Sound Transmission Loss Measurements by the Sound Intensity Technique

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ABSTRACT

Sound Transmission Loss Measurements
by the Sound Intensity Technique

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The Sound Intensity Technique is used to measure Sound Transmission Loss. A detailed measurement procedure is established and validated. Consequently the transmission loss is measured as a function of the following parameters: panel dimensions, the existence or absence of sills and reveals, and the lining of reveals with absorbent material of variable thickness.

In addition, because the intensity is a vector quantity, the acoustic power flow through partitions can be traced. This allows for the determination of the relative contributions to the overall transmission loss of the various sections of the panel, and the localisation of construction faults.

ACKNOWLEDGEMENTS

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NOMENCLATURE

f : frequency [Hz]

f_c : coincidence frequency [Hz]

f_r : resonance frequency [Hz]

$f_{c,D}$: Schroeder cut-off frequency [Hz]

T : period [s]

ω : angular frequency [rad/s]

k : wave number

c : speed of sound in air [m/s]

t : time [s]

t_{av} : averaging time [s]

d : measurement distance [m]

ρ : density [kg/m^3]

ρ_s : surface density (mass per unit area) [kg/m^2]

r : component

Δr : microphone spacing [mm]

R : distance between microphone probe and sound source [m]

V : volume [m^3]

S : surface area [m^2]

dS : elementary surface area [m^2]

$d\overline{S}$: surface vector normal to the elementary surface dS

B : bending stiffness [N.m]

E : Young's modulus [N/m^2]

M_I : moment of inertia [m^4]

L_x, L_y : panel length and width [m]

n_x, n_y : integers

$p(t)$: instantaneous pressure [Pa]

$\bar{v}(t)$: intantaneous velocity vector [m/s]

$v_r(t)$: component of the instantaneous velocity vector in the direction r [m/s]

P : space/time averaged sound pressure [Pa]

P_t : actual measured sound pressure [Pa]

P_{re} : sound pressure in a completely reactive field [Pa]

$\bar{I}$: sound intensity vector [W/m^2]

I : sound intensity [W/m^2]

I_r : intensity vector component in the direction r [W/m^2]

I_i : incident sound intensity [W/m^2]

I_t : transmitted sound intensity [W/m^2]

I_{me} : actual measured sound intensity [W/m^2]

I_{re} : residual sound intensity in a completely reactive sound field [W/m^2]

I_{dif} : diffuse field sound intensity [W/m^2]

W : sound power [W]

L_p : sound pressure level [dB]

L_I : sound intensity level [dB]

L_{ps} : sound pressure level in source room [dB]

L_{pr} : sound pressure level in reception room [dB]

L_{Ii} : incident sound intensity level [dB]

L_{It} : transmitted sound intensity level [dB]

τ : transmission coefficient

TL : sound transmission loss [dB]

TL_0 : normal incidence sound transmission loss [dB]

T_{60} : reverberation time [s]

A : sound absorption [metric sabins]

A_r : sound absorption in the reception room [metric sabins]

ϕ : phase difference [°]

G_{12} : cross spectral density

Im : imaginary part

INTRODUCTION

The Sound Transmission Loss of a panel or wall is a measure of its ability to reduce the transmission of sound from one space to another. Its evaluation is very important in many noise control problems.

Traditionally the sound transmission loss of a partition has been measured using the standard approach as described by the ANSI/ASTM E90-75* [9]. It has been shown both experimentally and theoretically that it is dependent on various boundary conditions. However, the numerous contradictions between reported results based on the standard method, although obtained under "ideal" laboratory conditions, indicate the need for further investigation. More detailed guidelines, not only concerning the room parameters, but including the measurement technique and procedure have to be established. In addition, special attention will have to be paid to the detailing of sound transmission paths, in particular, undesirable paths such as flanking, construction errors and material defects.

The present measurement technique makes it difficult to isolate the various parameters influencing the measurement of sound transmission loss and does not allow for fault

* American National Standard [9]

checking or finding. All elements constituting the system under test are considered as one single system. The measured transmission loss is relative to the system as a whole.

The recent development of new techniques and tools now enables the direct measurement of the flow of energy, or rather the flow of energy per unit area, that is, the intensity. As opposed to pressure, intensity is a vector quantity and therefore provides directional information. Source identification and location, source ranking and the determination of energy flow paths is now possible. With respect to the measurement of sound transmission loss, the total acoustic power transmitted through a partition can be determined by measuring the distribution of the intensity normal to the surface and integrating the results over the whole panel area.

This new method has several advantages, for example: the transmitted intensity is measured directly across the test surface, thus eliminating the effect of flanking transmission loss; it gives the transmission loss directly without having to make corrections for the panel area and the absorption characteristics of the reception room; no stringent restrictions are placed on its acoustic properties, it neither has to be reverberant or anechoic (this fact eliminates the need for an actual transmission loss suite, although currently the existence of at least one reverberant chamber is exploited); surface intensity patterns can be drawn and checked for irregularities, that is, eventual faults, after which the relative contributions to the sound transmission of different sections of the test panel can be determined.

Standards for the measurement of sound transmission loss based on the intensity technique do not yet exist and this work is intended to be a contribution towards their establishment. With this purpose in mind a series of test have been undertaken. The objective was three-fold :

1) Validation of the intensity technique by comparing its results to those obtained using the standard approach.
2) Establishment of a detailed measurement procedure.
3) Exploitation of its analytical capabilities.

The sound transmission loss was measured as a function of the following parameters:

- lining of the reveal with absorbent material of varying thickness.
- sills of different widths.
- panel dimensions.

Surface intensity profiles were drawn in order to:

- determine the relative contributions to the total sound transmission of the panel's various sections
- locate a deliberately introduced fault.

The description of this investigation starts with a literature survey on the sound transmission loss and the problems associated with its standard measurement (Chapter I). Chapter II deals with the measurement of sound intensity in a general way as well as its application towards the measurement of sound transmission loss. Chapter III describes the experimental test facility and measurement procedure, including the preliminary study necessary to its establishment. Once validated the technique is examined in use, the results of which are reported and discussed in Chapter IV. Conclusions are presented in Chapter V together with suggestions for further work.

CHAPTER I : SOUND TRANSMISSION LOSS AND ITS STANDARD MEASUREMENT

1.1. Definition

The Sound Transmission Loss of a partition is a measure of its performance to reduce the passage of acoustic energy from one space to another. Mathematically it is defined as :

$$TL = 10 \log(I_i/I_t) \qquad [dB] \qquad (1)$$

where I_i and I_t are respectively the incident and transmitted intensity [W/m^2].

The ratio I_t/I_i is also known as the transmission coefficient τ, and equation (1) can also be written as :

$$TL = 10 \log(1/\tau) \qquad [dB] \qquad (2)$$

1.2. General Aspects of Sound Transmission Loss

A partition's radiation characteristics depend on the frequency of the incident sound wave. Generally speaking four frequency regions are said to exist, as shown in Figure 1 [1].

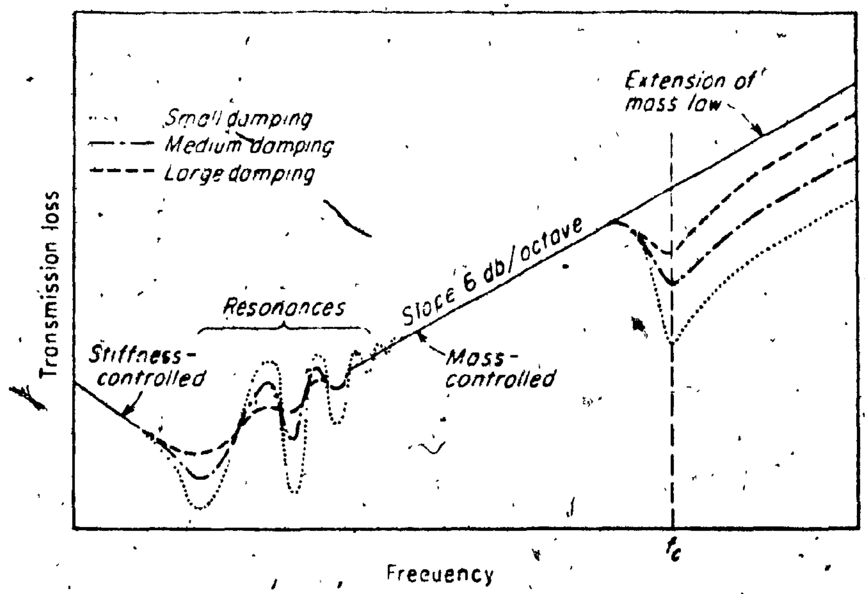


Fig. 1: General Behaviour of a Panel (Adapted from Beranek [1])

At the very low frequency end the transmission loss is stiffness controlled. Until the first resonance frequency (see below) each halving of the panel stiffness, or doubling of the frequency, will decrease the transmission loss by 6 dB per octave. However, in practice, in the case of finite panels, this frequency region is very small, is likely to be influenced by a backing room, and generally falls below the lowest frequency of interest.

With increasing frequency resonances occur. Their frequencies depend on the panel characteristics such as stiffness, mass, dimensions and boundary conditions. For example, a panel with simply supported edges has resonance frequencies given by (Beranek [1]) :

$$f_r(n_x, n_y) = \frac{\pi}{2} \cdot \left(\frac{B}{\rho_s}\right)^{1/2} \cdot \left\{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2\right\} \quad [\mathrm{Hz}] \qquad (3)$$

where $B = EM_I/L_y$: bending stiffness per unit width of panel [Nm]

E : Young's modulus [N/m^2]

M_I : moment of inertia of panel [m^4]

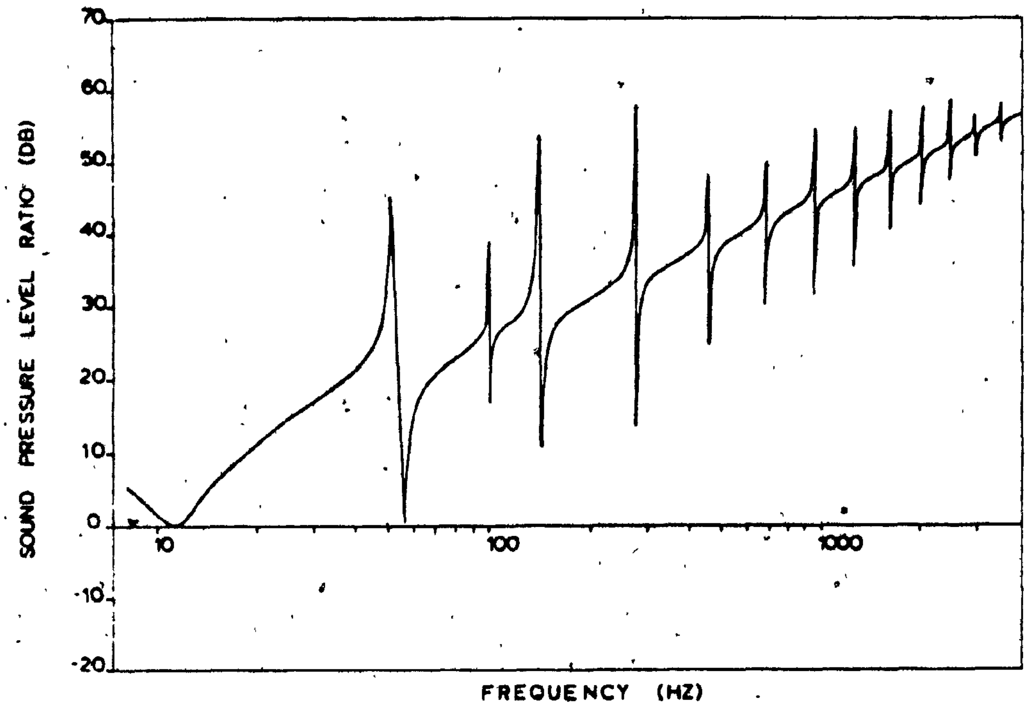
L_x : panel length [m]

L_y : panel width [m]

ρ_s : mass per unit area of panel [kg/m^2]

n_x , n_y : integers

The lowest resonance frequency is given for $n_x = n_y = 1$.



Sound Pressure Ratio for a single leaf panel of glass.
Thickness 9.525mm, Density 2300 kg/m³ Youngs Modulus 6.2 x 10¹⁰ N/m², Internal Damping η = 0.002

Fig. 2: Multiple Resonance Panel (from Guy [2])

Equation (3) predicts the presence of a resonance region extending from onset and throughout the frequency range; Figure 2 indicates the amplitude of resonances when only the internal energy losses of the plate itself are taken into account; this suggests that Figure 1 is incorrect. In practice however, as reported by Craick [3], energy losses at the panel boundaries raise the value of the loss factor considerably at lower frequencies. This results in far less pronounced resonances and eventually they completely disappear at high frequencies due to internal damping. The transmission loss curve then tends to the classic, linear mass-law as described below. This frequency region is called "mass controlled".

Within the "mass controlled" region the transmission loss decreases sharply about the coincidence frequency f_c, also called critical frequency, thus giving its name to this region.

The critical frequency is the frequency at which the wavelength of the bending waves in the panel equals the wavelength of the airborne excitation. Both waves 'coincide', thus increasing the panel vibration and decreasing its transmission loss. f_c is given by [1] :

$$f_c = \frac{c^2}{2 \cdot \pi} \cdot \left(\frac{\rho_s}{B} \right)^{1/2} \quad [\mathrm{Hz}] \qquad (4)$$

where c is the velocity of the incident sound wave [m/s] ; all other notations correspond to those mentioned above.

Beyond coincidence the transmission loss of the panel increases again. At frequencies above coincidence, mass, damping, and in particular the bending stiffness are important.

1.3. **Theoretical Models**

The object of this thesis is the measurement of sound transmission loss, thus only trends concerning its analytical modeling are reported here. In general, the stiffness controlled and the basic-resonance region will not be discussed because in many practical cases it is below the lowest frequency of interest.

1.3.1. Mass Law

The sound transmission of an infinite partition forced by a plane sound wave is given by the classical mass law for frequencies below coincidence. It is dependent on the angle of incidence of the sound wave. For normal incident waves (angle of incidence equal to 0) we have (Beranek [1]) :

$$TL_0 = 10 \log(1 + \frac{\omega \rho_s}{2\rho c}) \qquad [dB] \qquad (5)$$

where $\omega = 2\Pi f$: angular frequency of the sound wave [rad]

f : frequency of the sound wave [Hz]

ρ_s : mass of the panel per unit area [kg/m^2]

ρc : characteristic impedance of the medium (air) [rayls]

According to this law the transmission loss of a partition only depends on its mass. Its bending stiffness having been neglected, equation (5) is not applicable in the coincidence region. At and above the critical frequency the bending stiffness and energy losses of the panel will have to be taken into account in addition to ρ_s. Calculations become more difficult.

With respect to finite panels, the classical approach is to use the formula for infinite panels but with the introduction of a correction factor in order to produce closer agreement with experiments. Its precise formulation varies from one author to another, but because of their infinite panel basis the angle of airborne incidence assumes importance. Beranek [1], for example, suggests for frequencies below coincidence:

$$TL = TL_0 - 5 \quad [dB] \qquad (6)$$

where TL_0 is the transmission loss for normal incident waves and TL the transmission loss under diffuse field conditions.

These classical laws are simple but they don't take into account other parameters influencing the sound transmission loss such as panel size and shape, room dimensions and many other boundary conditions.

1.3.2. Contemporary Works

More recent theories do consider the effects of boundary conditions and two approaches may be identified.

The first is based on a study by Maidanik [4] who demonstrated that, although coincidence cannot occur below the critical frequency, there is a resonance transmission contribution due to edge effects in addition to the forced transmission according to the mass law. For resonance transmission, according to Sewell [5] and Crocker and Price [6], transmission loss decreases as the area increases. According to Sewell, the forced transmission has the opposite tendency, while reference [6] assumes it to be independent of the panel size. Generally, forced transmission prevails at low frequencies, the resonant transmission being dominant for higher frequencies up to the critical frequency. Thus one may conclude that for low frequencies the sound transmission loss decreases with increasing area, while the opposite is true at higher frequencies. Above coincidence the transmission loss is independent of panel dimensions. The influence of the panel shape as determined by Sewell [5] is of minor importance for standard panel geometries.

With respect to the influence of panel edge conditions, both reference [5] and [6] conclude that the transmission loss of a panel with boundaries that are highly constrained, that is clamped, is lower than in the case where they are simply supported. Above the critical frequency, boundary conditions theoretically have no effect.

Statistical analysis also enabled Crocker and Price [6] to take room dimensions into account. However, the influence of this parameter is considered to be of secondary importance provided the room modal density is such that diffuse field conditions can be assumed.

The second of the contemporary approaches is the modal theory analysis (Josse and Lamure [7], Nilsson [8]). This approach takes into account room volumes, panel dimensions, panel damping, and in the case of reference [8], edge and diffusing conditions as well. However, due to the large number of modes which have to be taken into consideration, the method is quite complex.

With respect to panel dimensions, while Nilsson [8] predicts that the transmission loss decreases with increasing panel size below coincidence, reference [7] finds the opposite is true. For both studies however, the area dependence is not very strong and above coincidence the effect of this parameter becomes negligible.

Moreover, as reported earlier, room dimensions are considered to be of secondary importance and the influence of the panel's edge conditions (Nilsson [8]) is also in accordance with the previous references.

Because so many parameters have to be taken into account, those theoretical sound transmission loss models are analytically very complex. Still, if proved correct, they could be effectively used. Their validation should be based on repeatable and consistent experiments but unfortunately, many conflicting results are reported.

1.4. Description of the Standard Measurement Procedure [9]

The standard method of measuring the sound transmission loss of a partition involves the use of 2 vibration-isolated reverberation chambers, forming a transmission loss suite, which are separated partially or completely by the partition to be tested. The test panel is mounted in the dividing wall between rooms. A steady sound is then produced in one of the rooms, the source room or transmitting room, the other chamber being called the reception or receiving room is used to monitor the sound energy passing through the panel under test.

Provided the sound field is diffuse in both rooms and that there is no flanking transmission, the sound transmission loss of the partition can be calculated from the measured space/time averaged sound pressure levels in each of the rooms. The correction factor can be deduced from a knowledge of the absorption of the receiving room.

In the case of a partition filling the whole aperture between the 2 chambers, the transmission loss is given by [9]:

$$TL = L_{ps} - L_{pr} + 10\log(S/A_r) \qquad [dB] \qquad (7)$$

where L_{ps} and L_{pr} are respectively the space averaged sound pressure levels [dB] in the source and receiving room, S[m^2] the partition's surface area and A_r [metric sabins] the sound absorption of the receiving room.

The value of A_r is obtained by measuring the decay rate of sound in the receiving room:

$$A_r = 0.921 \cdot Vd_r/c \qquad [\text{metric sabins}] \qquad (8)$$

where V : receiving room volume [m^3]
c : speed of sound in air [m/s]
d_r : decay rate [dB/s]

When the test panel is smaller than the aperture between the 2 rooms it is necessary to build a filler wall in order to accomodate the partition. The transmission loss of the test panel alone can be calculated when the transmission loss for both the filler wall and the composite wall has been determined according to :

$$TL_p = -10\log\left[\frac{S_c}{S_p} \cdot 10^{\left(\frac{-TL_c}{10}\right)} - \frac{S_f}{S_p} \cdot 10^{\left(\frac{-TL_f}{10}\right)}\right] \quad [dB] \qquad (9)$$

where the subscript 'p' stands for panel, 'f'for filler wall and 'c' for composite wall.

1.5. Experimental Work - The Effect of Some Physical Parameters upon the Measured Transmission Loss

Various studies (Jones [10], Kihlman and Nilsson [11]) indicate the non-repeatability of sound transmission loss measurements from one laboratory to another. Kihlman and Nilsson for example, in a round-robin comparison of 5 laboratories, found large fluctuations, with differences up to 10 dB, despite the fact that materials and measuring techniques were carefully controlled and all the test facilities were answering the ISO requirements. This implies that the measured transmission loss is not only dependent on the physical properties of the panel but also on various boundary conditions. Based on experimental results, the influence attributed to some of the parameters is reported below. Each effect is considered separately.

1.5.1. Mounting Conditions

Kihlman and Nilsson [11] found that the transmission loss below coincidence is generally lower for a clamped panel than for a simply supported one. Differences vary however. Above coincidence, mounting conditions have only little effect.

These trends are in agreement with theoretical predictions [5,6,8].

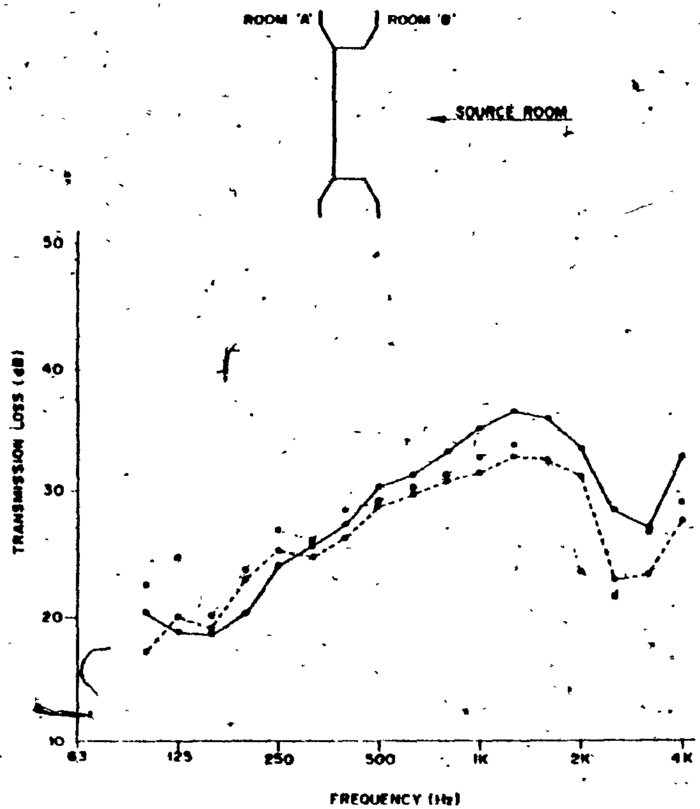
Lewis [12], on the other hand, found no difference in transmission loss as a function of the edge conditions for tests on a glass panel.

1.5.2. Panel Dimensions

Michelsen [13] studied the effect of size for various typical window constructions, the largest size being double the smallest one. Square, as well as rectangular shapes were tested. Generally speaking we can conclude that the highest transmission loss is obtained for the smallest widow size, except when hinged windows are tested. The square medium sized panel generally gives the lowest values. It is however difficult to rank the other results. The spread is of the order of 3 dB. Above coincidence differences are negligible as expected.

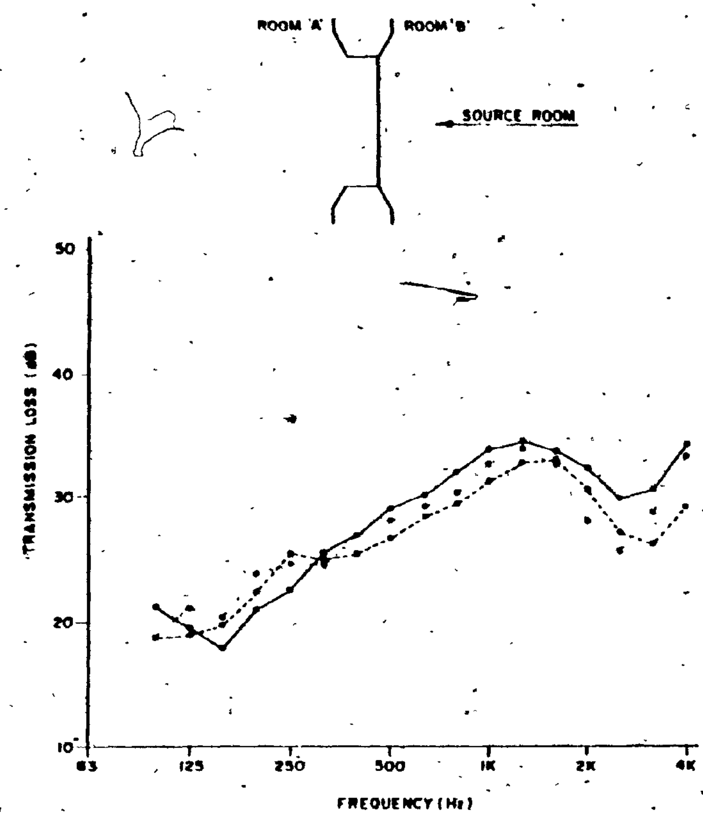
A second tendency can be observed. The transmission loss for a square panel is usually lower than that of a rectangular panel with the same surface area. This trend confirms the theoretical predictions by Sewell [5].

