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A STUDY OF ROOM GEOMETERY AND DIFFUSION IN SOUND CONTROL ROOMS

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1. INTRODUCTION

This paper is based on case study of a critical listening /music control rooms based on ideal room dimensions [1] and the methods employed to achieve a well diffused sound field at the listing position. This is also an attempt to find a correlation between the room geometry and shape of the room and the measured results at the critical listing position.

The effect of quadratic residue type diffusers in sound control rooms are also reviewed in non ideal shaped rooms and how they contribute towards achieving good early specular energy patterns at the listener position.

2. ROOM RATIOS

Early research suggests that many architects designing rooms for music performances generally followed the 1:2:3 ratio due to its similarity to the harmonic, integrally multiple relationship of the fundamental and overtones of so many musical instruments. However it was soon realised by acousticians that this issue should be investigated by the aid of wave acoustics in place of geometric acoustics[1].

Below are six of the formerly most prominent dimensional ratios.

Ratio	Description	Ratio for equal ceiling height
1:2:3	Harmonic	1:2:3
1.6:3:4	Vern O. Knudsen	1:1.88:2.5
3:5:8	European	1:1.67:2.67
1:1.6:2.5	J. E. Volkman	1:1.6:2.5
2:3:5	Sabine	1:1.5:2.5
(5 ½ - 1):2:5(5½ + 1)	Greek "Golden section"	1:1.62:2.62

It must be noted that these ratios, calculated for equal height are not very different to each other and one would imagine that it would be not be possible to appreciate the difference between them just by listening tests to establish that one is better than the other. There is no published research to date, where comparative acoustic measurements are carried out in rooms built to the above listed ratios.

Ratio	Ratio for Equal Ceiling Height
1:2:3	1:2:3
1.6:3:4	1:1.88:2.5
3:5:8	1:1.67:2.67
1:1.6:2.5	1:1.6:2.5
2:3:5	1:1.5:2.5
1.236:2:3.236	1:1.62:2.62

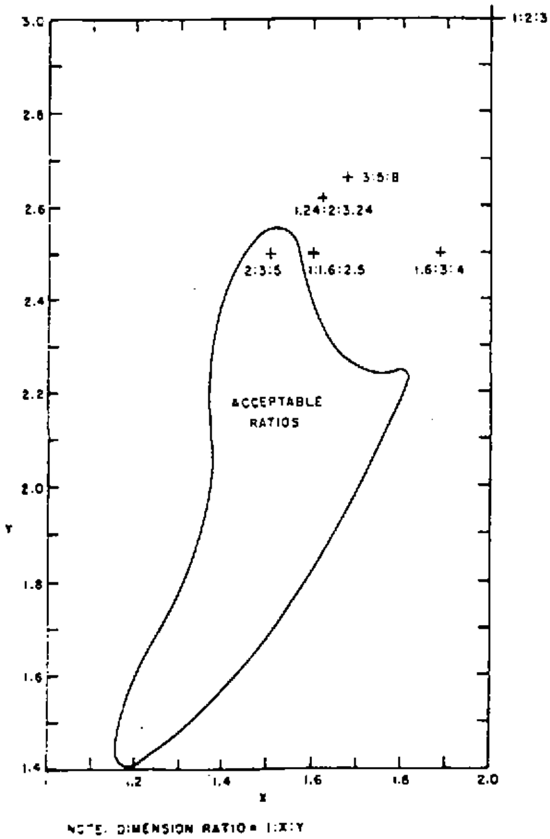


Fig. 1 Curve encloses dimension ratios for width to length of a rectangular room with unity ceiling height to give smooth response at low frequencies.

