EXAMINATION OF THE EFFECT OF SOURCE LOCATION ON SOUND POWER MEASUREMENTS AT LOW FREQUENCIES

by

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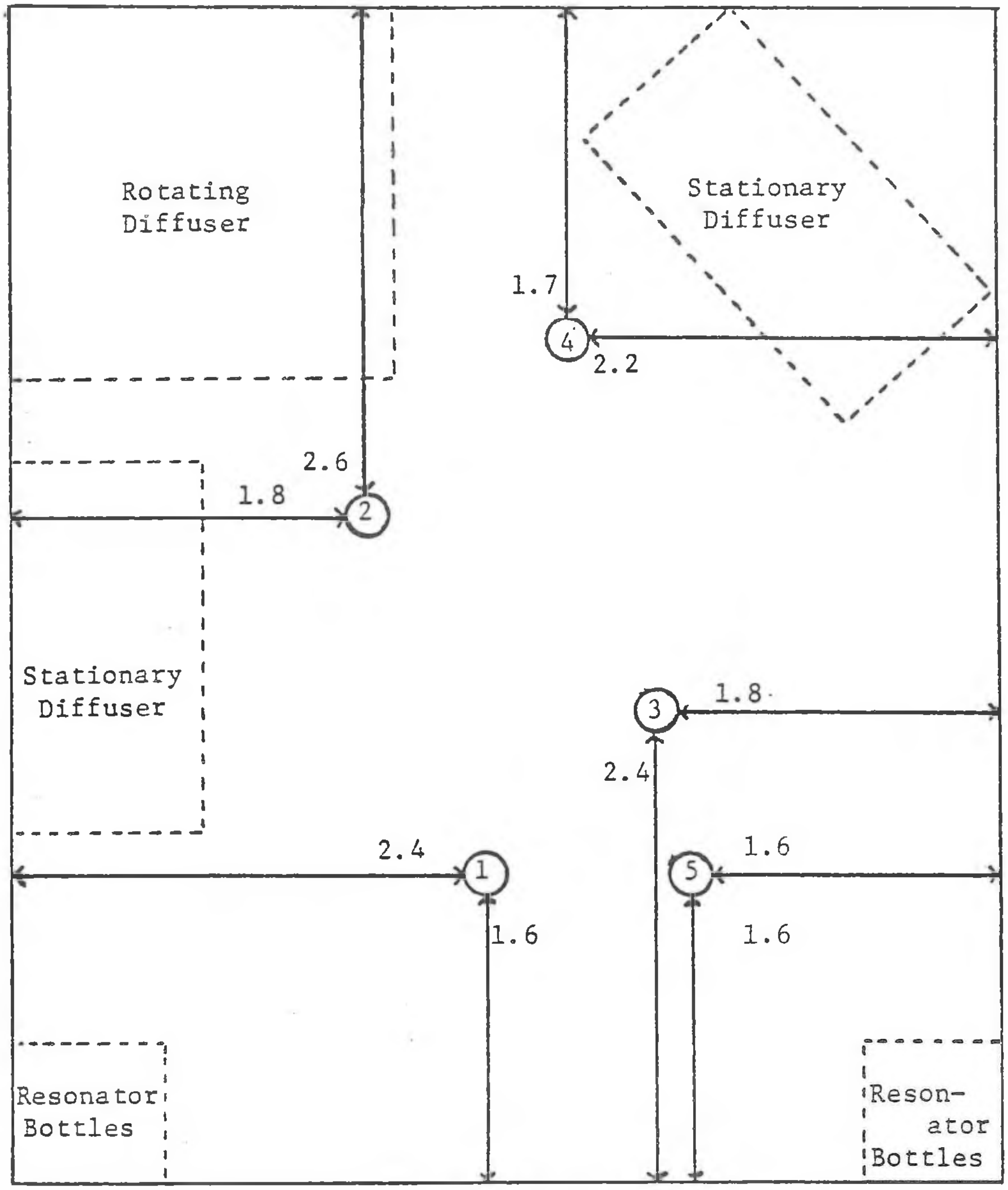
ABSTRACT

The influence of source location and room modifiers are examined with respect to the effectiveness of source position averaging in reducing measurement error for sound power measurements in reverberation rooms.