Anotner study done at the Centre for Building Studies [14] gives similar confusing results as shown in Figures 3 a and b. Three panel dimensions were tested, all of them



Transmission loss for 6.25 mm thick glass panels for varying panel area. Panels mounted in Room A, Room A receiving.

(a)



Transmission loss for 16 mm gyproc panels for varying panel area. Panels mounted in Room B, Room A receiving.

(b)

Key, ——, 0.54 m^2 panel, - - -, 2.32 m^2 panel, . . ., 3.93 m^2 panel

Fig. 3 : Transmission Loss Spectra for Varying Panel Area (from Guy et al.[14])

square. For the single panels, glass and gyproc, the results show that for the lower frequencies the transmission loss increases with increasing panel area. At the higher frequencies however, the smallest panel gives the highest transmission loss, the middle sized panel giving the lowest values. These tendencies remain above coincidence. The differences are generally of the order of 2 to 3 dB.

In addition it is seen that the 'dip' at the coincidence frequency increases with increasing panel dimensions.

1.5.3. Laboratory Design

Supporting his theoretical model, Kihlman [15] demonstrated experimentally that the sound transmission loss of a wall separating the 2 rooms of a transmission loss suite is lower when the rooms are equal than when their dimensions are unequal. Differences are shown to be as high as 7 dB.

In another study [11] the same author finds that the transmission loss is higher when the partition is mounted in a frame than when it extends from wall to wall and from floor to ceiling.

Other experimental results by Bhattacharya and Guy [16] show that when the direction of transmission between 2 rooms of unequal dimensions is changed, a difference of 5 to 6 dB can occur. The higher transmission losses are reported when the source is in the smaller room. These results are in contradiction with those found at the Center for Building Studies [14].

1.5.4. Sills and Reveals

For the clarity of this work, sills and reveals are considered to consist of equal depth projections around the perimeter of the test panel. The projection towards the source room is called a sill, whereas the projection towards the receiving room is referred to as a reveal.

In one of the first reports treating this subject, Gösele [17] notes that when a 0.5m sill is added to a flush mounted gypsum wall, the transmission loss of the panel decreases by as much as 4 dB in the low frequency region. The depth of the reveal is however not specified and it is therefore difficult to compare these results with later workers.

Kihlman and Nilsson [11] on the other hand report that sill or reveal configuration (not both) give quite similar results and the same holds for a symmetrically mounted sill and reveal compared to the no sill nor reveal condition. In addition they show that the existence of one niche (either sill or reveal) increases the transmission loss significantly with respect to the symmetrically mounted panel. The largest differences occur well below the critical

frequency with a maximum of 5 dB.
It has to be stressed however that the results presented in this paper were obtained at different laboratories.

The previously mentioned trends are partially confirmed by Lewis [12]. While his results also show that below coincidence the transmission loss increases considerably (up to 7 dB) in the presence of a sill or reveal compared to the symmetric sill and reveal condition, the differences between the sill or reveal conditions are slightly higher. Above the critical frequency the results are again very similar.

Moreover, experimental work at the Center for Building Studies [39] also shows that the presence of a predominant sill leads to higher transmission loss values than a more symmetric configuration. In addition, it was shown that the effect decreases with increasing panel area.

Guy and Mulholland [18] investigated the effect of lining the sill and/or reveal with absorbent material. The sound transmission loss increased considerably in all cases compared to the results for the bare sill and reveal. The optimum results were obtained when both sill and reveal were lined. Lining of the smaller sill gave the lowest increases. Below 250 Hz results were fairly irregular but above 500 Hz differences remained quite constant with a maximum of 10 dB improvement in the optimum case. The irregular results at the low frequency end were ascribed to the low absorption characteristics of the lining material over that frequency range and eventually to the predominance of the axial standing waves in the direction of the room depth.

1.6. Problems Associated with the Standard Measurement Technique

As reported above, many contradictions arise when trying to establish the effect of certain physical parameters on the sound transmission loss of a given partition. Human negligence or error is of course never to be excluded, but the problem seems to be of a more fundamental nature: the method's limited capabilities and even its concepts.

The method does not apply when flanking sound transmission paths exist in addition to the direct path through the partition. Test results will be jeopardized by possible construction errors or material defects. Unfortunately the measurement technique does not permit active checking of undesirable sound transmission paths. Their detection solely depends on the experimenters' experience and/or integrity.

Generally speaking, the measuring technique makes it difficult to isolate the various parameters influencing the sound transmission loss, whether they be panel dimensions, room volumes or construction errors. All elements constituting the system under test are considered as one single system. The measured transmission loss is relative to the system as a whole.

Measurements require a transmission loss suite for which the sound field in both rooms is diffuse. Unfortunately that is never completely true, especially at the lower frequencies. The position of the speaker plays an important role in determining which room modes will be excited, not all of them equally. The location(s) of the microphone(s) on the other hand will determine which room modes will be sensed.

In addition to the uncertainty of the experimental determination of the spaced averaged sound pressures and the reverberation time, other errors exist. Once the sound source has been switched off in the reception room (Mariner [19]), energy exchange between the two adjacent chambers takes place. This coupling effect between the two chambers is reflected in the measured reverberation time but can not be taken into account. One may therefore question the effectiveness of the room correction factor 10log(S/A) which is based on the measurement of that parameter. This may indeed explain the contradictory results when the room orientation is varied.

The whole concept of the room correction factor is debatable: if it were to fulfill its purpose, that of compensating for the influence of the receiving room and the panel surface area, no differences should be obtained when those parameters are changed.

The problems mentioned above are very much inherent to the measurement procedure and partially due to the limited capabilities of the conventional measuring devices. Recent developments in instrumentation have provided us with a new approach to determine the various factors involved in the transmission of sound through panels. More specifically, the Sound Intensity Measurement Technique and its use for the task will be explored in the following chapters.

CHAPTER II : SOUND TRANSMISSION LOSS MEASUREMENT BY THE INTENSITY TECHNIQUE

2.1. The Measurement of Sound Intensity - General Principles

2.1.1. Definitions

As opposed to sound pressure, intensity is a vector quantity and therefore provides directional information. In a given direction it is defined as the average rate of flow of energy through a unit area perpendicular to the direction in question.

2.1.1.1. Diffuse Field Intensity

Assuming diffuse field conditions, that is providing the "average energy density is the same throughout the entire volume of the enclosure and all directions are equally probable"[20], the sound intensity in any direction can easily be expressed as a function of the space/time-averaged sound pressure in the enclosure P [Pa] :

$$I_{dif} = P^2/4\rho c \qquad (10)$$

where ρ is the density of air [kg/m^3] and c the velocity of sound in air [m/s].

Thus in this instance intensity measurements can be made using a single microphone.

2.1.1.2. Non-Diffuse Field Conditions

It can be shown [21] that, in a medium without flow the three-dimensional intensity vector $\bar{I}$ is equal to the time-averaged product of the instantaneous sound pressure p(t) and the corresponding particle velocity $\bar{v}(t)$ at the same point, that is :

$$\bar{I} = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{+\frac{T}{2}} p(t).\bar{v}(t)\ dt \qquad [W/m2] \qquad (11)$$

If the intensity vector's component in a given direction 'r' is considered this becomes :

$$I_r = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{+\frac{T}{2}} p(t).v_r(t)\ dt \qquad [W/m^2] \qquad (12)$$

The particle velocity in the same direction can be expressed in terms of the sound pressure [21] :

$$v_r = -\frac{1}{\rho}\int\left(\frac{\partial p}{\partial r}\right) dt \qquad [m/s] \qquad (13)$$

where ρ is the density of air [kg/m3]. In practice, two microphones separated by a distance Δr are used for intensity measurements and hence the pressure gradient must be approximated by a finite difference. Equation (13) becomes [22] :

$$v_r = -\frac{1}{\rho}\int \frac{p_2(t) - p_1(t)}{\Delta r}\,dt \qquad [m/s] \qquad (14)$$

This approximation is valid as long as the separation Δr is small compared to the wavelength λ.

Equation (14) represents the particle velocity at a point midway between the microphones. Similarly, the pressure at the same point is given by :

$$p(t) = \frac{p_1(t) + p_2(t)}{2} \qquad [Pa] \qquad (15)$$

The intensity can then be calculated by substituting equations (14) and (15) in (12), thus giving the basic relationship on which all intensity measurements are founded. It is important to note that, because of the existence of two time-dependant pressure signals, the intensity depends both on their amplitudes and their phase difference.

Note : Unless stated otherwise all subsequent referrals to the measurement of sound intensity concern the two-microphone technique.

2.1.2. Instrumentation for the Measurement of Sound Intensity

There are basically two important types of instruments for the measurement of sound intensity: the Two Channel FFT

Analyzers and those based on Digital Filtering Techniques. Both types will be described in this section.

2.1.2.1. 2 Channel FFT (Fast Fourier Transform) Analyzers

Fourier transformation of equations (14) and (15) relates the intensity I to the cross-spectral density between the two measured pressures according to [22] :

$$I = -\mathrm{Im}\{G_{12}\}/\rho\omega.\Delta r \qquad \text{with } k.\Delta r <<< 1 \qquad (16)$$

where G12 : cross-spectral density between the 2 measured pressures p_1 and p_2

Im : imaginary part

ρ : density of air [kg/m3]

ω : angular frequency [Hz]

Δr : microphone spacing [m]

k : wave number

This is a commonly used method but it has certain disadvantages. For example, the analysis is performed in narrowbands. Although this can sometimes be advantageous, additional calculations will have to be made when third octave or octave band results are required. Moreover the analysis is generally not in real-time.

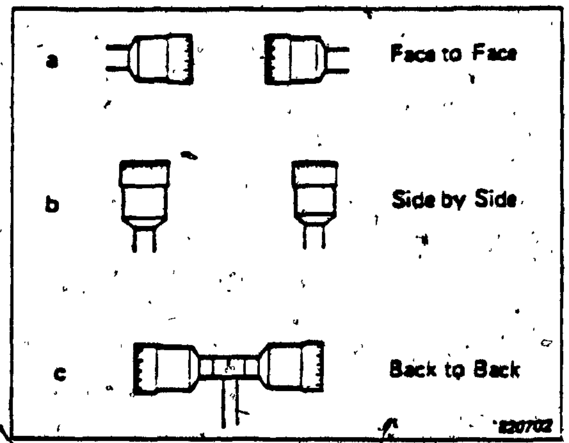


Fig. 4: Different Microphone Configurations for Sound Intensity Measurements (from Reference [21])

2.1.2.2. Analyzers Based on Digital Filtering Techniques

The sound intensity is analysed through a double digital filter with normalized third octave or octave bands, after which the necessary calculations are performed according to equations (14) and (15) substituted in (12). The operation is generally real-time.

A sound intensity analyzer based on this principle is used for the experiments described below.

In both cases mentioned above, two microphones separated by a distance Δr are used for the measurements. Different microphone configurations are possible (see Figure 4) although the most commonly used are the side-by-side and the face-to-face arrangements.

2.1.3. Limitations and Errors

The use of the 2 microphone technique to measure the sound intensity introduces a certain number of errors which limit the useful frequency range of the system.

2.1.3.1. Optimum Frequency Range

One of the errors is inherent in the approximation of the pressure gradient by a finite pressure difference. Thompson and Tree [22] and Elliott [24] show that the measurement accuracy is a function of $k.\Delta r$ and $\Delta r/R$, where k is the wavenumber, R the distance between source and measurement point (center of microphone pair) and Δr the microphone spacing. Generally finite difference errors can be minimized by employing the smallest possible values of the two previously mentioned parameters. The range of the optimum values decreases with increasing source complexity. From a practical point of view this sets the upper frequency limit of the measurement system for a given microphone spacing.

On the other hand, at the low frequency end and for small microphone spacings, the actual physical phase difference between the two signals becomes very small and can eventually reach the order of magnitude of the accuracy of the instrumentation (instrumentation phase mismatch). This in turn sets the lower frequency limit for practical systems.

The conditions on the minimum microphone-to-source distance can easily be met ([21],[24]).

2.1.3.2. <u>Instrumentation Phase Mismatch</u>

As a consequence of the preceding section the error introduced by the instrumentation phase mismatch causes much concern and has been well documented (23],[24],[25]. It can be limited by different techniques. One of them is to mechanically switch the two microphones or even the complete circuits involved. The disadvantage of this method is that two different measurements (forward and reversed positions of the microphones) have to be performed after which the 'mean' value has to be calculated. This is not practical for routine measurements. The phase errors may also be estimated by a separate calibration to determine the magnitude of the mismatch so compensation can be made for it in further calculations. Ultimately the phase errors can be reduced considerably by the use of carefully matched microphones and other electronic components. There is however always a certain residual instrumentation phase mismatch left which has to be taken into account.

2.1.3.3. Phase Errors

Accurate intensity measurements require that the residual phase mismatch between the two measuring channels is much smaller than the actual phase to be measured [26].

The phase to be measured is proportional to the frequency f and the microphone spacing Δr, and inversely proportional to the ratio between the sound pressure P and the sound intensity I according to :

$$\phi = \Delta r . f . I . 360 / P^2 \quad [^\circ] \qquad (17)$$

where the ratio P^2/I is also called the reactivity of the sound field. Consequently, for a given microphone spacing, the lower frequency limit is shifted towards higher frequencies by a factor which is equal to the measured reactivity at the measurement positions [29]. On the other hand the phase errors due to the reactivity can be balanced by increasing the microphone spacing.

It is therefore important to choose the optimum microphone spacing as a function of the frequency range of interest, the phase calibration of the instrument, the reactivity of the sound field and the calculation of the phase errors are described in Chapter III, 3.2.3.

2.2. The Measurement of Sound Transmission Loss by the Intensity Technique

In contrast with the standard approach as described in the previous chapter, the determination of the transmission loss of a partition is to be done through the direct determination of both the intensity incident on and transmitted through the test panel. There is no need anymore to introduce corrections for the panel surface and the receiving room absorption.

2.2.1. Incident Intensity

Assuming the sound field is diffuse, the incident intensity Ii can be calculated from the measured space/time-averaged sound pressure in the source room according to equation (10). The accuracy of this equation has been verified by Crocker et al [27] by comparing its prediction to the intensity directly measured through the aperture after removal of the test panel.

The following relationship between the incident intensity level L_{I1} and the space/time-averaged sound pressure level L_p can then be derived [28] :

$$L_{I1} = L_p - 6 \qquad [dB] \qquad (18)$$

2.2.2. Transmitted Intensity

The transmitted intensity I_t is measured on the receiving side of the partition to be tested, directly across its surface. The spatially averaged value is determined by measuring the distribution of the intensity vector's component perpendicular to the surface, after which the results are averaged over the whole panel area. This can be done in 2 ways: the first one is to slowly move the microphones manually over the entire surface area, completing an entire scan during the averaging period; the second way is to measure the transmitted intensity at an array of points uniformly distributed over the surface, after which the mean value can be calculated. In both cases the measurement distance is assumed to be constant. As reported by Cops and Minten [29] both methods give identical overall results. For the experiments described below the latter method was used because it allows one to determine the respective contributions of the different sections of a panel to the total radiated sound power; for example: edges versus center, or separate sections of a composite panel.

No stringent restrictions are placed on the acoustic properties of the reception room provided the background noise levels are low; any relatively non-reverberant room is acceptable. In fact, a very reverberant field on the reception side is to be avoided for it decreases the accuracy of the method ([30],[31]). Consequently the need for an actual transmission loss suite has been eliminated; in addition the reverberation chamber on the source side might also be eliminated, although it is found convenient to use because the incident intensity may be readily found.

2.2.3. Sound Transmission Loss

To conclude, the sound transmission loss can be calculated from the following expression :

$$TL = L_P - 6 - L_{It} \qquad [dB] \qquad (19)$$

where L_P is the average sound pressure level in the source room and L_{It} the transmitted intensity level [dB].

The next chapter will deal with the application of this theory.

Note : The Sound Intensity Technique lends itself to other areas of use; these are described in Appendix A.

CHAPTER III : EXPERIMENTAL PROCEDURE AND PRELIMINARY TESTS

3.1. Experimental Set-Up

3.1.1. Transmission Loss Suite

The transmission loss suite of the Center for Building Studies consists of two adjoining rectangular rooms of differing dimensions. For all but one of the reported experiments, the larger room was used as the source room because it gives a better approximation of the diffuse sound field throughout the frequency range. It has a volume of about 94 m^3. The smaller room, the receiving room in this case, has a volume of about 32 m^3. The test aperture between the two rooms has an area of 7.5 m^2. For actual dimensions and lay-out of the rooms refer to Figures 5 a and b.

The lowest acceptable frequency for a well designed reverberation room as suggested by Schroeder is defined by [32] :

$$f_{c,D} = 1200 \ (M \cdot T60/V)^{1/2} \qquad [Hz] \qquad (20)$$

where M : modal overlap index (assumed to be 3)

T_{60} : Reverberation time [s]

V : Room volume [m^3]

The Schroeder cut-off frequency for the larger room is 250 Hz and 400 Hz for the smaller one.

Diffusing elements consisting of one rotating and two

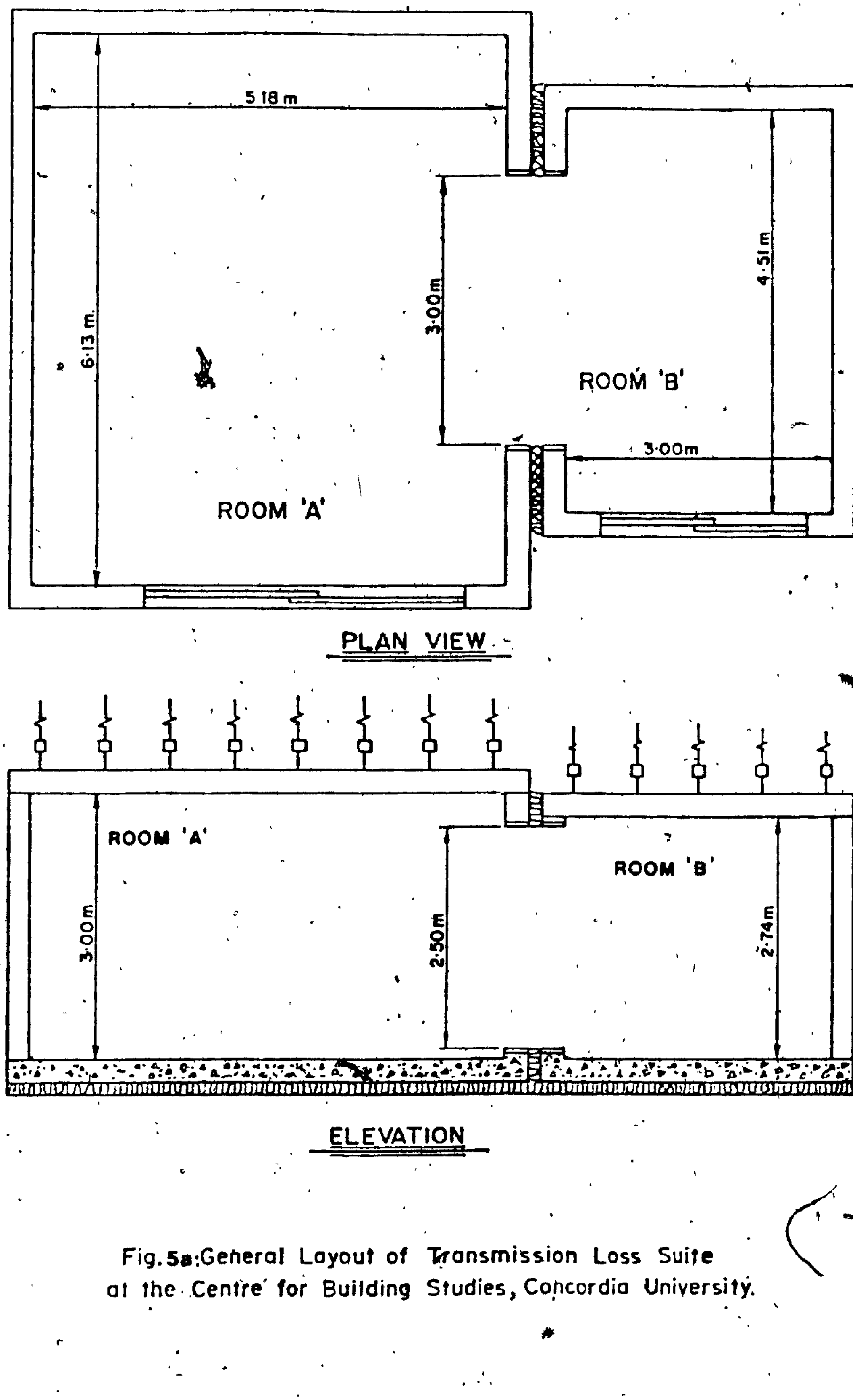


Fig. 5a: General Layout of Transmission Loss Suite at the Centre for Building Studies, Concordia University.

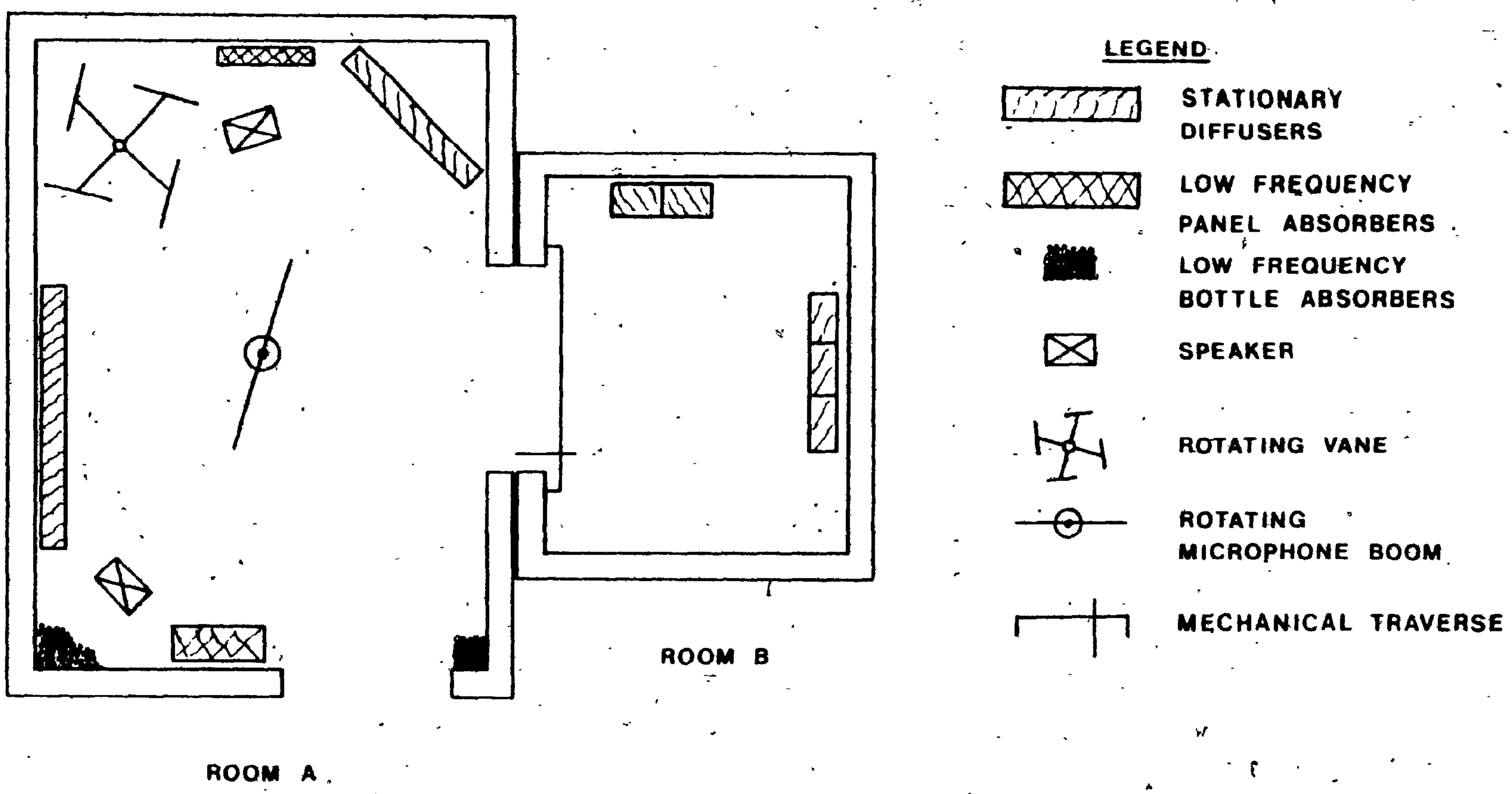


Fig.5b: Internal Room Arrangement

reception room two stationary diffusers were placed when the standard method for the measurement of the sound transmission loss was used; they were consequently removed for intensity measurements.

