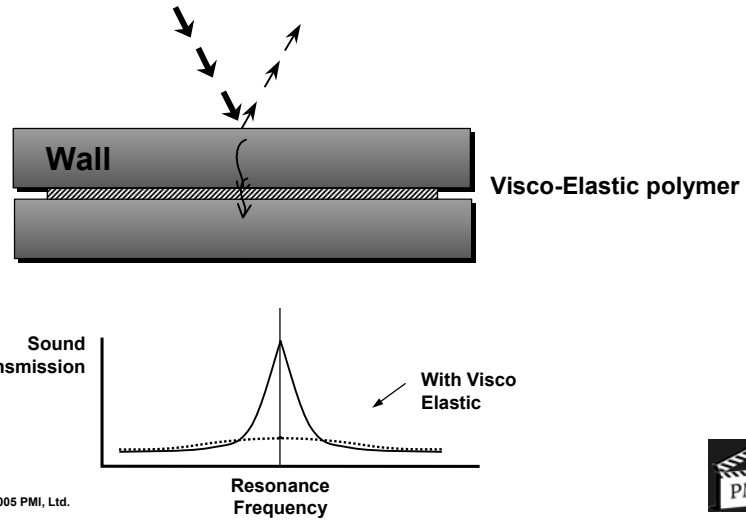
# Wall Construction
## Damped Resonance




Loaded Vinyl barrier or Sound board



# Wall Construction
## Constrained Layer Damping

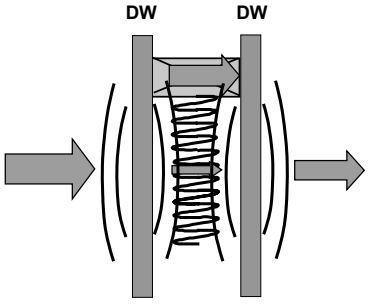




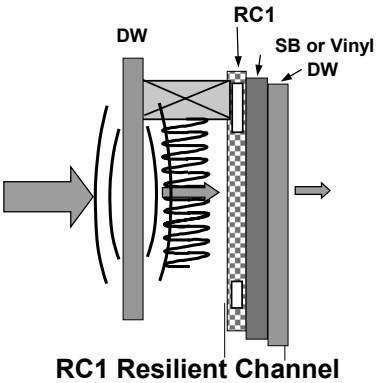

# Isolation Strategies

- More Mass
- Damp resonance
- Decouple
- Larger airgap

# Sound Isolation Strategies
## Wall Construction - Decoupling



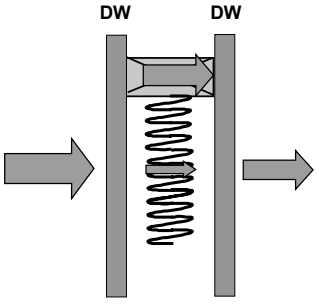

Single Stud



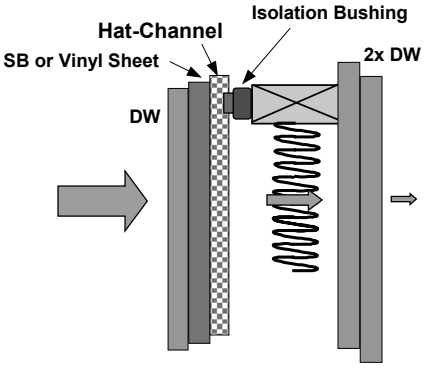

RC1 Resilient Channel
Warning:This is hard to make work!



# Sound Isolation Strategies
## Decoupling – A better solution

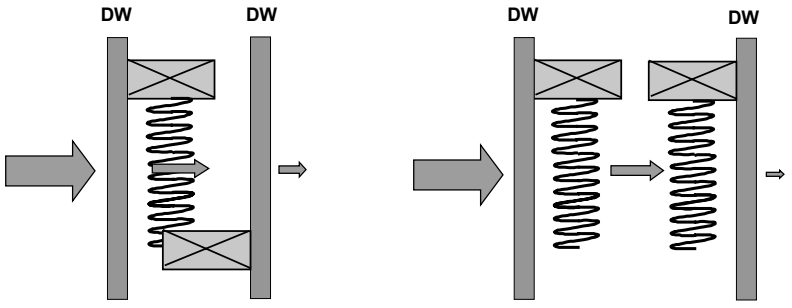



Single Stud
STC40




PAC RSCI-1 Isolators
Easy to install
STC 58 ! !

# Sound Isolation Strategies
## Wall Construction - Decoupling

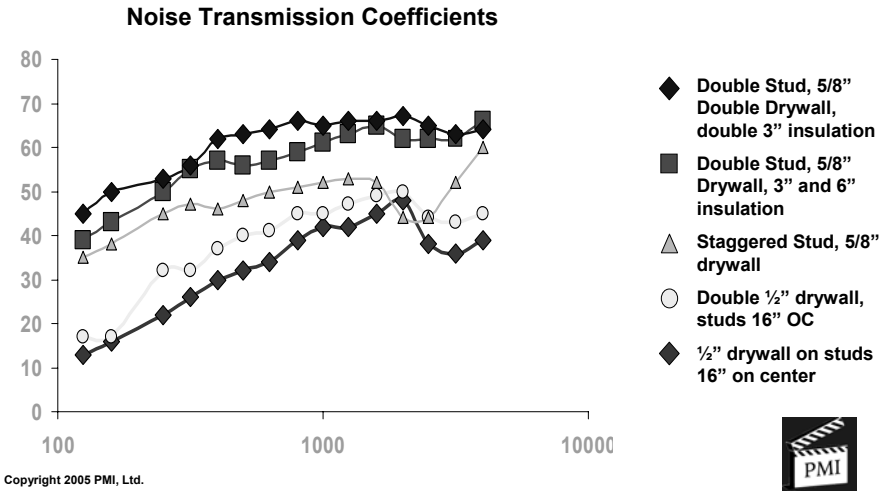



Staggered Stud

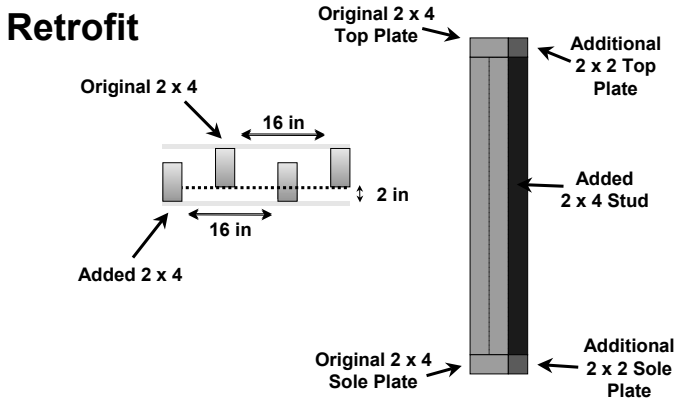
Double Wall



# Studwall Isolation



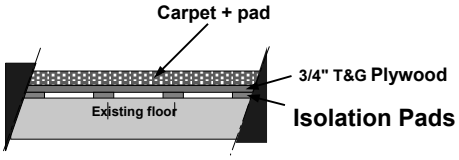
# Staggered Stud Construction



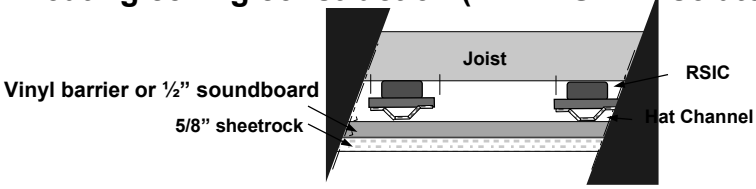



# Isolating the ceiling and floor

- Floating floor construction




- Floating ceiling construction (PAC RSCI-1 Isolators)




# Background Noise



## Background Noise

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

# 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)




# Sources of Background Noise

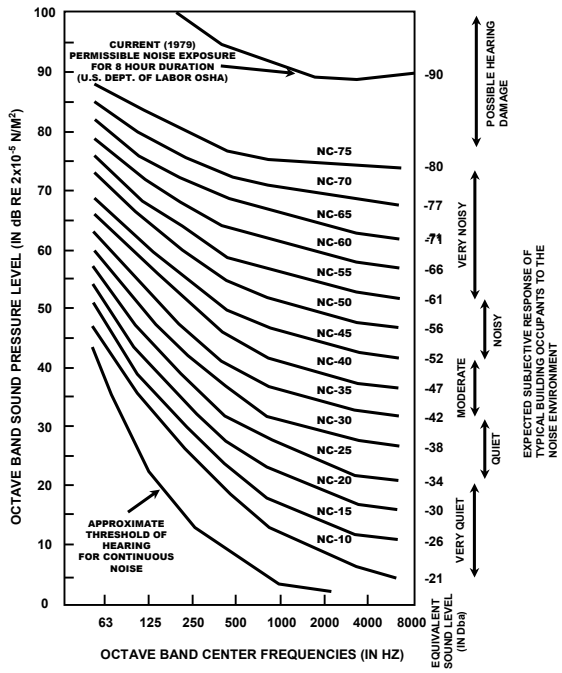
- Local sources
  - HVAC
  - Plumbing
  - Fans
  - Pumps/Compressors
  - Washer/Dryers
  - Garage door openers
  - Projectors



# Sources of Background Noise

- External sources
  - Traffic
  - Airplanes
  - Wind
  - Neighbors






**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




## 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.



# 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.





# Designing the Room

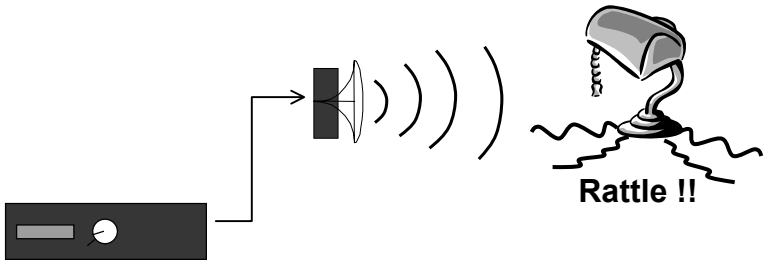
## Vibration Control and Rattles

# 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.

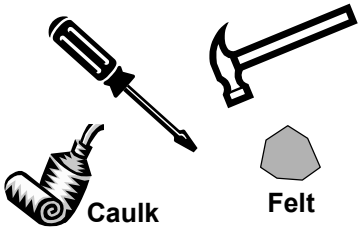


# Rattle Detection




Single Tone Oscillator –
Sweep slowly from
20 Hz to 1 kHz

Listen!
Look!
Fix It!