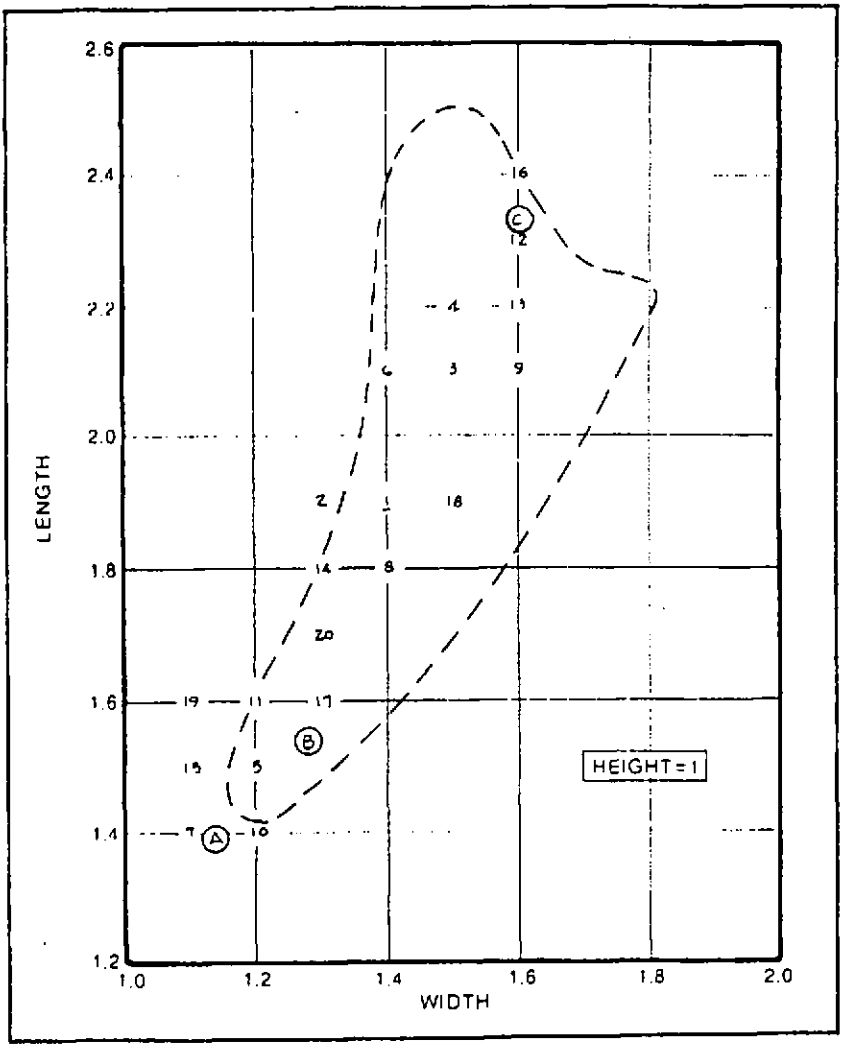


FIGURE 2