The test facility and its qualification process are described in detail by Lang and Rennie [33].

3.1.2. Filler Wall

Because the test panels are smaller than the total aperture, a heavy filler wall was erected between the two rooms. The composition of the wall is given in Figure 6 a and b. As can be seen, the filler wall actually consists of 2 separate walls, mounted one in each room on their respective room's aperture and separated from each other by insulation material. In turn, each single wall is composed of 2 staggered wood frames on separate bases in between which a layer of fiber glass insulation is placed. A single layer of gyproc (16 mm thick (5/8")) is attached to the woodframe on the side facing the test room, while 2 layers of differing thickness (16 mm (5/8") and 13 mm (1/2")) are attached to the other side.

In order to accommodate the different panel sizes tested, the woodframes were designed with concentric square openings. The 3 frames towards the source room all have the same dimensions (Figure 7.a), while the wall towards the reception room has somewhat larger openings (Figure 7.b), thus limiting the depth of the reveal (see below).

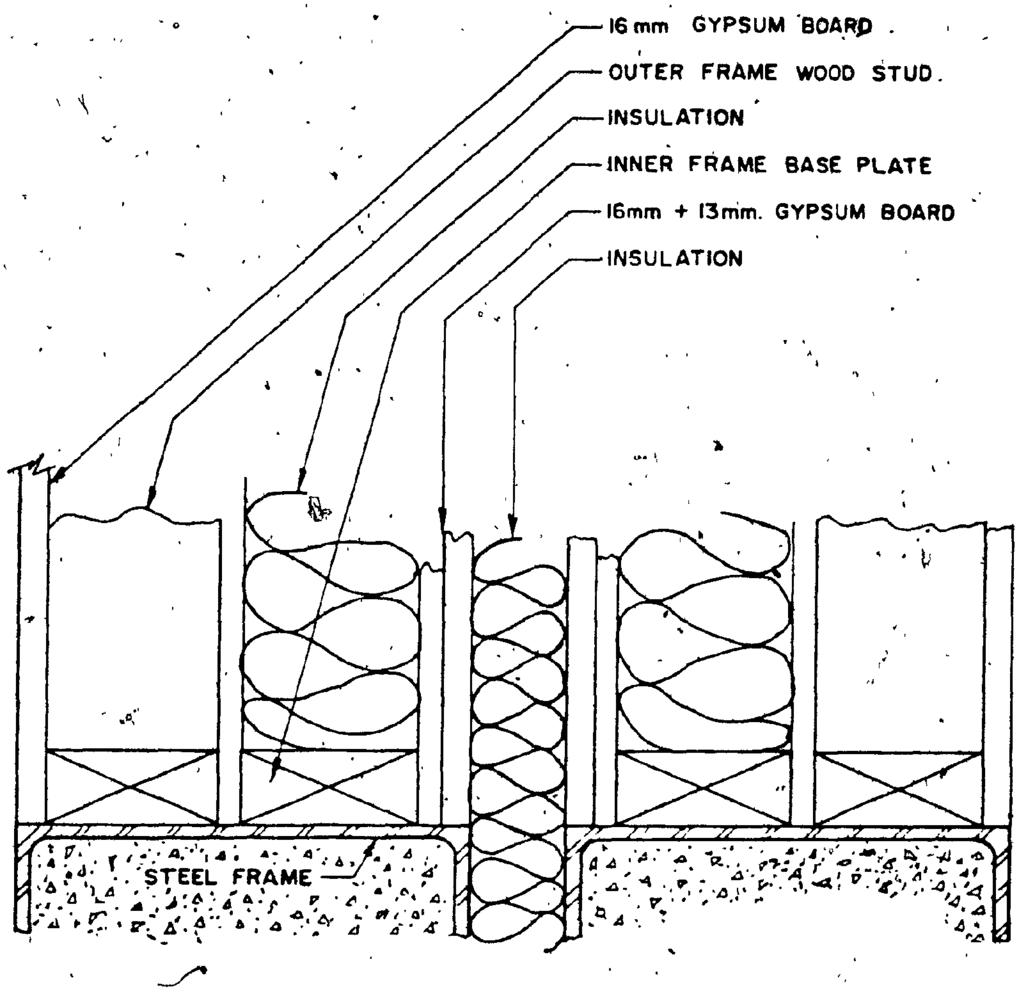


Fig.6.a:Cross Section of Filler Wall at Base Plate

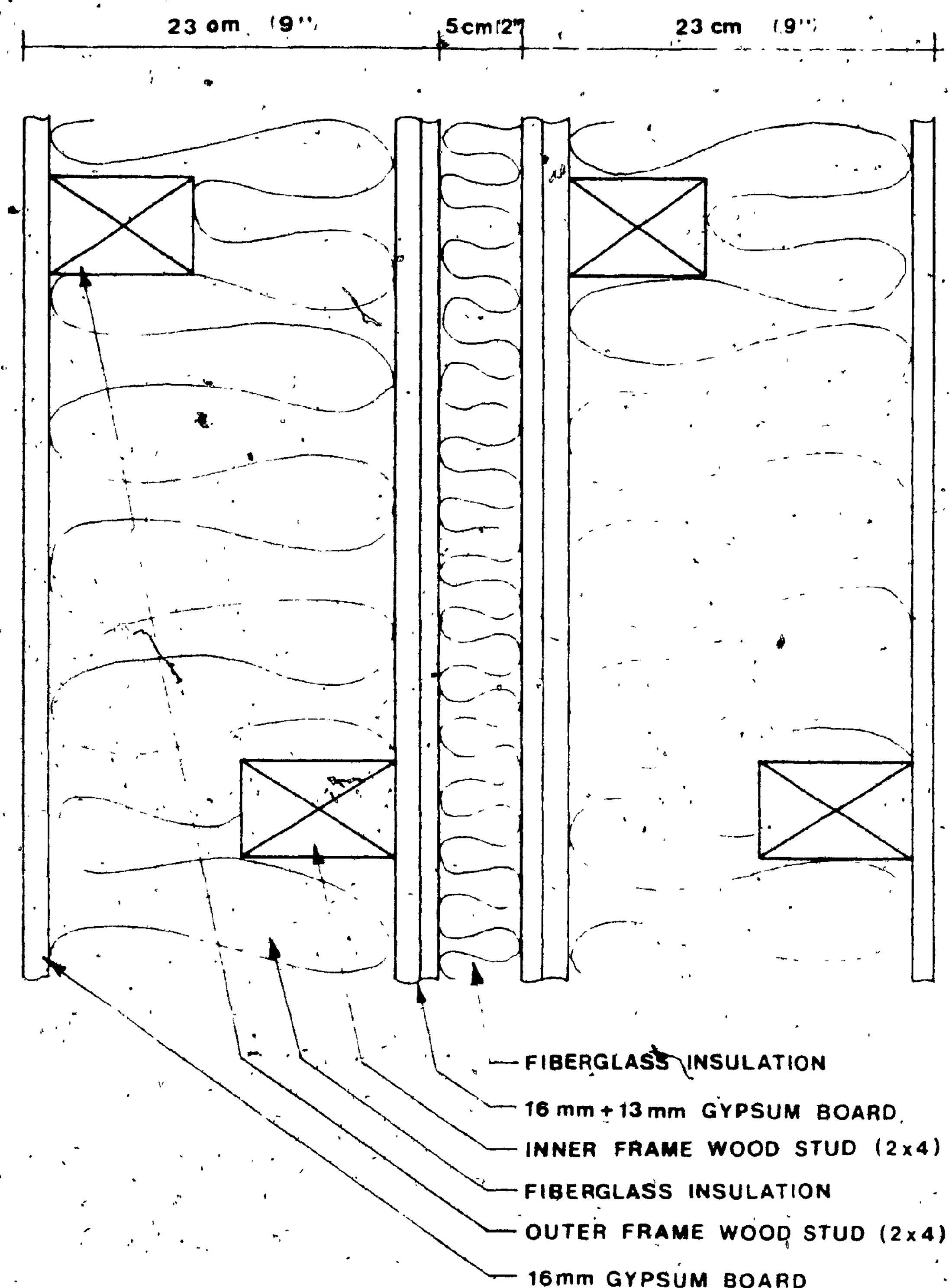


Fig.6b: Cross Section of Filler Wall

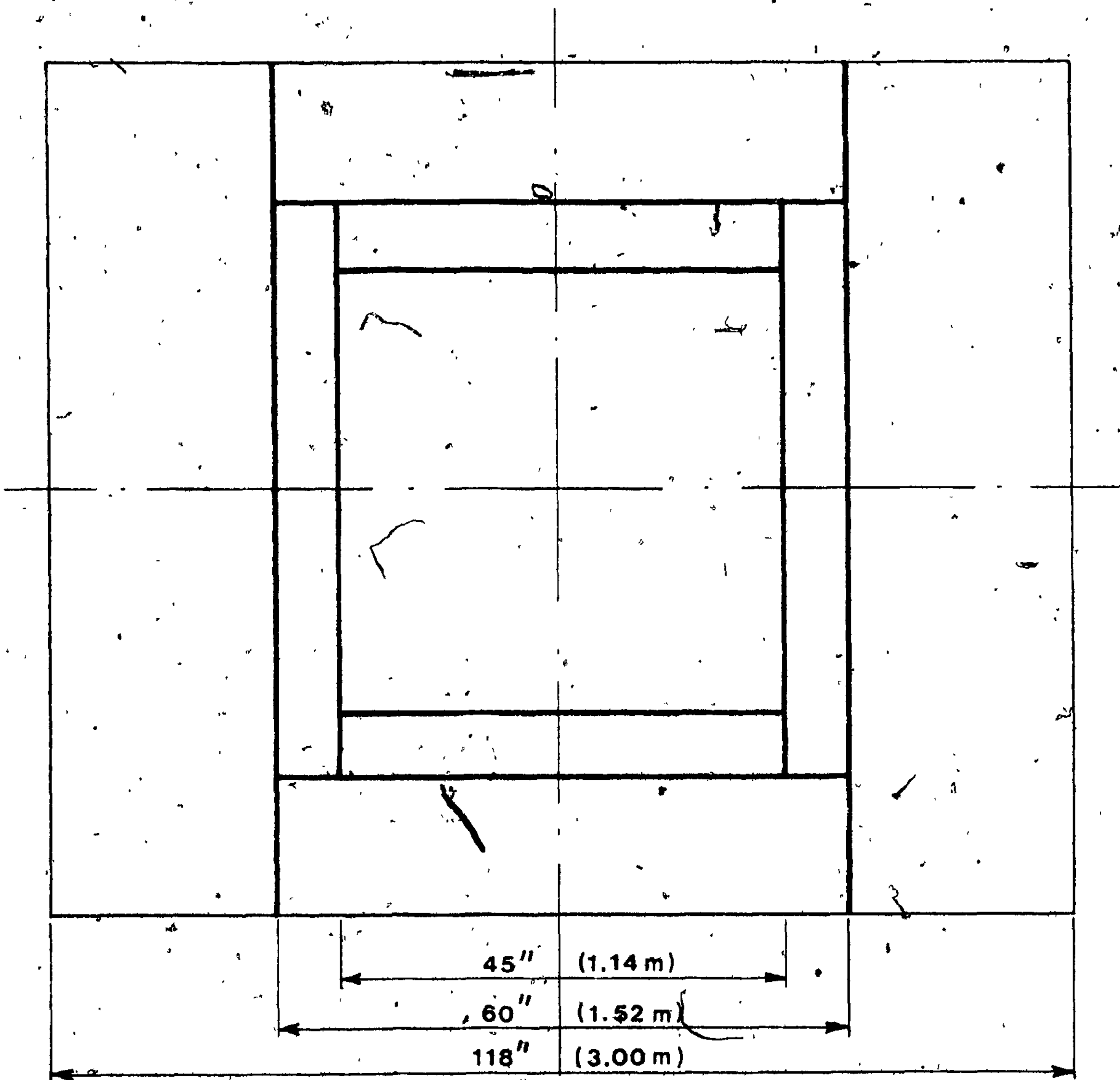


Fig. 7a: Framework Layout for Outer Wall Towards the Source Room and Both Inner Walls

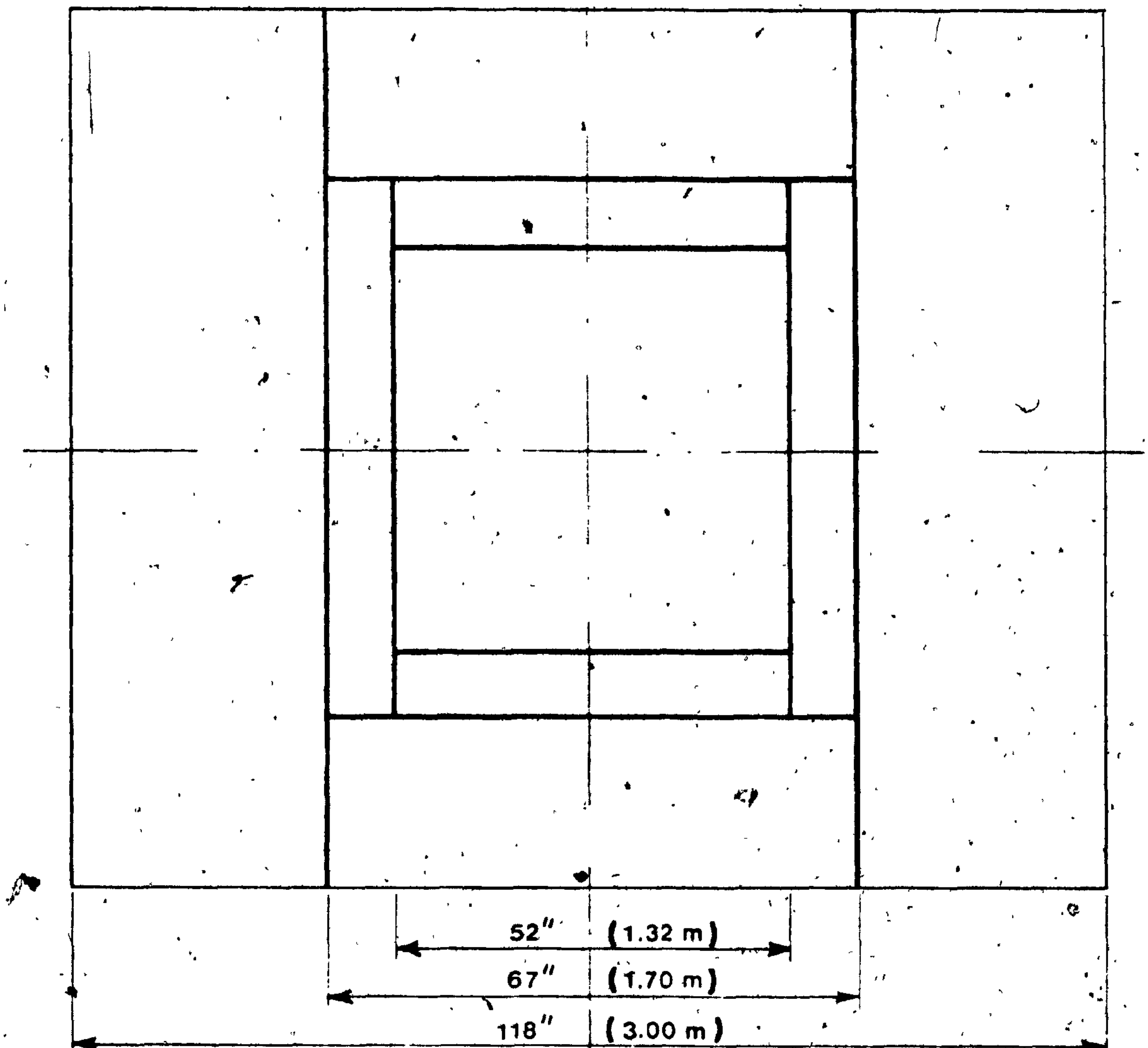


Fig.7b: Framework Layout for Outer Wall Towards the Reception Room

The STC value of the complete filler wall was 60 when the larger room was used as the source room, and 57 in the opposite direction. (The STC or Sound Transmission Class is a single number rating describing the performance of a wall. It is obtained by comparing the sound transmission loss spectrum of the wall with a reference curve.) All consequent experiments being performed with the larger room as the source room, the first value was kept for further calculations. The transmission loss curves of the filler wall for the measurements in both directions are given in Appendix B.

3.1.3. Mounting of the Test Panels

When the transmission loss tests for the filler wall were completed, the inner aperture was opened in order to mount the smaller test panel. Once the tests with the smaller panel were accomplished it was in turn removed, after which the opening was further enlarged in order to accommodate the next panel size.

The test panels used were nominally 6 mm (1/4") thick glass panels, respectively 1.14 m x 1.14 m (45"x45") and 1.52 m x 1.52 m (60"x60") large. The relevant material properties of glass are given in Table I.

Table I : Typical Material Properties of the Glass Panels

Young's Modulus E [N/m2]	[illegible]
Density ρ [Kg/m3]	2500
Thickness t [m]	6.4×10^{-3}
Mass per unit area ρ_s [kg/m2]	16.1
Coincidence frequency f_c [Hz]	2850

For either size, the test panel was mounted flush to the source room (larger room) leaving a 38 cm (15") deep reveal on the receiving side. The aperture was further splayed at 45° towards the reception room to minimize the effect of the remaining wall depth. The method of installation of the test panel is displayed in Figure 8.a.

Weather stripping around the perimeter on both sides of the panel mimizes any leakage of sound. The panel was held in place by a wood profile on the receiving side and a wood plate on the source side, both covering the entire perimeter. The panel's boundary condition may be described as 'flexible', that is neither clamped or simply supported. The depth of the reveal is covered with aluminum.

During the experiments the reveal on the receiving side was left either bare (as described above) or lined with an absorbent material of different thickness: Conaflex F (by Blachford), 2.54 cm (1"), 5.08 cm (2") and 10.16 cm (4") thick. For material properties see Table II.

Other experiments were performed with additional sills of varying depth mounted on the source side, Figure 8.b.

Table II : Absorption Coefficients of Conaflex F (*)

Frequency [Hz]	Conaflex F-100 (1)	Conaflex F-100 (2)	Conaflex F-200 (1)	Conaflex F-200 (2)	Conaflex F-400 (2) (*)
125	8	8	27	37	30
160	10	10	37	36	46
200	13	12	57	22	57
250	19	10	68	24	72
315	30	35	75	26	84
400	44	14	87	42	93
500	57	19	91	55	95
630	63	37	94	37	87
800	78	47	97	63	75
1000	88	69	98	62	80
1250	95	94	98	90	88
1600	97	96	96	82	92
2000	96	86	98	80	90
2500	93	76	97	97	95
3150	90	[illegible]6	97	97	95
4000	88	95	98	99	99
5000	96	99	95	100	100

(1) Approximate values derived from chart supplied by manufacturer.

Test method ASTM C423-66, Test sample 72 square feet.