SOMMAIRE

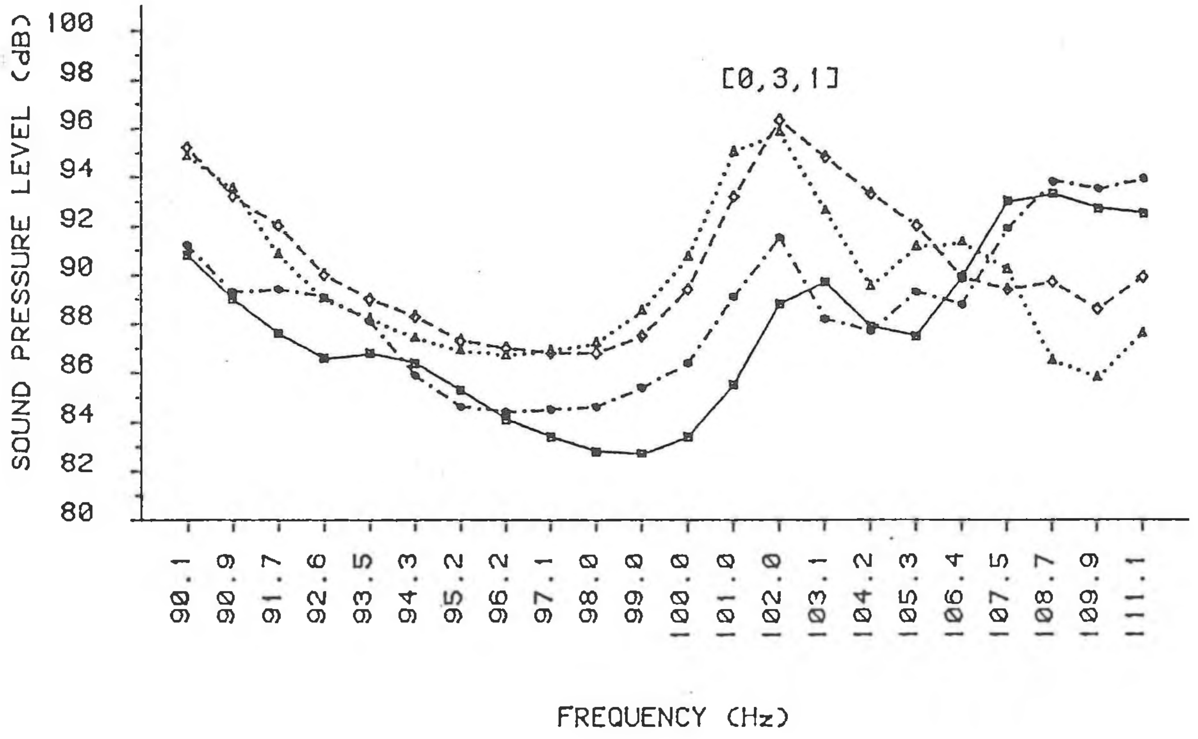
L'influence des modifications apportées à la chambre ainsi que l'incidence de la position de la source sont examinées en regard de la réduction des erreurs de mesures obtenues à partir d'une moyenne entre différentes positions de sources pour la mesure de puissance acoustique en chambre réverbérante.

It is well documented (1, 2, 3, 4, 5) that the precision with which low frequency sound power can be measured in a reverberation chamber depends not only on the effectiveness of the particular sound pressure sampling arrangement, but also on the position of the source within the room which affects the actual power radiated. In many cases, averaging of measured sound pressure levels over a number of source positions is required to determine 1/3 octave sound power levels within the limits of ANSI S1.21-1972 (6), the standard in effect at the time of this study (7).