## 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




## Solutions to Rattles

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

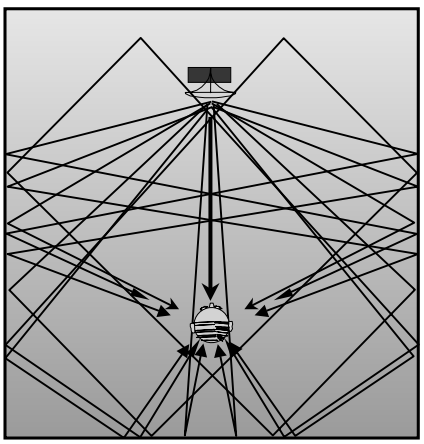


# Designing the Room

## Reflection Decay Time (aka Reverberation)



## Reverberation



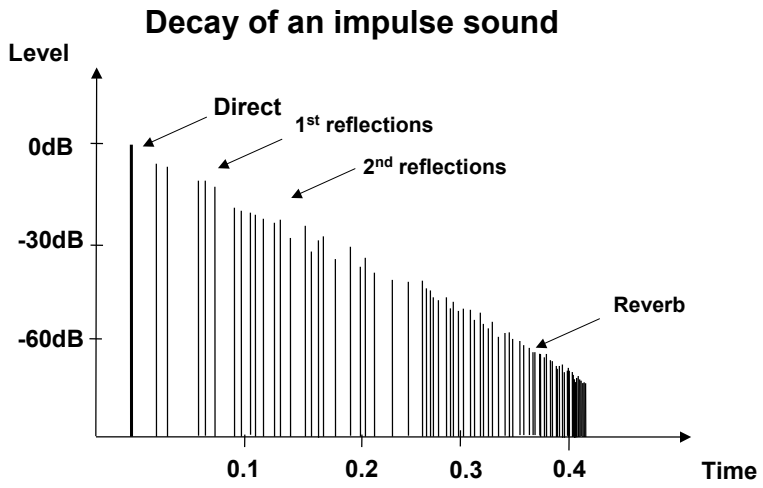
- Reverberation is the result of multiple reflections
- Decay time and spectrum have to be just right

# 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



# Decay Time

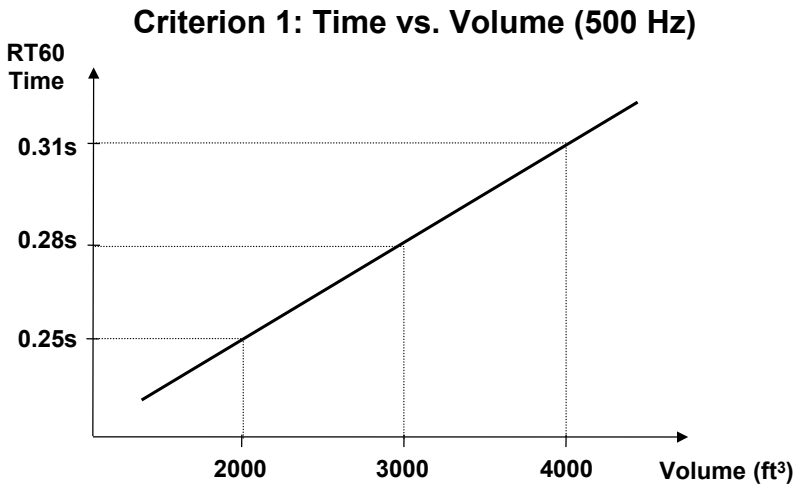


# Decay Guidelines

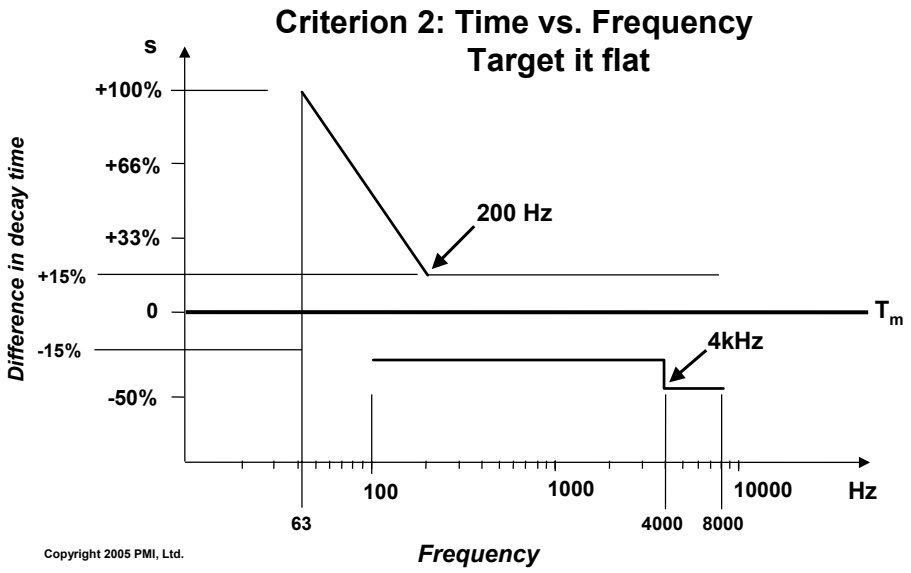
- Decay time should be .2 to .4 seconds
- Research shows that most people like the same range of decay time
- $T_m = 0.3\ (V/3532)^{1/3}$ ±15% where V=room volume in $ft^3$
- $T_m = 0.3\ (V/100)^{1/3}$ ±15% where V = room volume in $m^3$
- Handy rule of thumb for project studios, look for ~25% absorptive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



# Decay Time



# 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

# 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



# 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

# 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

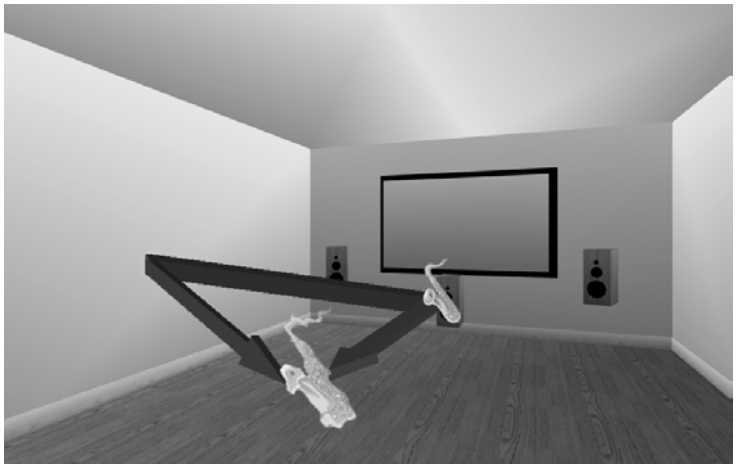




# Designing the Room

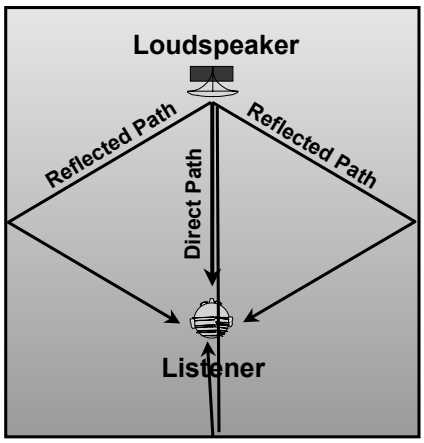
## Sound Reflection Control

# Reflections = Distortion



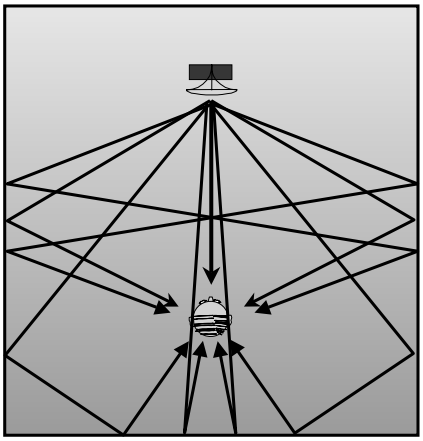


# Room Reflections




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

# Room Reflections
## Did you Know?!



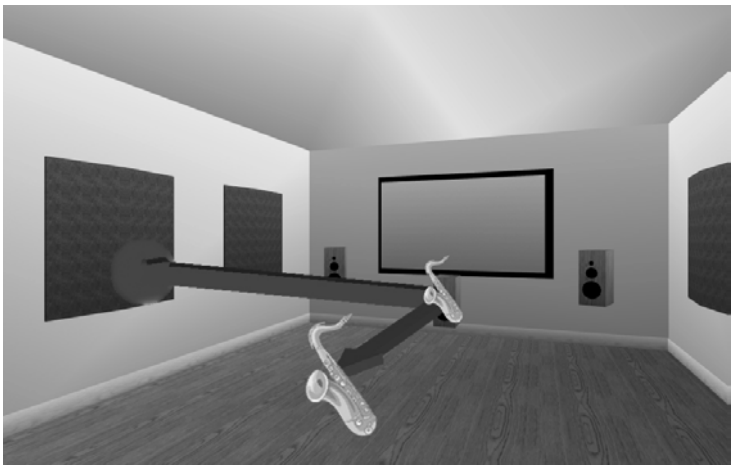
- At main seat you listen to as much reflected sound as direct!
- Need to get more direct sound



# Designing the Room

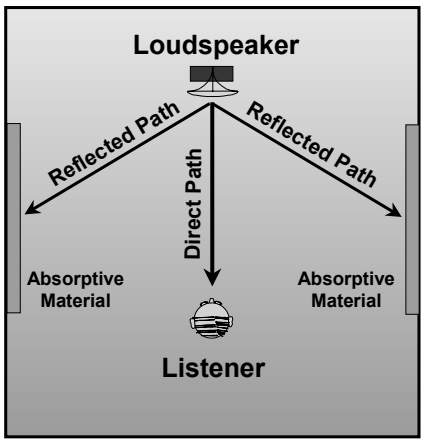
## Sound Reflection Control
## Absorption

# Solutions to Room Reflections
## Absorption





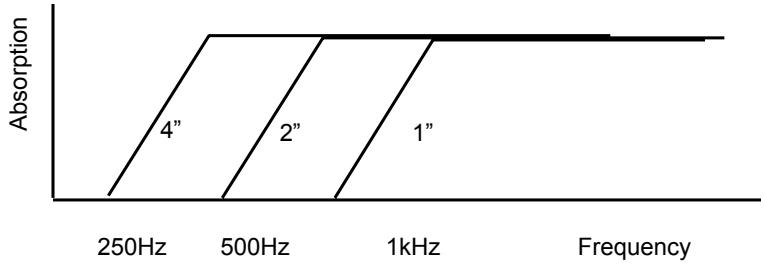
# Solutions to Room Reflections
## Absorption




- Absorptive materials
  - Mineral wool
  - Fiberglass
  - Dense foam
  - Draperies
  - Stuffed chairs
- "Scrub" off acoustic energy through friction
- Treat the ceiling too!

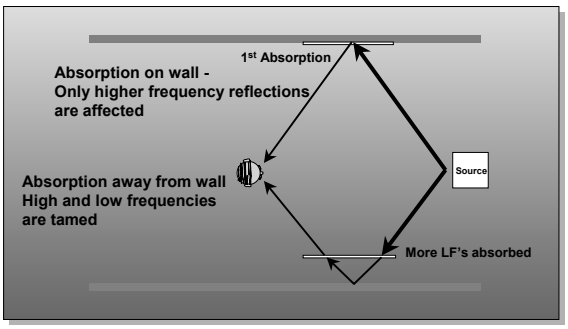
# Acoustical Treatments
## Absorption Thickness

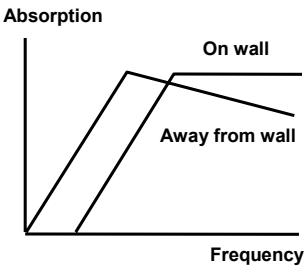
- 1” Panels work down to 1kHz (not enough)
- 2” Panels work down to 500Hz (better)
- 4” Panels work down to 250Hz (best)






# “Floating” an Absorption Panel



## Acoustical Treatments
## Notes on Absorption

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



## Acoustical Treatments
## Notes on Draperies

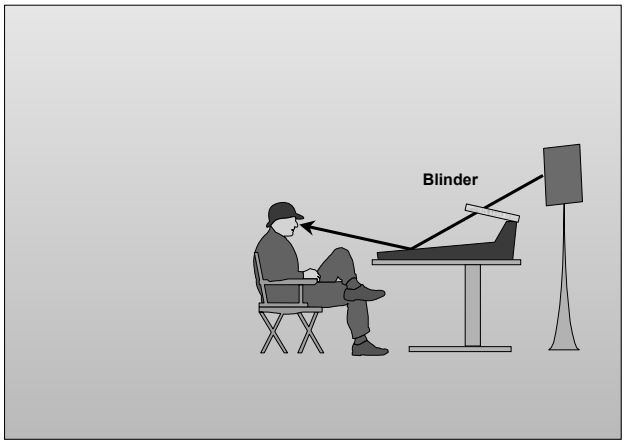
- Draperies are uneven acoustical absorbers
- Performance affected by fabric weight, pleat number, distance from boundary
- At least 3" air gap
- Velour mass 32 ounces per lineal yard
- 100% fullness