(2) Measured according to ASTM C 384-77

(*) Absorption coefficients for Conaflex F-400 not available from manufacturer

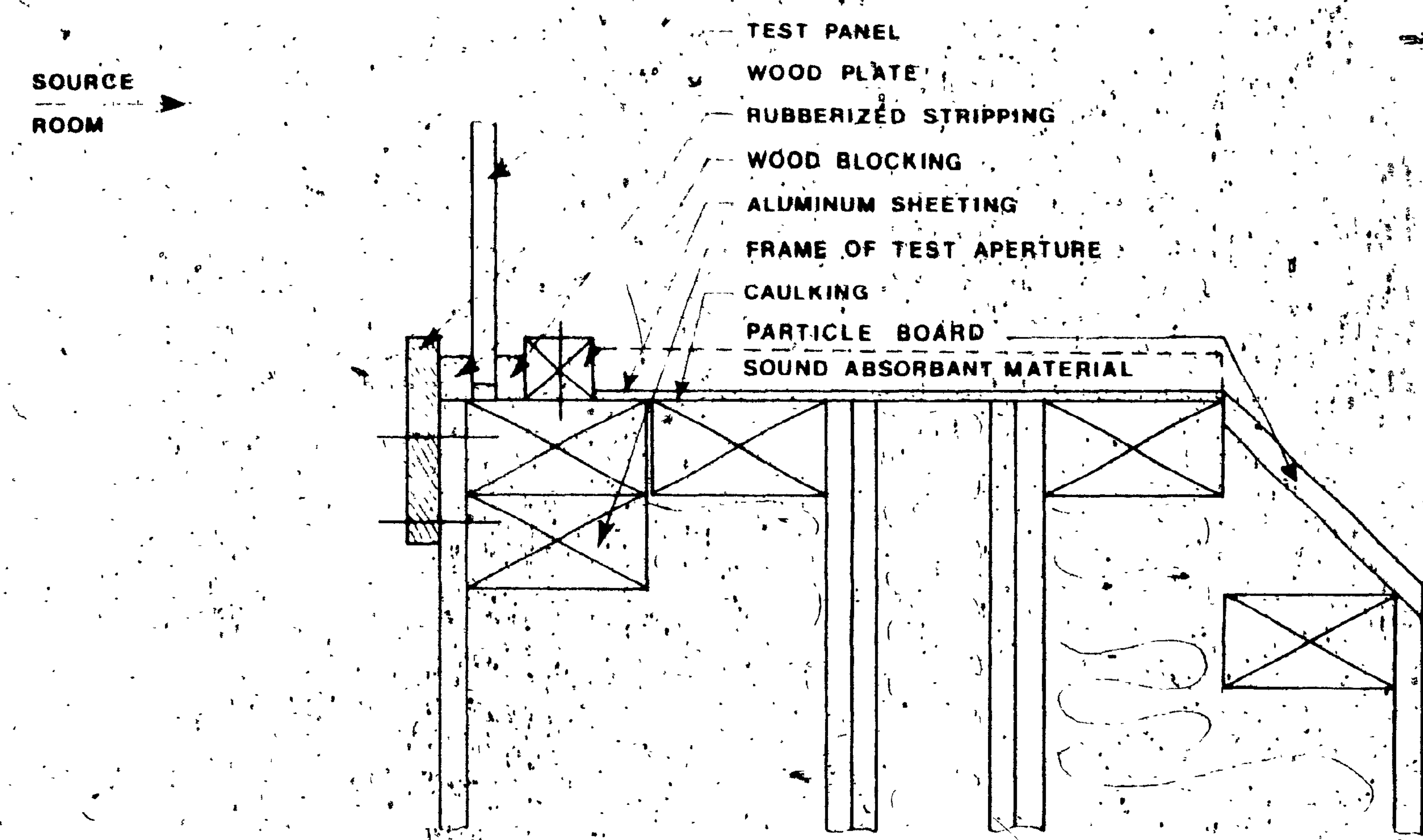


Fig 8a: Mounting of Test Panel on Filler Wall

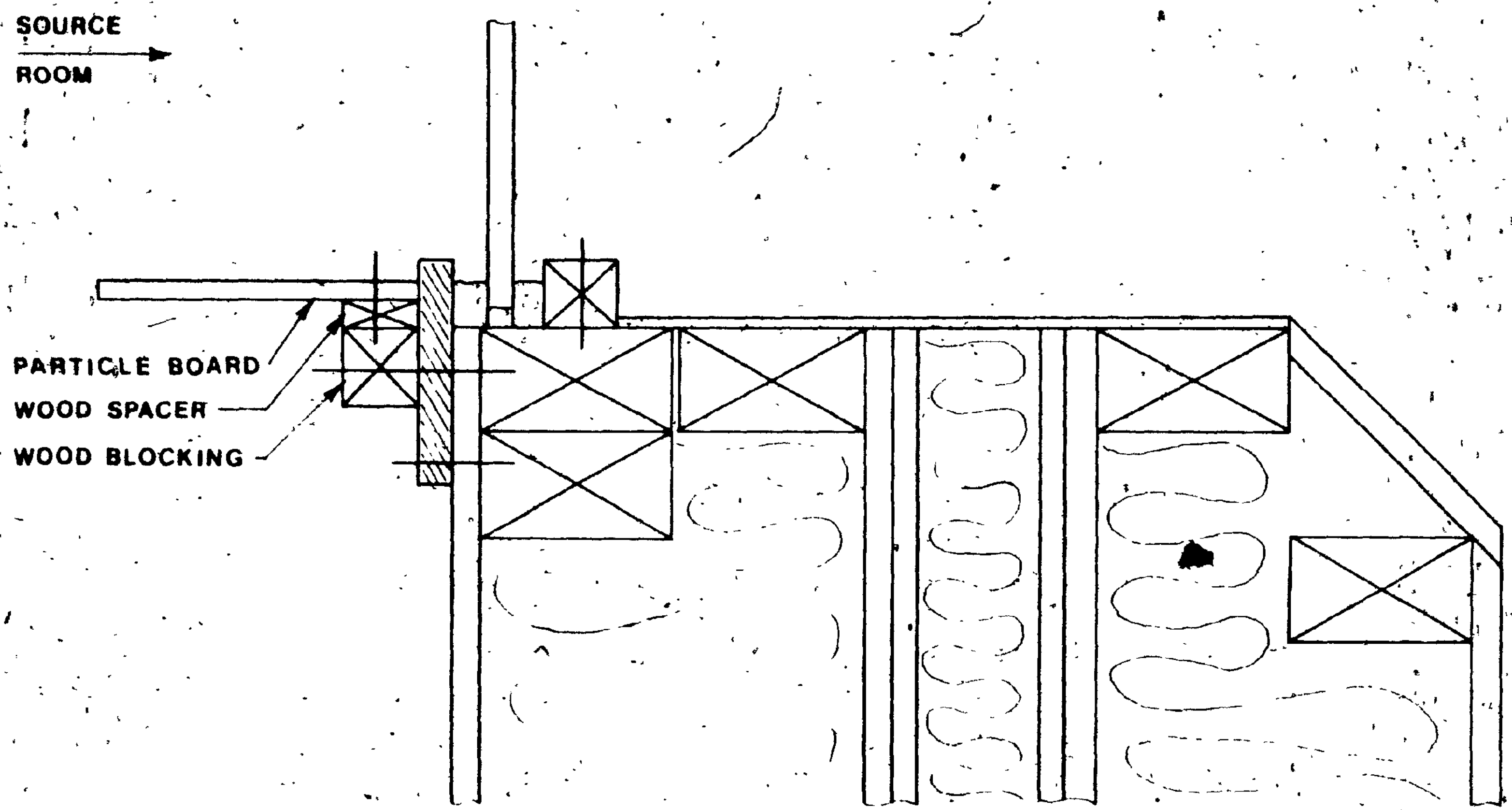


Fig. 8b: Mounting of Test Panel on Filler Wall With Sill

3.2. Test Procedures

3.2.1. Standard Transmission Loss Measurement

This type of measurement was performed in order to determine the STC value of the filler wall and as a reference for the results obtained with the intensity technique. All other measurements used the intensity method.

White noise was generated in the source room by two loudspeakers placed in the corners of the room opposite the test aperture.

The mean sound pressure levels in the source room were measured using a rotating microphone boom (B&K 3923) placed in the 3-dimensional center of the room. Their calculation was based on 30 measurement samples, each having an averaging time of 32 seconds. The microphone described a plane circular path at 70º from the horizontal and the length of the arm was 1.6 m. This configuration was chosen so that the microphone cleared the walls and stationary diffusers by at least 0.8 m. The ANSI/ASTM E90-75 Standards [9] requires a minimum of a half wavelength for the center-frequency of the lowest band of interest. This was chosen at 250 Hz which is the Schroeder cut-off frequency of the source room as well as the lower frequency limit for acceptably accurate intensity measurements for the experiments reported (see below), consequently the minimum distance required by the standards was 0.69 m.

On the other hand, the minimum required distance d from the microphone to the speakers is given by [9]:

$$10 \log(A/d^2) = 3.6$$

for an omnidirectional sound source placed on a hard surface. A is the room absorption [metric sabins]. When A is taken as the lowest absorption over the frequency band of interest (2.3 metric sabins), the calculated and actual value for d is 1 m.

A complete revolution of the microphone boom took 32 seconds.

In the receiving room, the mean sound pressure level measurement was performed in the same manner as in the source room. However, because of its smaller size, the length of the arm was changed to 0.95 m and the turntable was tilted at 60° from the horizontal, thus leaving a 0.7 m minimum clearance to the walls and diffusers and 1.2 m to the speakers.

The reverberation time in the receiving room was calculated from the averaged decay points (16 per second and 50 decay samples) with the turntable in the same position as described above and with the microphone rotating. A linear regression analysis was used in the range -5 dB below the upper decay points down to 10 dB above background level.

All measurements were performed in third octave frequency bands. They were computer controlled and fed to a third octave analyser, which was in this case the Sound

Intensity Analyser type 2134/3360 from Brüel & Kjaer. The instruments used and the relevant circuit diagram are shown in Figure 9. The listings of the computer programs used are given in Appendix C. The programs to measure the Reverberation Time, Transmission Loss and the Graphic Output were adapted from already existing programs [38]. The others were developed specificaly for this project.

3.2.2. Intensity Technique

The incident intensity was calculated from the space/time-, averaged sound pressure level as measured by the reverberant room method described in Chapter II,2.1.1.1.

The transmitted sound intensity was measured by the B&K Sound Intensity Analyser which is based on the digital filtering technique. This instrument is supplied with a Microphone Probe type 3519 which uses a face-to-face microphone configuration. The 1/2" microphones with 12 mm spacer were chosen, thus giving a useful frequency range of 125 Hz to 5 kHz with an accuracy of ±1 dB assuming a monopole source.

The intensity radiated through the panel was either measured at 5.08 cm (2") behind the surface or at the receiving side of the reveal at 12.7 cm (5") interval, uniformly distributed over the test surface. This resulted in 81 measuring points for the smaller test panel and 144 points for the larger size. The linear averaging time per point was 8 seconds.

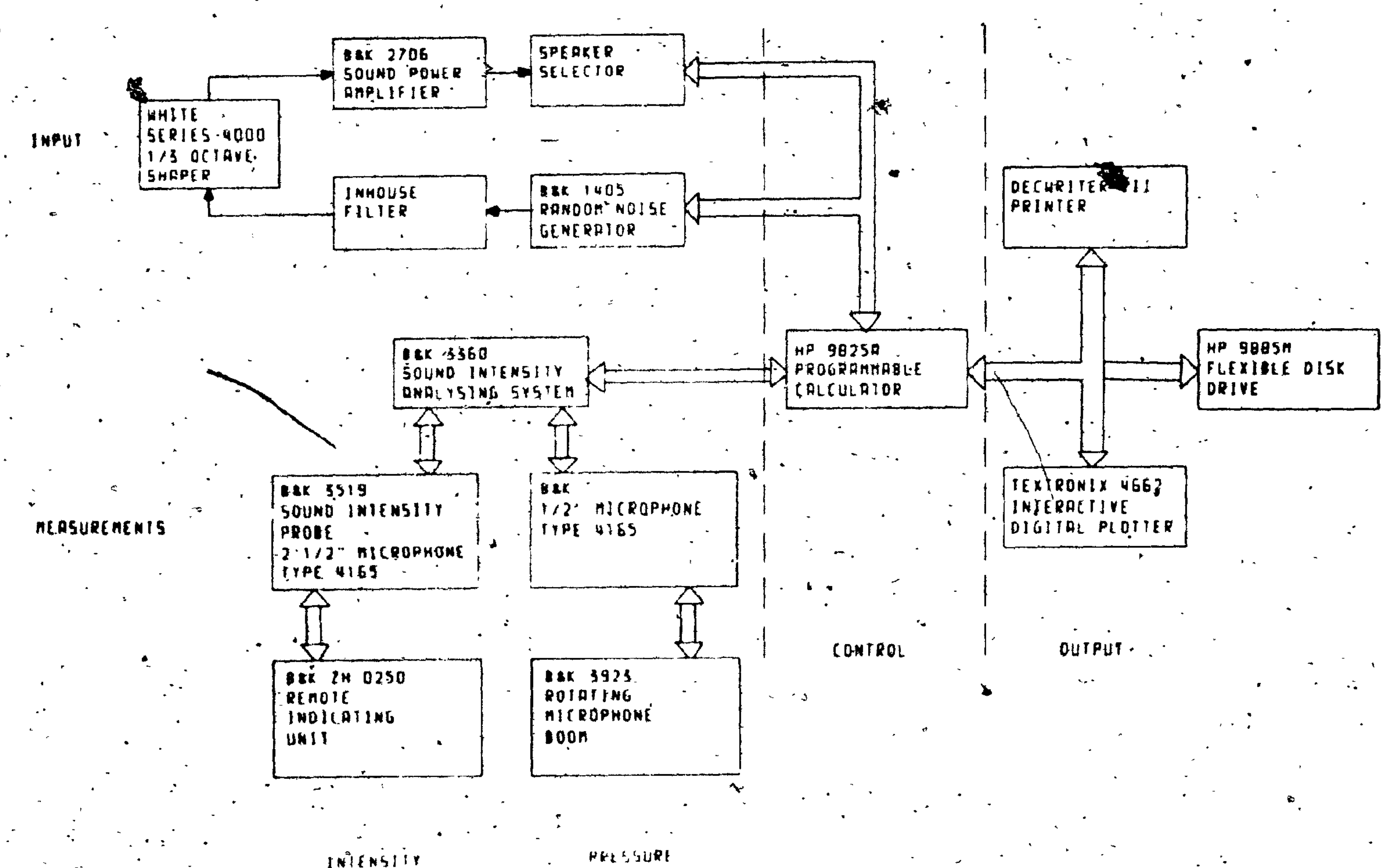


Fig. 9: Instrumentation Set-Up

The choice of the measuring parameters will be discussed later.

During the measurements the microphone probe was mounted on a mechanical traverse system which enabled the microphone probe to be fixed during each measurement interval. It was moved by hand from point to point.

All data was stored on disk, through the use of the Remote Indicating Unit ZH 0250 (B&K).

In order to avoid reverberant field effects which would reduce the measurement accuracy of the intensity method, three non-parallel walls of the receiving room were covered with a thick absorbent material Conaflex F-400, the same type of material used to line the reveal (see Table II). Naturally this material was removed for the corresponding sound pressure tests.

3.2.3. Estimation of the Phase Errors in the Intensity Measurements

Given the experimental conditions described above, the influence of the reactivity of the sound field on the accuracy of the measurements was determined in both measurement planes. The reactivity is the ratio between the sound pressure squared, and the sound intensity, or, when expressed in dB , the difference between the pressure and the intensity level.

Some researchers state a maximum value for the reactivity below which measurements are considered to be sufficiently accurate, regardless of the frequency. Villot and Roland [34], for example, use a limit of 10 dB; Waser and Crocker [35] take 12 dB. Others such as Brock [36] and P. Rasmussen [26] have expressed the phase errors as a function of the reactivity, frequency and microphone spacing. This approach has been followed here.

The error L_{er}, defined as the difference between the measured intensity level [dB] and the true intensity level [dB], can be calculated from [26] :

$$L_{er} = -10 \log(1 - \frac{I_{re} \cdot P_t}{P_{re} \cdot I_{me}}) \quad [dB] \qquad (21)$$

where P_{re} is the sound pressure in a completely reactive (reverberant) field, I_{re} [W/m^2] is the apparent or residual intensity associated with it, and P_t [Pa] and I_{me} [W/m^2] respectively the actual measured sound pressure and intensity.

The first two parameters were measured with both microphones placed in a small coupler fed with white noise, the latter two at a measuring point on the edge of the smaller test panel. The phase differences and errors calculated according to equation (17) and (21) respectively can be found in Table III. The results concern both measurement planes with the reveal left bare and the receiving room lined with absorbent material.

Table III : Phase Differences and Errors Due to the Reactivity of the Sound Field

frequency [Hz]	in coupler		5 cm from panel			receiving side of reveal		
	reactivity [dB]	ø [°]	reactivity [dB]	ø [°]	Ler [dB]	reactivity [dB]	ø [°]	Ler [dB]
125	8.3	0.24	4.3	0.6	2.20	8.6	0.3	infinity
160	11.5	0.15	5.2	0.7	1.20	4.9	0.7	1.07
200	16.4	0.06	10.0	0.3	1.13	4.0	1.0	0.26
250	18.7	0.05	5.9	0.8	0.20	3.7	1.5	0.14
315	23.6	0.02	4.7	1.5	0.56	2.6	2.5	0.04
400	30.0	0.01	4.0	2.0	0.01	2.7	3.0	0.01
500	30.0	0.01	6.0	1.7	0.02	3.5	3.0	0.01
630	24.4	0.03	6.6	1.8	0.07	3.2	4.0	0.03
800	26.2	0.03	6.5	2.5	0.05	3.4	4.5	0.02
1000	24.1	0.05	8.5	1.8	0.12	3.5	6.0	0.04
1250	19.9	0.17	7.0	3.5	0.23	3.4	7.5	0.10
1600	20.1	0.20	8.7	3.0	0.33	4.3	7.5	0.12
2000	22.7	0.14	7.1	5.0	0.12	3.4	11	0.05
2500	23.0	0.16	4.9	10	0.07	3.4	15	0.05
3150	30.9	0.03	3.8	18	0.01	3.4	18	0.01
4000	13.7	2.21	3.7	25	0.46	2.9	30	0.38
5000	**	**	2.9	35	**	2.3	40	**

(**) non reliable results due to resonance phenomena in the coupler volume

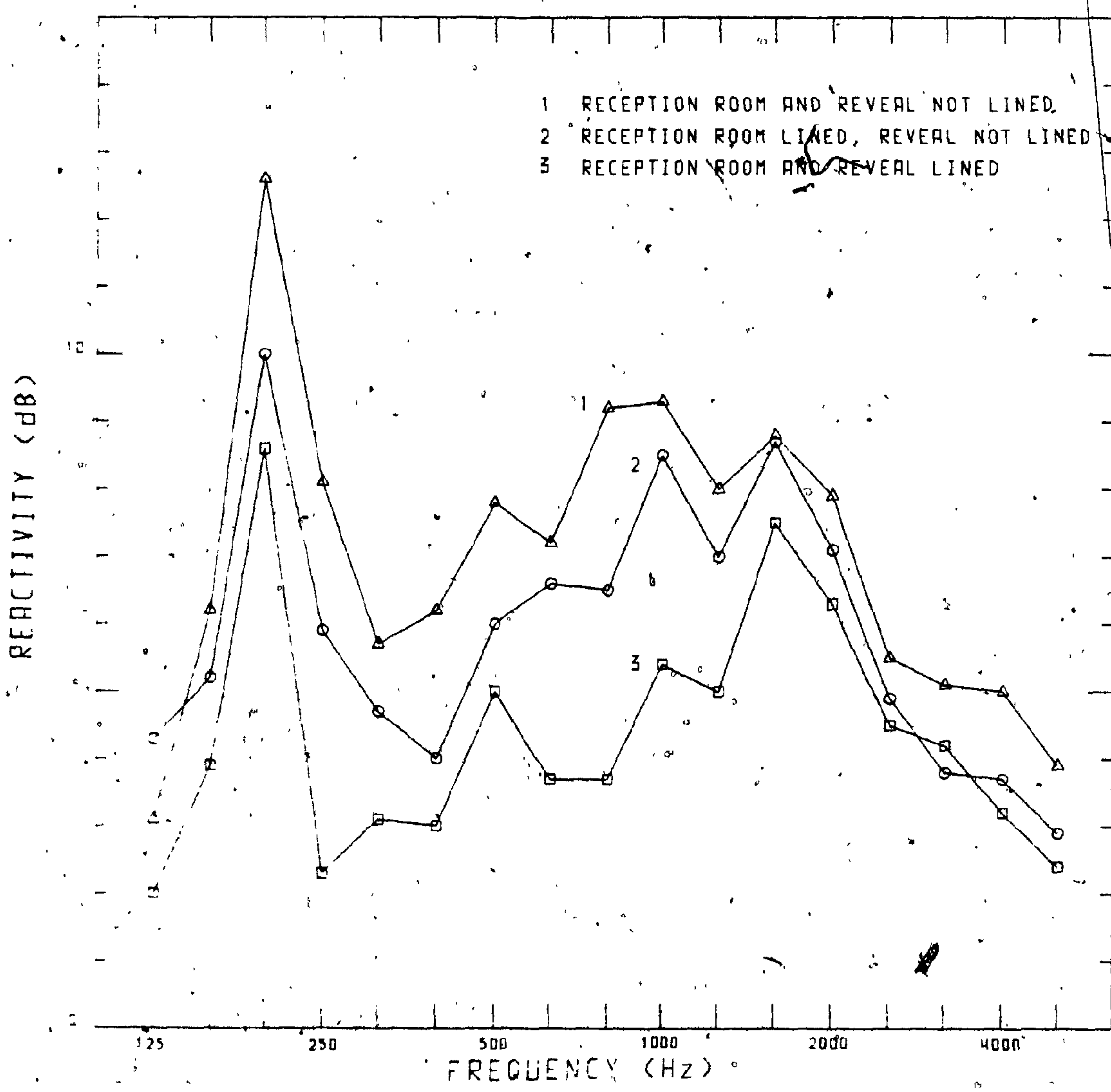


Fig.10.a: Reactivity of the Sound Field for Varying Third Octaves at 5 cm (2") from the Test Panel
1.14m x 1.14m (45" x 45") Panel

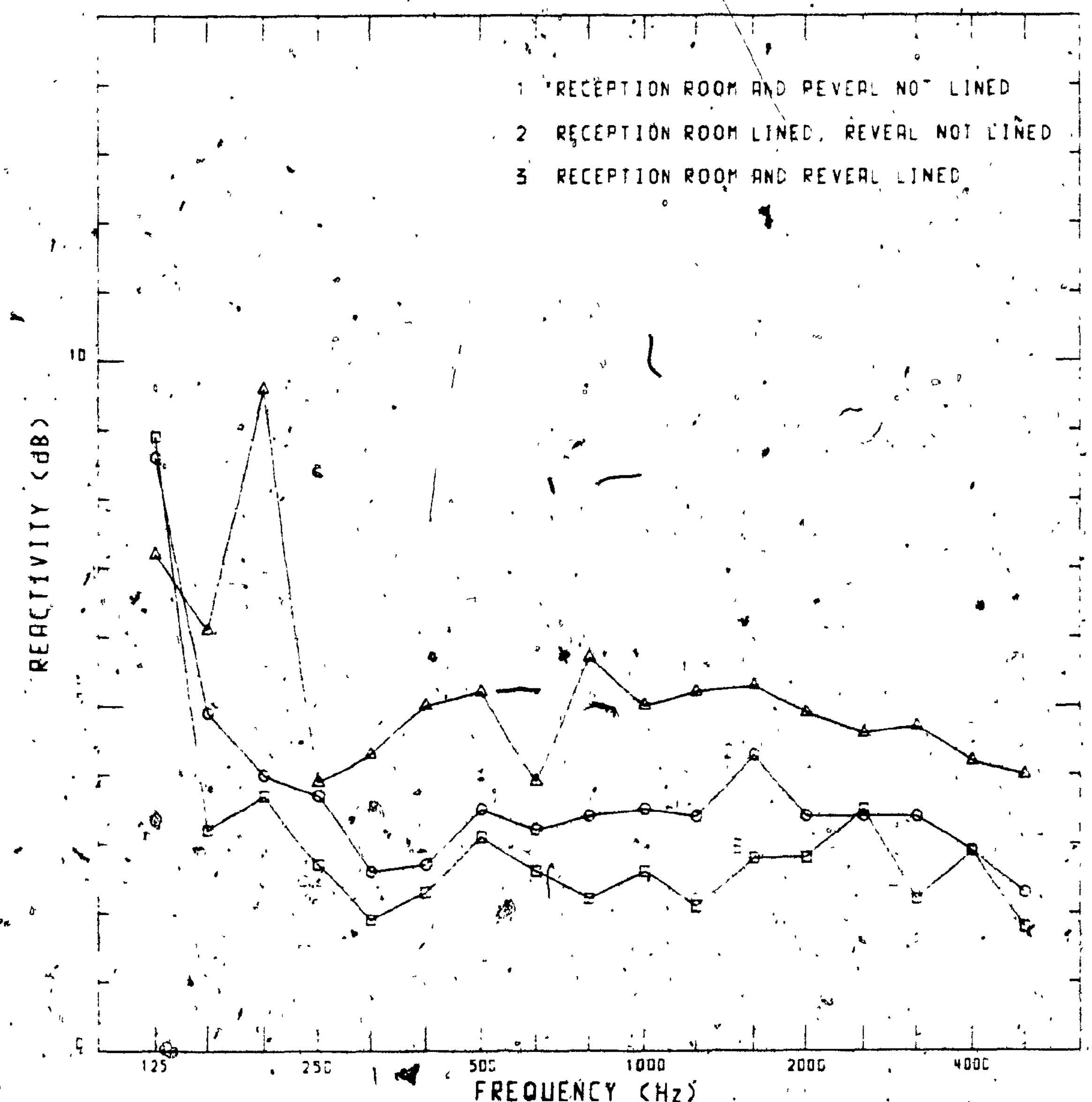


Fig. 10.b: Reactivity of the Sound Field for Varying Third Octaves at the Reception Room Side of the Reveal 1.14m x 1.14m (45" x 45") Panel

As can be seen, the measurement errors due to the instrumentation phase mismatch were relatively high (up to 2.2 dB) at the extreme lower frequency end. However, for frequencies equal to or higher than 250 Hz they were found to be maximum 0.6 dB at 5.08 cm (2") from the test panel, and less at the receiving room side of the reveal. One may notice that at 4000 Hz the phase difference between the 2 measuring channels in the coupler is higher than the 0.3° maximum phase error specified by Brüel & Kjaer. It is possible that resonance phenomena in the coupler volume were affecting the results in that particular third octave band as well as in the 5000 Hz band, in which case the result would be unreliable. Therefore, the measurement error is probably smaller than calculated.
These errors do not include the finite difference approximation errors but are nonetheless considered to be acceptable.

As a consequence, the microphone configuration and the experimental conditions were left unchanged but the useful frequency range was reduced to 250 Hz up to 5000 Hz.

Figure 10.a and b show that, had the receiving room not been lined, the reactivity of the sound field would have been higher, increasing the measurement errors even further. On the other hand, the same figures also show that the opposite is true when the reveal is lined. In both cases differences are most pronounced for the measurements directly behind the test panel. A comparison can be made

with results reported by Cops and Minten [29] who mentioned that their intensity measurements using the two channel FFT method showed less spread when the niche was lined with absorbing material. However, because no other reference to this problem was found in the article it was assumed that all the consequent reported measurements were made with the reveal left bare.

3.3. **Preliminary Tests**

Although the use of the sound intensity technique for transmission loss measurements has been established by others, experimental details of the procedure are still vague and left up to the user. In particular, the relationship between measurement distance and included radiation surface area (mesh size) is not well determined. The available solutions are quite variable and are summarized in Table IV.

Cops and Minten [29] for example, used a mesh size of 19.5 x 20.75 cm with a measurement distance of 4 cm, while Fahy [28] used the same distance but for a much smaller mesh of 7.1 x 7.1 cm. It was therefore necessary to determine the measurement parameters experimentally, before the actual transmission loss tests. All these preliminary tests were performed on the smaller panel. During these measurements only the transmitted intensity level was determined, the incident power being held constant for each of the series.