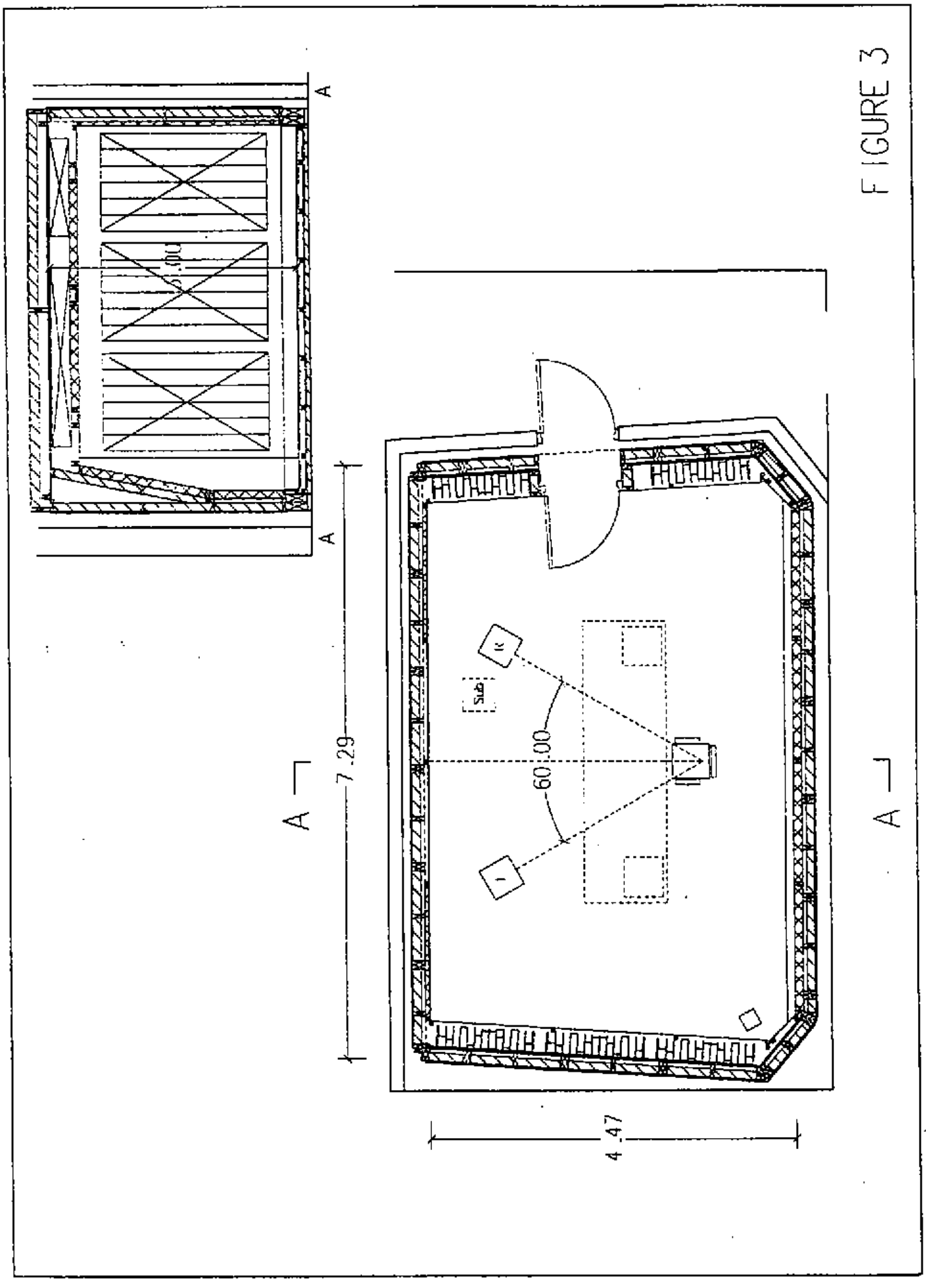
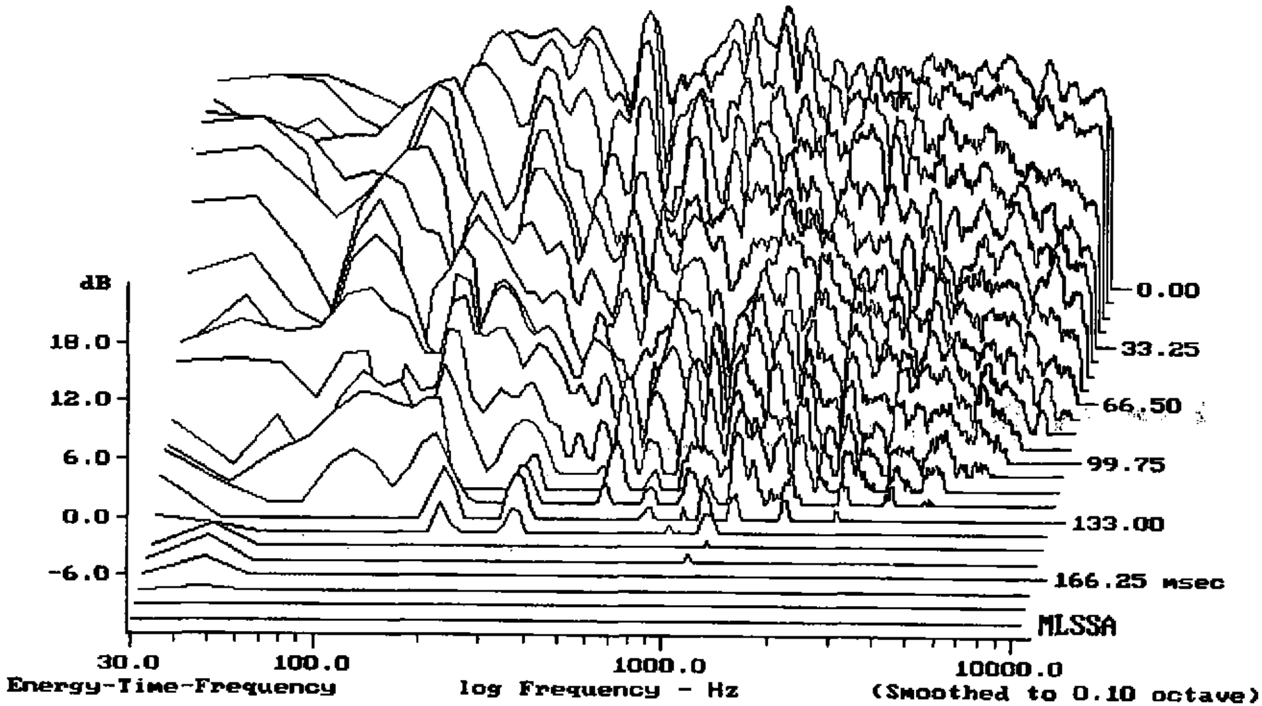