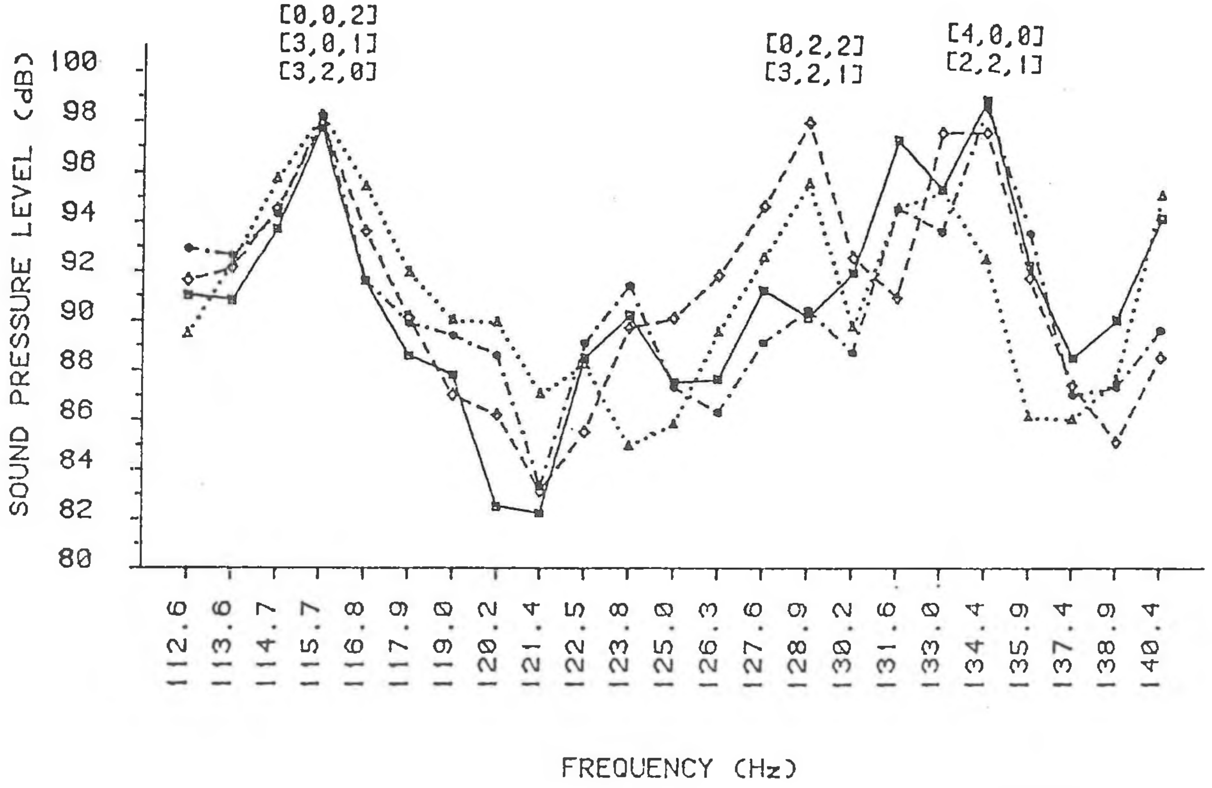


NOTE: All distances in meters

FIGURE 1: Source Position and Room Modifier Locations on 5.1 x 6.1 Meter Floor of Reverberation Room.