Table IV : Measurement Parameters in Previous Works

Reference Work	Total Surface Area [m^2]	Number of Measuring Points	Mesh Size [m^2] (*)	Measurement Distance[m]
Crocker [27]	1.17 x 1.17	spatially averaged (4m/s)		0.2
Fahy [28]	0.64 x 0.64	81	.071x.071	0.4
Cops [29]	1.56 x 1.56	64	.195x.2075	0.4 (**)
		spatially averaged		0.5
Villot [34]	0.60 x 0.40	12	.15 x .15	0.1
Mc Gary [37]	1.22 x 2.44	spatially averaged for each of the subdivisions (0.232 m^2 up to 0.323 m^2		0.12
Halliwell [42]	2.44 x 3.05	100	.0744	0.05
		25	.2977	0.05

(*) values infered from the preceding columns

(**) little difference was found for intensity levels measured at 4 to 10 cm from the partition

3.3.1. Influence of Absorbent Material in the Reception Room

Researchers agree that when the reactivity of a sound field increases, the accuracy of intensity measurements decreases. Therefore, absorbent material is usually placed in the reception room when transmission loss tests are performed using the intensity technique.

With regard to the test conditions at the Center for Building Studies, it has already been shown that when the reception room is left bare, the reactivity in the room is such as to increase the measurement errors above 1 dB. In addition the average transmitted intensity was determined with and without absorbent material in the reception room. In the former case, three non-parallel walls of the reception room were covered with Conaflex F-400.

As expected the measured average transmitted intensity levels for the unlined case were lower than those obtained in the presence of the absorbent material (decrease in net-intensity). The differences were however very small with a maximum discrepancy of 1 dB (Figures 11.a and b). On a point per point basis the differences were negligible at the high frequency end and although they were generally only slightly higher elsewhere (up to 2 dB), exceptions to that rule tended to be more frequent below 500 Hz, with differences up to 10 dB. Again this was not surprising for the influence of the reactivity on the accuracy of the measurements is most pronounced at the lower frequencies.

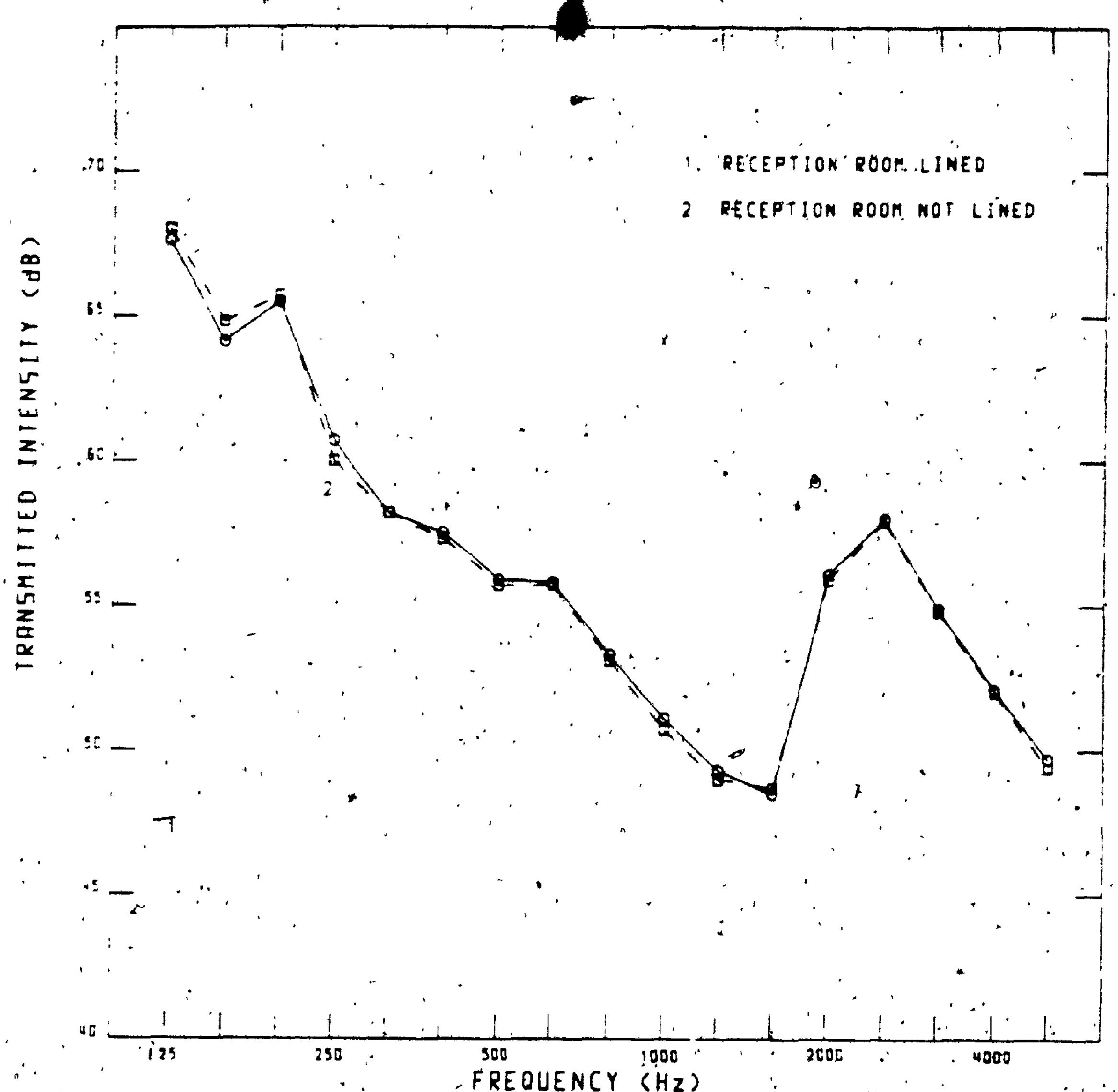


Fig. 11.a: Influence of Absorbent Material in the Reception Room Transmitted Intensity Measured at 5 cm (2") from Panel 1.14m x 1.14m (45" x 45") Panel

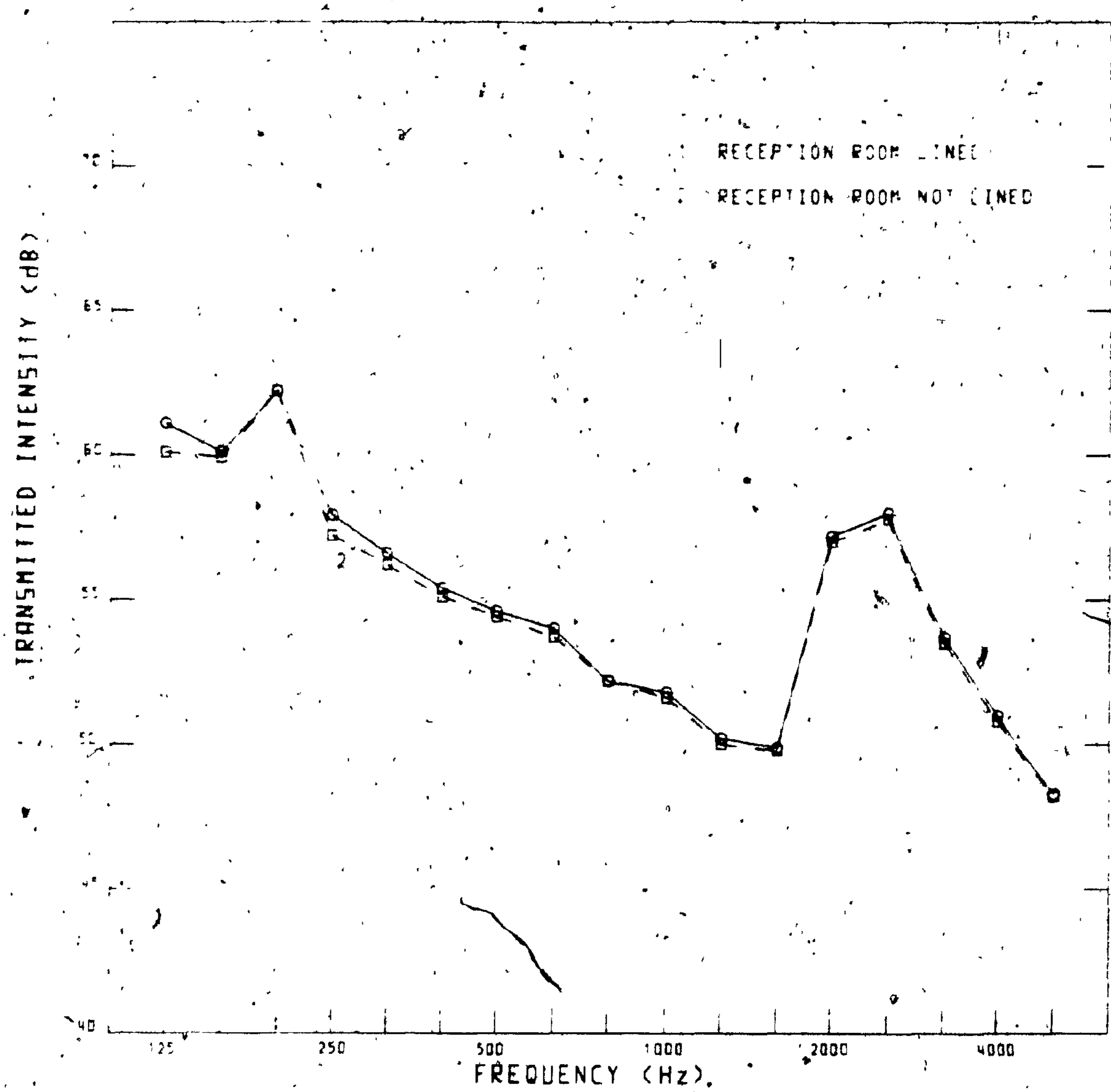


Fig. 11b: Influence of Absorbent Material in the Reception Room
Transmitted Intensity Measured at the Reception Room Side of the Reveal
1.14m x 1.14m (45" x 45") Panel

In contrast with the reactivity measurements where the differences were generally higher at the receiving room side of the reveal, no such finding could be reported in this case, both on an overall and on a point per point basis.

Consequently, the reception room was always lined as described for intensity measurements in order to optimize the accuracy of the method.

3.3.2. Averaging Time and Method

The averaging time is an important parameter in a measurement procedure both for accuracy and for total duration of the test. The object was to minimize time without loss of accuracy.

Spatial averaging would probably have given the fastest excecution time and, according to Cops and Minten [29], also the most accurate one. However the results thus obtained are transmission loss values averaged over the whole panel area. The present purpose including the determination of the distribution of the radiation characteristics of the panel, it was necessary to establish a fixed array of measuring points. This method has an additional advantage in that it allows for a more precise determination of the measurement distance. It has therefore also been recommended by Brüel and Kjaer in their proposal for a Standard concerning Sound Power Determination [44] (see also Appendix A)

With regard to the averaging time per point, the transmitted intensity was measured using different linear

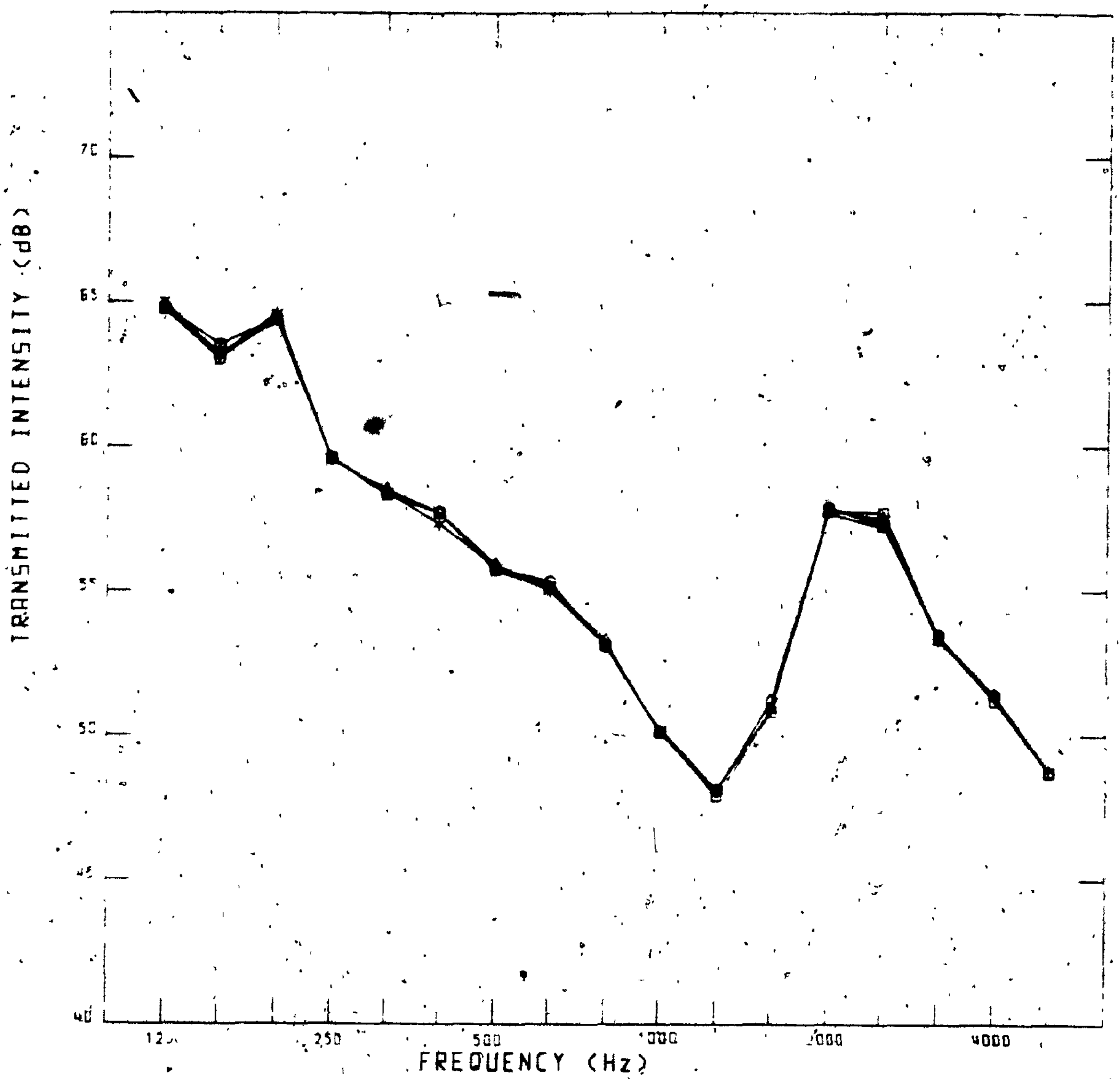


Fig. 12: Influence of the Averaging Time on the Transmitted Intensity
12.7cm x 12.7cm (9x9) Mesh ; t_{av}: 8 sec
Measurement Distance: 6.3 cm (2.5")
1.14m x 1.14m (45" x 45") Panel

averaging times : 4,8,16 and 32 seconds, for a fixed array of 81 points. The results obtained were compared with the 32 second averaging time which was deemed accurate for steady state measurements and therefore used as a reference. As can be seen in Figure 12 the intensities averaged over the total test panel's surface were very similar in all cases (± 1 dB). However, after a comparison of the results point per point, a linear averaging time of 8 seconds was chosen since the maximum deviation from the 32 seconds measurement did not exceed 1 dB.

3.3.3. Mesh Size

Four different mesh sizes were tested : 38.1 x 38.1 cm (15" x 15"), 22.86 x 22.86 cm (9" x 9"), 16.33 x 16.33 cm (6.5" x 6.5") and 12.7 x 12.7 cm (5" x 5"), giving a total number of measuring points of respectively 3x3 (9), 5x5 (25), 7x7 (49) and 9x9 (81) evenly distributed over the panel's surface. No attempt to increase the total number of points has been made because of the time penalty incurred. Each time the power flow was measured at the center of the subarea so created at a distance (test panel to center of microphone pair) of half the mesh size.

The results with respect to the average transmitted intensity show the following (see Figure 13) :

Little difference is seen between the results of the 7x7 and 9x9 meshes; with one exception differences were less than 0.5 dB.

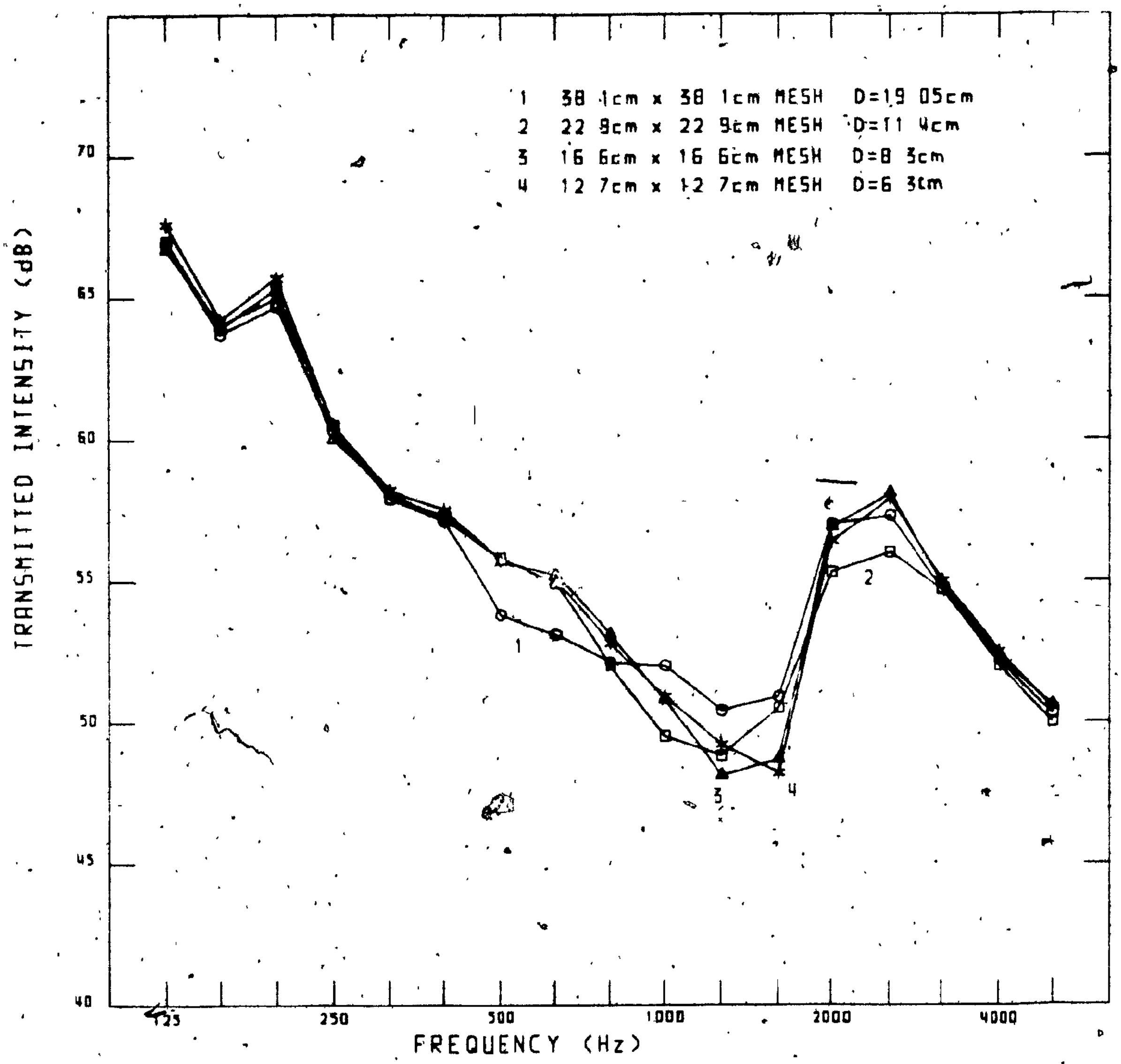


Fig. 13: Influence of the Mesh Size on the Transmitted Intensity
t_{av}: 8 sec
1.14m x 1.14m (45" x 45") Panel
(D: Measurement Distance)

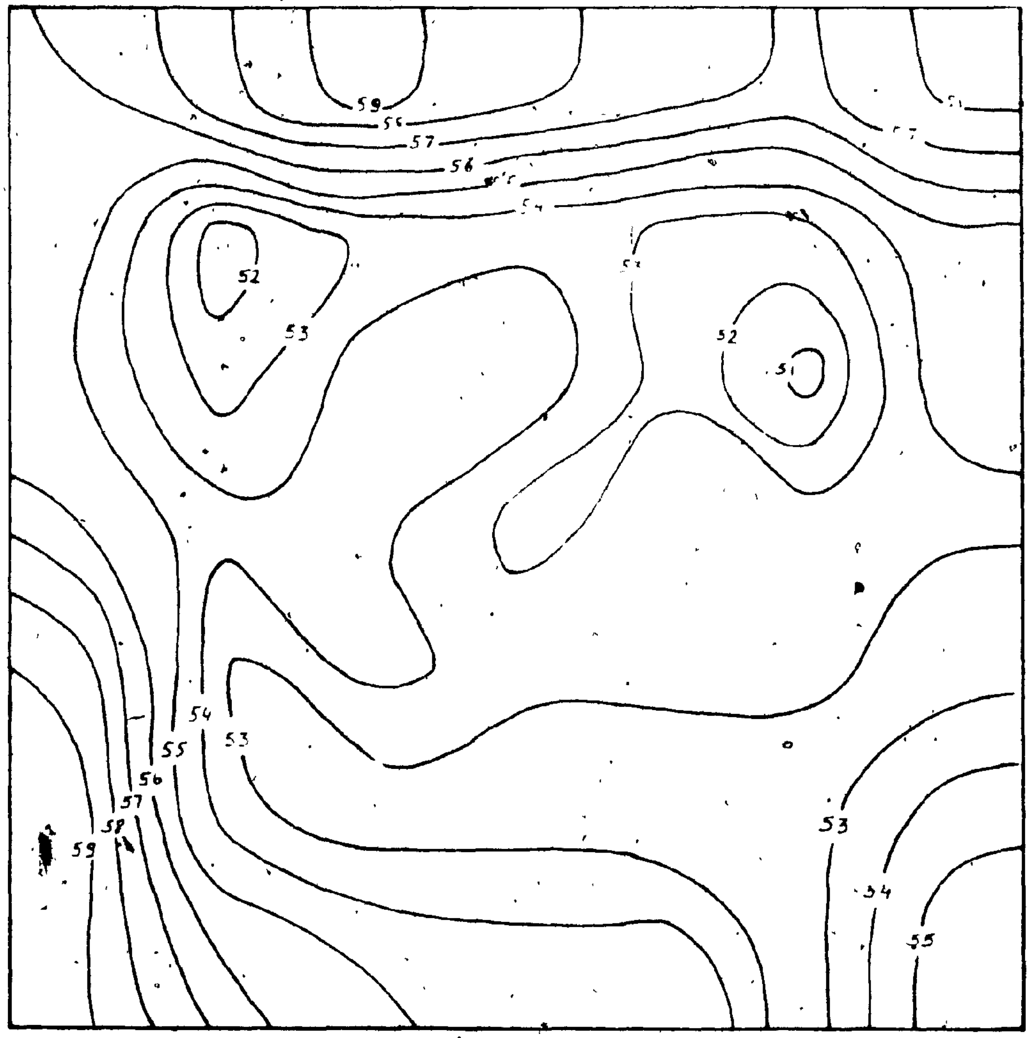


Fig. 14.a: Influence of the Mesh Size : Intensity Contours for the 630 Hz third octave band based on the 16.6cm x 16.6cm (7x7) Mesh
Measurement Distance: 8.3 cm
1.14m x 1.14m (45" x 45") Panel

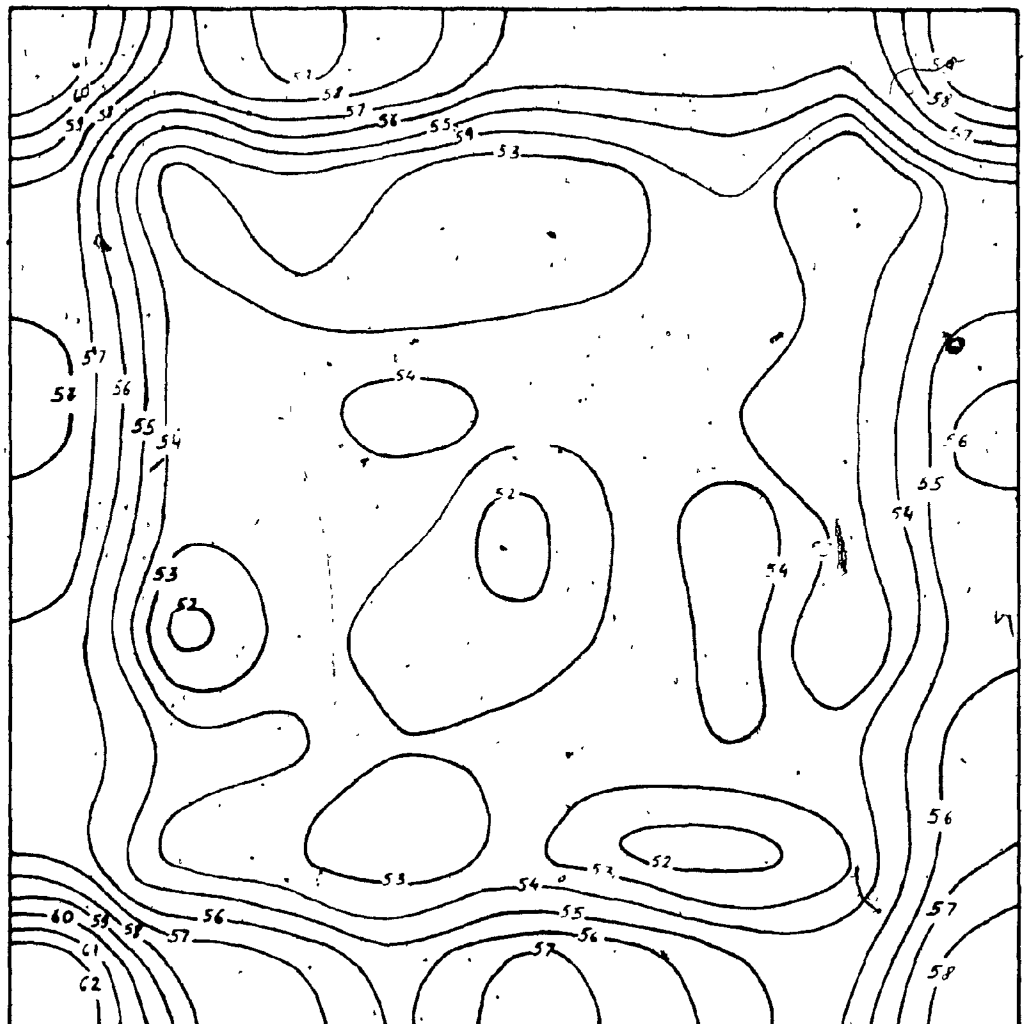


Fig. 14.b: Influence of the Mesh Size : Intensity Contours for the 630 Hz third octave band based on the 12.7cm x 12.7cm (9x9) Mesh

Measurement Distance: 6.3 cm

1.14m x 1.14m (45" x 45") Panel

For the 5x5 mesh, the only large deviation observed was around the coincidence frequency, in particular in the 2500 Hz third octave band. The peak in the transmitted intensity, which gives rise to the coincidence dip in a transmission loss plot, is seen to be much lower and wider.