FIGURE 3



7.87 dB, 2511 Hz (171), 0.000 msec (0)

Figure 4

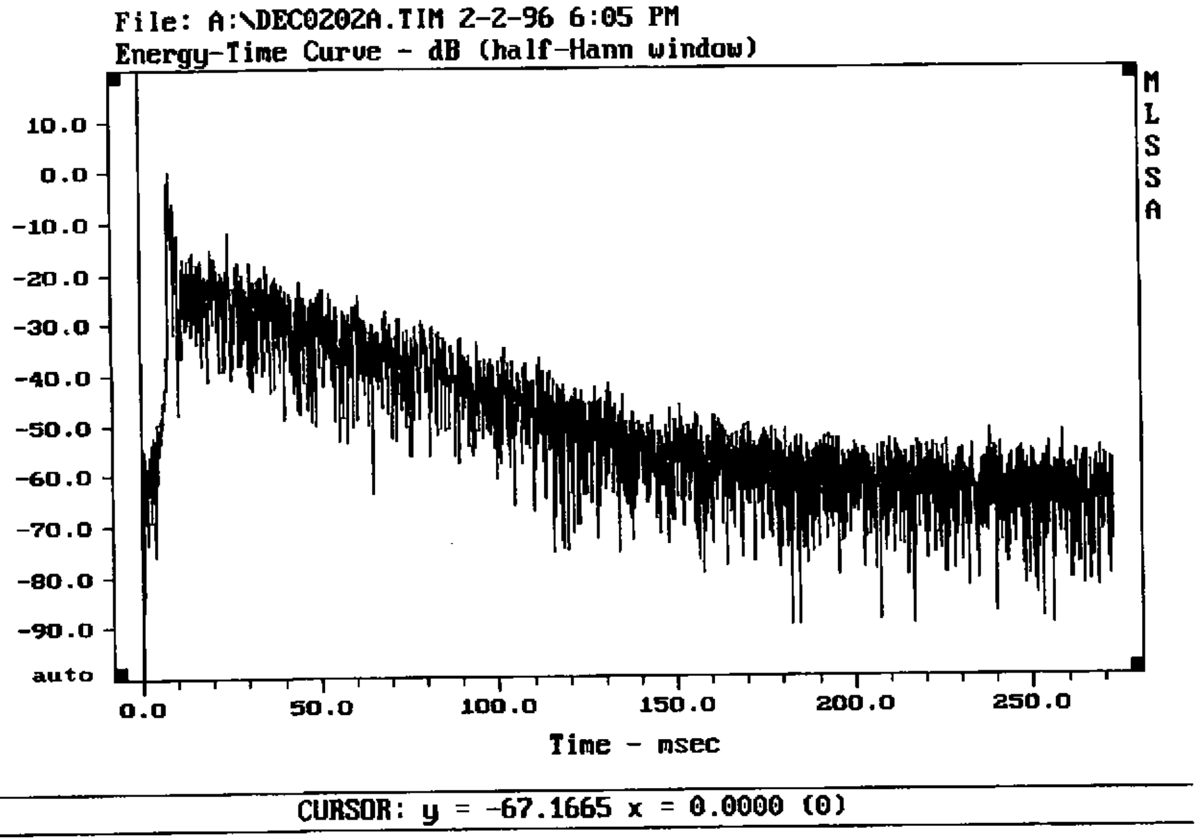


Figure 5

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MLSSA: Time Domain

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As this issue was investigated by more advanced physical and mathematical methodology, it was found that there is no one optimal ratio of dimensions, only a range of acceptable ratios.