## 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



## Reflection issues
## Control room surfaces



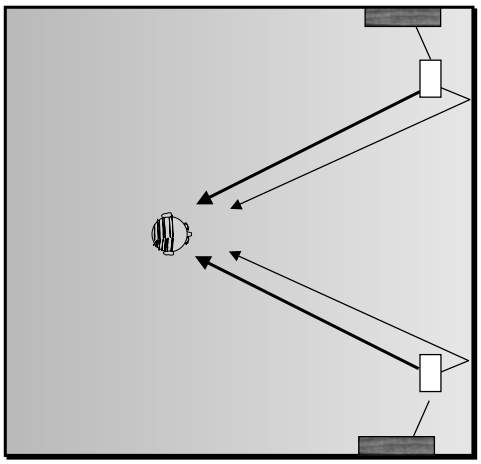

- Place speakers on stands
- Use an acoustic blinder to cut out the reflection

## Low Frequency Reflection Control Strategies

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



## Bass Absorption

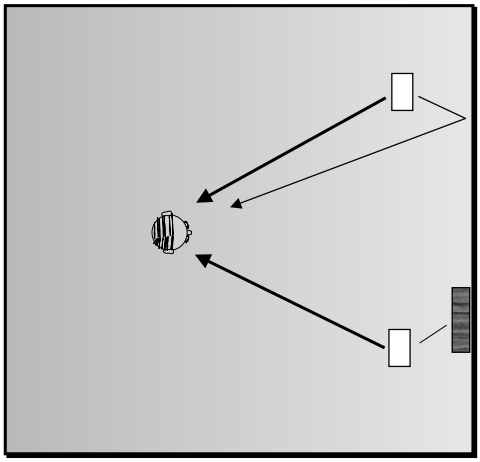


- Use Perforated wood surface on box
- Tuning equation:

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

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

# Bass Absorption on the front wall

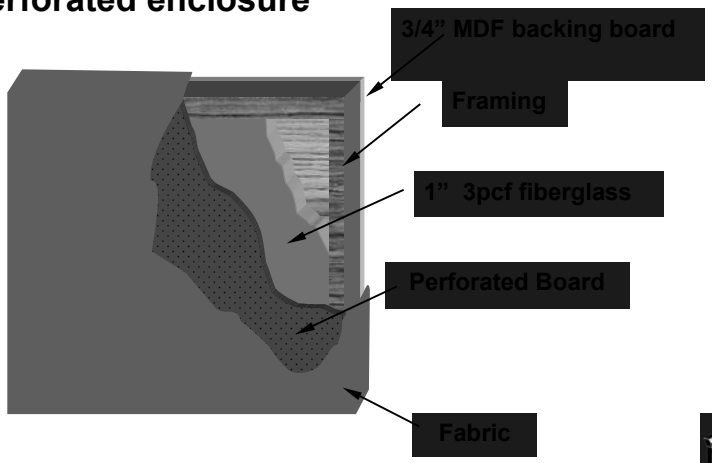


- Use Bass absorber to kill front wall reflection



# A Bass Absorber

Perforated enclosure

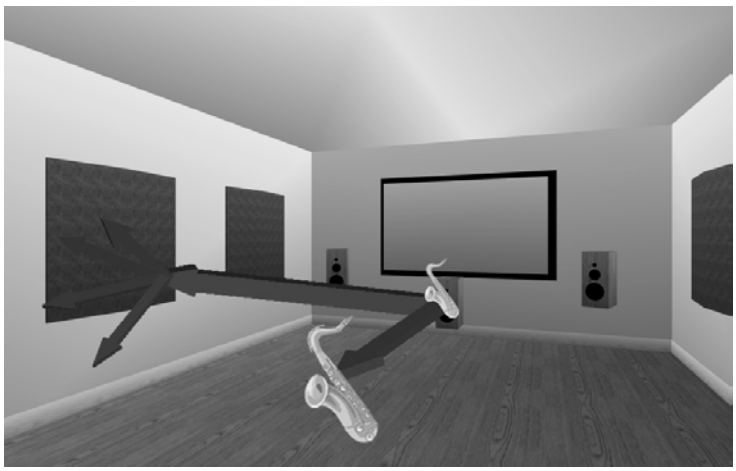


# Designing the Room

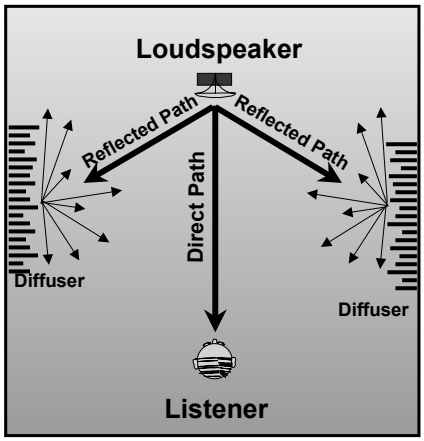
## Sound Reflection Control
## Diffusion



# Solutions to Room Reflections
## Diffusion



# Solutions to Room Reflections
## Diffusion




- Diffusive materials
  - Purpose-built panels
  - Bookcase



# Acoustical Treatments
## Diffusion

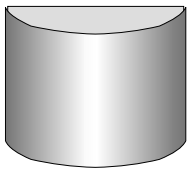
- Need enough diffusion surface to "smooth out" the soundfield
- Balance diffusion and absorption
- Keep some liveness to the room
- Mix diffusion in with absorption
- It's the stuff that high-end studios are made of

# Acoustical Treatments
## Diffusion types

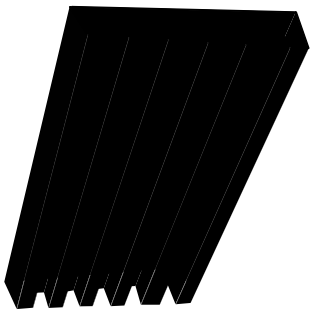
- 2D diffusion redistributes incident sound to a plane
  - Use along front portion if side walls to diffuse front speakers
- 3D diffusion redistributes sound to a hemisphere
  - Use it towards the rear of room for surround speakers



# Acoustical Treatments
## Diffusion – 2D Diffusers

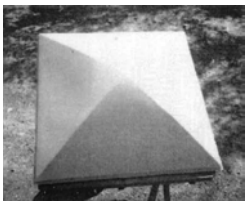


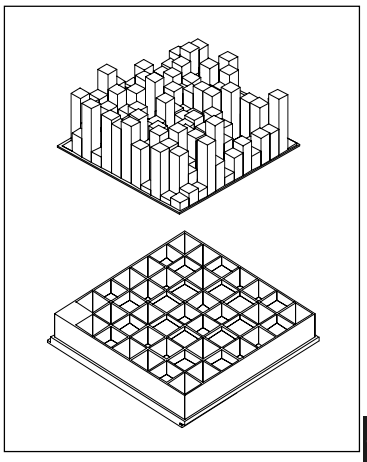
Cylindrical



Slotted

# Acoustical Treatments
## Diffusion - 3D Diffusers







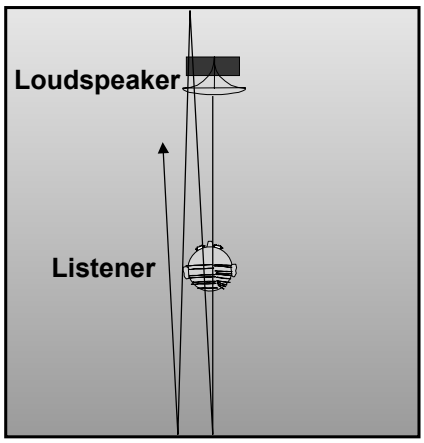
# Acoustic Treatment
## Manufacturers

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

# Slap Echoes

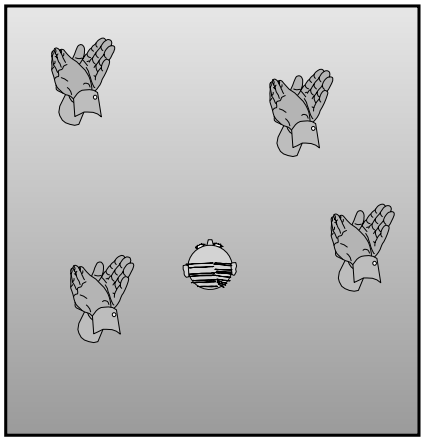


# Slap Echoes




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

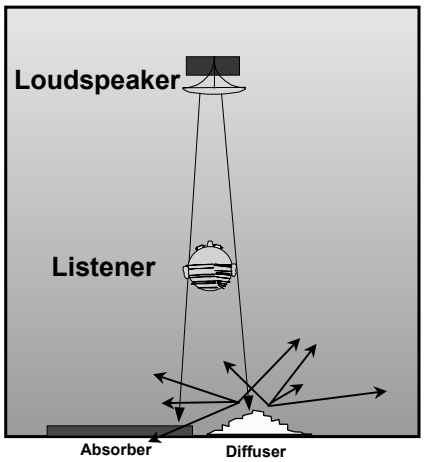
# Slap Echoes
## Detection Methods



- 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



# Solutions to Echoes
## Materials




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

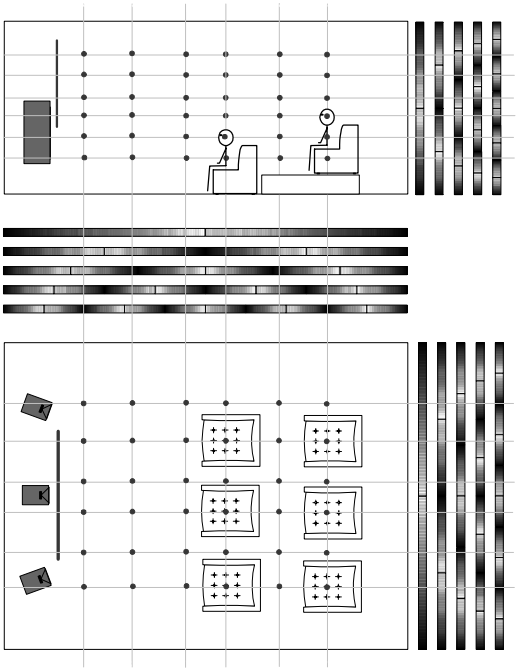

# Placing listeners



## Seating Placement

- Don’t sit at Standing Wave Peaks or dips

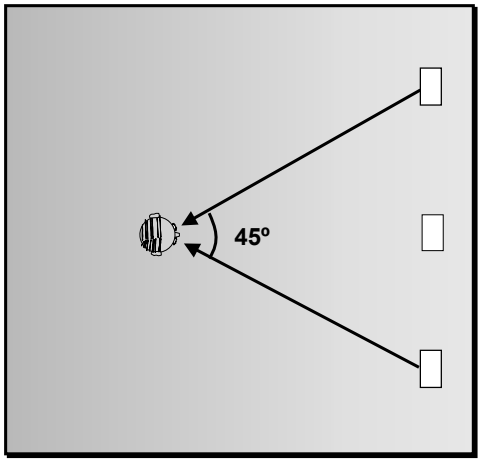




# Solutions to Standing Waves
## Seating Placement



# Listener/Speaker placement

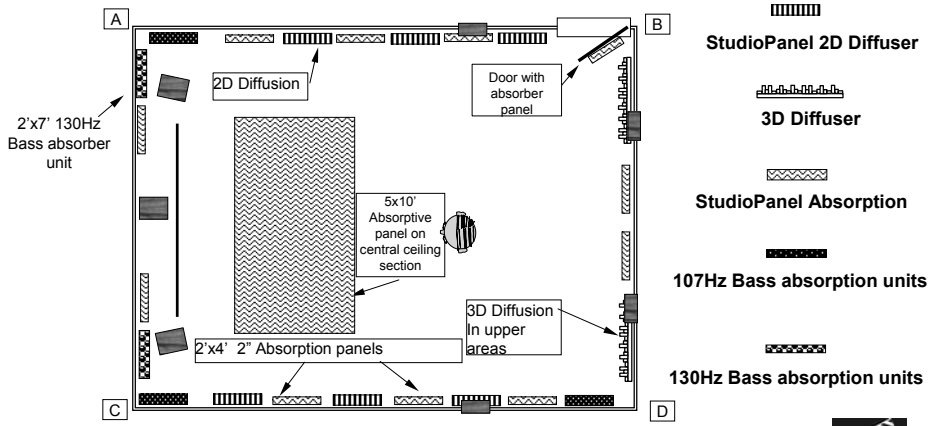



- Position Left and Right to form a 45 degree angle to seating area
- Balance between stereo phantom image and multichannel separation

