Acoustics of Small Rooms

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Small Room (geometrically speaking)

- 70 m³ (~2500 ft³) small classroom, home theater or studio with a characteristic dimension:

$$L \sim \sqrt[3]{V} = 4.1\ \text{m}\ (\sim 13\ \text{ft})$$

Small Room (in the acoustic sense)

$$\lambda / L >> 1$$

- Lowest frequency band of the human voice: 125 Hz

$$\lambda / L = 0.7$$

- Lowest frequency of a home theater subwoofer or studio monitor: 20 Hz

$$\lambda / L = 4.2$$

Room Acoustics Methods

Critical Frequency:

$f_c = 2000 \sqrt{T/V}$ (Hz)

For T = 0.3 s, which is not an unreasonable goal for a small classroom or studio with V = 70 m³ → f_c = 130 Hz

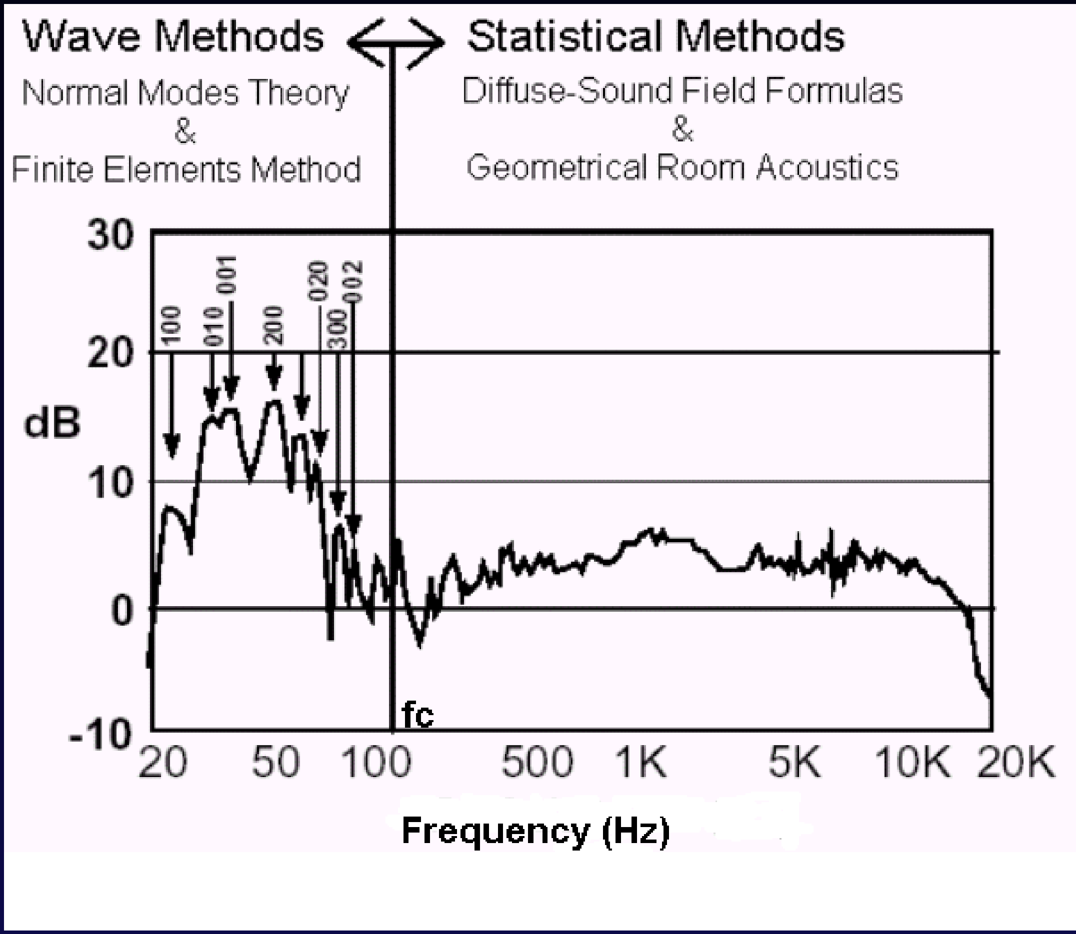


Figure 1

Types of Small Rooms

Small Critical Listening Spaces

- Home Theatres and Listening Rooms

Studios

- Voice and Music Studios and Control Rooms

Small Rooms for Speech

- Classrooms and Meeting Rooms

Frequencies and Strength of Modes

$$f_N = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_x}{L_x}\right)^2}$$

$$\hat{p} = \frac{i\rho\omega c^2 Q_o}{V} e^{-i\omega t} \sum_N \frac{\varepsilon_{n_x}\varepsilon_{n_y}\varepsilon_{n_z}\psi(S)\psi(R)}{\omega^2 - \omega_N^2 + 2i\omega c k_N}$$

$\hat{p}$ = complex sound pressure

Q_o = volume velocity of the source

ρ = density of the medium

c = speed of sound in the medium

V = volume of the room

ω = angular frequency

ω_N = mode natural angular frequency

k_N = 3-dimensional damping factor

ε_n = scaling factors (1 for zero order modes and 2 for all other orders)

$\psi(S)\,\psi(R)$ = source and receiver coupling function

n_x, n_y and n_z, are integers from 0 to, say, 3

L_x, L_y and L_z, are the length, width and height of the room

Figure 2

Classes of Room Modes

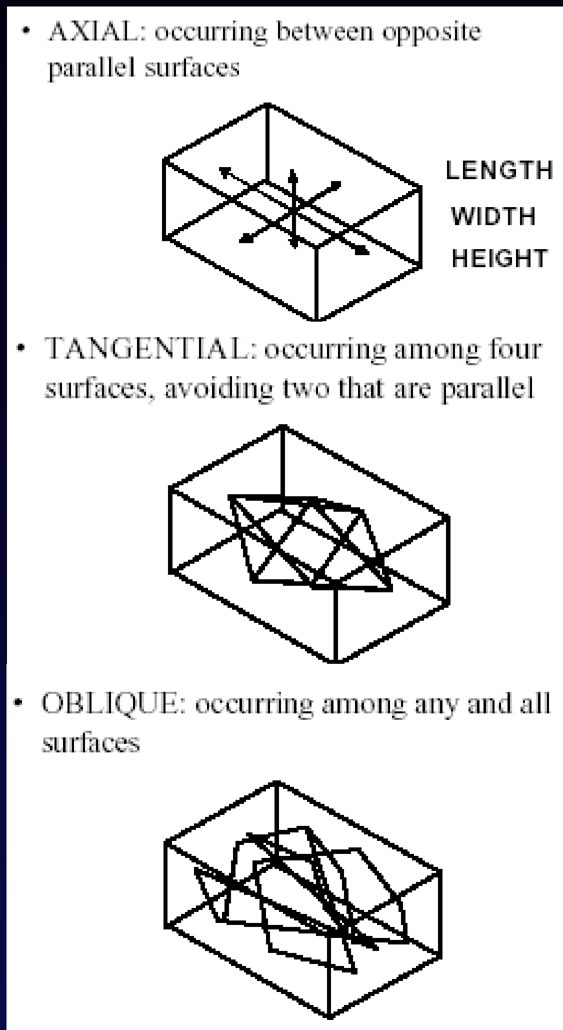


Figure 3

In Terms of Causing Audio Problems

AXIAL MODES are the *dominant* factor

TANGENTIAL MODES can be significant in rooms with very stiff/massive walls

OBLIQUE MODES are rarely, if ever, relevant

A Simple Way to Calculate the Axial Modes

e.g. the first length mode of a room 20 feet long can be calculated as follows:

$$f_{1,0,0} = \frac{\text{speed of sound in ft/s}}{2 \times \text{length in feet}} = \frac{1130}{40} = 28.25 \text{ Hz}$$

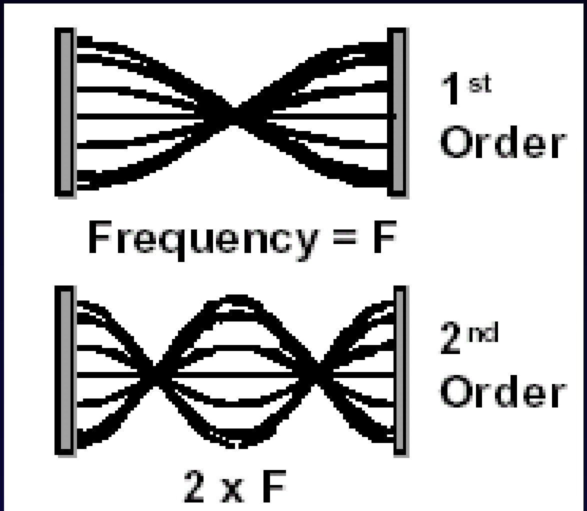
other length modes are simple multiples of this:

2 x 28 = 56 Hz, 3 x 28 = 84 Hz, 4 x 28 = 112 Hz, and so on.

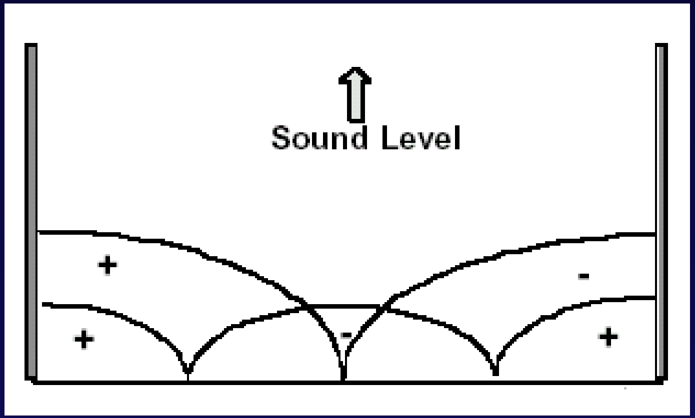
Then do the same for the width and height modes.

Figure 4

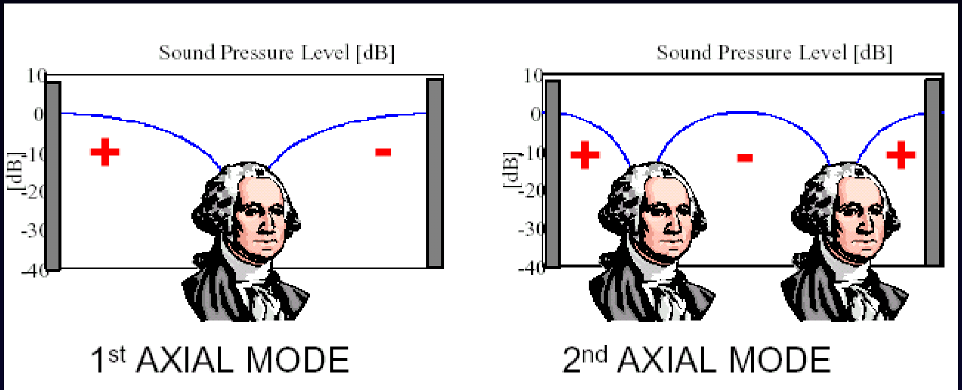
Orders of Axial Standing Waves



Visualizing Standing Waves



No Sound at Nulls



No Coupling at Nulls (No Excitation)

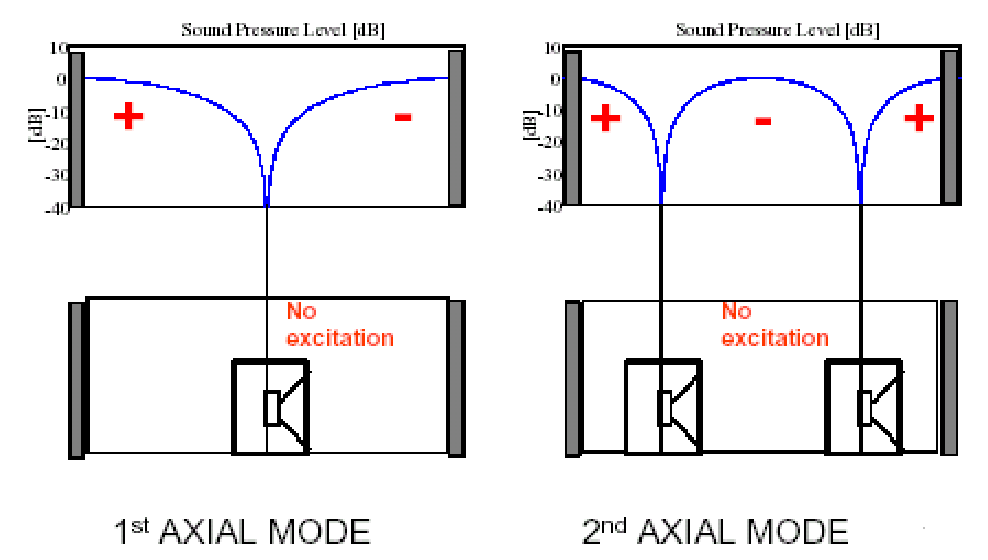


Figure 5

Room Mode Calculator

(available for download from e.g.: www.harman.com)