a) 100 Hz Band



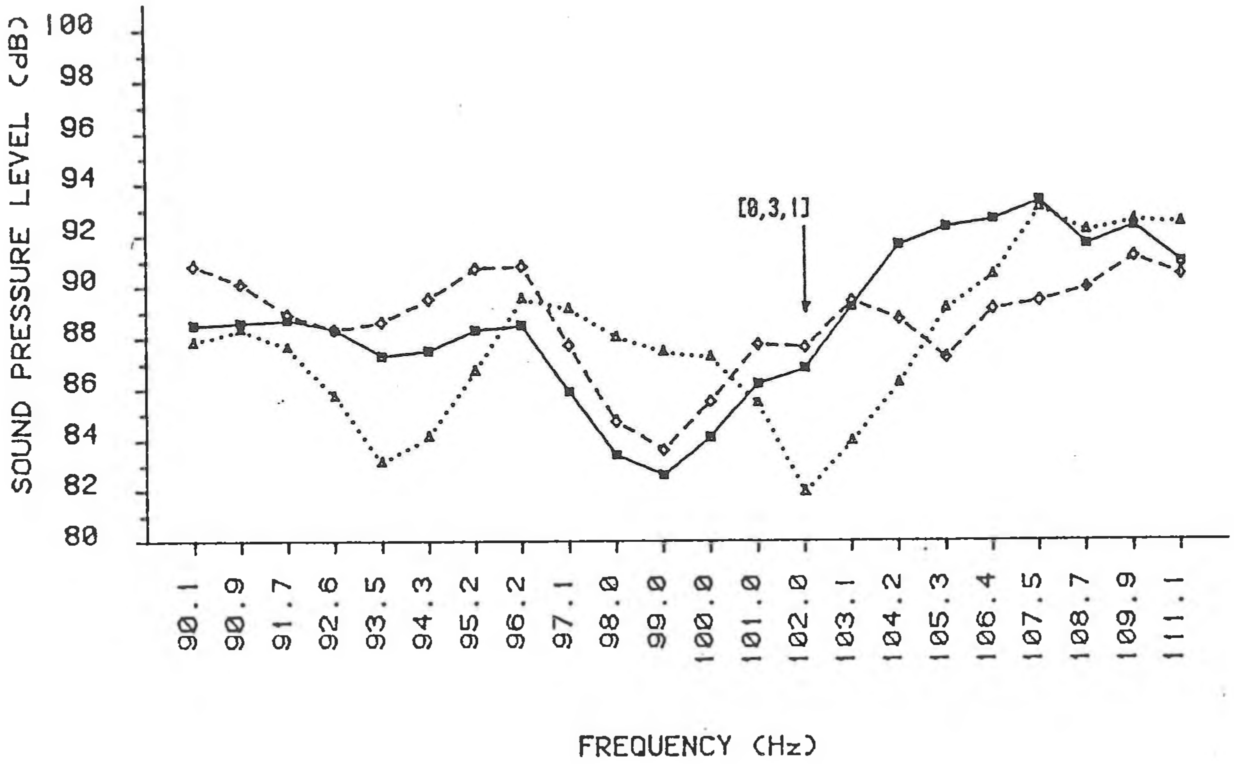
b) 125 Hz Band

FIGURE 2: Sound Pressure Level vs. Frequency in the Bare Reverberation Room.