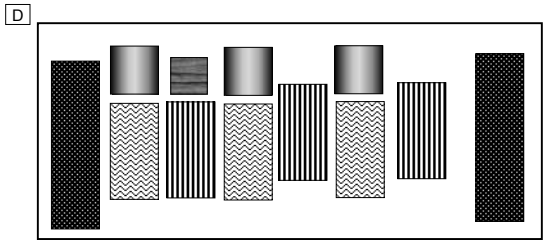
# Example Layout



# Example Treatment Layout



# Example Treatment Layout
## Left Wall




Surround speaker

Cylindrical Diffuser
2ftx2ft

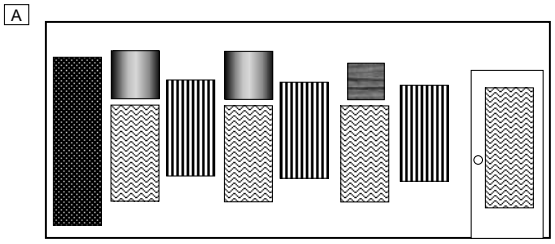
StudioPanel Diffuser
2ftx4ft

StudioPanel Absorber
2ftx4ft

107Hz Diaphragmatic Absorber
2ftx5ft



# Example Treatment Layout
## Right Wall




Surround speaker

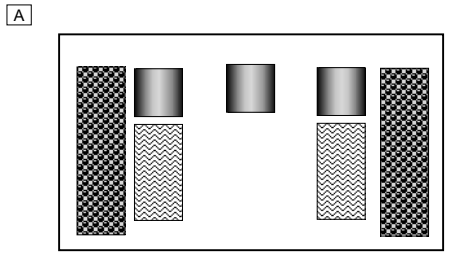
Cylindrical Diffuser
2ftx2ft

StudioPanel Diffuser
2ftx4ft

StudioPanel Absorber
2ftx4ft

107Hz Diaphragmatic Absorber
2ftx5ft

# Example Treatment Layout
## Front Wall



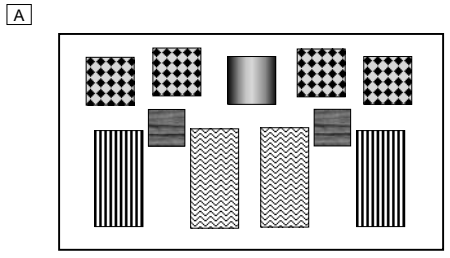

Cylindrical Diffuser
2ftx2ft

StudioPanel Absorber
2ftx4ft

130Hz Diaphragmatic Absorber
2ftx5ft



# Example Treatment Layout
## Rear Wall




Rear speaker

Cylindrical Diffuser
2ftx2ft

StudioPanel Absorber
2ftx4ft

StudioPanel Diffuser
2ftx4ft

3D Diffuser
2ftx2ft

# Designing the Room

## The Picture



## 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

## 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

## 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



## Designing the Room
## Interior Design Guidelines

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



## Designing the Room
## Interior Design Approaches

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



## 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

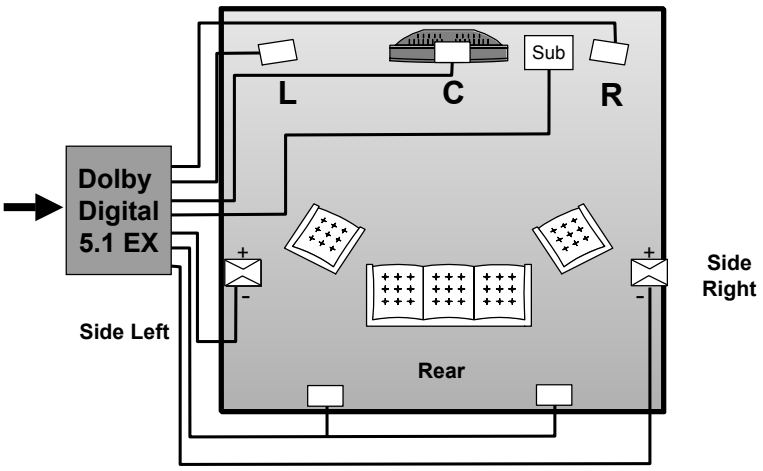
# Acoustical Treatments
## Acoustically Transparent Fabric

- 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



# Specifying the Gear
## The Audio System

# Dolby Digital 5.1 EX
## "6.1" Channels






# 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

## The roles of each channel

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




## 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 !

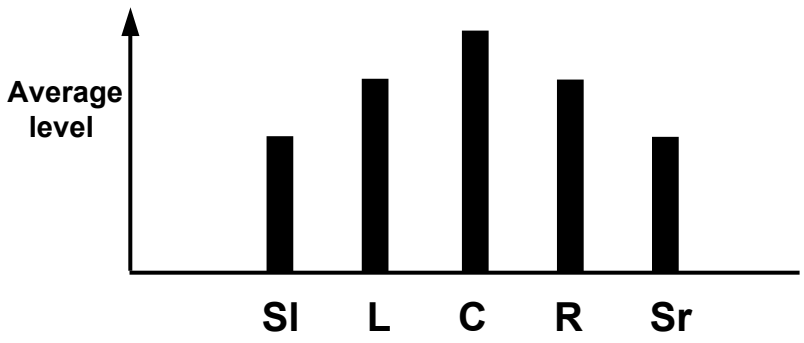


## The roles of the Subwoofer output

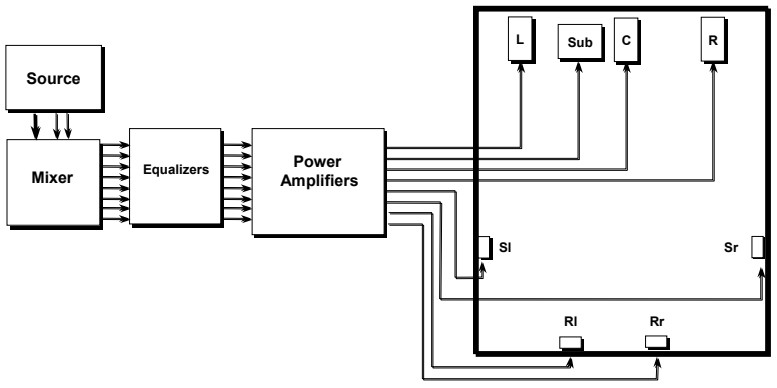
- Low bass below cutoff of your main monitors
- Low bass that would overload your monitors
- Low bass distributed through multiple subs for cleaner, tighter bass
- Sum of L/C/R/Sl/Sr+LFE



## Roles of each channel
### Distribution of sound energy



# Studio Audio System Diagram






# Basic System Requirements

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

## 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



## 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

## What to look for in Sources
### Keyboards

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




## What to look for in Sources
### Direct boxes

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



## What to look for in Sources
### Direct / Reamping converter

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



## What to look for in controllers

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

## What to look for in controllers

- Metering
- Multichannel metering
- Remote control



## Which DAW to use ?

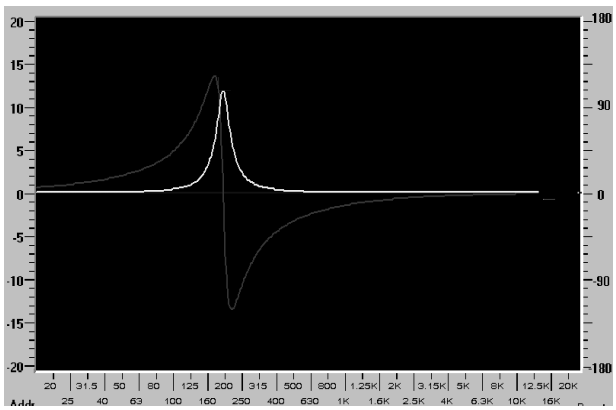
- You choose !!

# Minimum System Requirements

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



# Frequency Response Calibration
## Room + Equalizer Phase Response



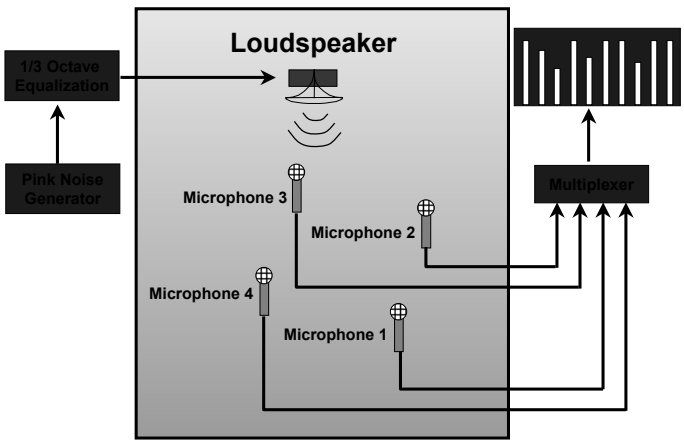

- 12 dB peak error at 200 Hz (yellow line)
- Phase error (red line)
- Equal cut introduces inverse phase error
- Amplitude and phase are corrected!

# 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



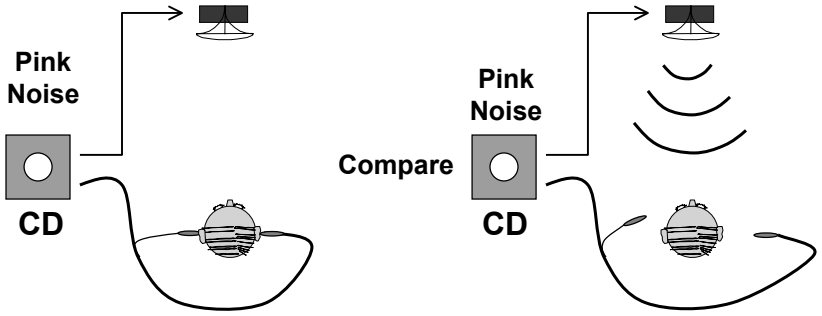
# Analysis – the useful way




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

# Quick Check of Overall Frequency Response

**Using Etymotic ER-4S or ER-6 Earphones**




**Set earphone level to match speaker**



# 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!**

## 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




## Minimum System Requirements
## Front Speakers

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



## Minimum System Requirements Front Speakers

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



## What to look for in Speakers:

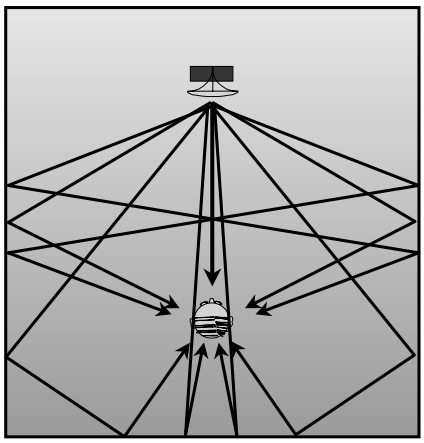
- Flat response in pass-band
- Uniform off-axis response
- Good dispersion (no “lobing”)
- Power handling
- Efficiency
- Bass Headroom
- Reliability
- Good sound!

## 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



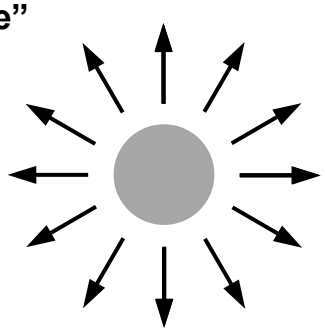
## Room Reflections: Did you Know?!



- 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

## What's all this about directivity?

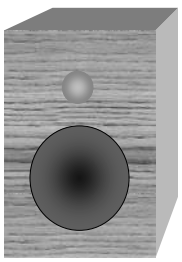
- An idealized speaker:
  - The "pulsating sphere"
- Flat axial response
- Radiates evenly in all directions
- Flat "sound power" response





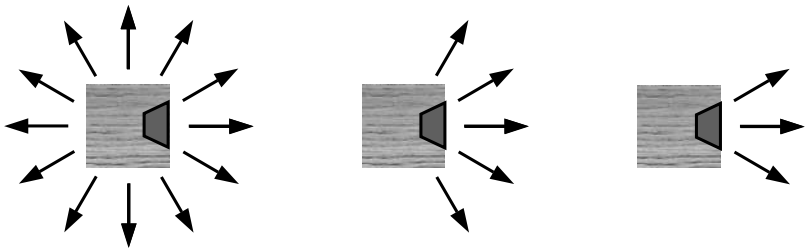
## What's all this about directivity?