The results of the 3x3 mesh were generally more irregular with large differences from the smaller mesh sizes.

For the present purpose, the smaller mesh size was chosen because it was thought to give the most accurate results and because of the more detailed information possible with respect to establishing the radiated intensity distribution by means of equal intensity contours. Compare for example Figure 14.a with 14.b; both figures represent the equal intensity contours at 630 Hz but are based on different mesh sizes, 7x7 and 9x9 respectively. However, for normal sound transmission loss measurements it seems that even the 5x5 mesh could be used to yield acceptable accuracy.

3.3.4. Measurement Distance

In order to optimize the measurement distance, the transmitted intensity was measured at several distances from the test panel. With regard to the 9x9 mesh (12.7 x12.7 cm or 5" x 5"), the distances chosen were : 3.81 cm (1.5"), 5.08 cm (2"), 7.62 cm (3"), 10.16 cm (4") and 12.7 cm (5").

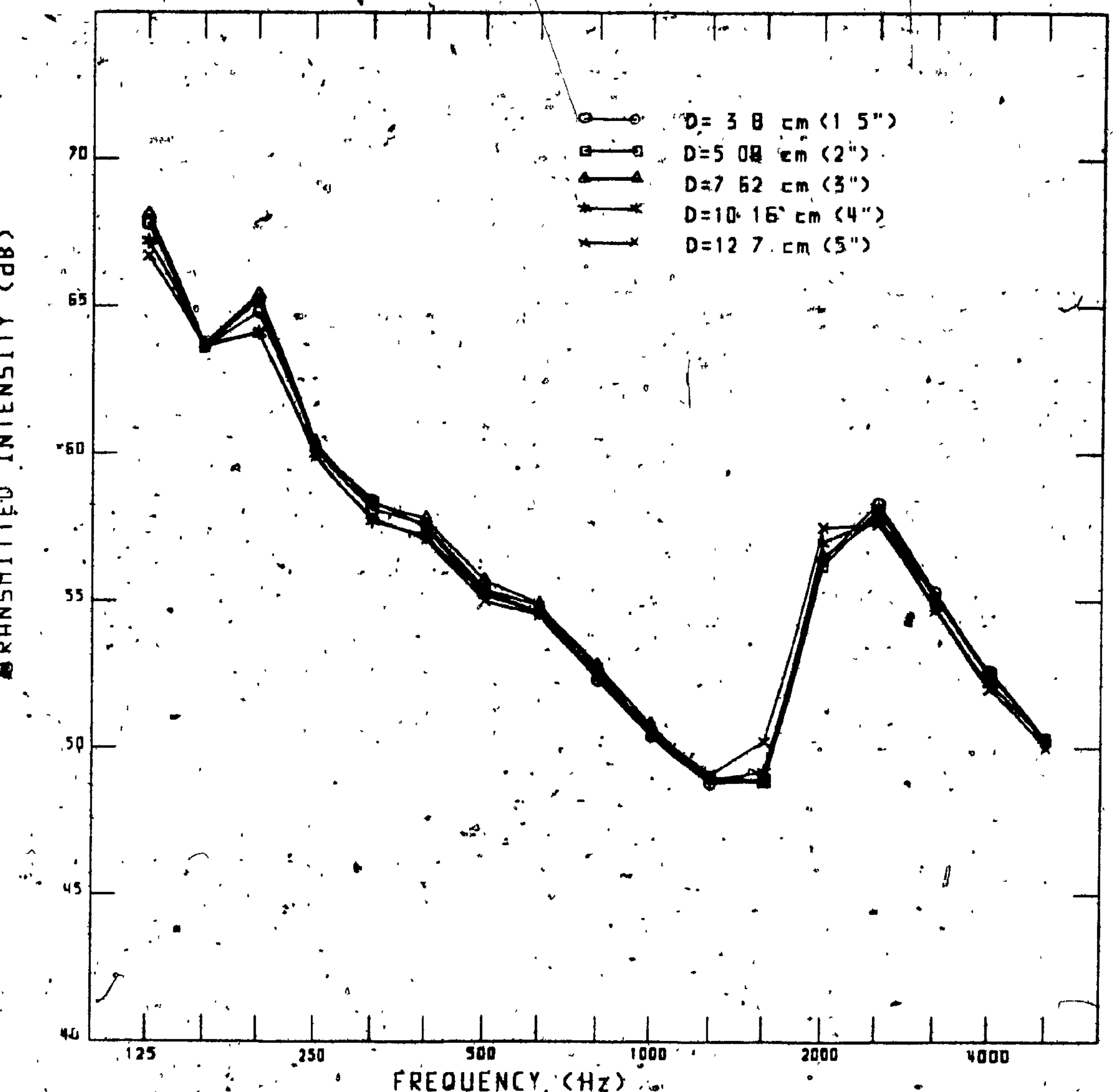


Fig. 15: Influence of the Measurement Distance on the Transmitted Intensity
12.7cm x 12.7cm (9x9) Mesh; t_{av}: 8 sec
1.14m x 1.14m (45" x 45") Panel

Certain trends can be observed (see Figure 15) :

. When the distance is smaller than 10 cm (4") there is very little difference between the results (± 0.6 dB). However, the transmitted intensity increases with increasing distance below coincidence; this trend reverses above coincidence.

The larger the measurement distance, the less prominent the coincidence peak with the measured coincidence frequency finally falling to the next lower third octave frequency band.

As a consequence to these experiments and taking into consideration the fact that the higher the measurement distance, the larger the influence would be of the eventual lining of the reveal, the measurement distance chosen was 5.08 cm (2").

CHAPTER IV : TRANSMISSION LOSS TESTS - RESULTS AND DISCUSSION

The Sound Transmission Loss was measured as a function of the following parameters:

- lining of the reveal with sound absorbing material (Conaflex F) of varying thickness: 0, 2.5 cm (1"), 5 cm (2") and 10 cm (4").
- sills of different depths: 0, 19 cm (7.5") and 38 cm (15'), in the presence of a 38 cm (15") reveal
- panel dimensions: 1.14 m x 1.14 m (45" x 45") and 1.52 m x 1.52 m (60" x 60").

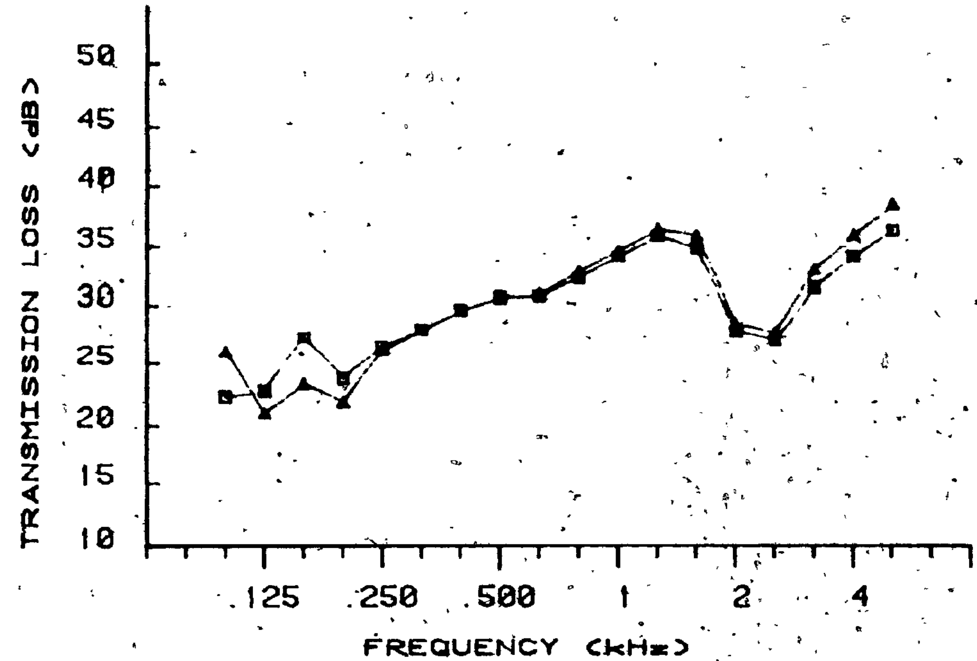
Surface intensity contours were drawn in order to:

- determine the transmitted intensity distributions.
- locate a deliberately introduced construction fault.

However, at first the new measurement method had to be validated. This was done by comparing its results to those obtained by the standard method [9].

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	△
100	21.4	25.0
125	21.8	20.0
160	26.3	22.4
200	22.8	20.9
250	25.6	25.1
315	27.1	27.0
400	28.6	28.8
500	29.6	29.7
630	29.8	29.9
800	31.2	31.7
1000	33.1	33.6
1250	34.9	35.4
1600	33.8	34.9
2000	26.9	27.5
2500	26.0	26.7
3150	30.4	31.8
4000	33.1	34.9
5000	35.4	37.5



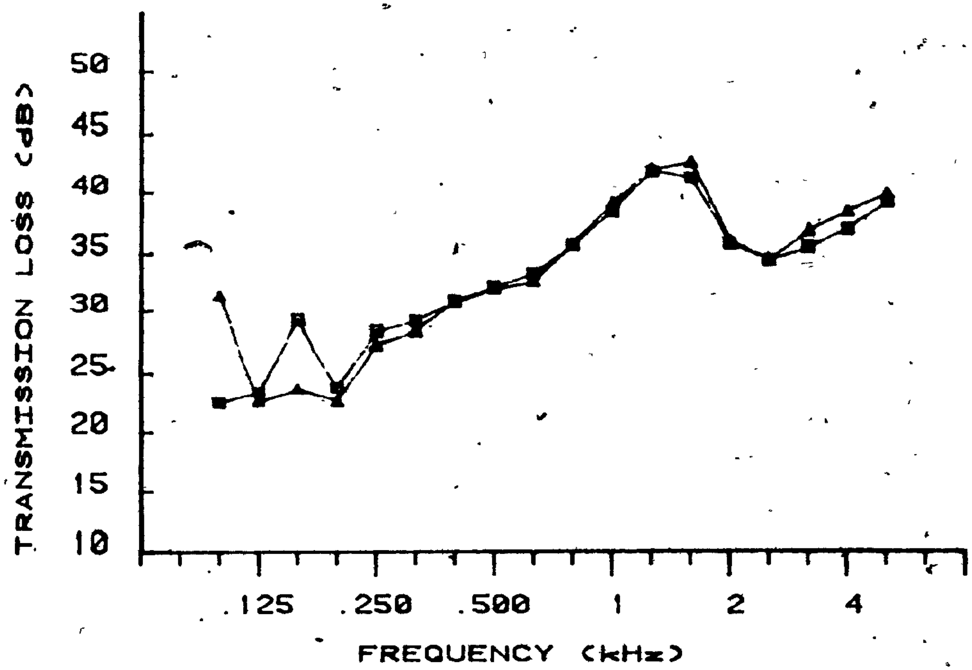
LEGEND

□——□ PRESSURE
△——△ INTENSITY AT RECEPTION ROOM SIDE OF REVEAL

Fig. 16a: Comparison Between Standard and Intensity-Based Transmission Loss Measurements
1.14m x 1.14m Panel - No Sill - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	■	▲
100	21.3	30.4
125	22.2	21.4
160	28.3	22.5
200	22.7	21.4
250	27.4	26.3
315	28.2	27.4
400	30.0	29.8
500	31.3	31.1
630	32.4	31.7
800	34.7	34.8
1000	37.5	38.1
1250	41.0	41.2
1600	40.4	41.8
2000	34.8	35.0
2500	33.5	33.5
3150	34.6	36.8
4000	36.1	37.5
5000	38.3	39.0



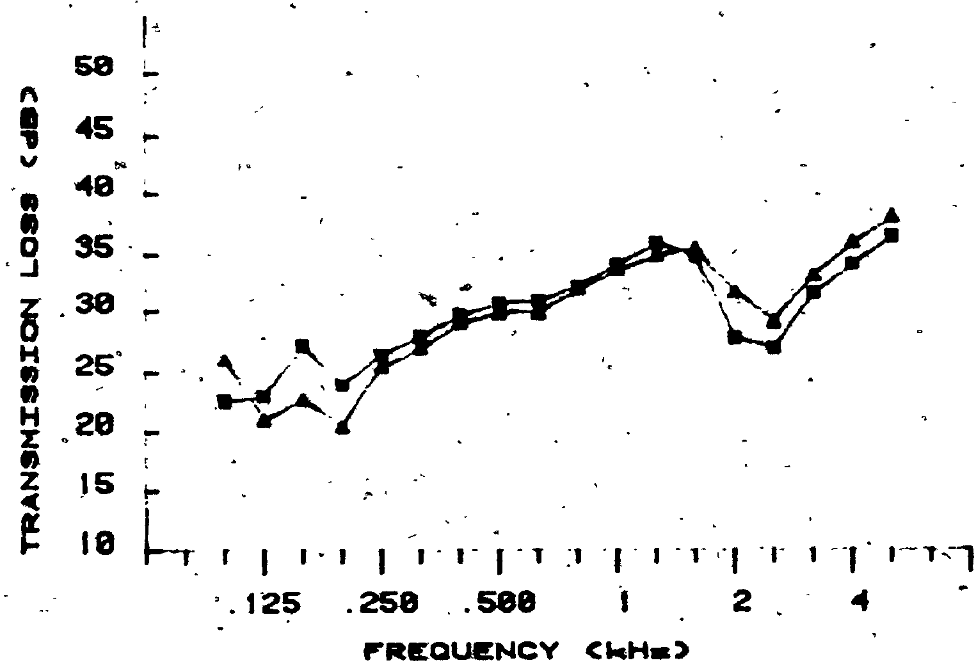
LEGEND

■——■ PRESSURE
▲——▲ INTENSITY AT RECEPTION ROOM SIDE OF REVEAL

Fig. 18b: Comparison Between Standard and Intensity-Based Transmission Loss Measurements
1.14m x 1.14m Panel - No Sill - 2.5cm (1in) Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	21.4	25.8
125	21.6	19.9
160	26.3	21.5
200	22.8	19.4
250	25.6	24.4
315	27.1	26.1
400	28.6	28.0
500	29.6	28.6
630	29.8	28.8
800	31.2	30.8
1000	33.1	32.6
1250	34.9	33.5
1600	33.8	34.4
2000	26.9	30.5
2500	26.8	28.1
3150	30.4	32.8
4000	33.1	34.9
5000	36.4	38.9



LEGEND

■——■ PRESSURE

▲——▲ INTENSITY AT 5 CM (2in) FROM TEST PANEL

Fig. 18c: Comparison Between Standard and Intensity Based Transmission Loss Measurements
1.14m x 1.14m (45in x 45in) Panel - No Sill - No Lining

4.1. Comparison of Standard and Intensity Based Transmission Loss Measurements

This test series was performed on the smaller sized panel only.

The reception room, the smaller chamber, was left bare except for four stationary diffusers during the standard measurements. It was otherwise always lined with absorbent material. For the sake of comparison, the transmitted intensity reported in this section was measured on the reception room side of the reveal.

As shown in Figure 16.a. and 16.b, respectively for the reveal left bare and with 2.5 cm (1") lining, the results were very similar with a maximum difference of 2 dB above 250 Hz. Generally, the intensity method gives the highest values close to and above the coincidence frequency whilst the opposite is true at the lower frequency end. This tendency is also supported by Cops et al. [29,40] and Halliwell and Warnock [41,42]. The greater differences at the lower frequencies are probably due to inaccuracies in both methods: the small size of the reception room affects the reliability of the conventional method and the reactivity that of the intensity method.

The results compare very well with those of most other authors [27,28,29,40], thus demonstrating again the validity of the intensity technique applied to the measurement of sound transmission loss. However, with regard to the works of Cops and Minten [29,40] it appears that the transmitted intensity was always measured directly behind the test panel's surface, even in the presence of a prominent reveal (up to 70 cm deep). The position of the panel within the test aperture was varied (the measurement distance was clearly specified in Reference [29] but could only be assumed to be the same in Reference [40] by the same authors) The agreement between the two methods is generally good in Reference [29], but in Reference [40] large differences (up to 3 dB) can be seen around the coincidence frequency and at the lower frequency end.

The measurement procedure was similar as reported by Halliwell and Warnock [41,42]. For their experiments the total depth of the reveal was 1.22m and 5 panel positions were considered. However, the differences between the two methods are higher, in particular at both ends of the frequency range. When the panel is moved towards the reception room, the differences become smaller at the lower frequencies but the opposite is true at the high frequency end. On the other hand the same authors point out in Reference [42] that the agreement between the 2 methods becomes significantly better, more in particular at the low frequency end, when a correction term is added in the case of the conventional method. This correction, which is ascribed to Waterhouse*, takes into account the higher energy densities at surface junctions and in corners, and thus increases the relevant sound pressure level in a room. The correction is only applied to the levels in the reception room and therefore increases the transmission loss. Its effect is most pronounced at the lower frequency end. In this particular case, differences between the 2 methods are much reduced at the lower frequencies, but they remain high (up to 6 dB) at the other end of the frequency range.

In contrast with the conventional two room method, intensity measurements directly behind the test panel cannot take into account eventual sound absorption over the depth of the reveal (see also section 4.3.2). This effect could be negligible in the case of a massive structure, but in practice a transmission loss suite reveal allows the prospect of untoward error as discussed below.

In References [41] and [42] the test aperture consists of two vibration isolated lightweight steel stud frames. The structure was not specified in References [29] and [40] but it is shown to consist of two separate constructions separated by a gap. Thus in all four instances sound

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* R.V. Waterhouse, "Interference patterns in Reverberant Sound Fields", Journal of the Acoustical Society of America, Vol.27 (1955), pp 247-258.

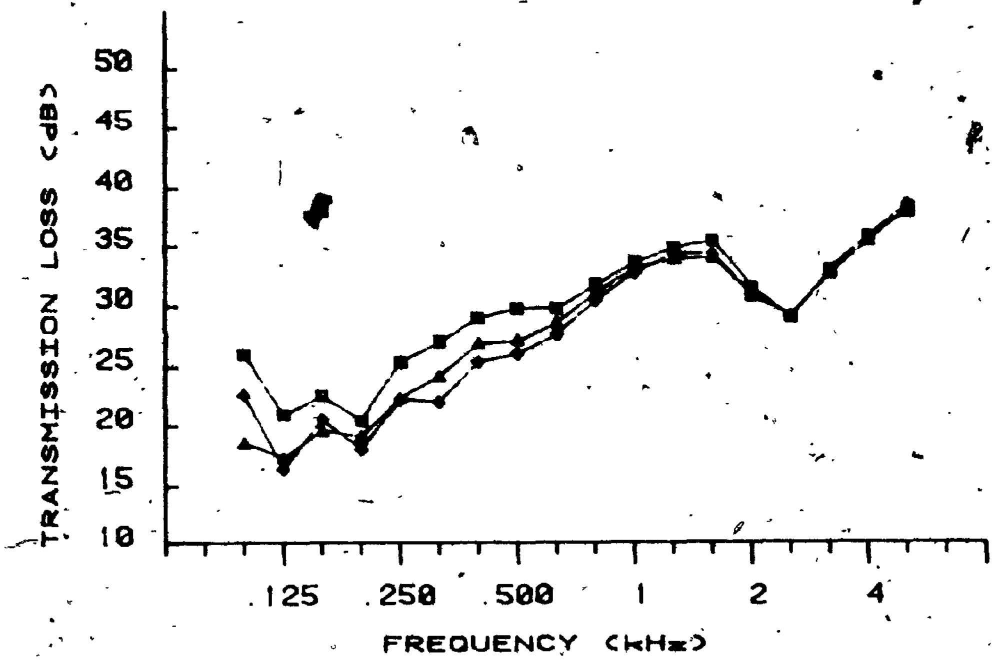
absorption might have occured over the depth of the reveal, or sound energy might have been transmitted 'through' the structure of the reveal away from the reception room.

With regard to the present work, Figure 16.c shows the comparison between the transmission loss spectra obtained by the standard method and by the intensity technique. However, this time the transmitted intensity was measured directly behind the test panel. As can be seen the differences between the two methods have increased as compared to Figure 16.a. The intensity method generally gives lower values up to coincidence whilst the opposite is true above that frequency. The largest differences occur around coincidence. These tendencies are similar to those displayed by Reference [40] thus demonstrating that the larger differences are probably caused by the measurement procedure. In References [41] and [42] the coincidence frequency was beyond the frequency range displayed.

As a consequence one may conclude that in practical situations, and in order to make valid comparisons between the two measurement methods, the transmitted intensity should be measured at the reception room side of the reveal, for this is the energy flow which will ultimatly manifest itself as the pressure levels monitored by the standard technique.