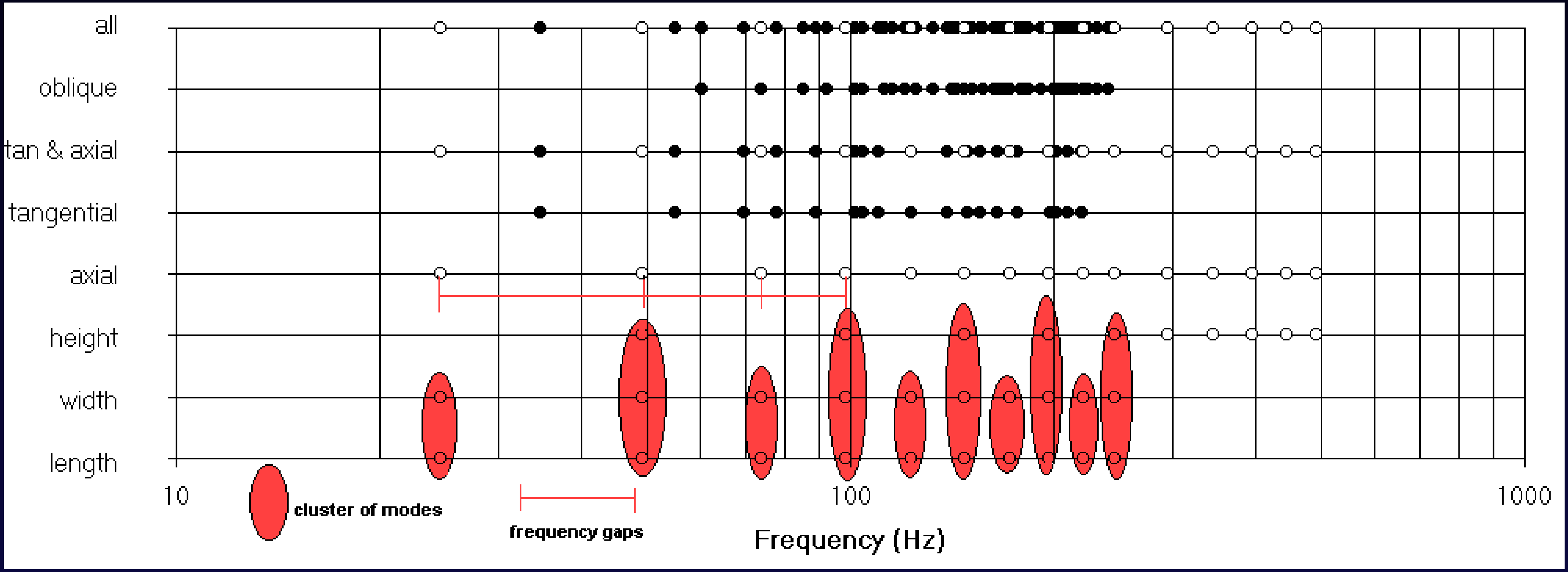


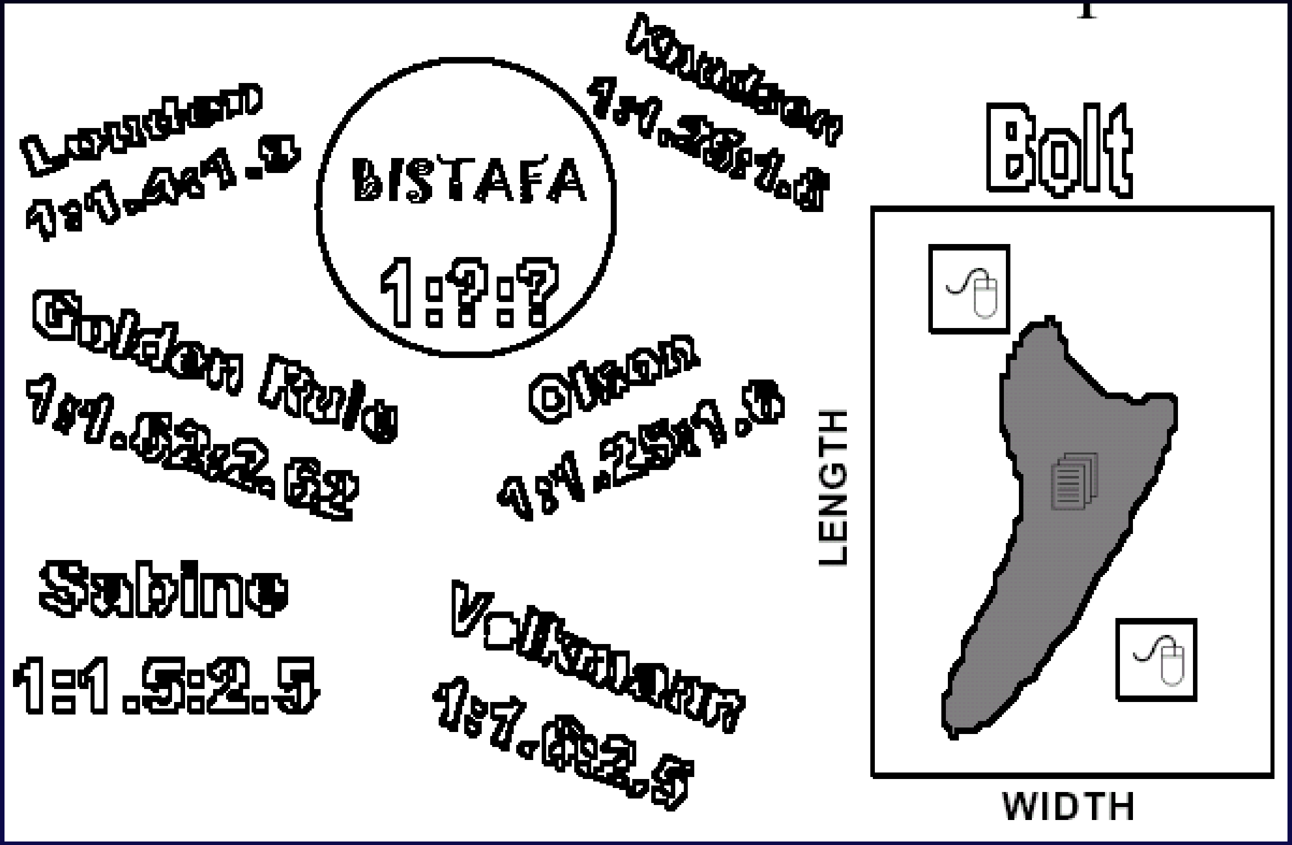
Figure 6

L:W:H = 11.5 x 23 x 23 ft

Is There an Ideal Room Shape?

(to avoid clustering of modes near certain frequencies and excessive gaps between adjacent frequencies)

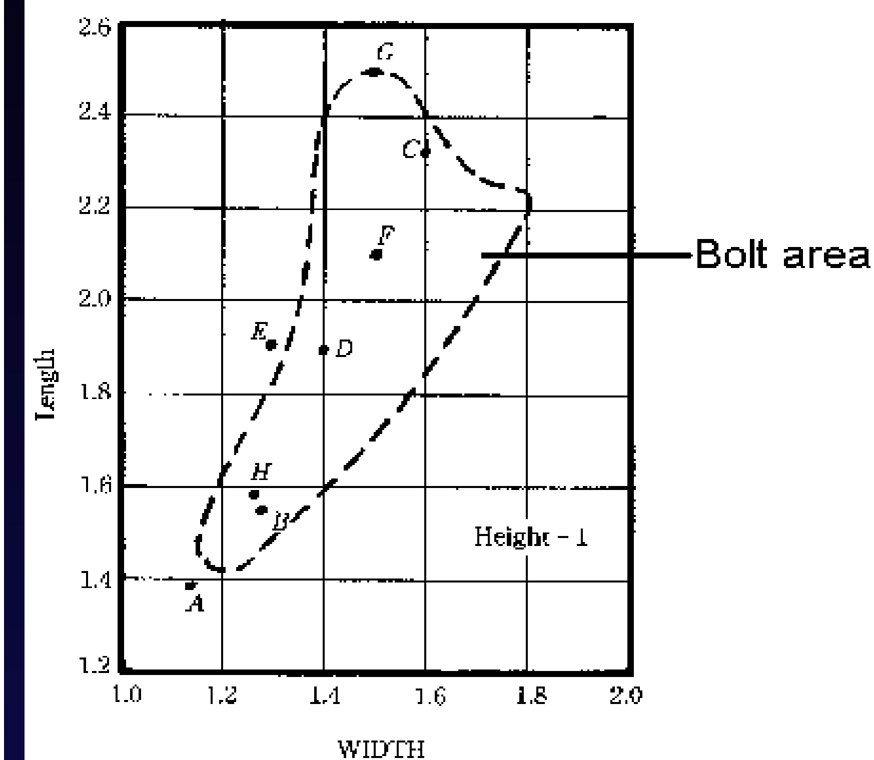
Figure 7



Recommended Room Ratios

Rectangular room dimension ratios for favorable mode distribution.

Author		Height	Width	Length	In bolt's range?
1. Sepmeyer[5]	A	1.00	1.14	1.39	No
	B	1.00	1.28	1.54	Yes
	C	1.00	1.60	2.33	Yes
2. Louden[6] 3 best ratios	D	1.00	1.4	1.9	Yes
	E	1.00	1.3	1.9	No
	F	1.00	1.5	2.5	Yes
3. Volkmann[3] 2:3:5	G	1.00	1.5	2.5	Yes
4. Boner[4] $1:\sqrt[3]{2}:\sqrt[3]{4}$	H	1.00	1.26	1.59	Yes



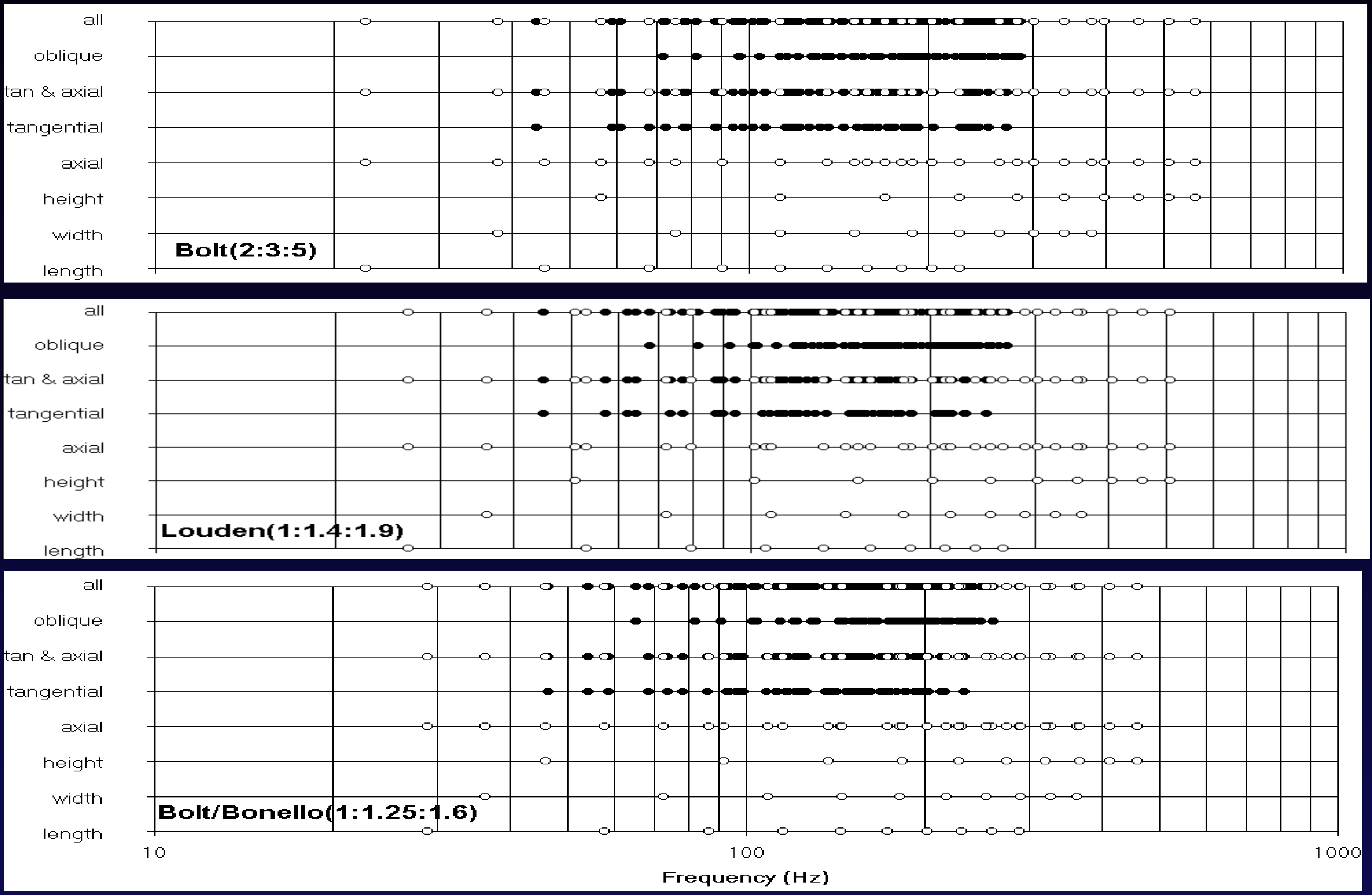
Bolt Chart

Figure 8

Figure 9

Room Modes for Some Room Ratios

(*107* m³/3770 ft³ Room)