According to R.H. Bolt's [2] findings the low-frequency limit of acceptability was more a function of room volume than dimensional ratio. He produced a chart (fig 1) which plots the area of acceptable ratios for uniform low frequency modal distribution. The above listed ratios are also plotted on this chart.

In 1965 Sepmeyer[3] published the results of another mathematical study of normal mode distribution which primarily listed three ratios for equal ceiling height. Two of these ratios fall within Bolt's acceptable ratios area.

His ratios are	A	1 : 1.14 : 1.39
	B	1 : 1.28 : 1.54
	C	1 : 1.6 : 2.33

Fig 2 shows the Sepmeyer ratios plotted on Bolt's chart.

Louden's findings published in 1971 [4] listed 125 room dimensional ratios arranged in order of decreasing "quality". First twenty best ratios are as follows:

order of Quality	1	:	x	:	y
1			1.9		1.4
2			1.9		1.3
3			1.5		2.1
4			1.5		2.2
5			1.2		1.5
6			1.4		2.1
7			1.1		1.4
8			1.8		1.4
9			1.6		2.1
10			1.2		1.4
11			1.6		1.2
12			1.6		2.3
13			1.6		2.2
14			1.8		1.3
15			1.1		1.5
16			1.6		2.4
17			1.6		1.3
18			1.9		1.5
19			1.1		1.6
20			1.3		1.7

Only five of the above ratios fall out side Bolt's area of acceptable ratios.

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More recently, the ITU recommendation document ITU-R BS.1116-1 [5] relating to critical listing room standards gives a formula to check the room dimensions for a reasonably uniform distribution of the low-frequency eigentones of the room:

$$1.1\, w/h \leq l/h \leq 4.5\, w/h - 4$$

Where w : width , l : length and h : height

Additionally, the condition $l/h < 3$ and $w/h < 3$ should apply

4. A REAL EXAMPLE

A case study of a Munro Associates project is presented where the brief was to acoustically design a critical listening room within a given floor space in an existing building. The client 's requirements very clearly stated that all of the given floor space must be utilised to make the finished room as big as possible.

Also, the technical engineers brief required that the room to have a domestic living room type acoustic environment as the main tasks to be carried out in this room was the mastering of Classical music. The aim was that the acoustic environment at the mastering stage should be representative of the end user's playback environment.

4.1 ROOM SIZE AND SHAPE

The given floor space to construct the room was approximately 8m x 5.4m but, unusually, the on site clear floor to ceiling was more than 5m.

In line with the client's brief, the internal walls of the room were built with a 100mm gap between the existing walls to maximise the finished internal floor area. The only dimension we had to choose was the height of the room, which was decided to be 3m. Figure 3 shows the plan and section view of the final design.

The final internal dimensions of the room, that is, 3m x 4.47m x 7.29m (V=97.7m3) are compared with the room ratios listed in section 3 are as follows:

Final room ratio		1	:	1.49	:	2.43

The closest matches are:

Sabine		1	:	1.5	:	2.5
Sepmeyer	C	1	:	1.6	:	2.33
Louden	4	1	:	1.5		2.2

More importantly, the final ratio fell well within the Bolt's area of acceptable ratios. It also satisfied the ITU criteria of:
$1.1\, w/h \leq l/h \leq 4.5\, w/h - 4$ and $l/h < 3$ and $w/h < 3$

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4.2 INTERNAL ACOUSTIC TREATMENT

As this room was to be used for critical listing applications, specially for classical music programs recorded in large performance space having reverberation times of more than one second, it was realised by us at the design stage that an initial time gap of more than 15ms should be achieved between the first arrival of sound and the first significant reflection.

It was also established that in order to create a realistic living room acoustic environment, the first 50ms energy time decay pattern must be very well diffused with a relatively high level of specular reflection off the room surfaces.

Figure 3 shows the layout of full height quadratic residue diffusers on the side walls to achieve a well diffused specular energy sound field at the monitoring position. The theoretical operational bandwidth of these diffusers were from 500Hz to 4KHz.