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



## What's all this about directivity?

- A real speaker: Variable dispersion



Low Frequency 100Hz

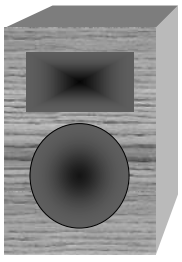
Mid Frequency 1kHz

High Frequency 10kHz



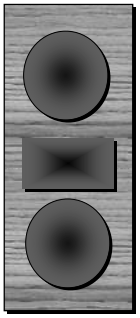
## How to get directivity?

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

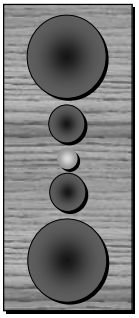


The Obvious: Two way with Horn loaded tweeter

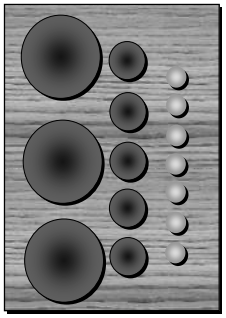
## How to get directivity?



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

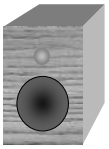


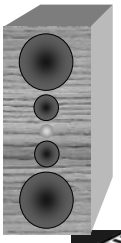
## What's all this about directivity?

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

## 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 !

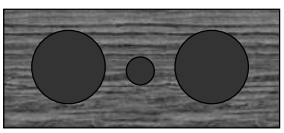






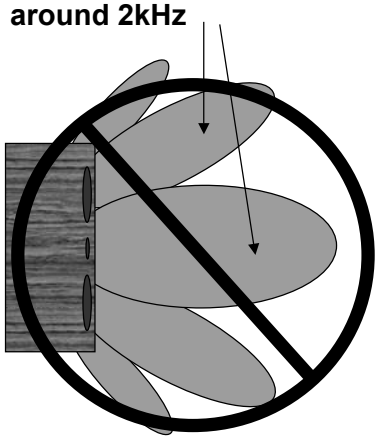
## Center Speaker

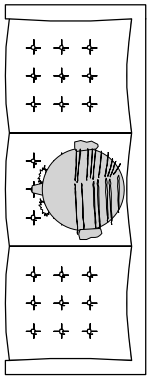
- Beware of this type of center speaker
- Sound should be identical throughout the listening area



# Center Speaker Dispersion
## No Lobing Allowed

**Radiation pattern of traditional center speakers around 2kHz**



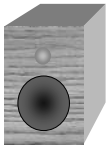




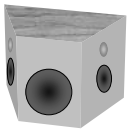
PMI

## What about directivity of Surrounds?

- **The traditional 2 way speaker is OK – Sound dominated by reflections from 3kHz down**

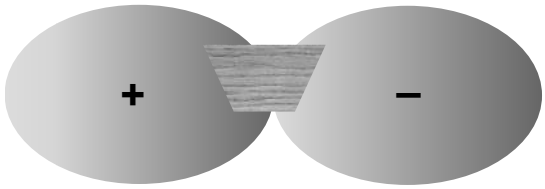


- **5.1 channel music and film may benefit from more envelopment to avoid distraction: Dipoles and Bipoles**

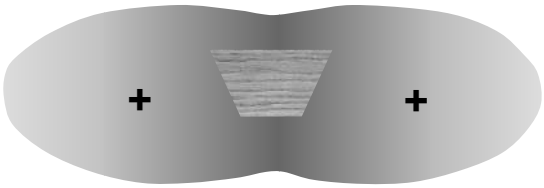


PMI

## What about directivity of Surrounds?




**Dipole:**
**Deep null and lots of envelopment**

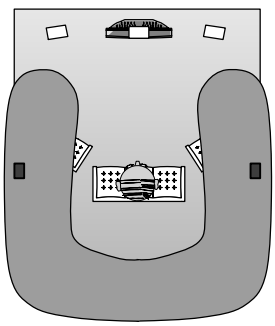



**Bipole:**
**Broader waistline**
**More directionality**

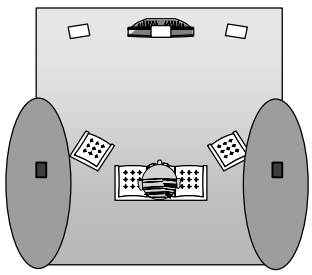


## Surround Loudspeakers
### Home Theatre Surround Soundfield Effect

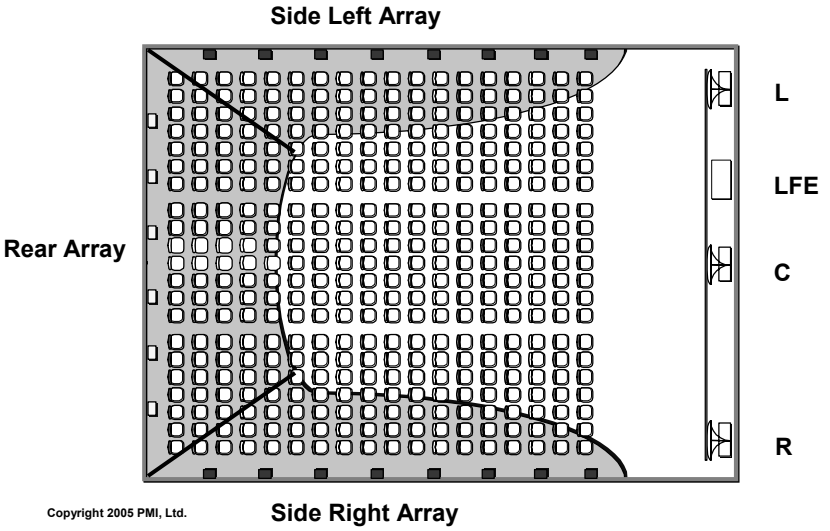
**Dipole**



**Direct**

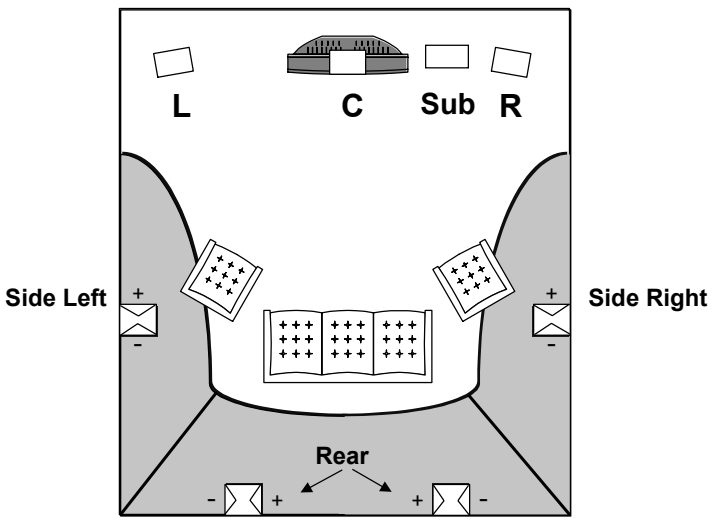


# Surround EX Soundfield in Cinemas






# Surround EX for Home Theatres



## 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




## 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



## 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





# Audio Gear Placement

## Gear Placement considerations

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



## 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

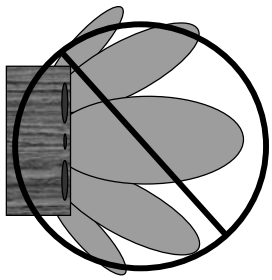
## Speaker Placement
### Several Considerations

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



## 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



## 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




## 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



# Boundary Effects
## Goals

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

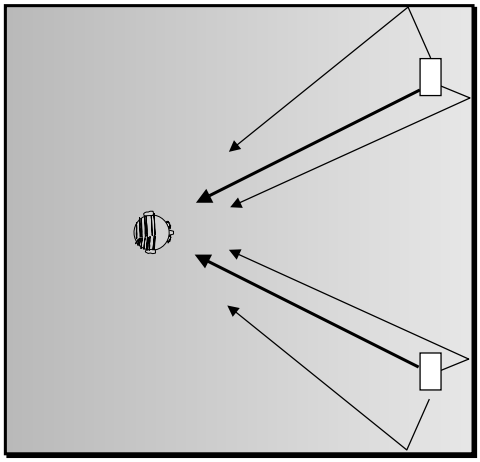



# Boundary Effects

- Evaluation
  - Computer predictions
    - CARA
    - RPG Room optimizer
  - Use circulating pink noise and listen for timbral variations
  - Use pink noise and RTA to measure spectral variations
- Correction
  - Avoid multiple equal boundary distances
  - Change speaker position
  - Match boundary conditions for the front speakers
  - Flush mount speakers
  - Use low frequency absorption
  - Equalize



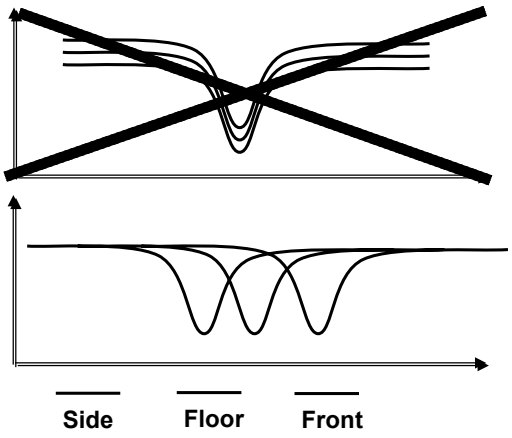
# Front Speaker Placement
## Unequal Boundaries



**Unequal Reflected Path Lengths**

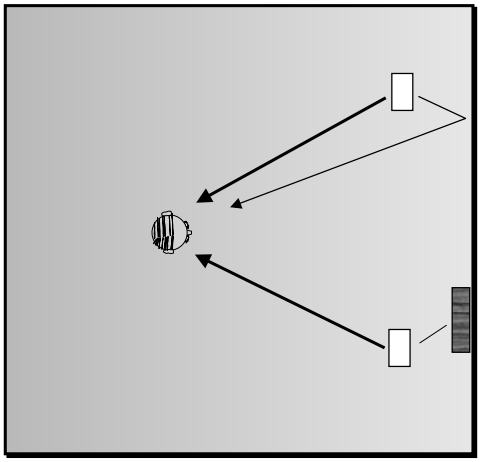


# Front Speaker Placement




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

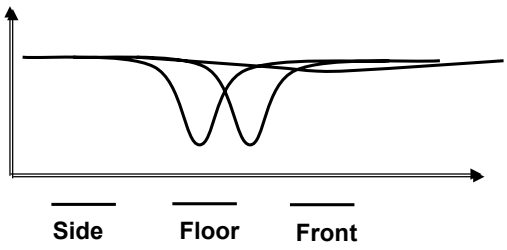
# Bass Absorption on the front wall



- Use Bass absorber to kill front wall reflection



# Solutions to LF Reflections
## Bass Absorption



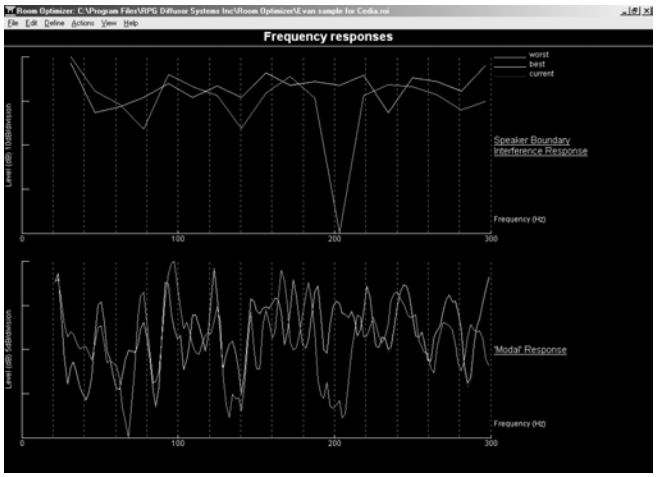

- With Bass absorber, front wall response is smoother
- The remaining error can be equalized
- Can also use Bass absorbers on front wall