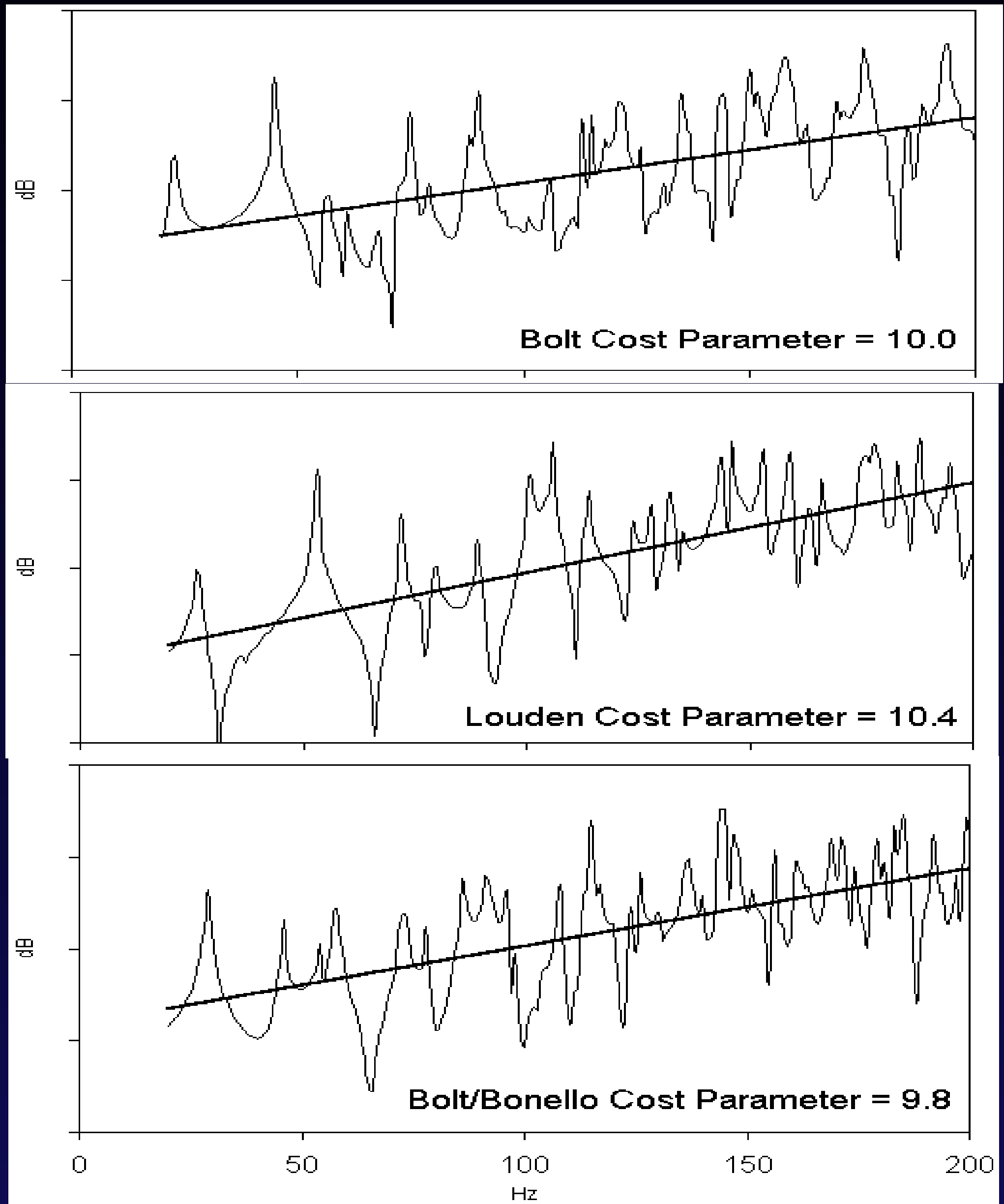


Uniformity of the Frequency Response

Described by the Cost Parameter

If this approach has some merit, the room with the dimension ratios recommendation of Bolt/Bonello should have some audio advantages. Does it?

Figure 10



Usefulness of Room Ratios

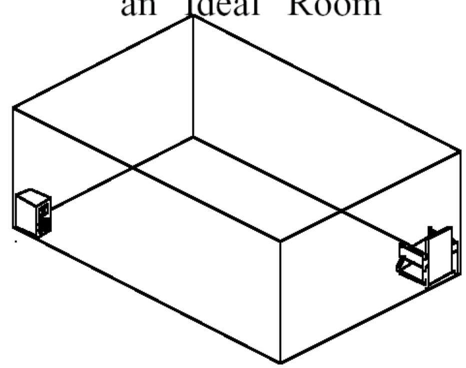
This all makes a very nice story, but does it *really* matter?

Maybe…..Somewhat……It all depends….

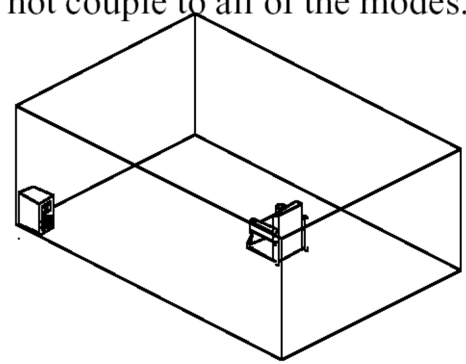
Oh, all right,…..**No!**

Why not?

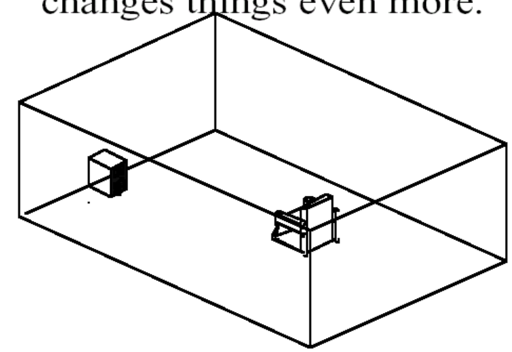
How To Experience the Modes in an "Ideal" Room



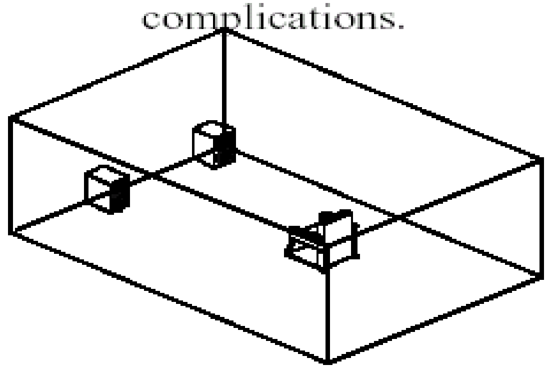
A practical listening location does not couple to all of the modes.



A practical loudspeaker location changes things even more.



Two loudspeakers add more complications.



And with five loudspeakers we have serious complications.

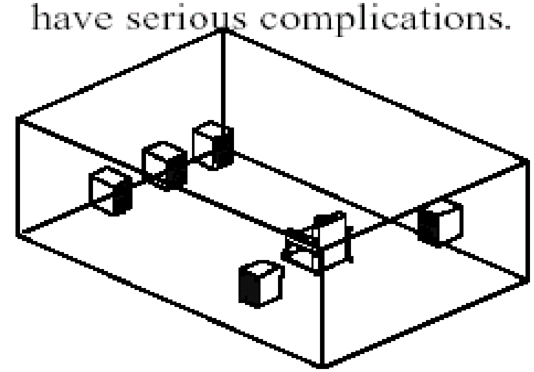


Figure 11

To Get a Good Bass Balance

➢*Modify the acoustical coupling of the loudspeakers to the room boundaries and/or room modes; i.e move the:*

- *Listener*
- *Loudspeaker*
- *Both*

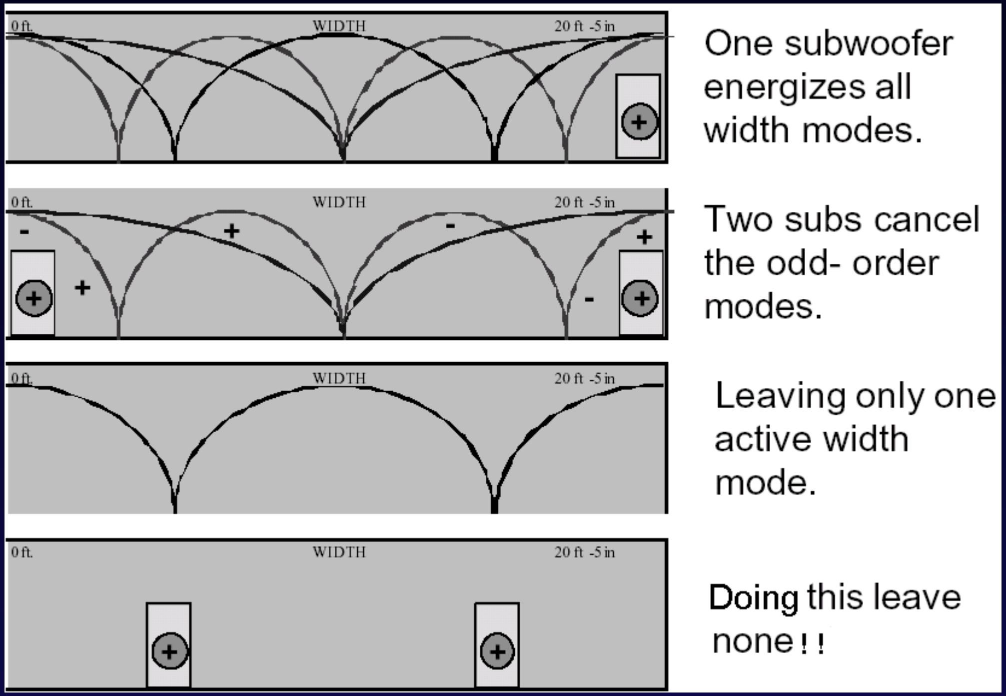


Figure 12

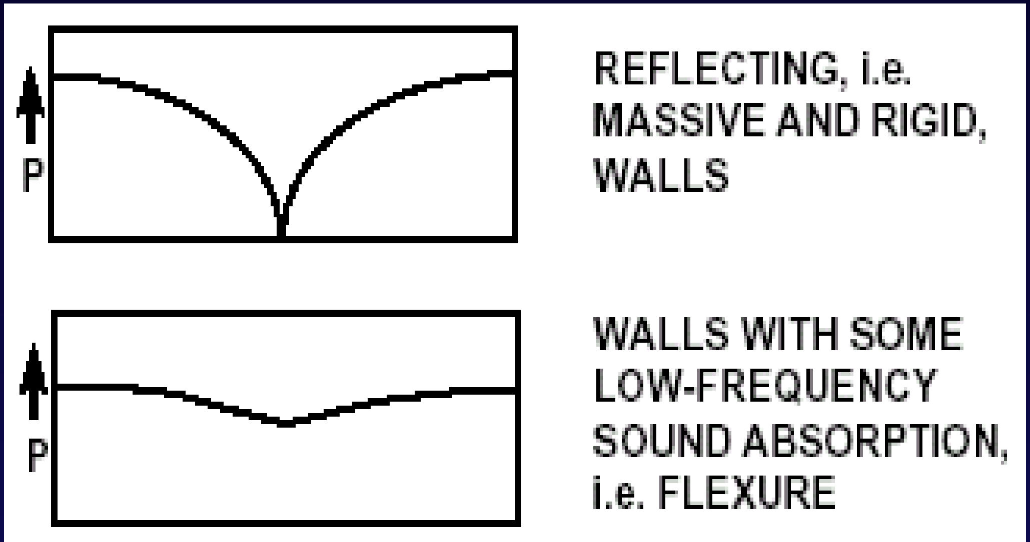
Selective Mode Cancellation

➢*Acoustically modify the room; get out hammers and saws.*

The Damping of Room Modes

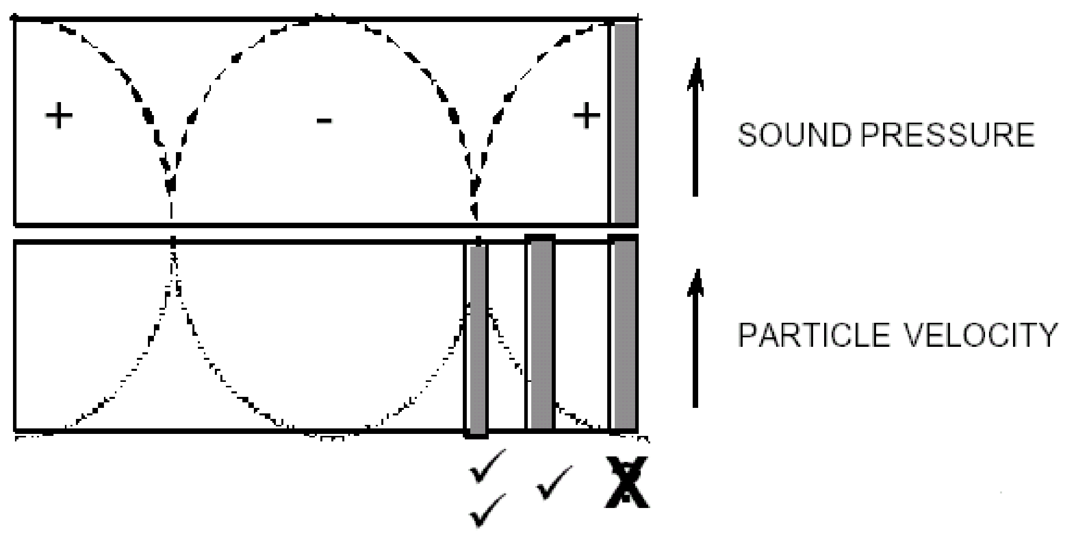
- *The damping of room modes is especially useful in home theater applications where several listeners need to have a similar auditory experience.*

Figure 13



The Damping of Room Modes (with resistive absorbers)

Figure 14



<u>Resistive absorbers are not practical at low frequencies !</u>

¼ wavelength at 100 Hz = 0.34 m (2.8 ft)

¼ wavelength at 50 Hz = 0.68 m (5.7 ft)

¼ wavelength at 30 Hz = 11.33m (9.4 ft)

The Damping of Room Modes (with membrane absorbers)

- *Diaphragmatic, or membrane absorption in room boundaries is one few practical mechanisms of acoustical absorption at very low frequencies.*