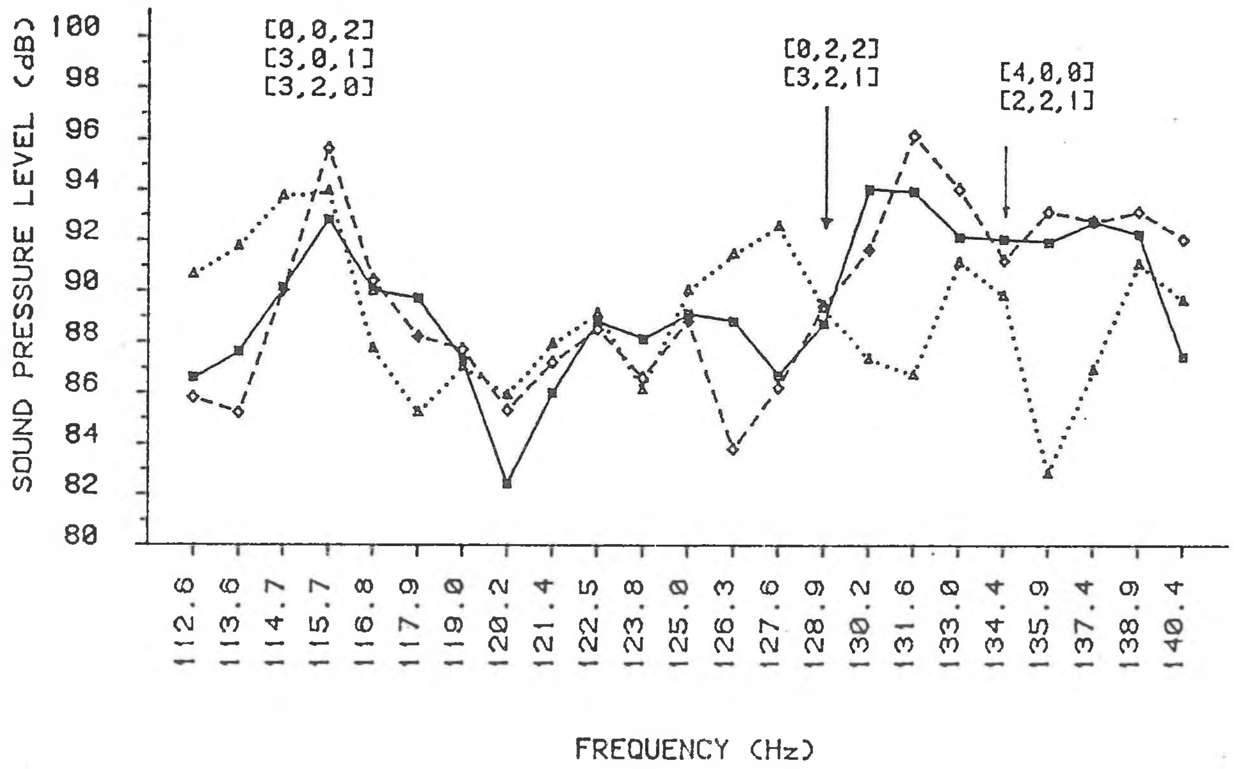
The reverberation chamber at the Centre for Building studies has a volume of 94 cubic meters and is constructed of timber framing on an isolated concrete floor. The interior walls and ceiling have an aluminum finish to provide suitably low absorption. To permit qualification of the chamber for sound power measurement of sources with discrete frequency components, it was necessary to introduce a rotating diffuser, stationary diffusers, and panel and bottle absorbers (see Figure 1). The chamber was able to qualify under ANSI S1.21 with the exception of the room volume (specified as 180 m^3 minimum) and the minimum microphone distance from the room surfaces. Room size restricted this distance to $\lambda/4$ at the lowest frequency of interest while $\lambda/2$ is recommended in the standard. The qualification procedure followed is described elsewhere (6,7).

During the qualification procedure, it was observed that averaging pressure levels over different source positions was generally ineffective in reducing measured standard deviations without the aforementioned diffusing and absorbing elements in the room, i.e. in the bare chamber. The introduction of the room modifications substantially improved source position averaging effectiveness at low frequencies. The following investigation of the measured sound pressure/frequency curves over the 100, 125, 160 and 200 Hz 1/3 octave bands illustrates the reason for the variation in averaging effectiveness.