# Front Speaker Placement

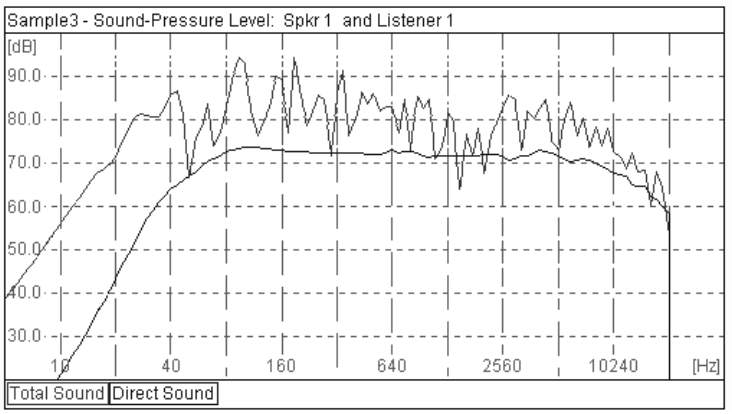
- Use planning and modeling for best boundary conditions
  - RPG room optimizer
  - CARA



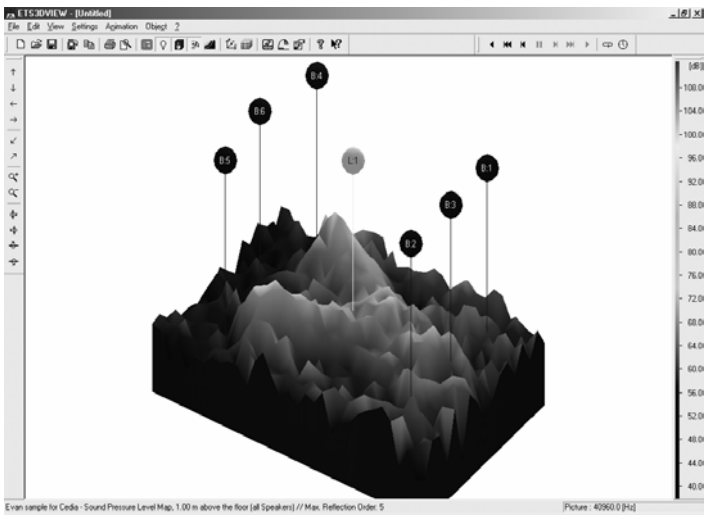
# Modeling Software
## RPG Room Optimizer



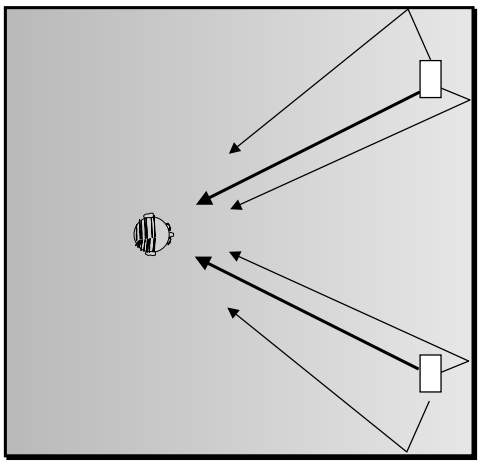
# Modeling Software
## CARA




# Modeling Software
## CARA

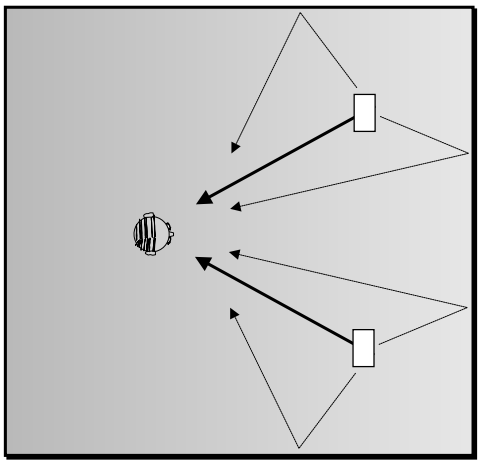


# Front Speaker Placement





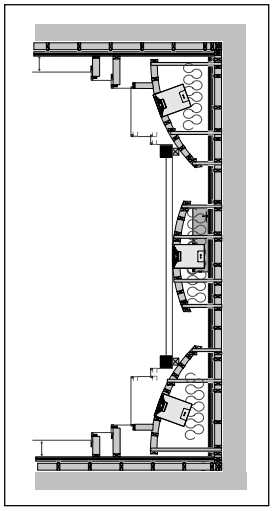
# Front Speaker Placement
## Reducing boundary effects



- 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





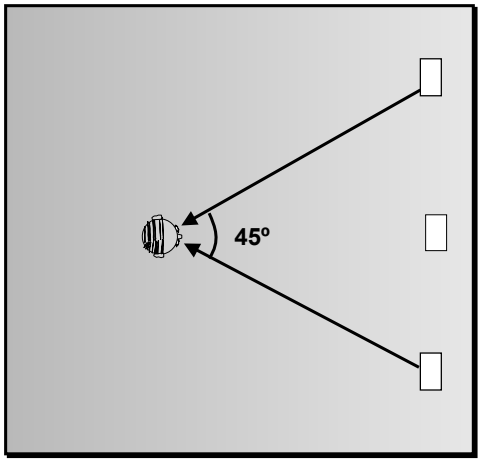
# Front Speaker Placement
## Baffle mounting example

## Front Speaker Placement Guidelines
# Vertical Plane

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



## 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

## 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

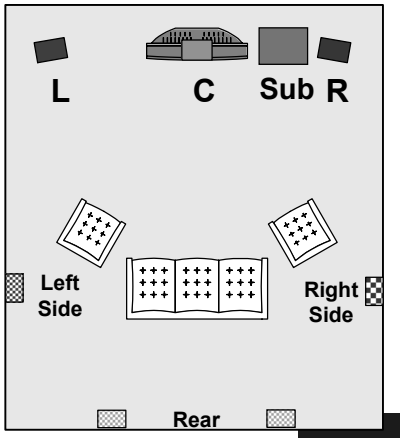


## Front Speaker Placement Guidelines
## "Nearfield" or "Farfield"

- 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

# Layout of a typical Home Theater:

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



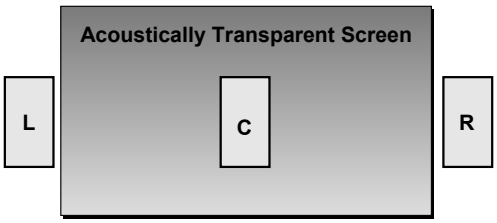



## Front Speaker Placement Guidelines
# "Nearfield" or "Farfield"

- 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!

## Front Speaker Placement
### The Best Solution for post work

- Use acoustically transparent screen whenever possible



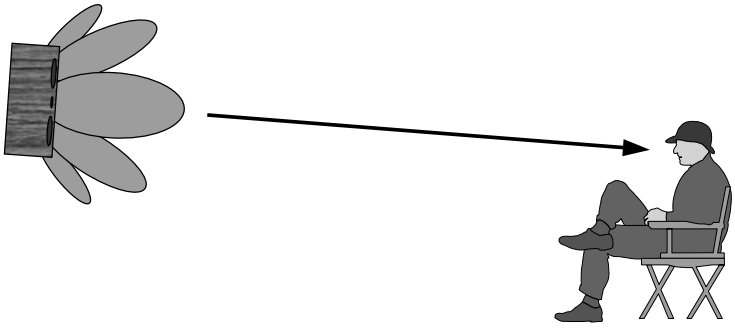



## Front Loudspeaker Aiming

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

# Front Speaker Coverage
## Lobing Problems

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





# Subwoofer Placement

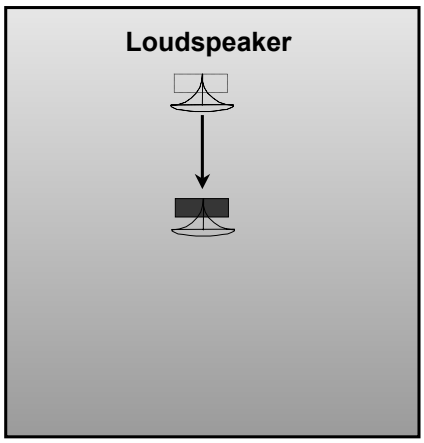
- Use planning and modeling
- Esthetics vs. Acoustics
- Use in mono
- Eliminate a room resonance

## Subwoofer Placement

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



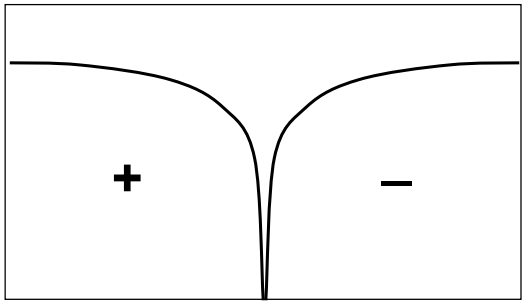
## Subwoofer Placement




- Driving room standing waves in cancellation areas can improve response

## Standing Waves
## Pressure Polarity

1st Harmonic



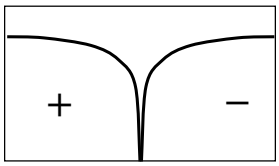

1/2

- The acoustic polarity changes around the null



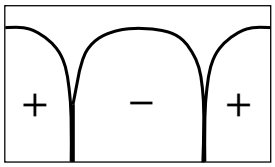
## Standing Waves
### Pressure Polarities

1st Harmonic



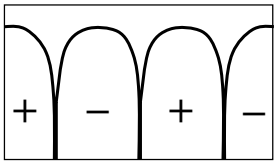

1/2

2nd Harmonic



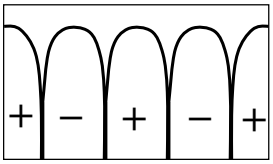

1/4 3/4

3rd Harmonic



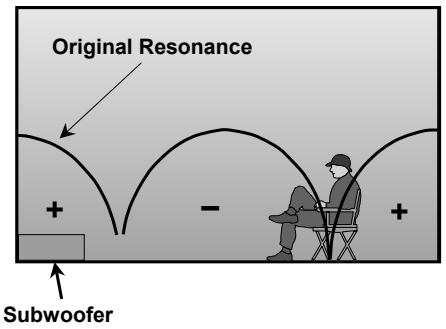

1/6 1/2 5/6

4th Harmonic




1/8 3/8 5/8 7/8

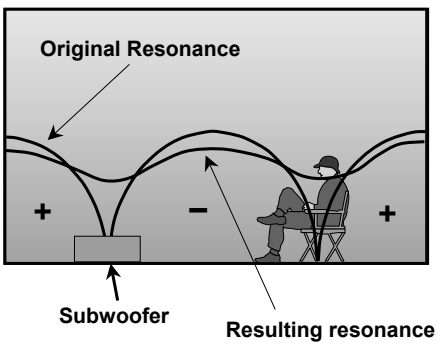
# Subwoofer Placement
## Driving Standing Waves




- The subwoofer drives the 2nd order standing wave resonance

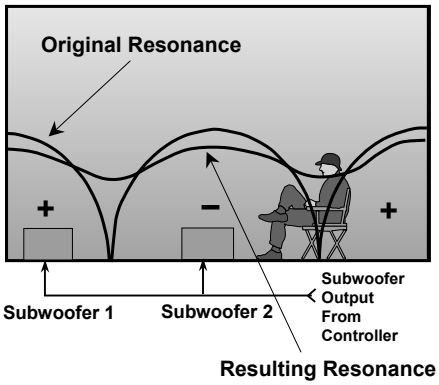


# Subwoofer Placement
## Reducing Standing Waves




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

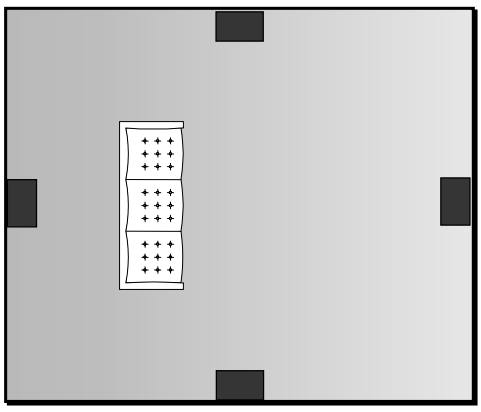
# Subwoofer Placement
## Reducing Standing Waves (continued)