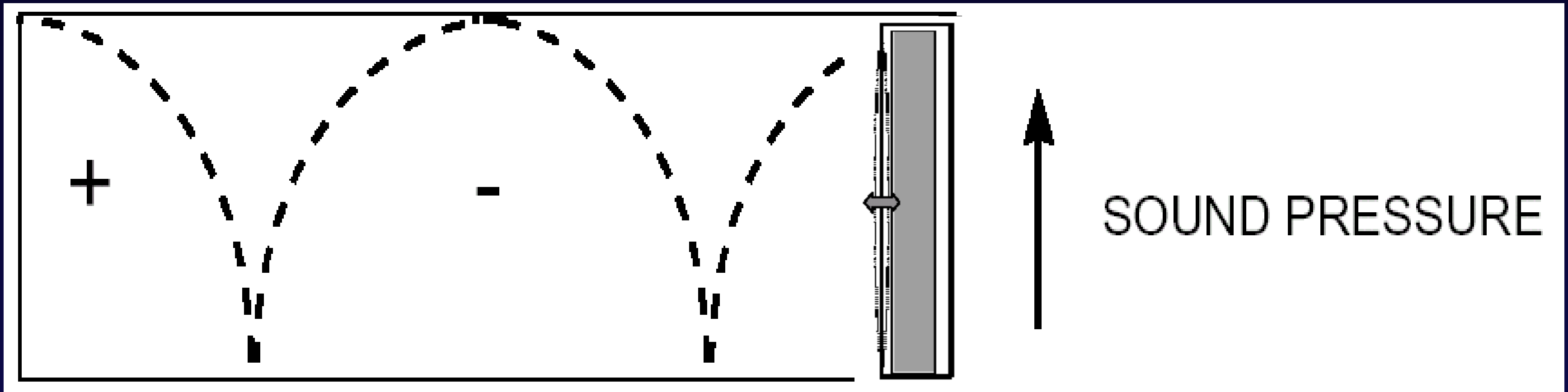
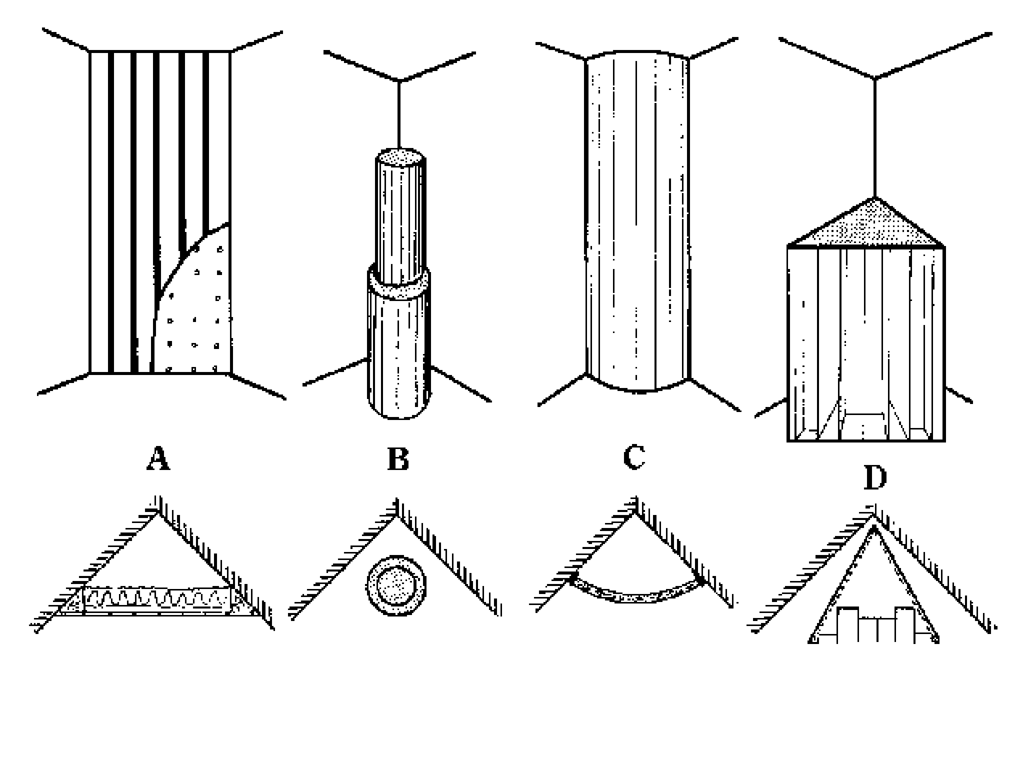


Figure 15

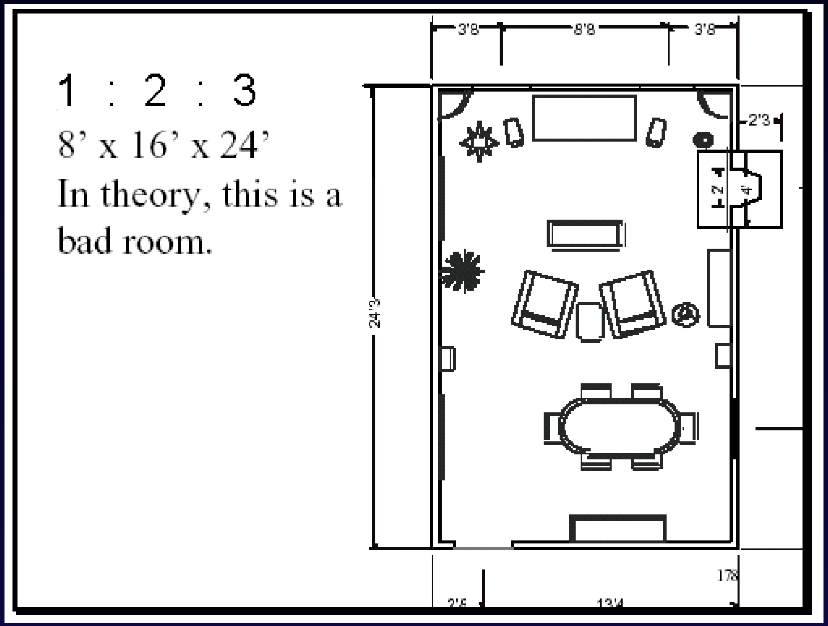
The Damping of Room Modes (with bass traps)

Figure 16



A Practical Example
(From Ref. 3.3 - Part 3)

A Leaving/Dining Room with a RPTV



Room Dimensions

Figure 17

Standing Wave Calculator

(available for download from e.g.: www.harman.com)

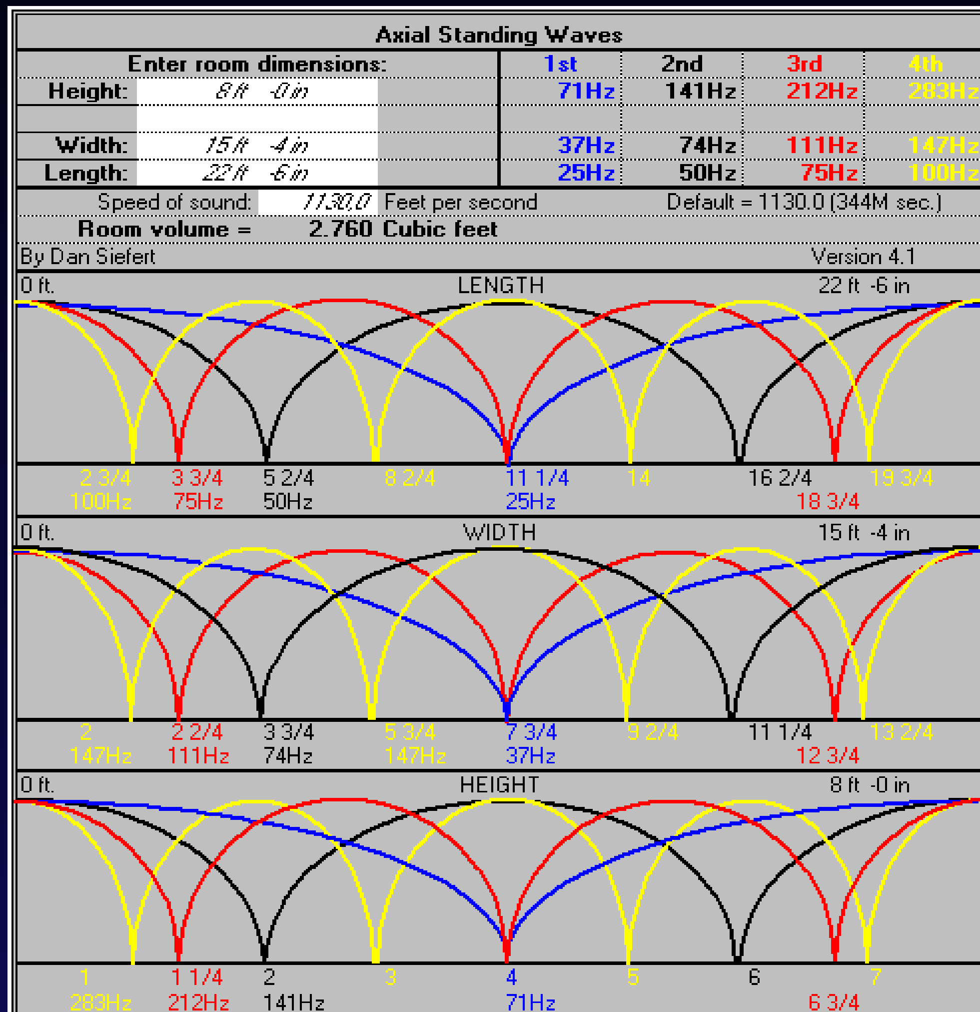


Figure 18

Woofer Location
(Decides How Much Energy Each Mode Receives)

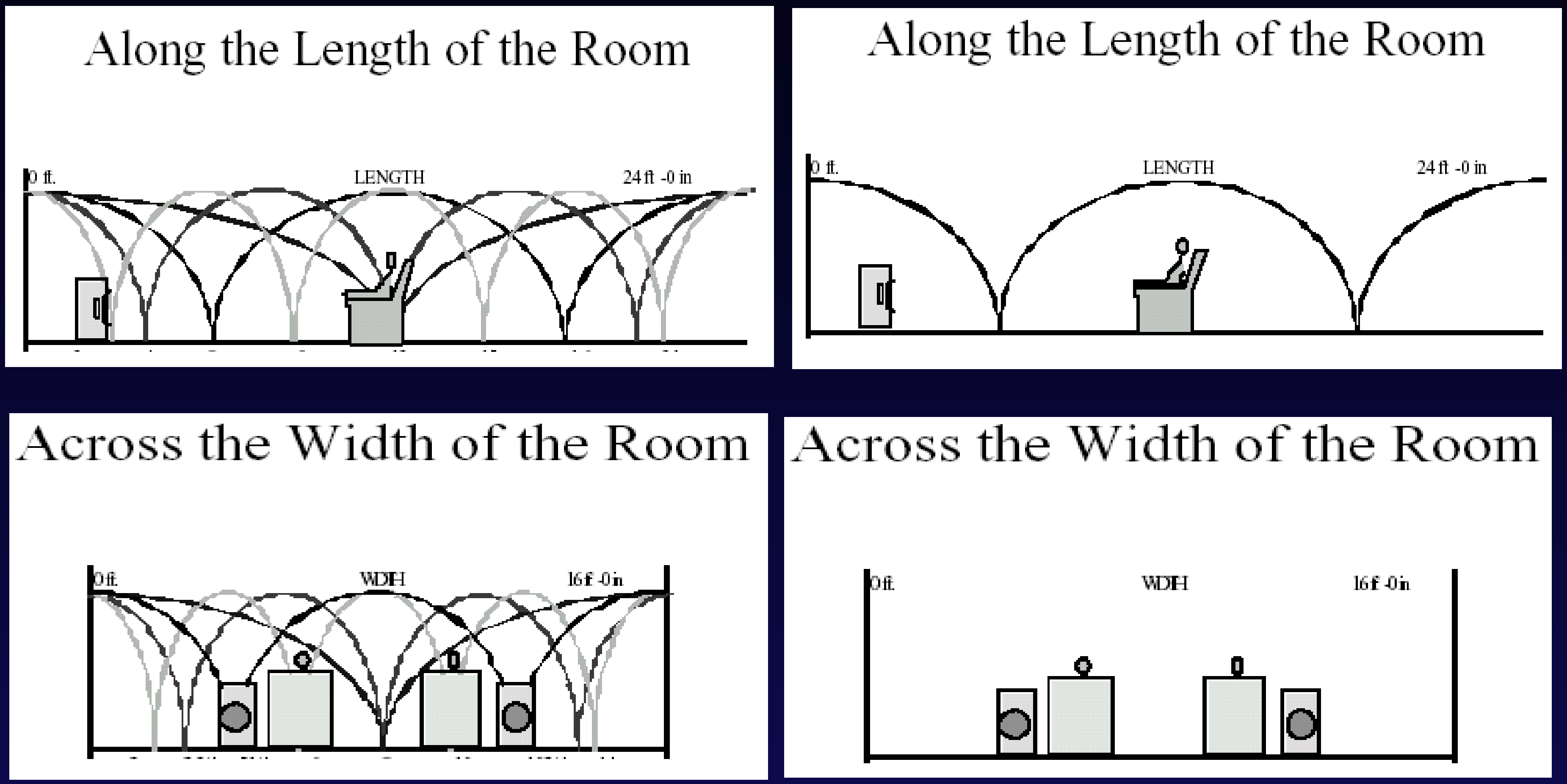


Figure 19

And guess what we found?

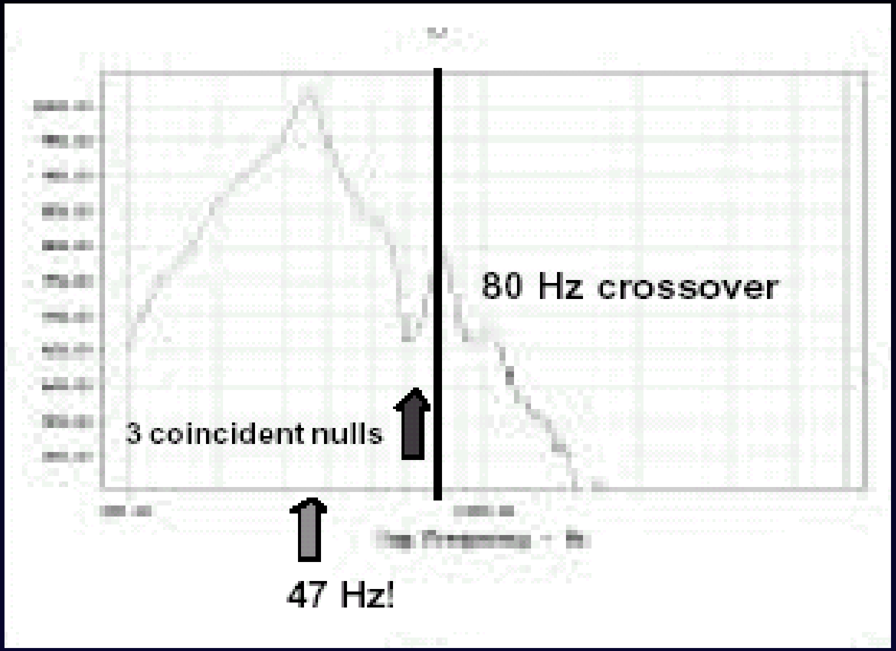


Figure 20

A simple fix!