The acoustic treatment at the ceiling position was broad band, low and mid frequency tuned absorbers with a layer of acoustic foam in front to minimise the level of early reflections from the surface. Front and back walls were treated in similar fashion and the floor finish was thick carpet.

In addition to the above, the electro-acoustic set-up of the room was laid-out in line with the ITU recommendation for monitoring angles and speaker placements, as shown in figure 3.

5. MEASURED RESULTS

A range of acoustic measurements were taken at the commissioning stage.

5.1. REVERBERATION TIMES

The measured RT with all finishes in place were recorded as:

Octave bands	63	125	250	500	1000	2000	4000	8000
Time in sec	0.33	0.32	0.28	0.28	0.24	0.245	0.22	0.22

The measured RT are in line with the ITU recommendations for rooms up-to 100m3 with a slight deviation at low frequencies. The lack of rise in RT at frequency bands below 250Hz was due to the relatively light weight shell construction, that is, two layers of 12mm plasterboard on each face of timber studs.

5.2. HVAC NR CRITERIA

The measured octave band background noise levels due to the HVAC system was well with-in the NR 15 ISO NR curve[6] which complies with the ITU recommendations.

5.3. MODAL DECAY PATTREN

Figure 4 shows the MLSSA waterfall plot of a measurement taken at the operators / critical listing position with the signal being played through the left and right loudspeakers simultaneously. There is an indication of an un-damped room mode at around 80 Hz and possibly the first harmonic of the same mode at 160Hz.

This phenomena was further investigated with frequency domain measurements and the effect was minimised by placing the sub-woofer off centre, towards the right speaker [7].

In general the modal decay pattern is very uniform, with consistent decay rates across the frequency bands.

5.4. ENERGY TIME CURVE

Figure 5 shows the measured MLSSA energy time decay curve. The initial time gap was recorded to be 18.2ms. The first 50ms energy decay pattern suggests that the level of early reflections is only 20 to 25dBs lower than the direct sound level but the decay pattern is dense and follows a gradual slope.

6. CONCULSION

It must be noted that all the theories relating to ideal or preferred room ratios are for rectangular rooms only . The room used as an example in this paper had angled side walls and it maybe argued that the theory does not apply. In the given example the side walls were angled to ensure that the room did not have any flutter and slap-back echoes.

In small rooms such as the one mentioned in this paper ($V \leq 100m3$) , angling of walls up-to 5 to 10 degrees will not have a major effect on the low frequency modal distribution and it is considered that the theoretical rectangular room model would still apply.

In addition to the room geometry, to achieve the desired acoustic environment within a room, it is absolutely vital that targets are set at the design stage for acoustic parameters such as reverberation times, HVAC noise criteria, frequency responses and early reflection patterns.

The current standard documents such as the ITU recommendations is a good guide to set the targets for critical listing rooms.

The acoustic absorbing and diffusing surface should be placed at strategic positions to achieve the desired sound field at the critical monitoring position.

7. REFRENCES

1. M. Rettinger, 1977, Acoustic design and Noise Control - Chemical Publishing Co.
2. R.H.Bolt, 1946, Note on normal frequency statistics for rectangular rooms - Journal of Acoustic Society of America, Vol. XIX, No. 1
3. L.W.Sepmeyer, 1965, Computed Frequency and Angular Distribution of the Normal Modes of Vibration in Rectangular Rooms - Journal of Acoustic Society of America Vol. 37, No. 3
4. M.M.Louden, 1971, Dimension-Ratios of Rectangular Rooms With Good Distribution of Eigentones - Acustica, Vol. 24
5. Rec. ITU-R BS.1116-1, 1994 1997, Methods for the Subjective Assessment of Small Impairments in Audio Systems including Multi-channel Sound Systems
6. ISO Recommendation R1996 (1972)
7. R. Walker, 1996, The Effects of Low-Frequency Room Modes - Proc. IOA Vol 18 Part 18

8. RE-PRODUCED MATERIAL

1. Figure 1 is reproduced from M. Rettinger, 1997, Acoustic design and Noise Control - Volume 1 Acoustic Design - Page 88 - Chemical Publishing Co.
2. Figure 2 is reproduced from F.Alton Everest, 1984, Acoustic Techniques for Home & Studio 2nd Edition - Page 119 - TAB Books Inc.