TRANSMISSION LOSS (dB)

FREQ. (Hz)	■	▲	◆
100	25.8	17.5	21.8
125	19.9	16.3	15.3
160	21.5	18.5	19.5
200	19.4	18.1	17.8
250	24.4	21.3	21.2
315	26.1	23.2	21.0
400	28.0	25.9	24.4
500	28.8	26.2	25.1
630	28.8	27.6	26.7
800	30.8	30.1	29.5
1000	32.6	32.1	31.7
1250	33.8	32.8	33.3
1600	34.4	33.0	33.2
2000	30.5	29.8	29.9
2500	28.1	28.1	28.1
3150	32.0	31.7	32.0
4000	34.9	34.4	34.6
5000	36.9	37.3	37.7



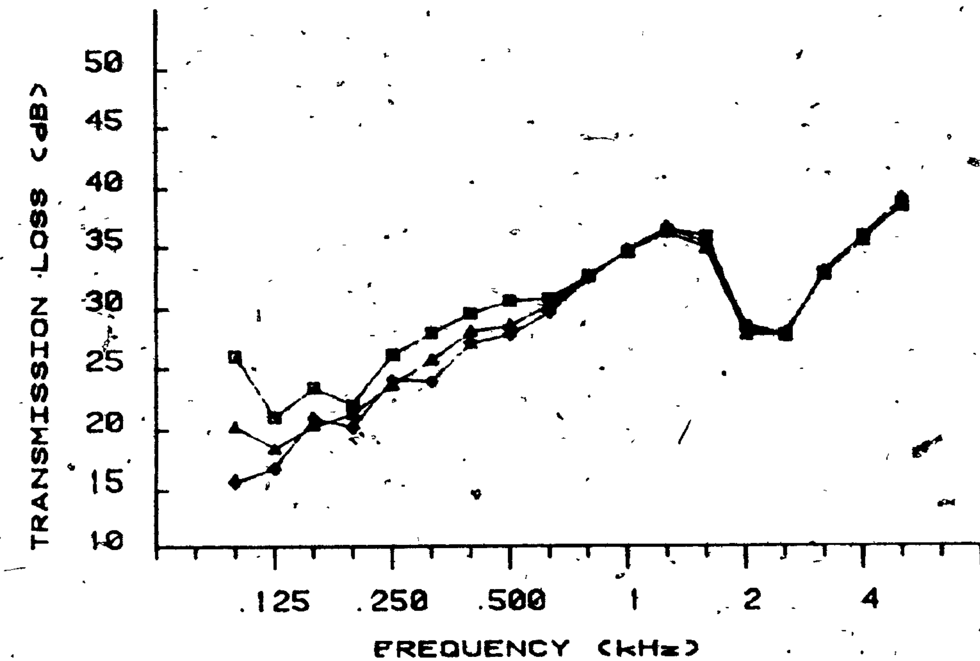
LEGEND

■—■ NO SILL
▲—▲ 19cm (7.5in) SILL
◆—◆ 38cm (15in) SILL

Fig. 17a: Influence of Sills — Transmitted Intensity Measured at 5cm (2in) from Test Panel
1.14m x 1.14m Panel - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲	◆
100	25.0	19.2	14.6
125	20.0	17.3	15.6
160	22.4	19.3	19.0
200	20.9	20.3	19.1
250	25.1	22.6	23.0
315	27.0	24.7	22.6
400	28.6	27.1	26.2
500	29.7	27.6	26.9
630	29.9	29.3	28.7
800	31.7	31.6	31.5
1000	33.0	33.7	33.7
1250	35.4	35.1	35.7
1600	34.9	33.8	34.2
2000	27.5	26.8	27.1
2500	26.7	26.7	26.9
3150	31.6	31.8	32.0
4000	34.9	34.5	34.9
5000	37.5	37.7	38.1



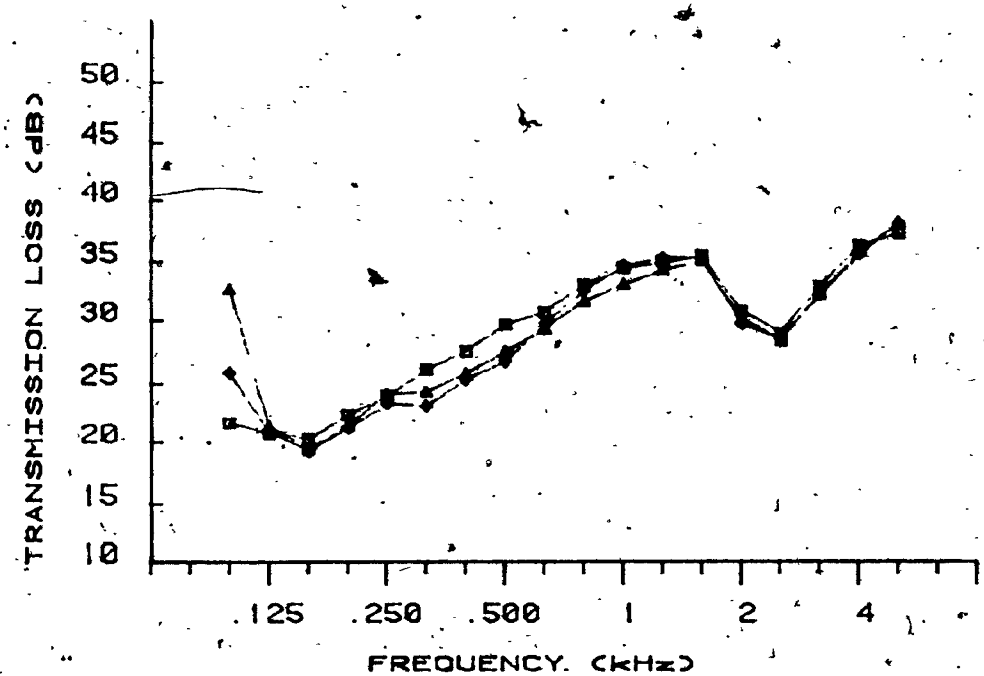
LEGEND

- □—□ NO SILL
- ▲—▲ 19cm (7.5in) SILL
- ◆—◆ 38cm (15in) SILL

Fig. 17b: Influence of Sills — Transmitted Intensity Measured at the Reception Room Side of the Reveal
1.14m x 1.14m Panel - No Lining

TRANSMISSION LOSS (dB)

FREQ.(Hz)	□	△	◇
100	20.6	31.7	24.9
125	19.7	20.3	19.8
160	19.9	18.9	18.2
200	21.9	20.4	20.2
250	23.0	23.2	22.9
315	25.2	23.3	22.0
400	26.8	24.9	24.3
500	26.7	26.6	25.8
630	29.7	28.4	28.7
800	32.1	30.7	31.6
1000	33.5	32.1	33.7
1250	34.0	33.3	34.3
1600	34.5	34.2	34.3
2000	29.8	29.1	28.7
2500	27.9	27.4	27.5
3150	32.0	31.3	31.2
4000	35.4	34.9	34.6
5000	36.4	37.1	37.1



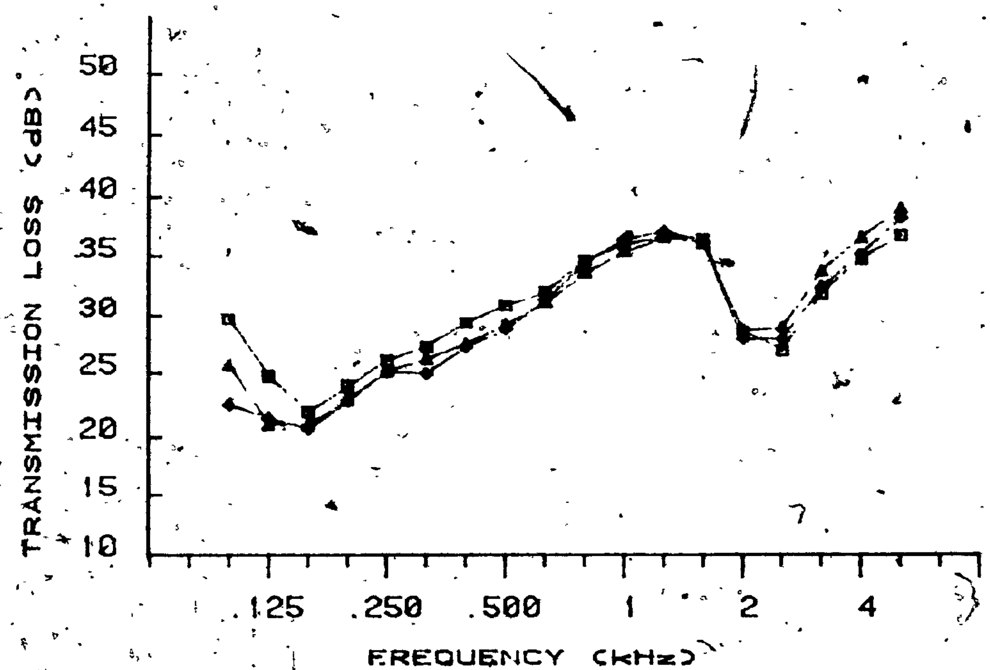
LEGEND

- □——□ NO SILL
- △——△ 19cm (7.5in) SILL
- ◇——◇ 38cm (15in) SILL

Fig. 18a: Influence of Sills — Transmitted Intensity
Measured at 5cm (2in) from Test Panel
1.52m x 1.52m Panel – No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲	◆
100	28.7	24.6	21.5
125	23.7	20.0	20.5
160	21.0	20.0	19.7
200	22.9	21.9	21.8
250	25.0	24.1	24.0
315	26.2	25.1	23.9
400	28.4	26.5	26.2
500	30.0	28.2	27.7
630	31.1	30.2	30.3
800	33.7	32.6	33.4
1000	35.0	34.4	35.5
1250	35.8	35.6	36.1
1600	36.4	35.1	35.3
2000	27.6	27.7	26.6
2500	25.8	27.9	26.8
3150	31.0	32.8	31.5
4000	33.9	35.6	34.2
5000	35.8	38.1	37.3



LEGEND

- □ NO SILL
- ▲ 19cm (7.5in) SILL
- ◆ 38cm (15in) SILL

Fig. 18b: Influence of Sills — Transmitted Intensity Measured at the Reception Room Side of the Reveal
1.52m x 1.52m Panel - No Lining

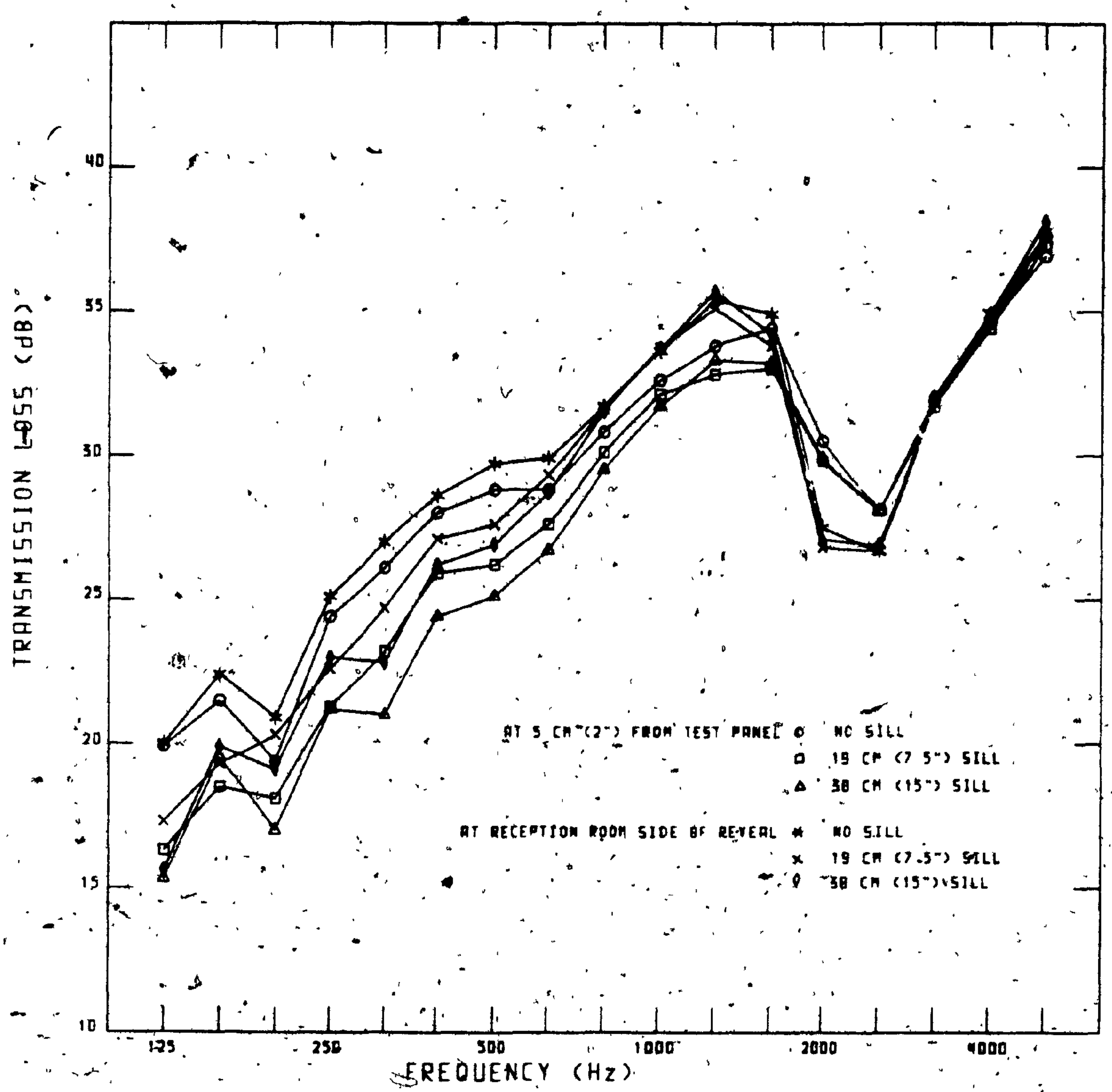


Fig. 19.a: Transmission Loss Spectra for all Sill Configurations
1.14m x 1.14m (45" x 45") Panel

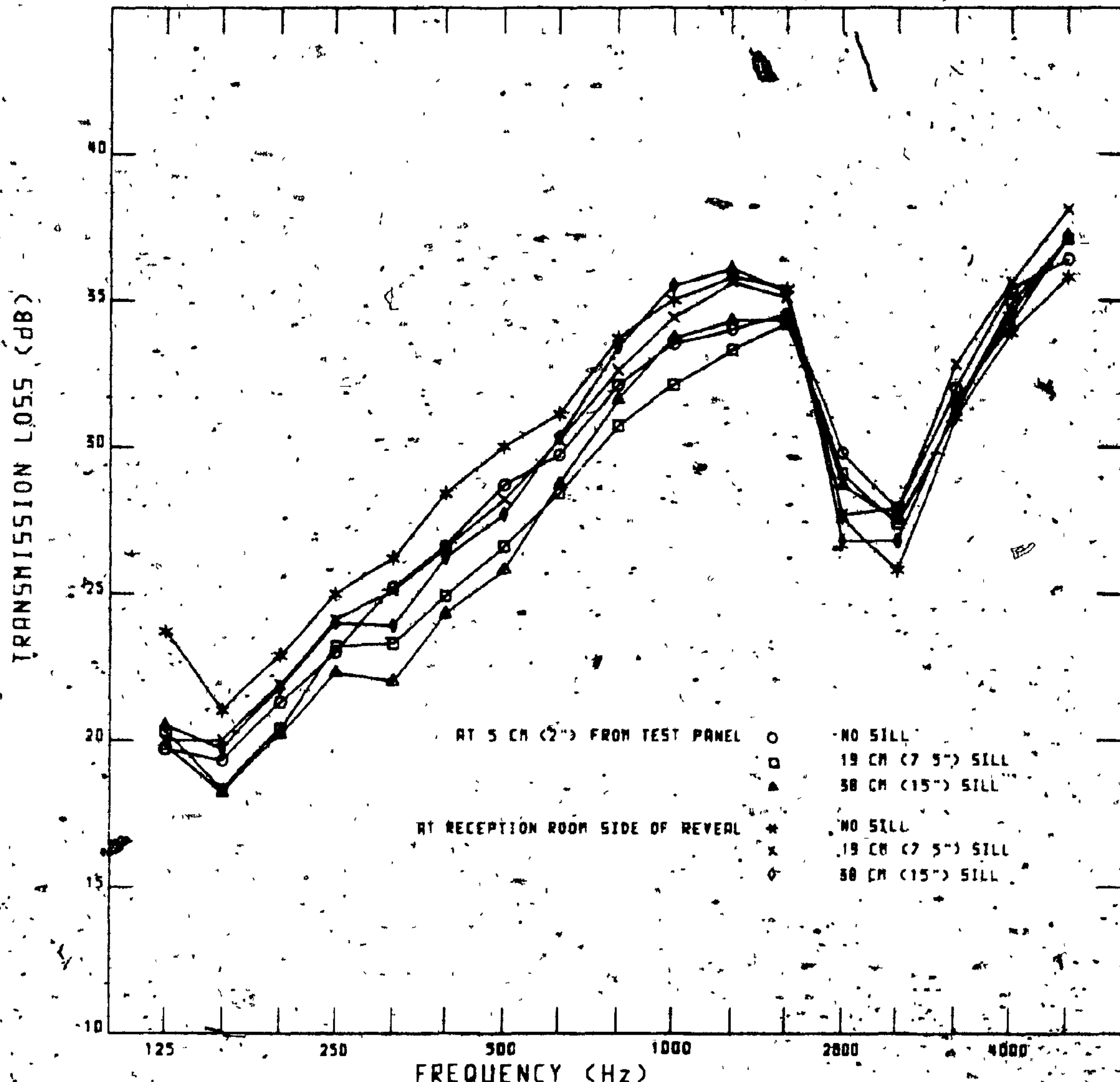


Fig. 19.b: Transmission Loss Spectra for all Sill Configurations
1.52m x 1.52m (60" x 60") Panel

Note : All the experiments reported below are based on the Intensity Technique with the reception room lined as described earlier.

4.2. The Effect of Sills and Reveals

Both test panels were always mounted flush with the source room, thus leaving a 38 cm (15") reveal on the reception room side. The depth of the reveal is kept constant, but the intensity technique allows for measurements in any plane; in the present work measurements directly behind the test panel (at 5 cm) and at the reception room side of the reveal were generally performed. In addition sills of two different depths were constructed to yield a total of six test configurations.

The test results for both panel sizes are shown in Figures 17 to 19. Figures 17 and 18 show the effect of adding sills for measurements directly behind the test panel and at the reception room side of the reveal respectively. Figures 19. a and b give general overviews of all configurations for both panel sizes.

The following observations can be made:

- The highest values are obtained for the no sill configuration with measurements at the reception room side of the reveal.
- With regard to measurements in a given measurement

plane, the addition of sills always decreases the measured transmission loss. The deeper the sill, the lower the transmission loss.

- The highest differences occur below the coincidence dip, in particular at frequencies below 630 Hz. Above that frequency, differences are generally less pronounced in the case of the larger test panel and become minimal above 1600 Hz for measurements directly behind the test panel. With regard to the smaller panel, there is little or no influence above 630 Hz.

- Measurements at the reception room side of the reveal give rise to a deeper and wider coincidence dip. The effect is clearest in the case of the smaller panel.

- The effect of a sill and or the measurement position is slightly higher in case of the smaller test panel up to 630 Hz. The largest differences occur for the 38 cm (15") sill configuration.

- Comparing all the different configurations for a given panel size, one can rank them in order of decreasing transmission loss :

Table V: Transmission Loss Performances for Sill and Reveal Configurations

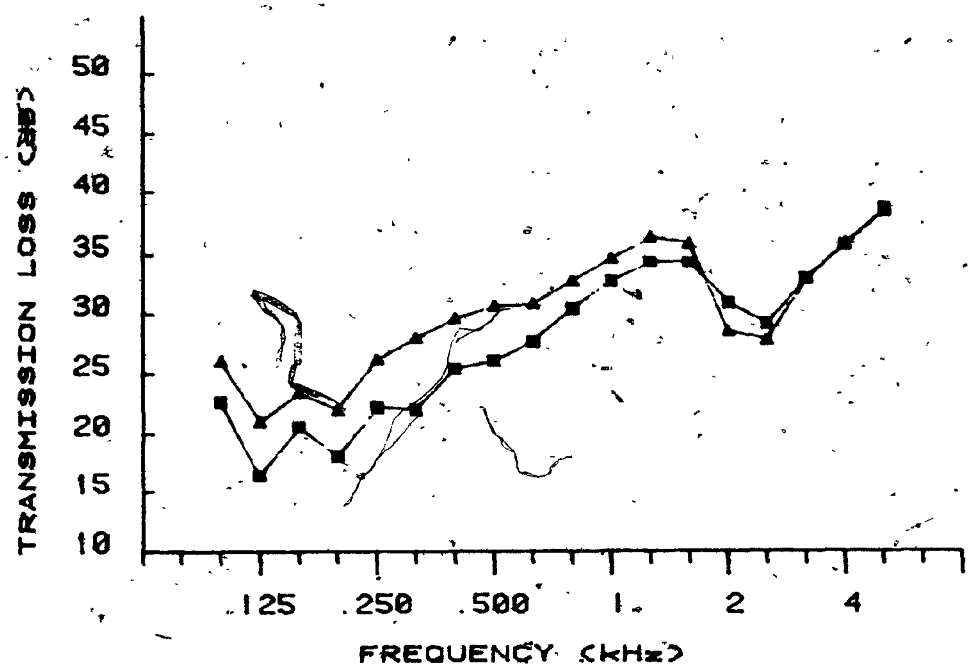
frequency range	(1.14 m x 1.14 m) panel (45" x 45")		(1.52 m x 1.52 m) panel (60" x 60")	
	measurement plane for sound intensity	sill configuration	measurement plane for sound intensity	sill configuration
up to 630 Hz	reception room side of reveal	no sill	reception room side of reveal	no sill
	directly behind test panel	no sill	directly behind test panel	no sill
	reception room side of reveal	19 cm sill	reception room side of reveal	19 cm sill
	reception room side of reveal	38 cm sill	reception room side of reveal	38 cm sill
	directly behind test panel	19 cm sill	directly behind test panel	19 cm sill
	directly behind test panel	38 cm sill	directly behind test panel	38 cm sill
from 630 Hz to 1.6 kHz	reception room side of reveal	all configurations	reception room side of reveal	38 cm sill
	directly behind test panel	no sill	reception room side of reveal	no sill
	directly behind test panel	19 cm sill	reception room side of reveal	19 cm sill
	directly behind test panel	38 cm sill	directly behind test panel	38 cm sill
from 1.6 kHz to f_c	directly behind test-panel	all configurations equivalent	directly behind test panel	no sill
	reception room side of reveal equivalent	all configurations	directly behind test panel	19 cm sill
above f_c	all configurations equivalent		indeterminate	

From the results reported here, one can conclude that the symmetrically mounted panel has a lower sound transmission loss than the no sill and reveal configuration; the differences being most pronounced at the lower frequency end. This is in agreement with previous works [11,12,39] based on the conventional two room method.

References [11] and [12] also indicate that a sill or a reveal configuration (not both) are basically equivalent and according to reference [11] the same is true for the sill plus reveal configuration compared with the plane frame. With regard to the present measurements this would indicate that, in the presence of a prominent reveal, intensity measurements directly behind the test panel can not be compared with the no reveal configuration. Indeed, transmission loss values for the no sill configuration with intensity measurements at the reception room side of the reveal are generally much higher than those for the reverse situation, that is a 38 cm (15") sill with intensity measurements directly behind the test panel, except around and beyond the coincidence frequency (Figures 20.a and b). Differences are as high as 6 dB for the smaller panel and 4 dB for the larger one. There are also discrepancies (up to 3 dB) between the no sill configuration with intensity measurements directly behind the test panel and the symmetrically mounted panel with measurements at the reception room side of the reveal (see Figures 21.a and b).