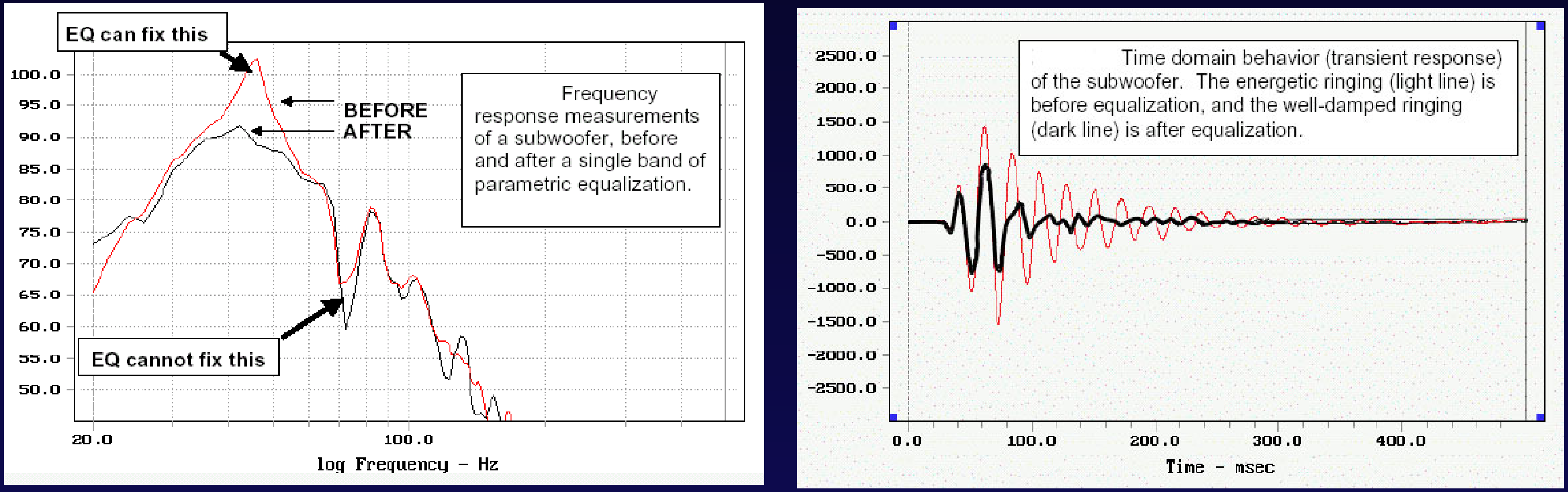
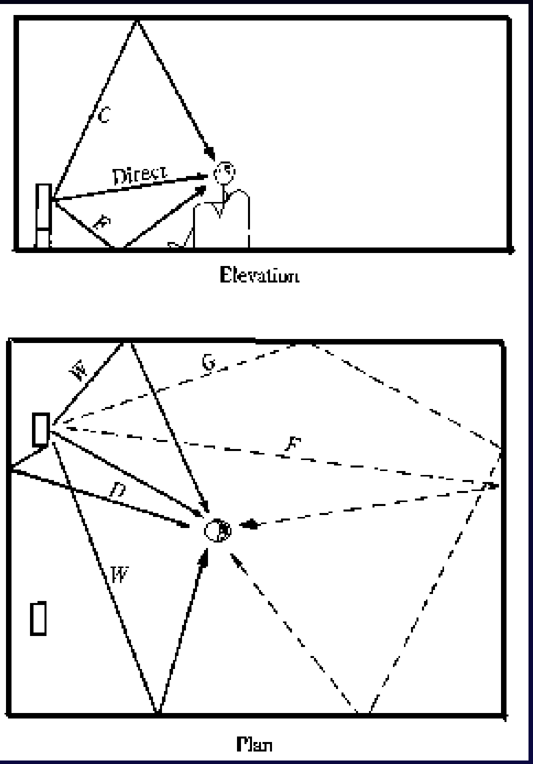
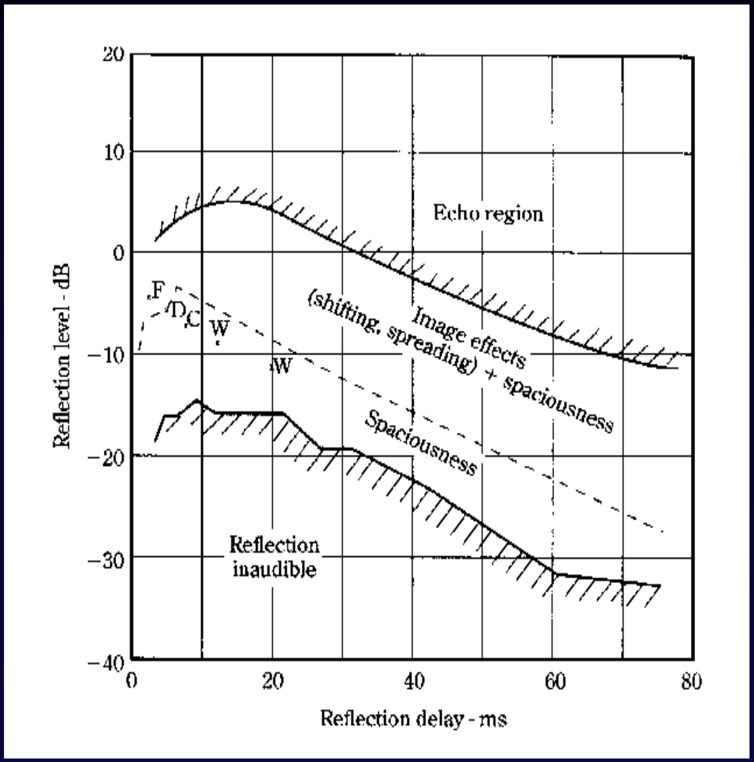


Figure 21

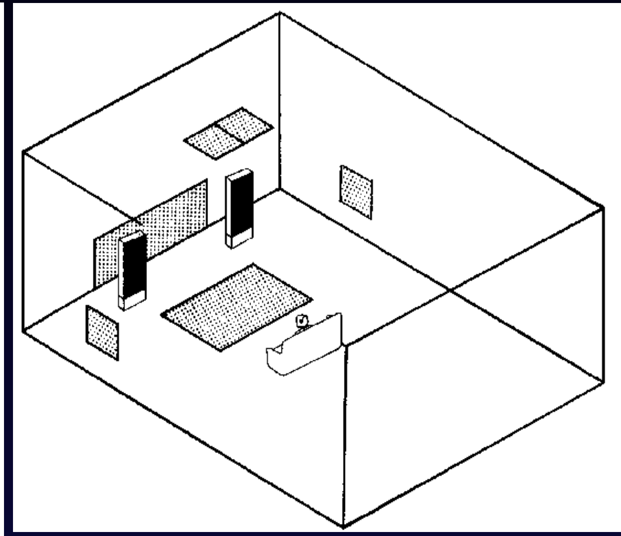
The Mid-High Frequencies



Early Reflections



Subjective Effect
of a Lateral Reflection



Sound Absorbing Treatment to Reduce the Level of Early Reflections

Figure 22

Studios and Control Rooms

Studio Volume

Studio dimensions.

	Ratio	Small studio	Medium studio	Large studio
Height	1.00	8.00 ft	12.00 ft	16.00 ft
Width	1.28	10.24 ft	15.36 ft	20.48 ft
Length	1.54	12.32 ft	18.48 ft	24.64 ft
Volume		1,000 cu ft	3,400 cu ft	8,000 cu ft

Studio resonances in Hz.

	Small studio	Medium studio	Large studio
Number of axial modes below 300 Hz	18	26	33
Lowest axial mode	45.9	30.6	22.9
Average mode spacing	14.1	10.4	8.4
Frequency corresp to room diagonal,	31.6	21.0	15.8
Assumed reverb, time of studio, second	0.3	0.5	0.7
Mode bandwidth (2.2/RT60)	7.3	4.4	3.1

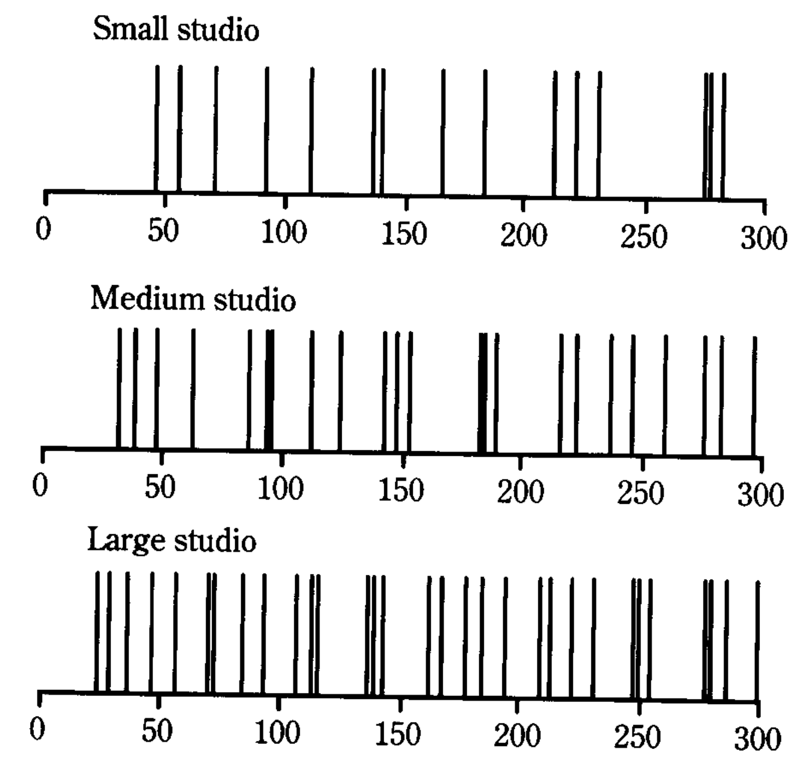


Figure 23

Mode Bandwidth = 2.2/RT

Average Mode Spacing = 4.0/RT (for $f > f_c$)

Studio Reverberation Time

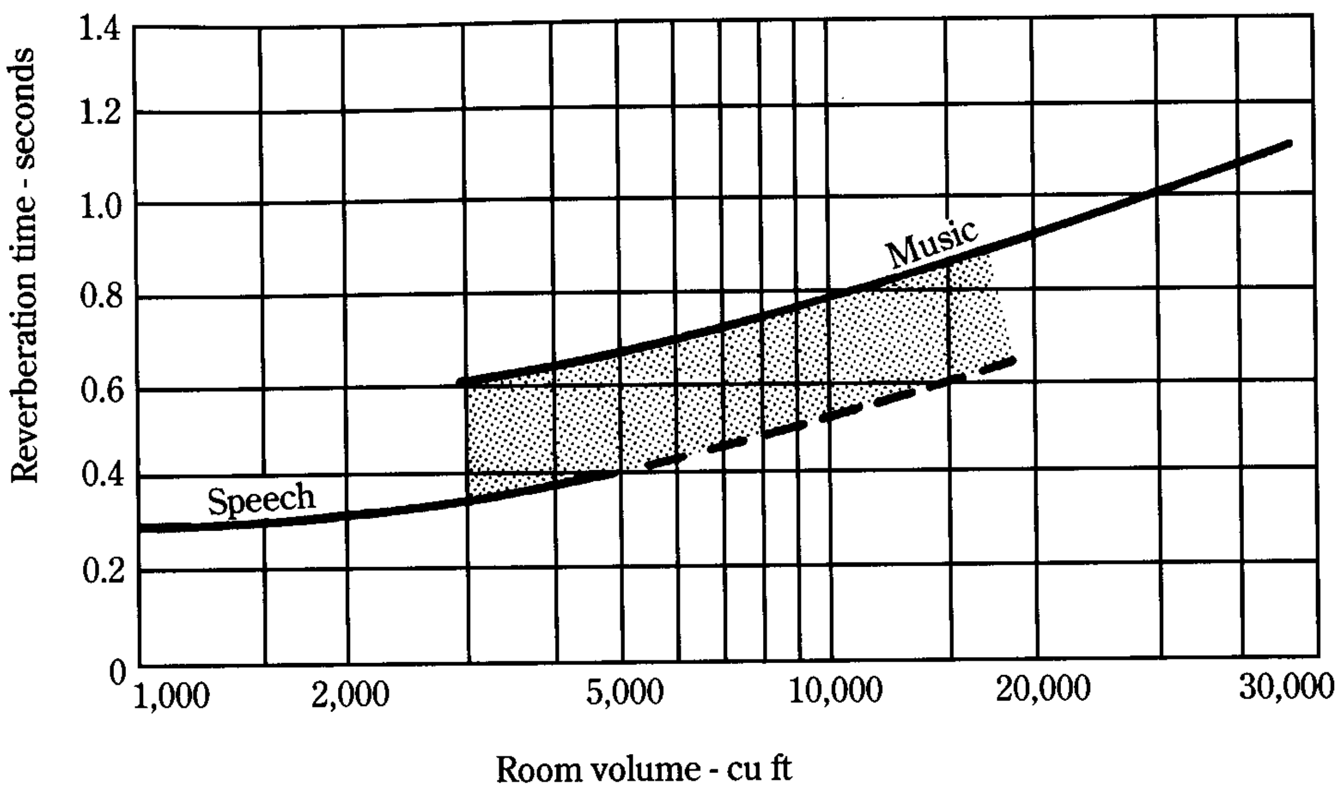
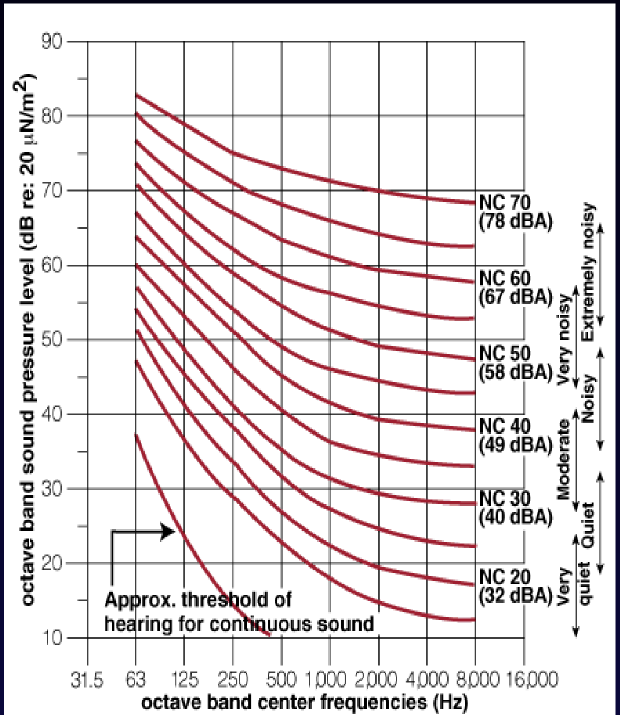