Figure 2(a) illustrates the space-time average sound pressure levels for the 22 frequencies in the 100 Hz band specified in ANSI S1.2.-1972, for the bare chamber condition. The absorption coefficient in this frequency band is 0.06, giving a modal overlap (M) of 0.58. Modal overlap is a measure of the amount of overlap of the finite-bandwidth modes which occur in a room and can be expressed as a function of room absorption, frequency, and room volume (8). The peak observed appears to correspond to the [0, 3, 1] mode at 102 Hz. What is striking about the response curves illustrated is the remarkable similarity in shape for the four source positions. The calculated standard deviations are similar as well, ranging from 2.9 to 3.4. The similarity leads to an ineffectiveness in source position averaging the average of positions 1 (σ = 3.4) and 4 (σ = 3.1) is only 3.1 and is representative of this behavior. Where improvement is observed, the improvement is small, typically no greater than 0.4 dB of deviation. It can also be seen that for any given frequency, the measured pressure level and hence power level are highly dependent on source position, even allowing for errors resulting from the limited spatial sampling of the sound field at these frequencies (~ 2dB). Variations between source positions are as much as 8 dB.



a) 100 Hz



b) 125 Hz

LEGEND

■———□	POSITION NO. 1
▲·········▲	POSITION NO. 4
◆– – – –◇	POSITION NO. 5

FIGURE 3: Sound Pressure Level vs. Frequency with Diffusers and Absorbers in Reverberation Room.

The curves for the 125 Hz band in Figure 2(b) show the same trends, especially where strong modal responses occur. The first peak at 115.7 Hz appears to correspond to the degeneracy of the [0, 0, 2] , [3, 2, 0] and [3, 0, 1] modes, and the second peak to the [4, 0, 0] and [2, 2, 1] modes. Again we see from the illustrated deviations that source position averaging is ineffective. It should also be noted that while modal overlap is increased in this band, deviations are rising for the individual source positions.

In the 160 and 200 Hz bands the pressure/frequency response curves become more uncorrelated with respect to source position, as might be expected with the rapidly increasing number of modes present. It can be shown that averaging can become much more effective at these frequencies depending on the relative correlation between source locations.

Let us now compare these results to those observed in the final room configuration, where resonator bottles, panel absorbers, and rotating and stationary diffusers were in place. From the 100 Hz band shown in Figure 3(a), it is apparent that the curves for the three source positions are not nearly as similar in shape as those for the bare room configuration. In particular, the averaging of positions 1 and 4 is now effective, reducing overall deviation to 2.5 dB. Position 5, a new position chosen because averaging over the original source positions did not permit the qualification limits to be met for all frequencies of interest, has a very low standard deviation in this band ($\sigma = 2.0$ dB).

In Figure 3(b), the previously strong modal pattern at 125 Hz that was so highly correlated over source position has disappeared, and averaging becomes generally more effective. At the higher frequencies 160 and 200 Hz averaging effectiveness is good but not clearly improved over the bare chamber conditions.

Based on the room modifications made, it appears that the combination of diffusing elements and additional absorption cause decreased correlation between source positions with consequently improved averaging effectiveness. As a means of quantifying the improvement, the equation relating total measurement variance to sound power and pressure variance can be used:

$$\sigma_t^{\,2} = \frac{1}{N_S}\left(\sigma_w^{\,2} + \sigma_p^{\,2}\right)$$

where Ns = number of source positions, $\sigma_t^{\,2}$ = total normalized variance, $\sigma_w^{\,2}$ = normalized variance of sound power output with source position, and $\sigma_p^{\,2}$ = normalized variance of space averaged reverberant pressure squared.