- 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

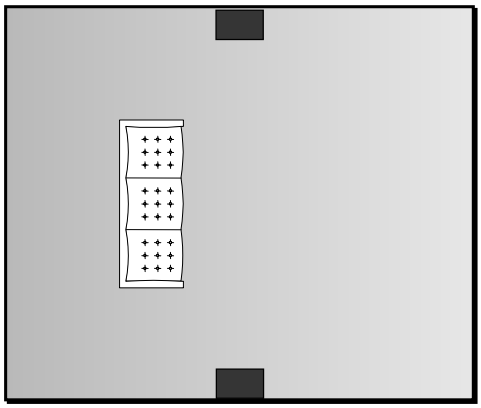


# Subwoofer Placement
## Reducing Standing Waves - A good solution



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

## Subwoofer Placement
### Another good solution



- 2 subwoofers
- More SPL
- More standing waves

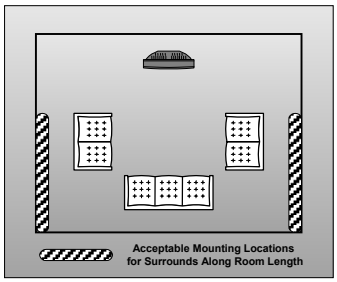


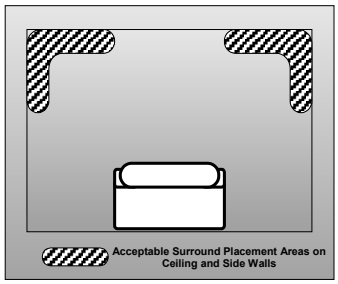
## Side Speaker Placement

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

# 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

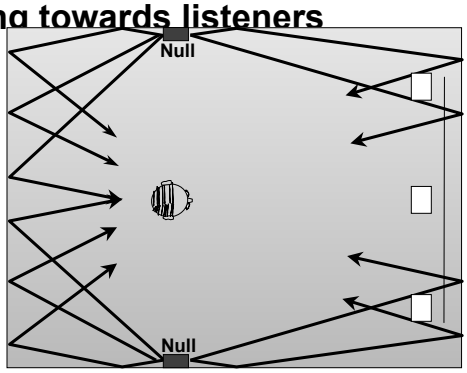


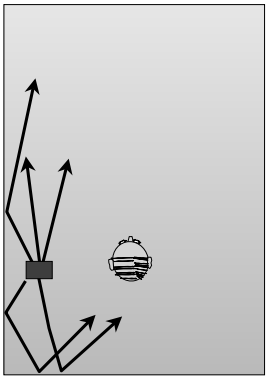


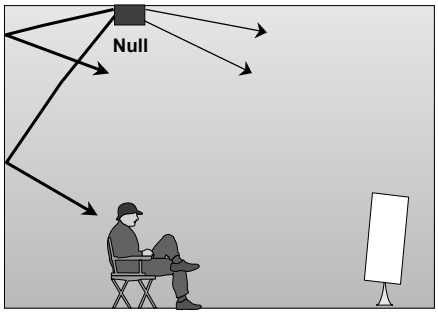

# Dipole Side
## Speaker Typical Position

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



# Dipole Side Speaker Placement
## Ceiling Placement

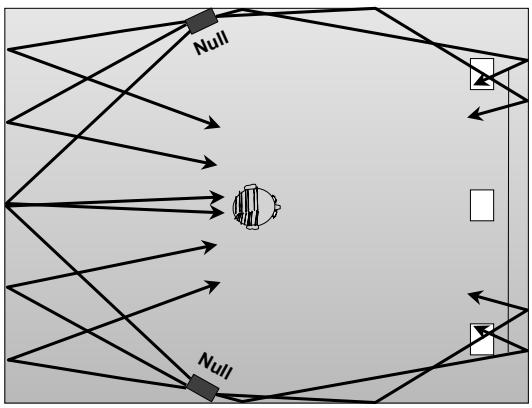





- Aim null at listening position
- Good alternative to sidewall placement
- Good for aesthetics

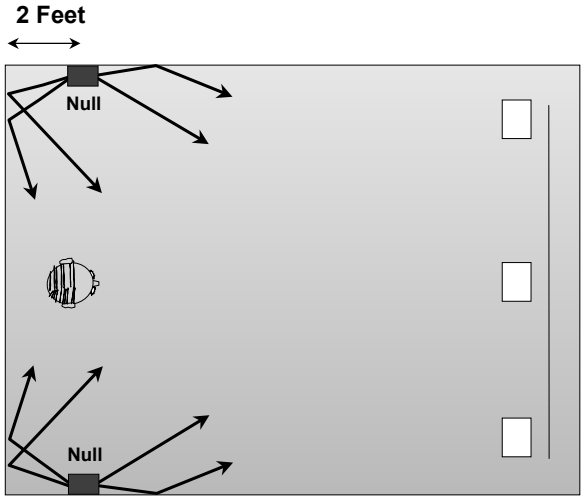


# Dipole Side Speaker Placement
## For Mid-Room Seating Position



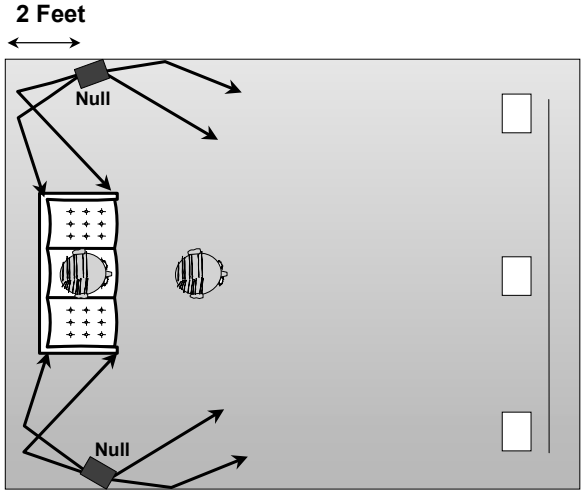

- Make rear wall the first reflection to ensure surround effect
- Aim null at listening position

## Dipole Side Speaker Placement
### Seat on Back Wall



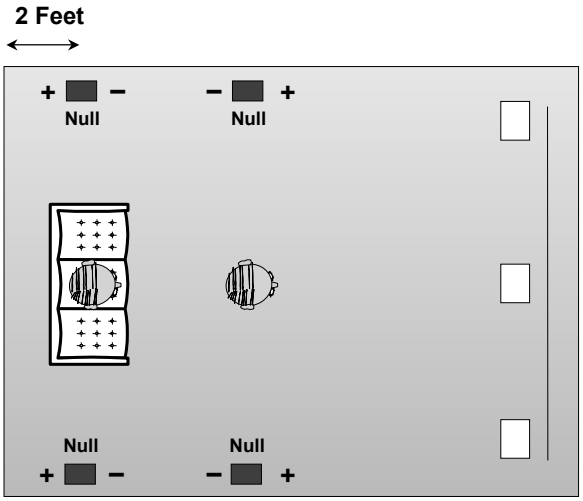

- Place on side walls or ceiling, 2 feet (60cm) from rear wall
- Aim null at listening position if needed

## Dipole Side Speaker Placement
### Room with Multiple Rows - 1



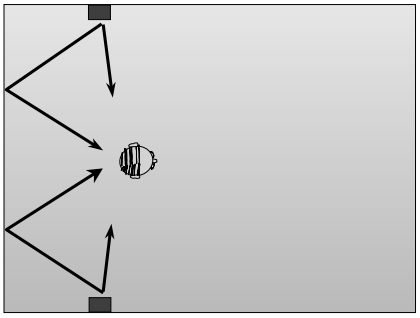

- Aim null for most even coverage

## Dipole Side Speaker Placement
### Room with Multiple Rows - 2



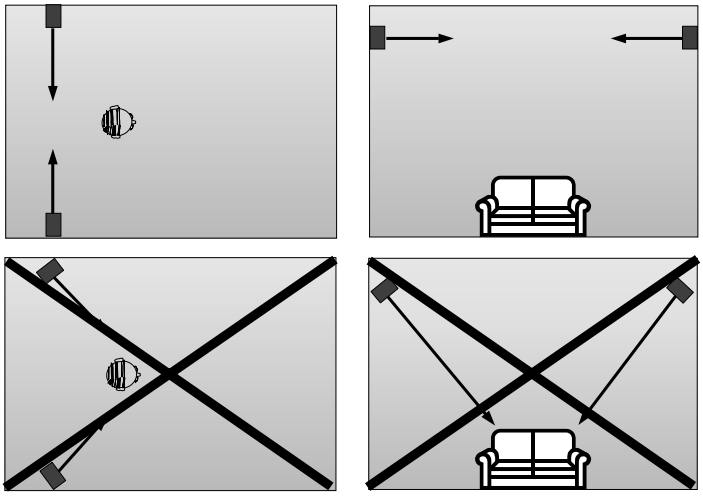

- Invert polarity of rear pair
- Adjust position for even coverage

## 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

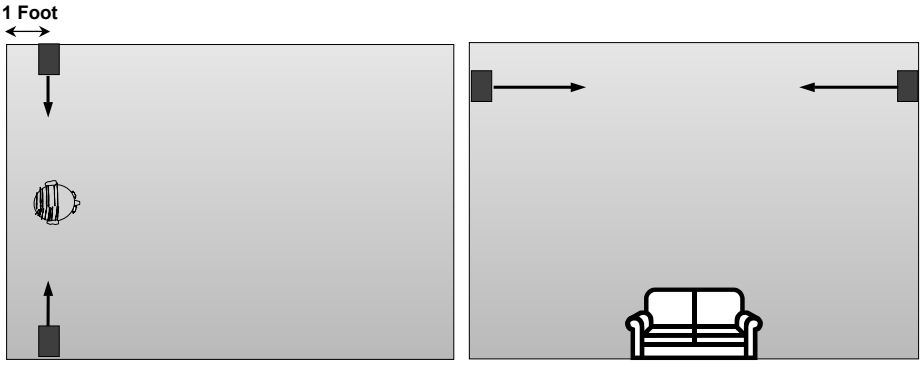
# Direct Surround Speakers
## Placement and Aiming



- Aim across room
- Don't aim toward listener

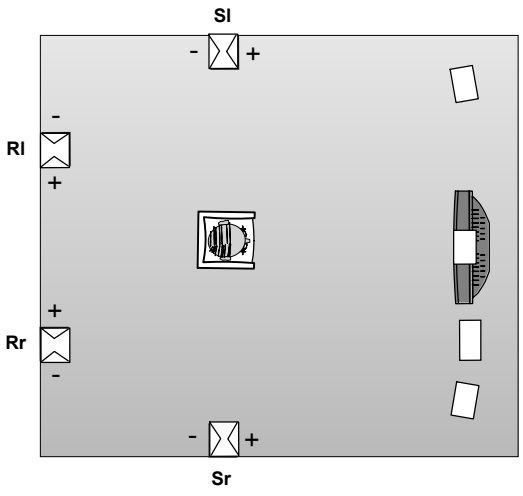


# Direct Surround Speaker Placement
## Seat on Back Wall




- Aim across room

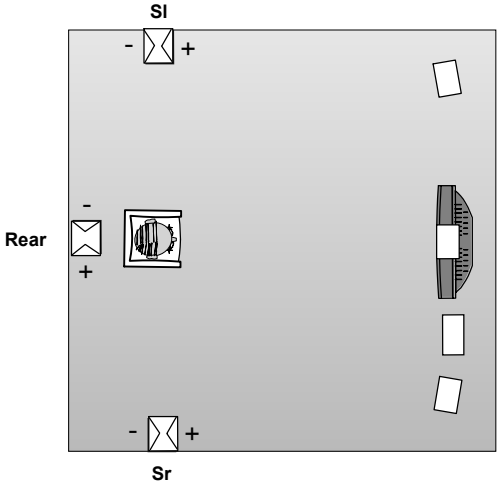
# Dipolar Rear Speaker Placement for Surround EX