Figure 24

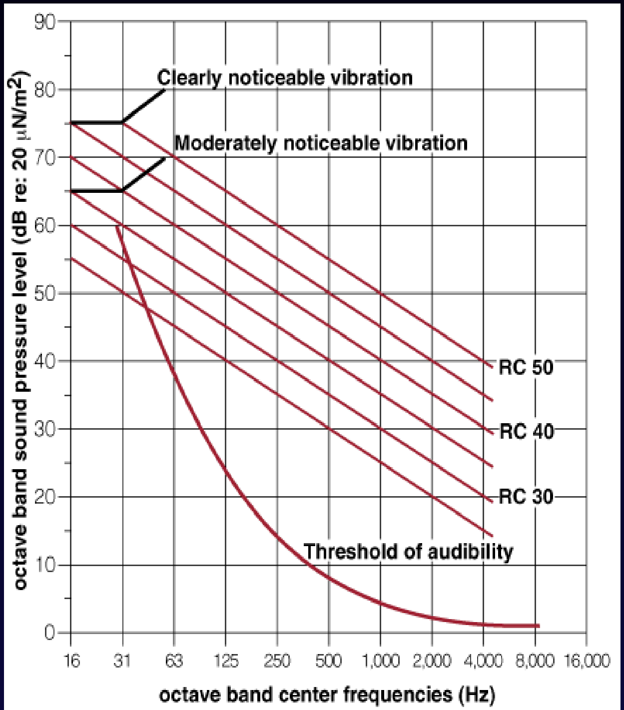
Suggested reverberation times for recording studios. The shaded area is a compromise region for studios in which both music and speech are recorded.

Figure 25

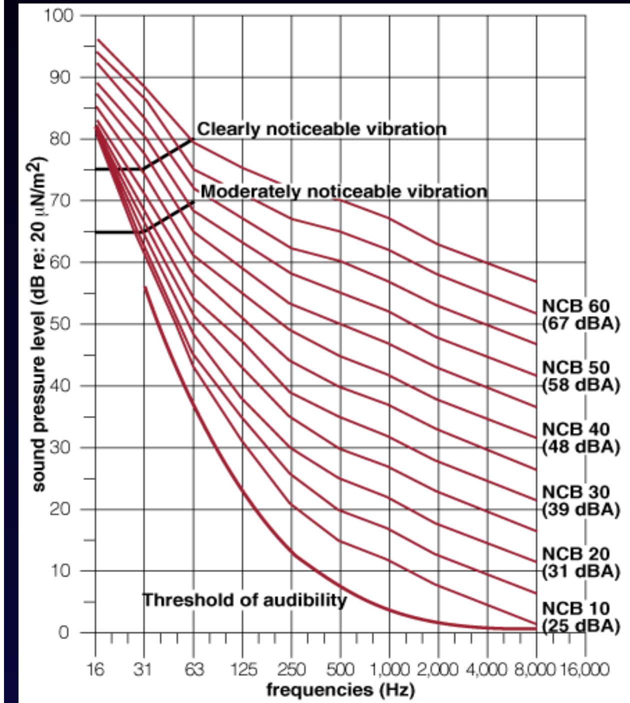
Studio Noise Levels



NC Curves



RC Curves (ANSI S12.2)



NCB Curves (ANSI S12.2)

Studio Type	RC Levels	NCB Levels
Recording and TV	20-25 (N)	15-25
Broadcast		10

Acoustics of the Control Room

In the recording studio:

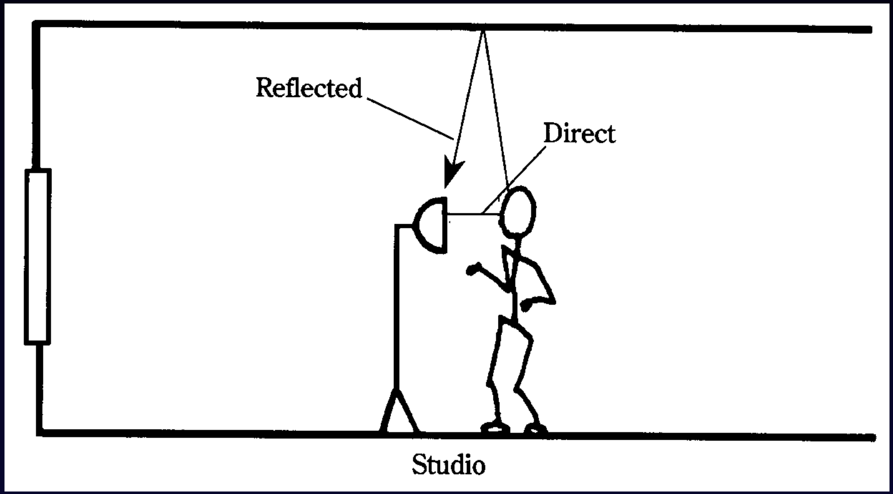


Figure 26

In the untreated control room:
many reflections from surfaces near the speaker obscure the ambience of the recording room.

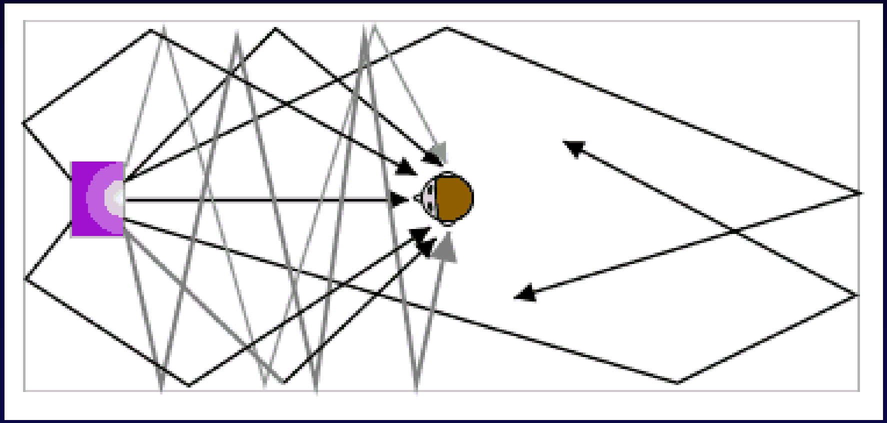
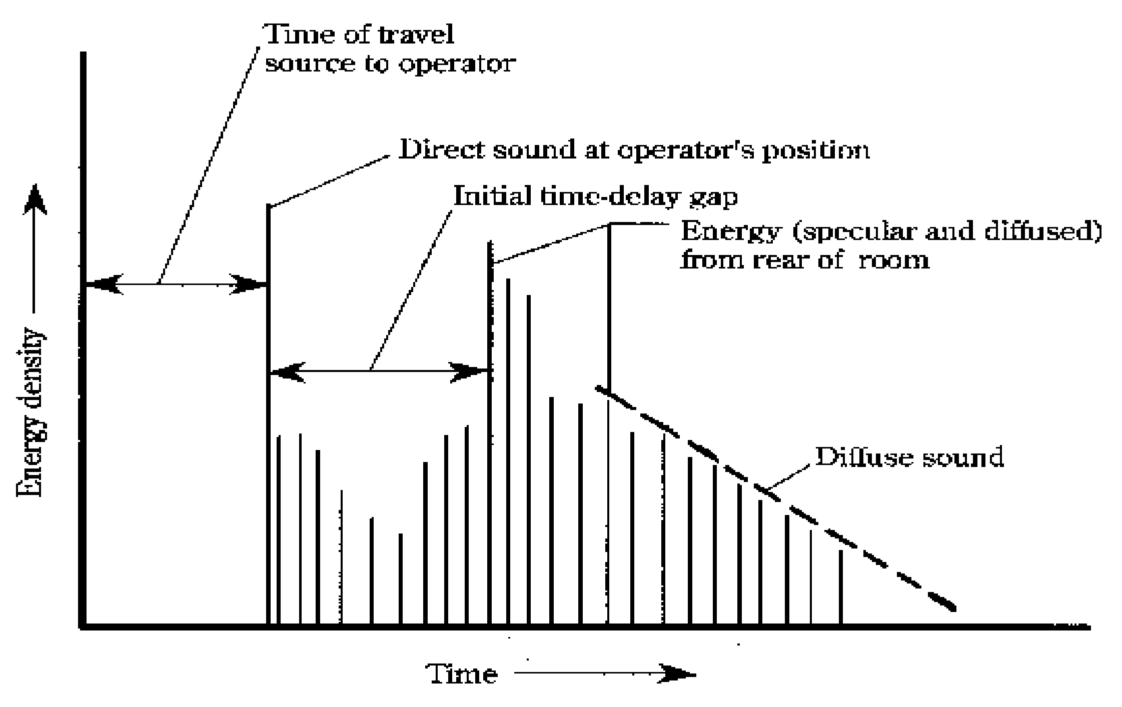


Figure 27

Acoustics of the Control Room

IN THE '80s Beranek's Initial Time Delay Gap (ITDG) was incorporated into the design of control rooms by Don Davis and Chips Davis.

<u>The idea is</u>: the ITDG of the control room has to be wide enough to avoid masking that of the recording studio.



The definition of the initial time-delay gap for a control room.

Figure 28

Live End Dead End (LEDE™)