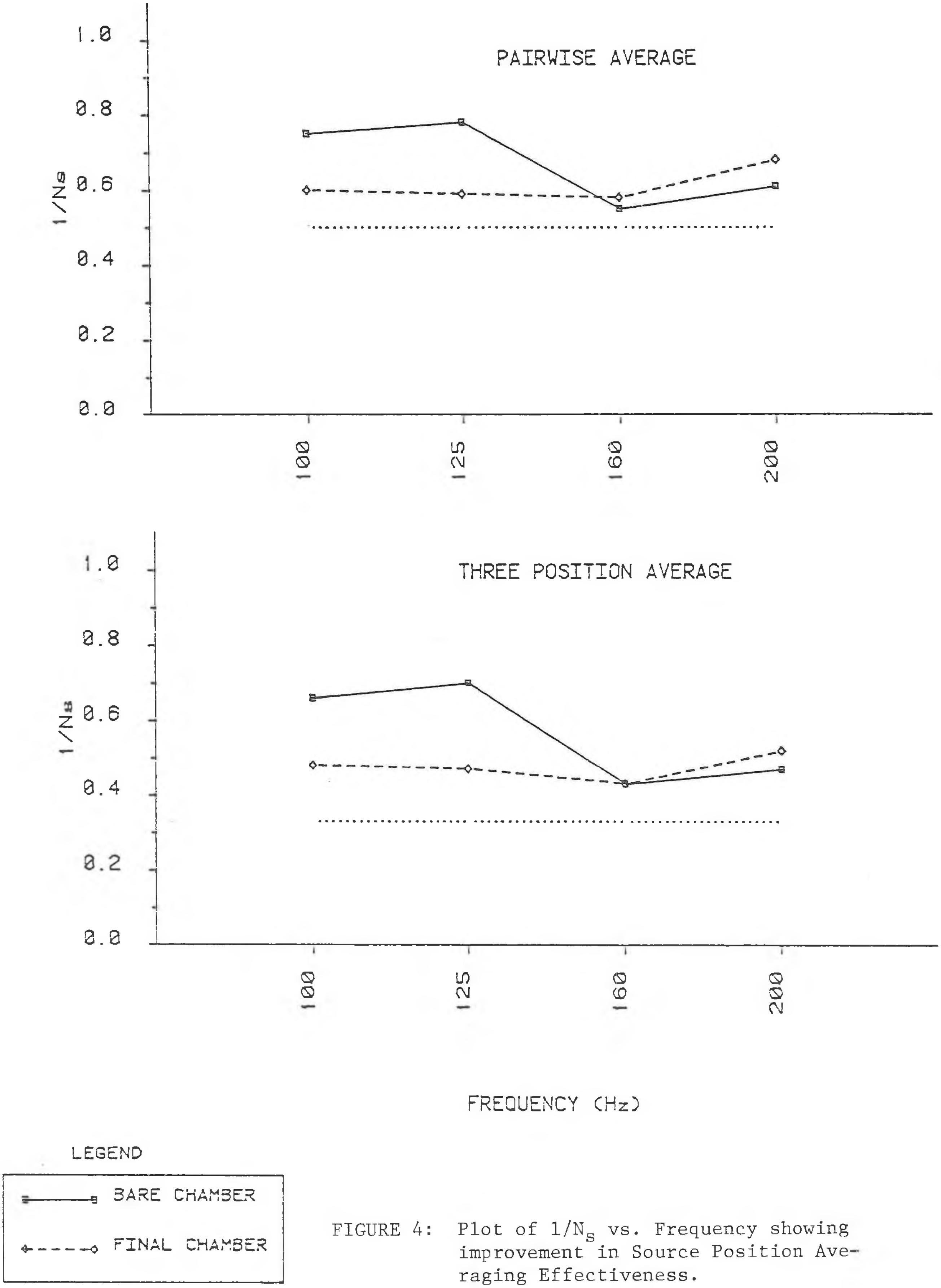


FIGURE 4: Plot of $1/N_s$ vs. Frequency showing improvement in Source Position Averaging Effectiveness.

Thus by using 2 source positions, the total variance should be reduced by a factor of 0.5, and using 3 source positions by 0.33, etc... Figure 4 shows a plot of the average values of 1/Ns for pairwise and three-way source position averages for both the bare room and final room configurations. The improvement in source position averaging effectiveness at low frequencies is clearly illustrated as the final room curves more closely approach the theoretical values.

It should be noted that a $\lambda/4$ or greater separation of source positions does not guarantee uncorrelated responses, at least for this chamber. One must be fortunate in choosing source positions that will give the desired results for reverberation chambers of this size.

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