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

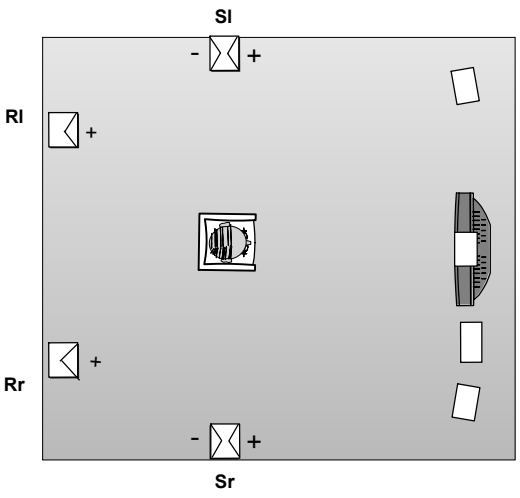


# Dipolar Rear Speaker Placement for Surround EX




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

# Direct Rear Speaker Placement for Surround EX

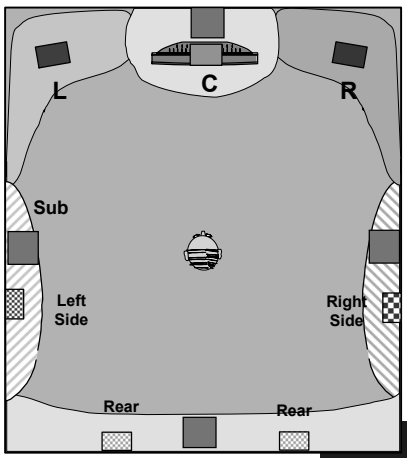



- Place rear speakers at 2 meter (6 feet) height
- Place at 150° from front center
- Watch for Psycho-Acoustic inversion
  - Try asymmetrical placement

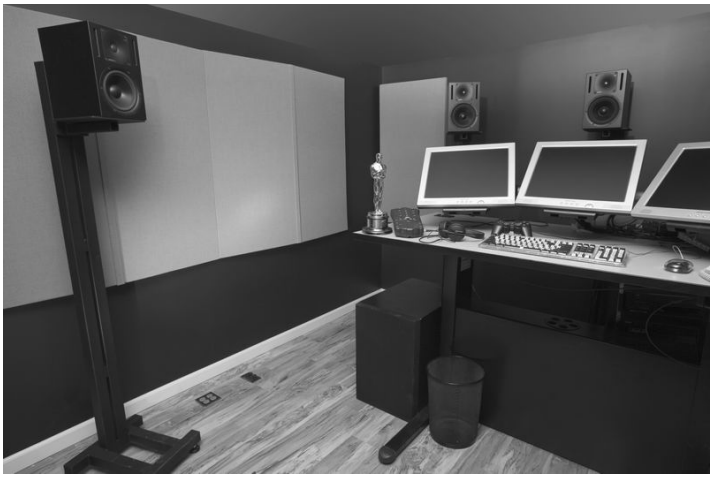


# Speaker Placement The "Magic Layout"

- 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



# An example room
## studio.jory.org





# An example room
## studio.jory.org

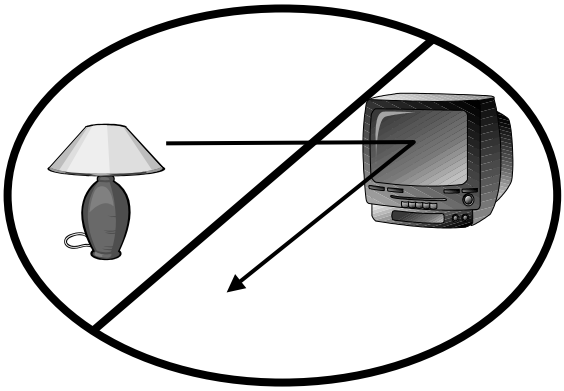
## An example room
### studio.jory.org



# Video Gear Placement

## Video Component Placement

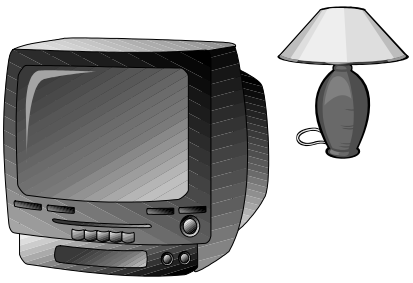
- No direct light onto the screen





## Video Component Placement

- If possible provide low level neutral light behind the screen

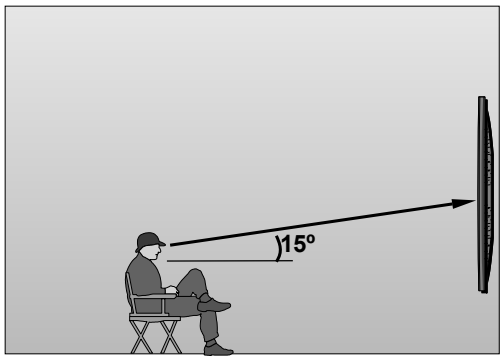


## Screen placement guidelines

- Vertical viewing angle to middle of screen <15º

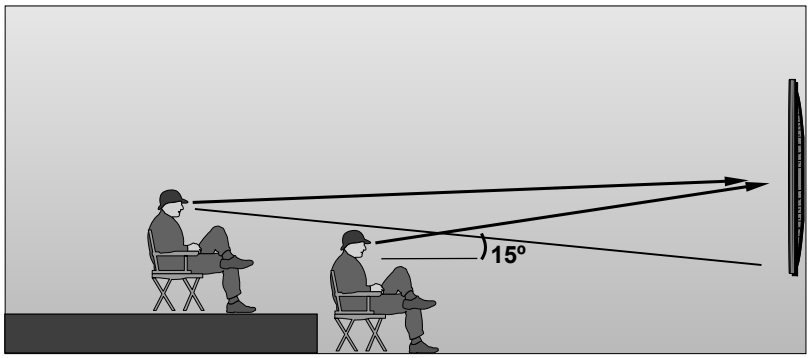


## Screen height




**Comfort Angle limit: 15º**

# Screen height - Sight Lines




Clear sight line



# Wiring it all up

## 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




## Wiring Considerations

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



## Wiring – Color coding

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



# Tuning it All

## Analysis and equalization

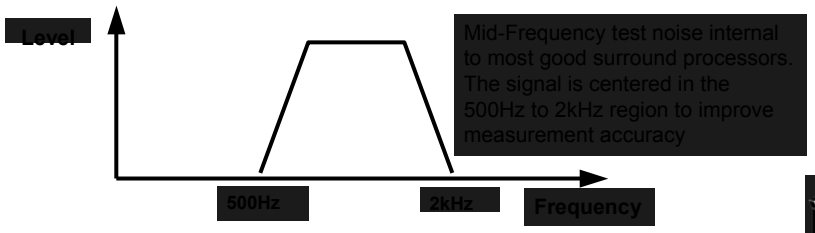
# Electrical Level Calibration

- 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



# 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



# Level Calibration
## External multichannel source

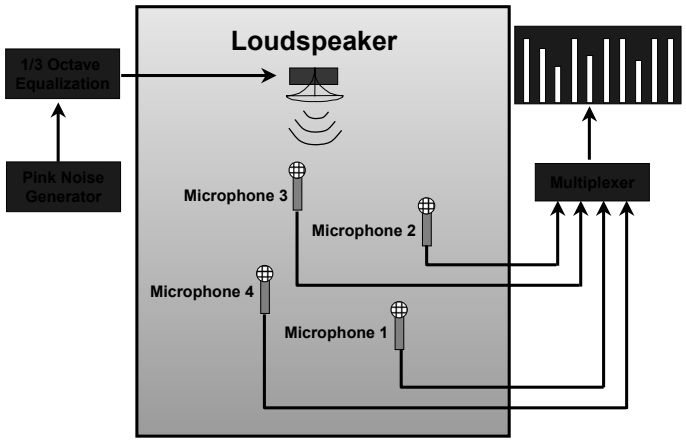
- Electrical:
  - Use –10/+4dB balanced adapter with gain controls
- Acoustic: Use test DVD with midband pink noise
  - Calibrate for 85dB across all channels



# Level Calibration
## Time synchronization

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

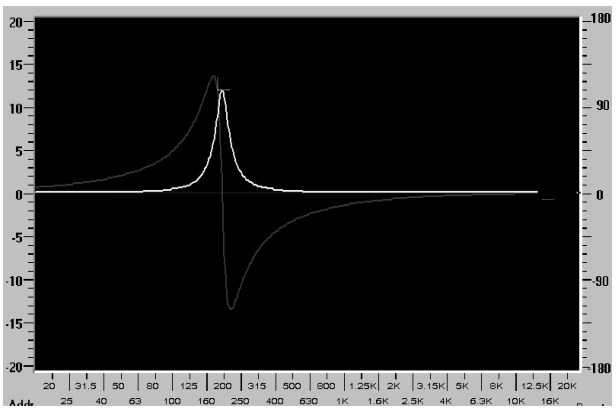
# Analysis – the useful way




- 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!

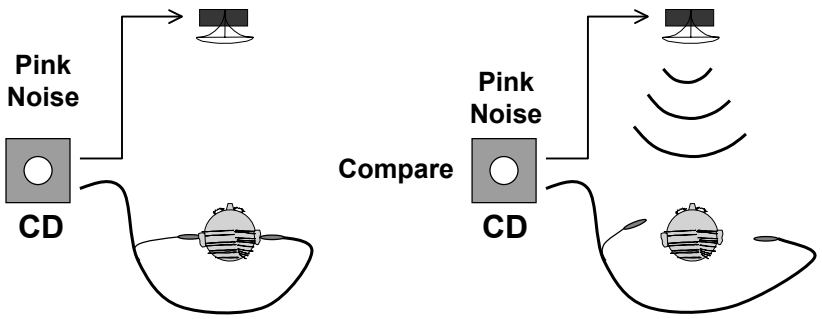
# Equalization Requirements

- 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



# Quick Check of Overall Frequency Response

**Using Etymotic ER-4S or ER-6 Earphones**

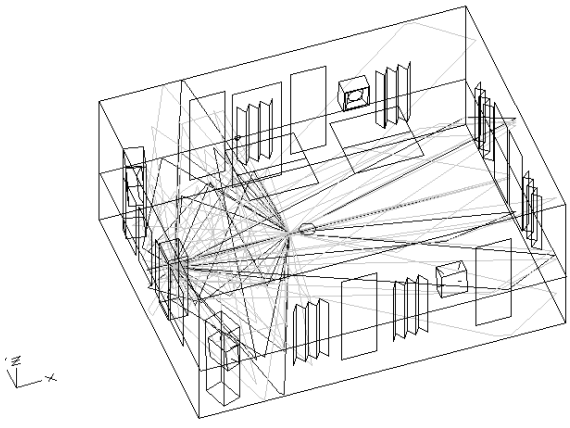



**Set earphone level to match speaker**

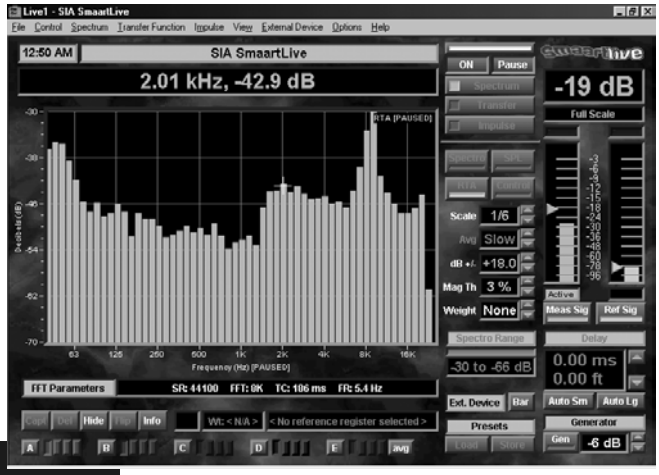
# Tools



# Ulysses Ray Tracing



# SMAART Live




# Gold Line DSP30

- RTA
- 1/3, 1/6, 1/12$^{th}$ Octave
- Averaging
- NC
- RT60
- Integrated solution

# TEF 25

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





# Planning

## Planning is key

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



## 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

# 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*



# Contact Info

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