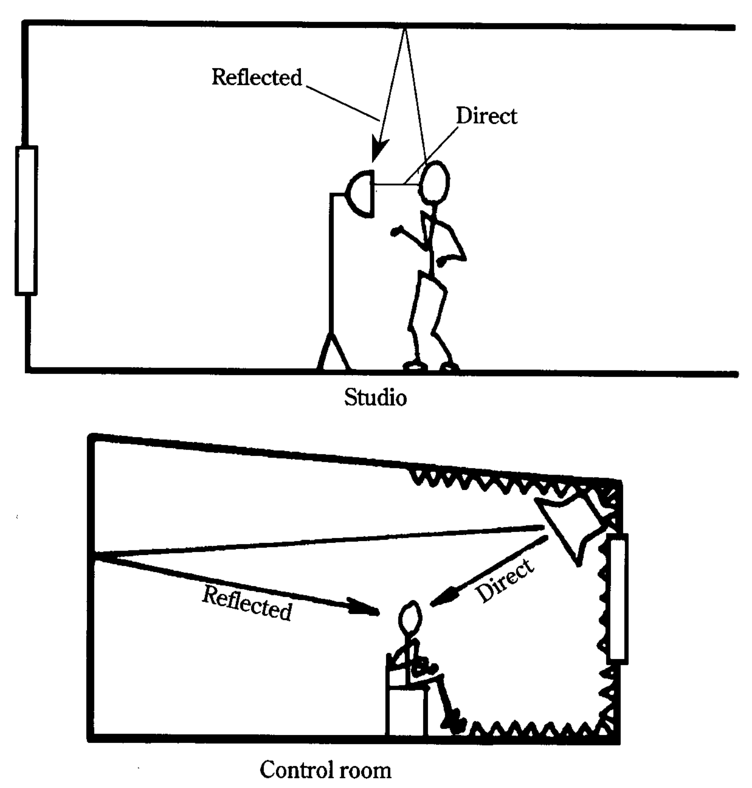


Figure 29

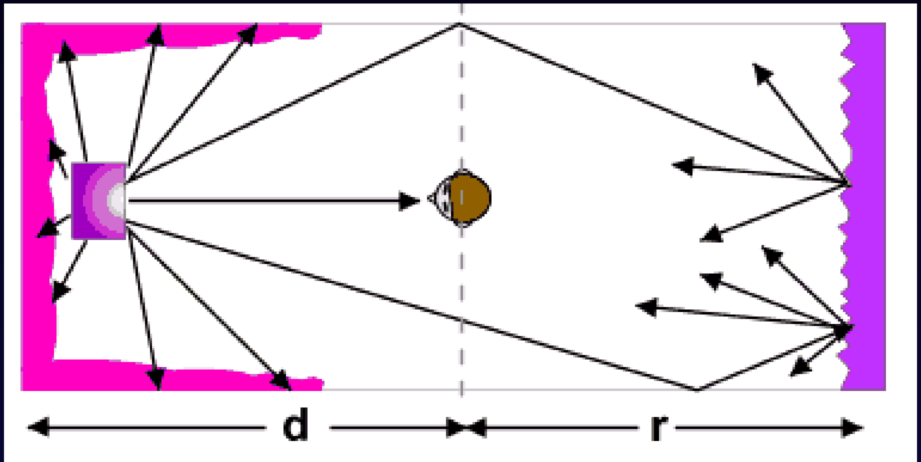
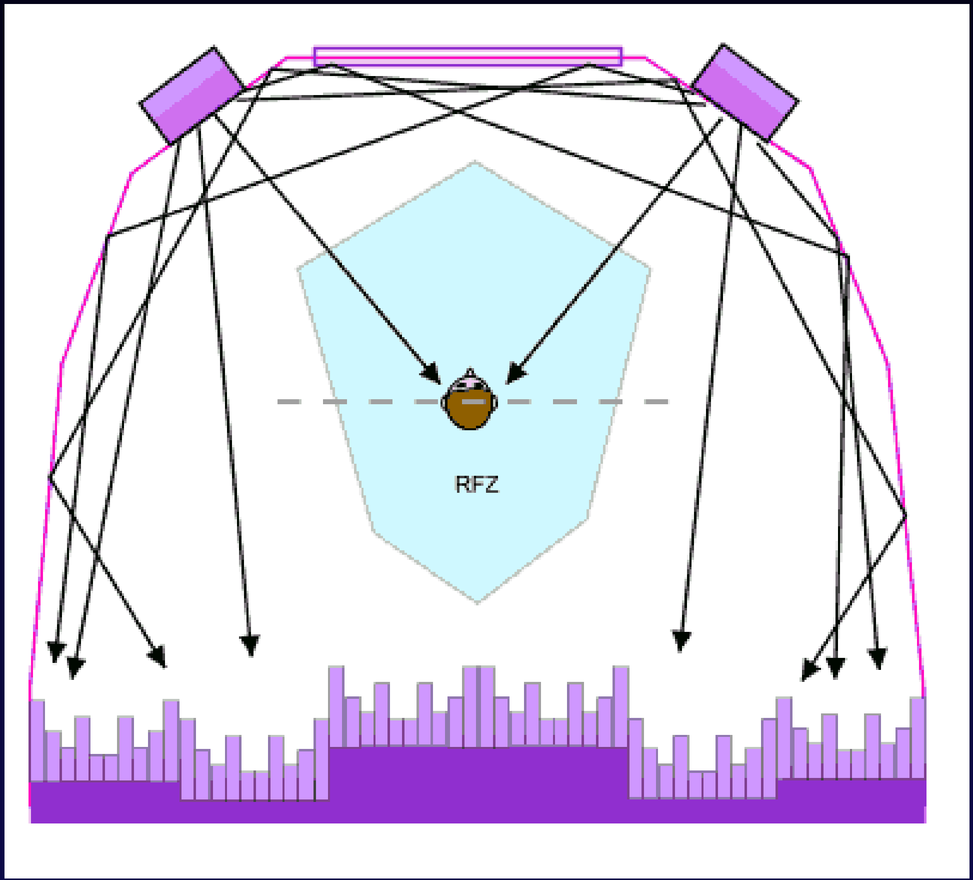


Figure 30

The studio ITGD can then be heard, resulting in a truly "neutral" control room.

Reflection Free Zone (RFZ)



Geometrically arrange the surfaces of the control room so that the reflections miss the mix position…..

Figure 31

Early Sound Scattering (ESS)

The early reflections are sufficiently diffused to mask the unavoidable reflections from the desk and racks.

The reflections from such diffusers are smoothly random, and so without character.

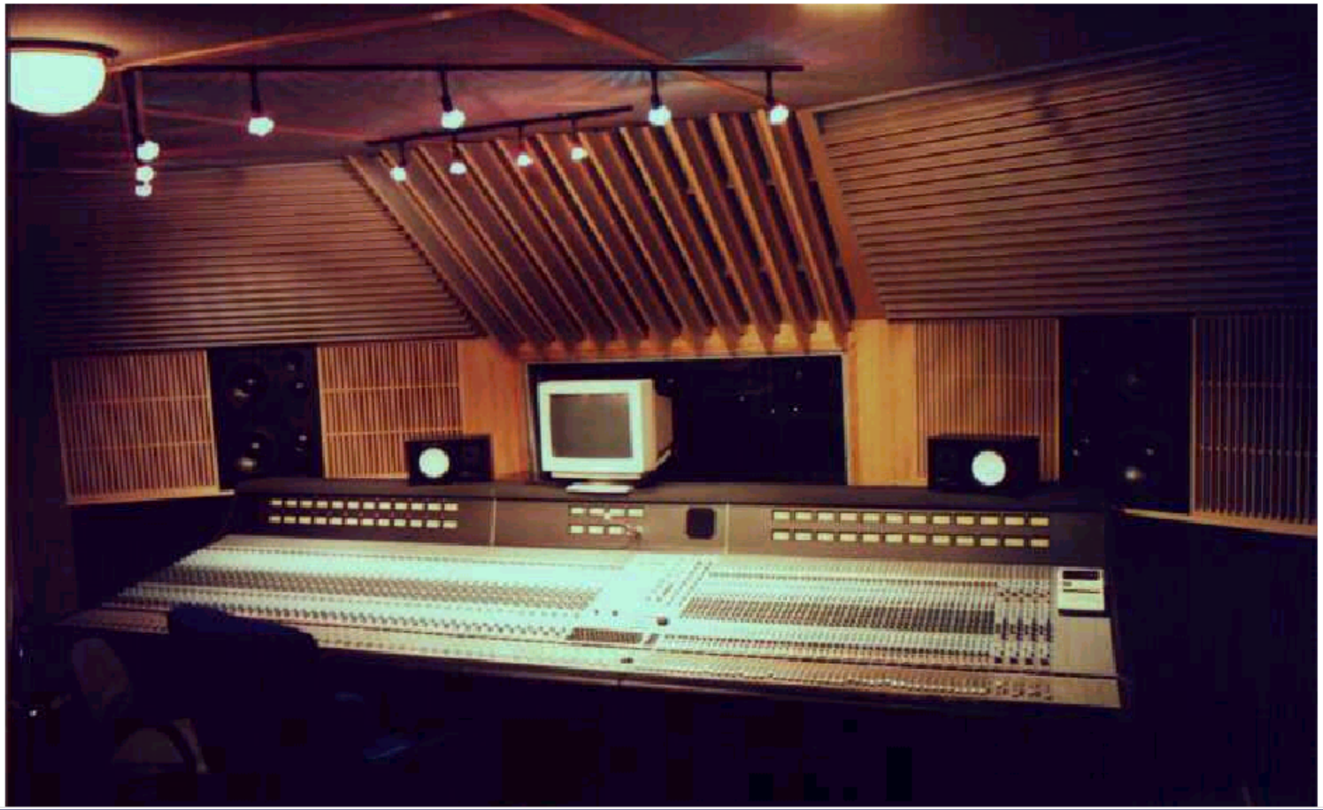
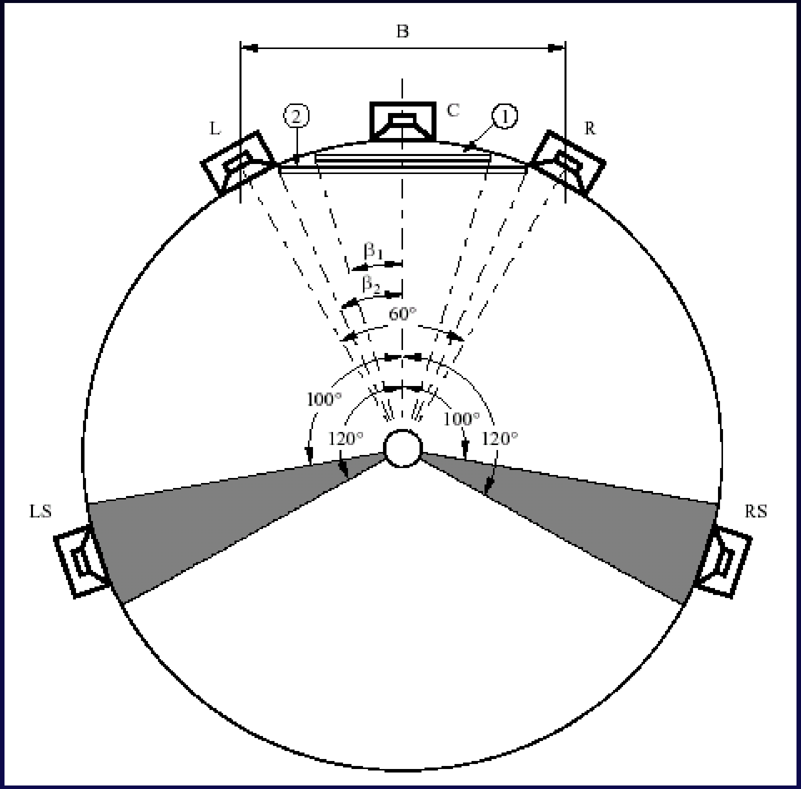


Figure 32

5.1 & 7.1 Sound Treatment

Since rear ambience is no longer needed (that is what the rear channel is for), what is important is: Room Symmetry, Bass Trapping, (See Ref. 16 for a Discussion on <u>Absorptive X Diffusion Treatments</u>)



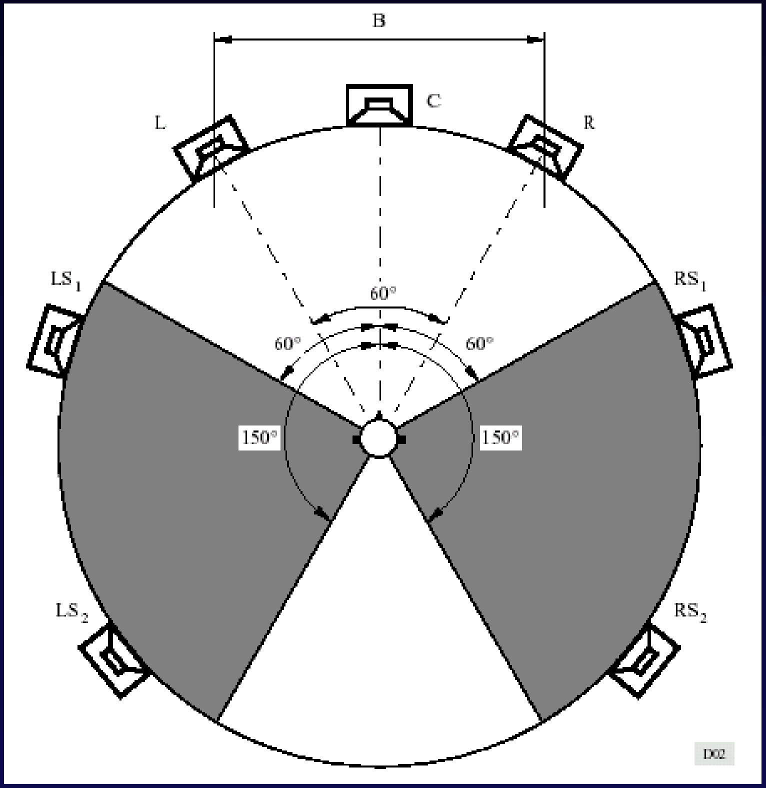
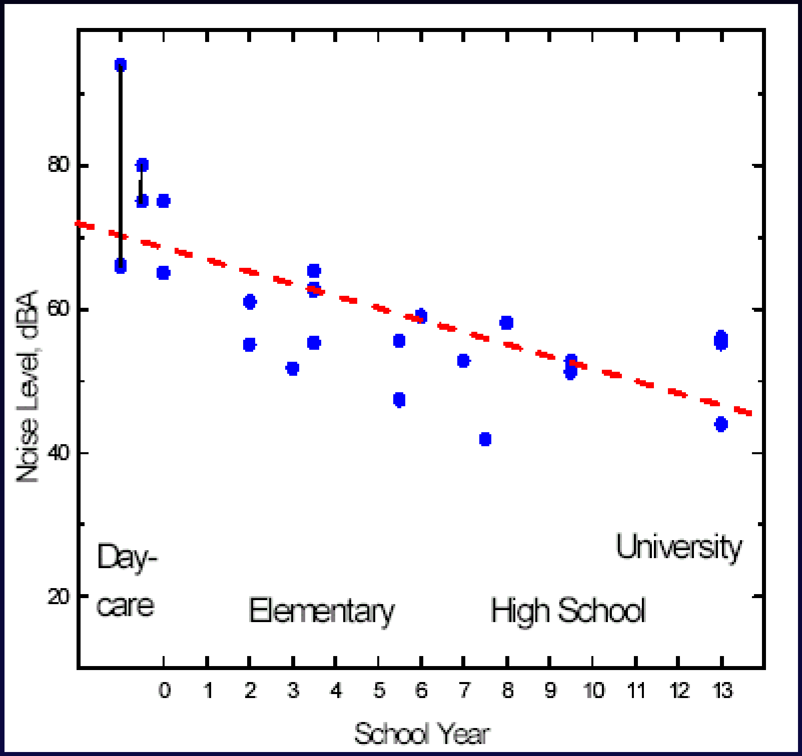


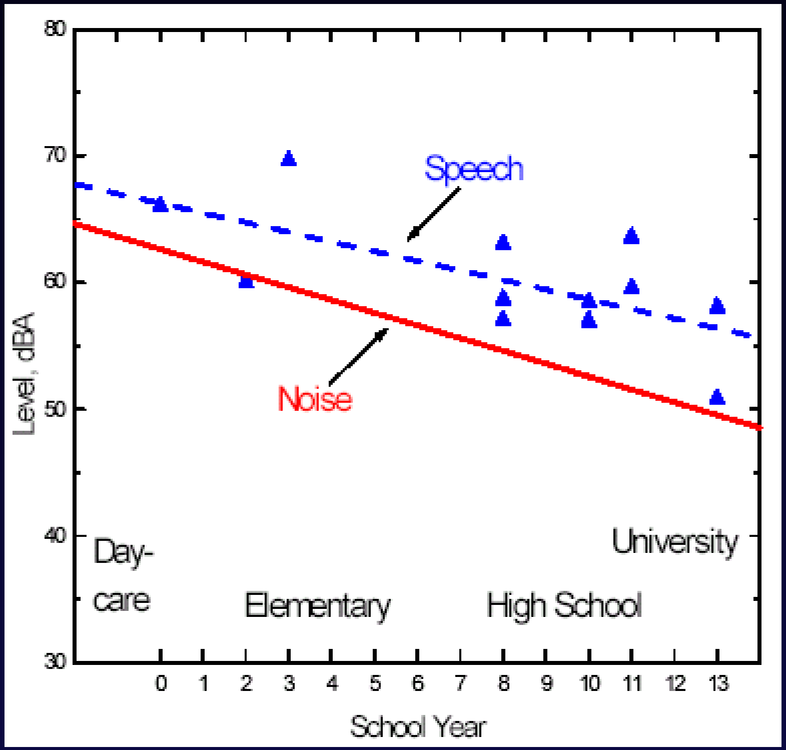
Figure 33

Acoustics of Classrooms

Ambient Noise Levels and Speech Levels of Teachers in Classrooms



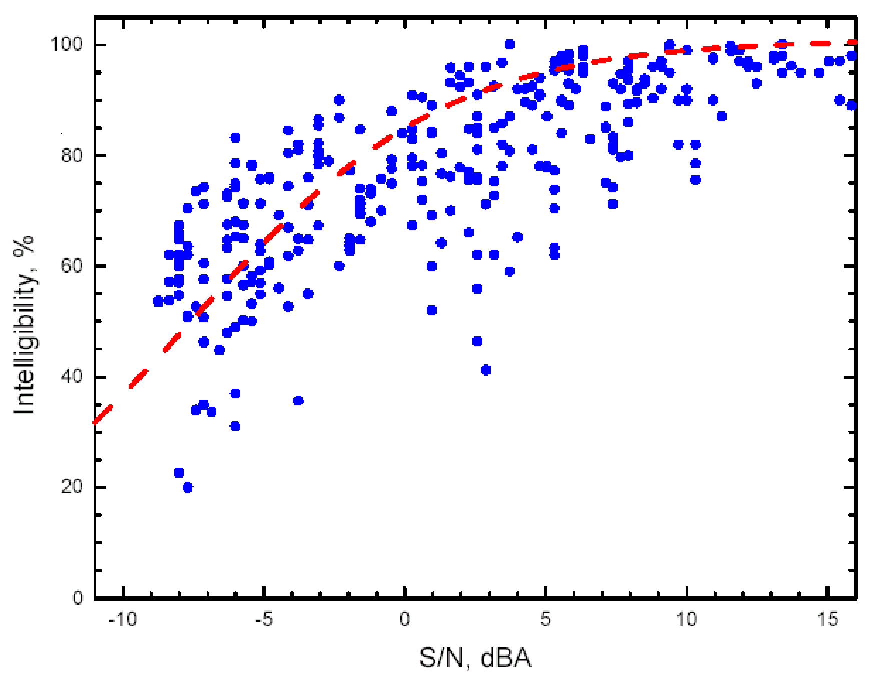
Ambient Noise Levels In Classrooms



Speech Levels of Teachers Measured in Classrooms

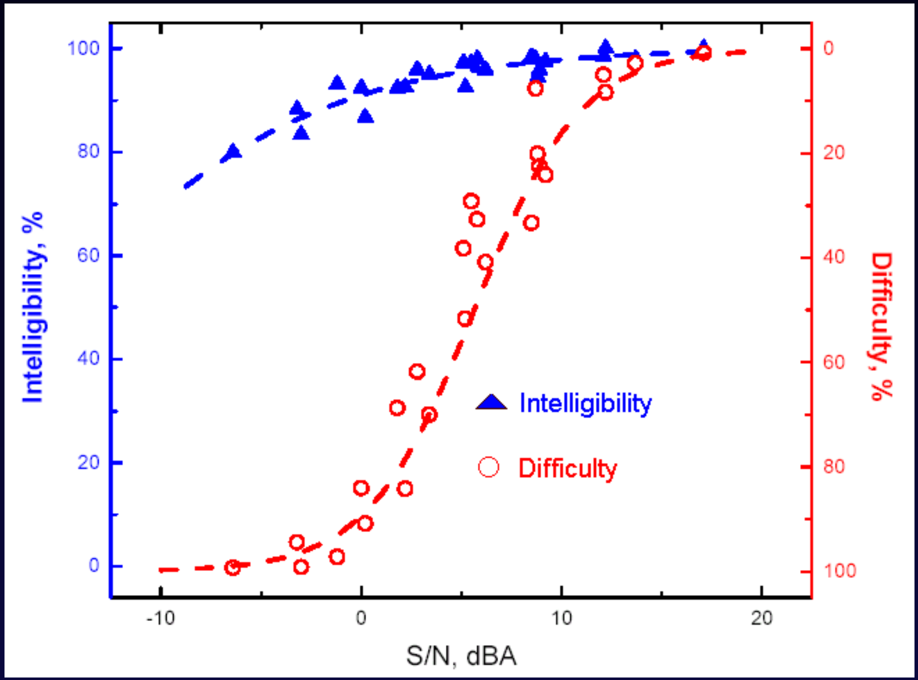
Figure 34

Speech Intelligibility and "Difficulty" of Listening to Speech X S/N Ratios



Speech Intelligibility (%) Versus A-Weighted S/N Ratios.

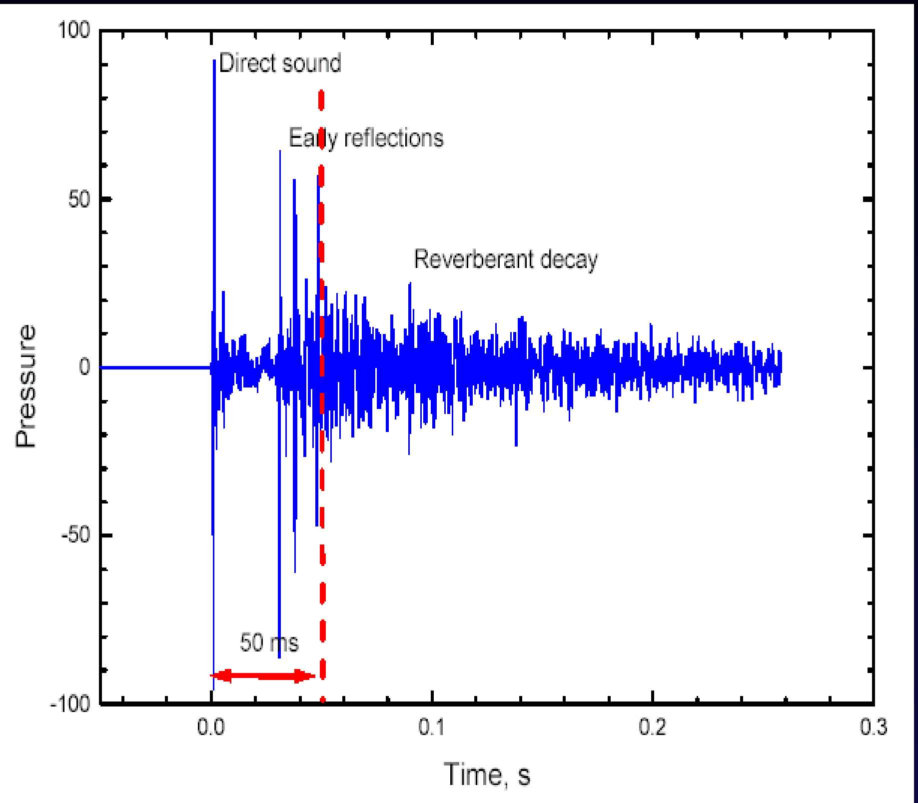
Figure 35



Speech Intelligibility (%) and "Difficulty" of Listening to Speech (%) Versus A- Weighted S/N Ratios.

Figure 36

Room Acoustic Measures Related to Speech Intelligibility



Example of a room impulse response showing the direct sound, early reflections and later-arriving reflections

The Speech Transmission Index STI is Derived From The Impulse Response

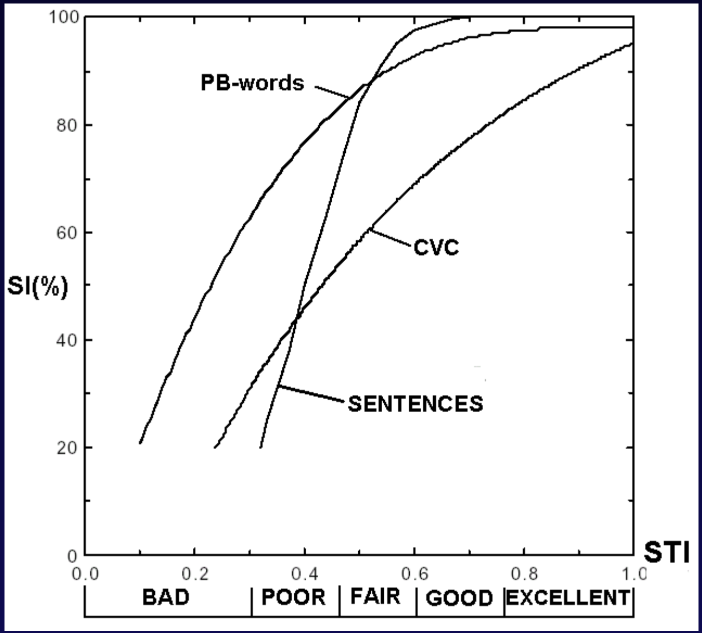


Figure 37

Speech Intelligibility for a 300 m³ *Classroom According to STI for Different Reverberation Times and S/N Ratios*

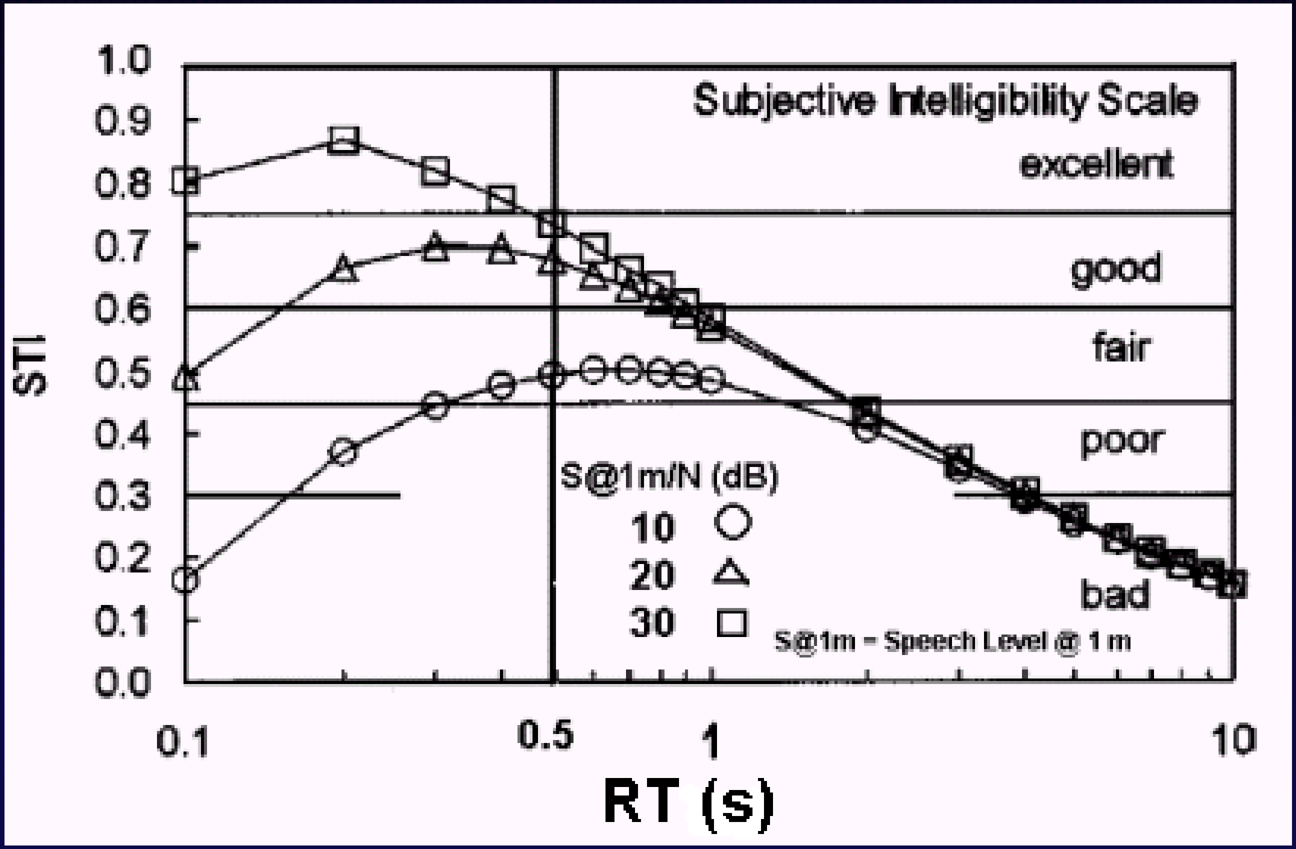


Figure 38

Maximum Acceptable Ambient Noise

Two Example Estimates of Maximum Acceptable Ambient Noise Levels	#1	#2
Speech source level @ 1 m	60 dBA	55 dBA
Required S/N	-15	-15
Room effect	-5	-5
Extra for 0% difficulty or special needs groups	-5	0
Maximum noise level	35 dBA	35 dBA

References

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