FREQ. (Hz)	□	▲
100	21.6	25.0
125	15.3	20.0
160	19.5	22.4
200	17.0	20.9
250	21.2	25.1
315	21.0	27.0
400	24.4	28.6
500	25.1	29.7
630	26.7	29.9
800	29.5	31.7
1000	31.7	33.6
1250	33.3	35.4
1600	33.2	34.9
2000	29.9	27.5
2500	28.1	26.7
3160	32.0	31.6
4000	34.6	34.9
5000	37.7	37.5

TRANSMISSION LOSS (dB)



LEGEND

■—■ INTENSITY AT 5 CM FROM PANEL, 38 CM SILL
▲—▲ INTENSITY AT RECEPTION ROOM SIDE OF REVEAL, NO SILL

Fig. 20a: Influence of the Measurement Plane
1.14m x 1.14m Panel - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	■	▲
100	24.9	28.7
125	19.8	23.7
160	18.2	21.0
200	20.2	22.9
250	22.3	25.0
315	22.0	26.2
400	24.3	28.4
500	25.6	30.0
630	28.7	31.1
800	31.6	33.7
1000	33.7	35.0
1250	34.3	35.6
1600	34.3	35.4
2000	28.7	27.6
2500	27.5	25.8
3150	31.2	31.0
4000	34.6	33.9
5000	37.1	35.6

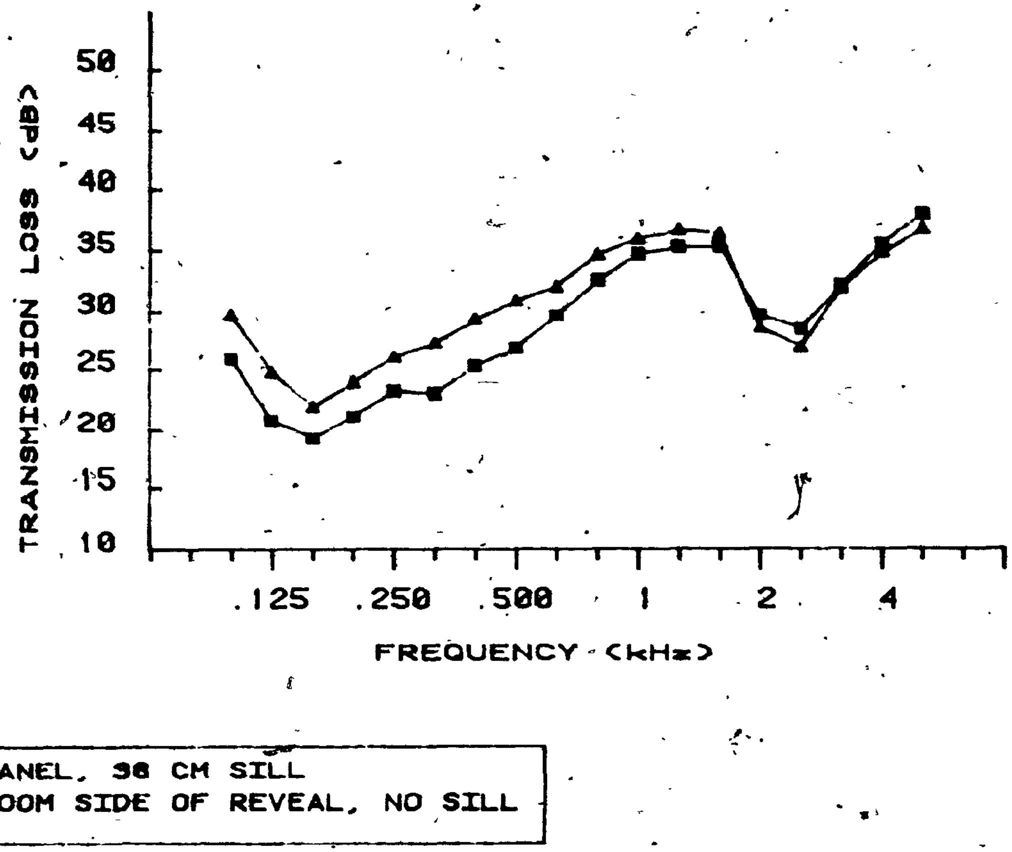
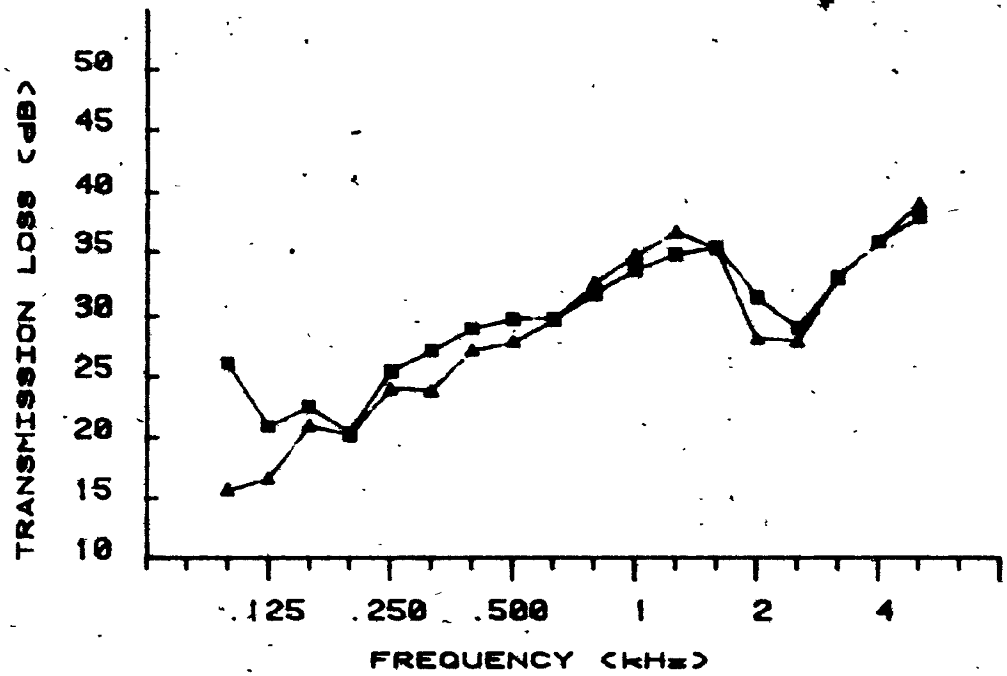


Fig. 20b: Influence of the Measurement Plane
1.52m x 1.52m Panel — No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	▫	▲
100	25.0	14.6
125	19.9	15.6
160	21.5	19.9
200	19.4	19.1
250	24.4	23.0
315	26.1	22.6
400	28.0	26.2
500	28.6	26.9
630	28.6	28.7
800	30.6	31.5
1000	32.6	33.7
1250	33.6	35.7
1600	34.4	34.2
2000	30.5	27.1
2500	28.1	26.9
3150	32.0	32.0
4000	34.9	34.9
5000	36.9	36.1



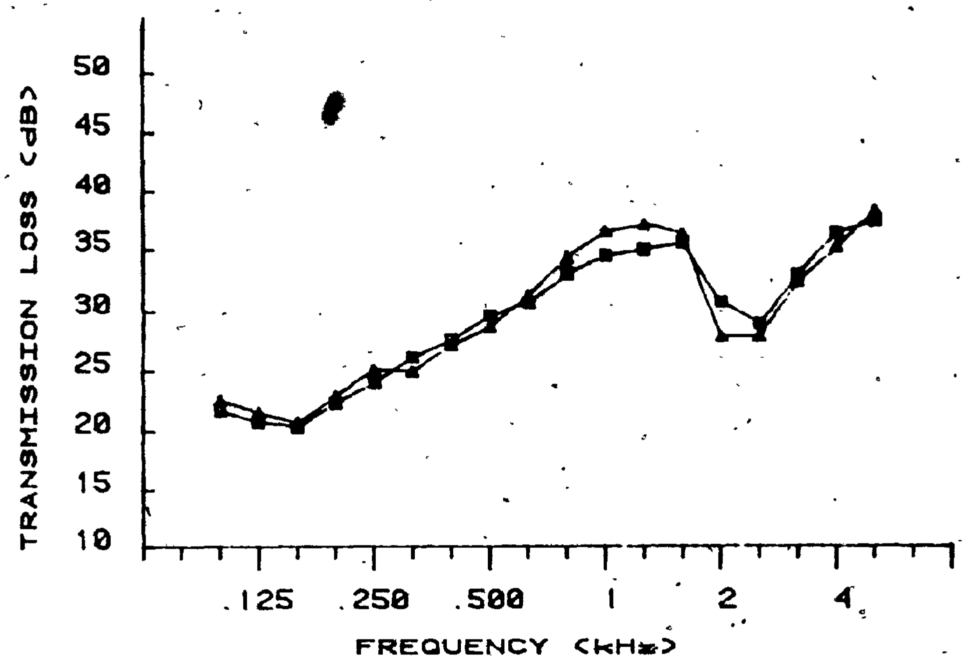
LEGEND

- ▪——▪ INTENSITY AT 5 CM FROM PANEL, NO SILL
- ▲——▲ INTENSITY AT RECEPTION ROOM SIDE OF REVEAL, 38 CM SILL

Fig. 21a: Influence of the Measurement Plane
1.14m x 1.14m Panel - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	20.6	21.5
125	19.7	20.5
160	19.3	19.7
200	21.3	21.8
250	23.8	24.0
315	25.2	23.9
400	26.6	26.2
500	28.7	27.7
630	29.7	30.3
800	32.1	33.4
1000	33.5	35.5
1250	34.0	36.1
1600	34.5	35.3
2000	29.6	26.8
2500	27.9	26.8
3150	32.0	31.6
4000	35.4	34.2
5000	36.4	37.3



LEGEND

■——■ INTENSITY AT 5 CM FROM PANEL, NO SILL
▲——▲ INTENSITY AT RECEPTION ROOM SIDE OF REVEAL, 38 CM SILL

Fig. 21b: Influence of the Measurement Plane
1.52m x 1.52m Panel - No Lining

However, in this case the differences are not consistent throughout the frequency range.

On the other hand, the present discrepancies between the two niche configuration with intensity measurements directly behind the test panel,as compared to the case with just one niche with the intensity measured at the reception room side of the reveal, might be caused by the different construction method of the sill and reveal. The reveal is part of the filler wall, and therefore rigid, while the sills are merely extensions and are able to move slightly. Moreover any sound absorption that might occur is treated as a loss in the case of the filler wall but is accounted for by the incident field measurement in case of the sills. With the exception of references [17] and [19], in all studies concerned with the effect of sills and/or reveals, construction for both were similar.

In addition, the present finding that the influence of sills decreases with increasing panel area is also supported by a previous study [39].

The effect of sills and reveals has also been studied using the intensity technique by Cops, et al. [29,40] and Halliwell and Warnock [41]. In both studies, the total depth of the aperture was constant, respectively 70 cm (twice) and 1.22 m, but the position of the test panel within it was varied. There were respectively 3, 2 and 5 positions with the panels always mounted on the source side for the first two references, but uniformly spaced in the latter one. However for both studies the transmitted intensity was always measured directly behind the test panel. According to the present findings and as has been demonstrated in section 4.1., this procedure is generally unacceptable. In order to take into account all effects caused by the presence of a reveal, intensity measurements have to be made at the reception room side of the reveal.

4.3. **The Effect of Lining the Reveal with Absorbent Material**

4.3.1. Measurements at the Reception Room Side of the Reveal

The transmitted intensity was measured at the reception room side of the reveal.

The results display the same characteristics for both panel sizes as can be seen in Figures 22 a and b:

- The effect of the lining thickness increases gradually over the frequency range up to 1 kHz, peaks between 1 kHz and 2.5 kHz, then decreases slightly above that frequency.

- The improvements to the measured transmission loss are quite substantial, in particular around the coincidence frequency, with maximum increases of 7 dB for the 2.5 cm (1") thick lining, 10 dB for the 5 cm (2") and 11 dB for the

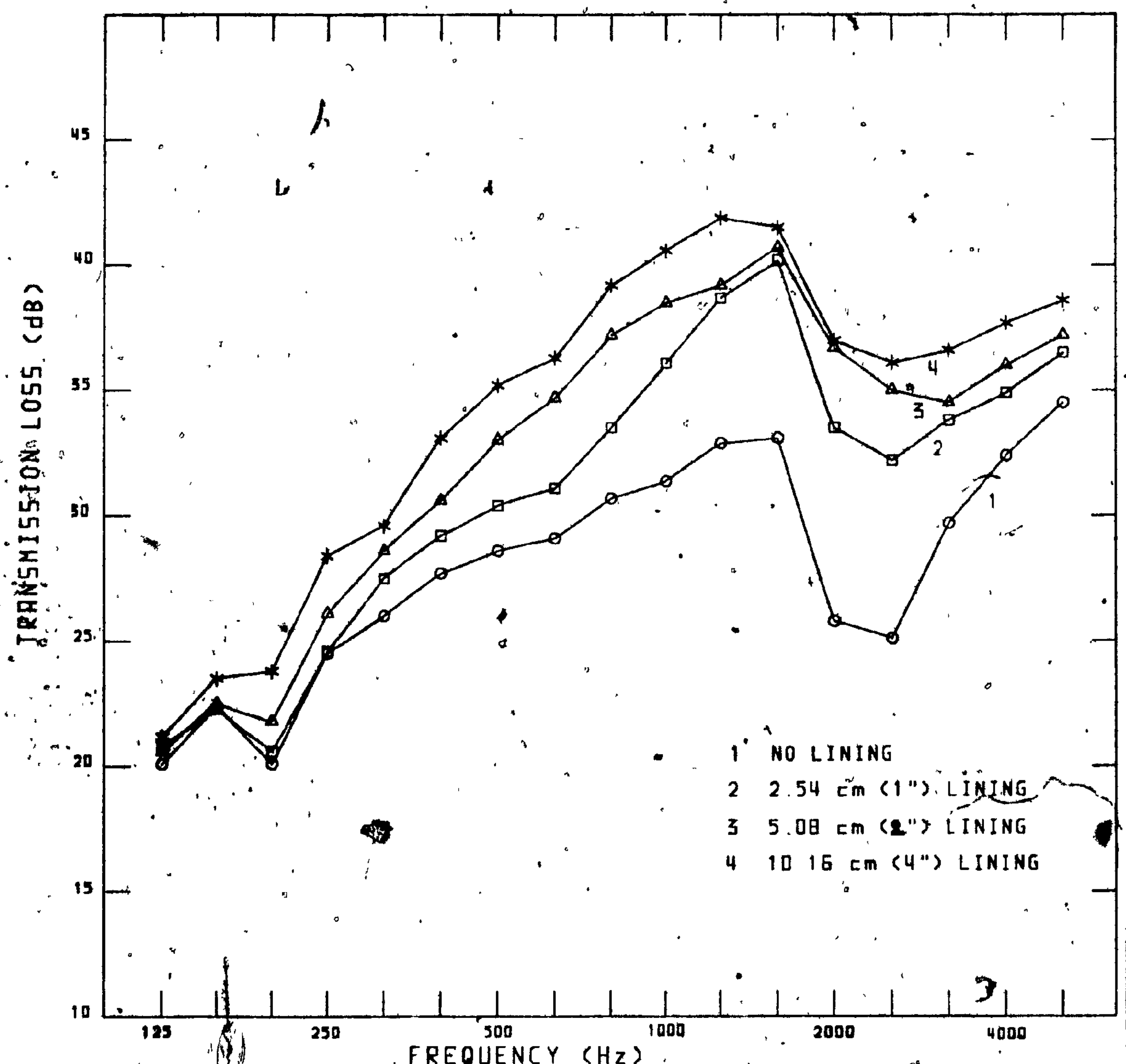


Fig. 22.a: Influence of Lining the Reveal. Transmitted Intensity Measured at the Reception Room Side of the Reveal.
1.14m x 1.14m (45" x 45") Panel

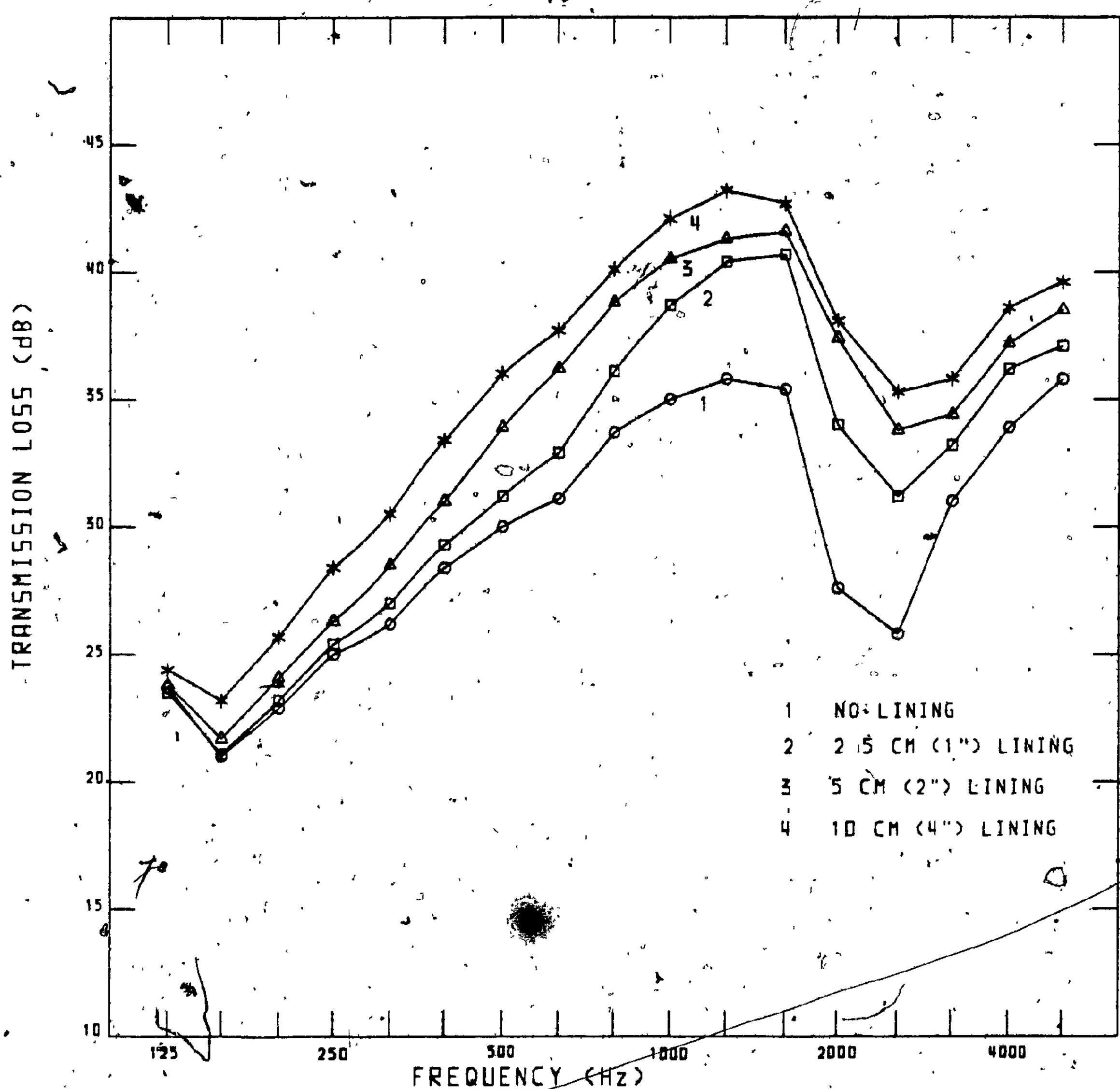


Fig. 22 b: Influence of Lining the Reveal. Transmitted Intensity Measured at the Reception Room Side of the Reveal.
1.52m x 1.52m (60" x 60") Panel

10 cm (4") thick lining. All values quoted refer to the smaller size panel.

- The effect of the lining is slightly less for the larger panel with a maximum difference of 2 dB compared to the smaller panel case, more specifically around the coincidence frequency. All three material thicknesses display the same tendencies.

Generally the influence of the lining thickness seems to be related to the absorption characteristics of the lining material (see Table II).

Little differences can be observed at the lower frequencies. This can probably be attributed to the low frequency characteristics of the lining material although at those frequencies room depth standing waves may predominate and these will be only slightly affected by the lining of the reveal (Guy and Mulholland [18]).

All three thicknesses display approximately the same increase at 1600 Hz after which the influence of the 2.5 cm (1") and the 5 cm (2") lining decreases again. Similarly, the absorption coefficients for all three thicknesses reach an early maximum at 1600 Hz, followed by a decrease and an eventual second increase.

The effect of the lining reaches its peak between 1 kHz and 2.5 kHz although, according to the manufacturers specifications, the absorption coefficients above coincidence are similar or even higher. This might be explained by the radiation characteristics of the panel. As will be demonstrated later on, below coincidence the panels radiate strongly around the borders while above the critical frequency radiation occurs uniformly over the panel area. Therefore one might expect the effect of the lining to be more pronounced in the former case.

The stronger influence of the lining in the case of the smaller panel is probably caused by its higher perimeter to area ratio.

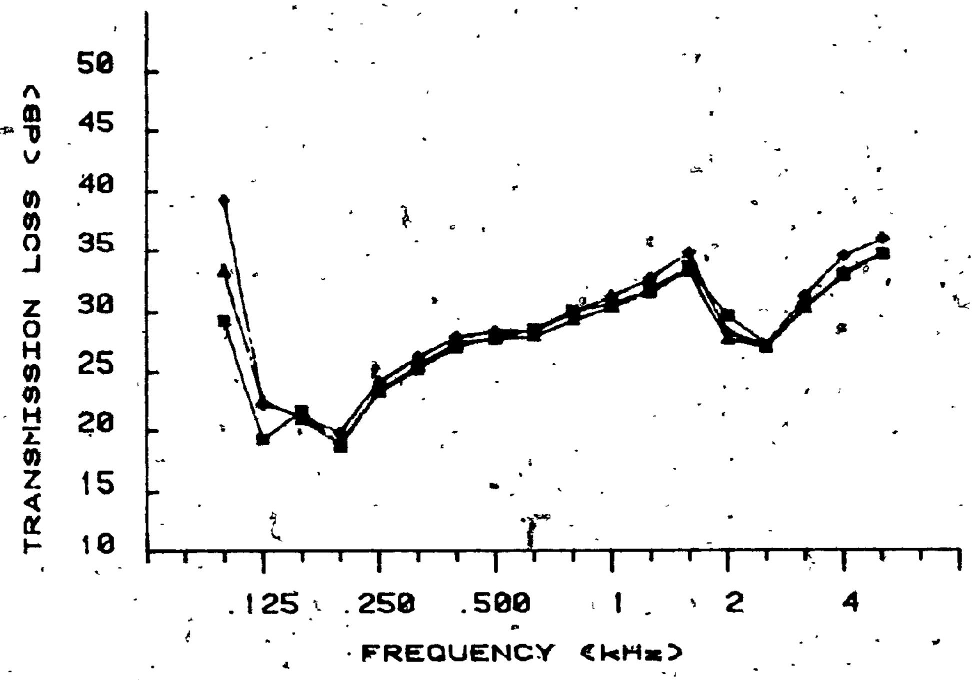
4.3.2. Panel to Reveal/Room Coupling

When the transmitted intensity was measured directly behind the test panel, at a 5 cm (2") distance, the measured transmission loss was basically the same whether the reveal was lined with a 0, 2.5 cm (1") or 5 cm (2") thick absorbant material. This test was not performed with the 10 cm (4") thickness because the thickness of the material would have interfered with the measurement mesh.

Thus, from the results displayed in Figures 23.a and b one can conclude that the transmission loss of the test panel alone is not influenced by the presence of the lining on the reveal, that is sound absorption on the reveal. In addition it has been shown in section 3.3.1. that the same is true for absorption in the reception room. This suggests that the panel is only loosely coupled to the airborne modes

TRANSMISSION LOSS (dB)

FREQ. (Hz) =	□	▲	◆
100	28.2	32.3	38.3
125	18.2	21.5	21.2
160	20.7	19.9	20.2
200	17.8	17.7	18.7
250	22.4	22.4	23.2
315	24.2	24.4	25.1
400	26.0	26.2	26.7
500	26.8	26.6	27.3
630	27.4	26.8	27.2
800	29.1	28.2	28.9
1000	29.7	29.4	30.3
1250	30.8	30.6	31.6
1600	32.5	32.3	33.7
2000	28.6	26.5	27.0
2500	26.0	25.8	25.9
3150	29.4	29.4	30.3
4000	32.0	32.1	33.5
5000	33.7	33.8	35.1



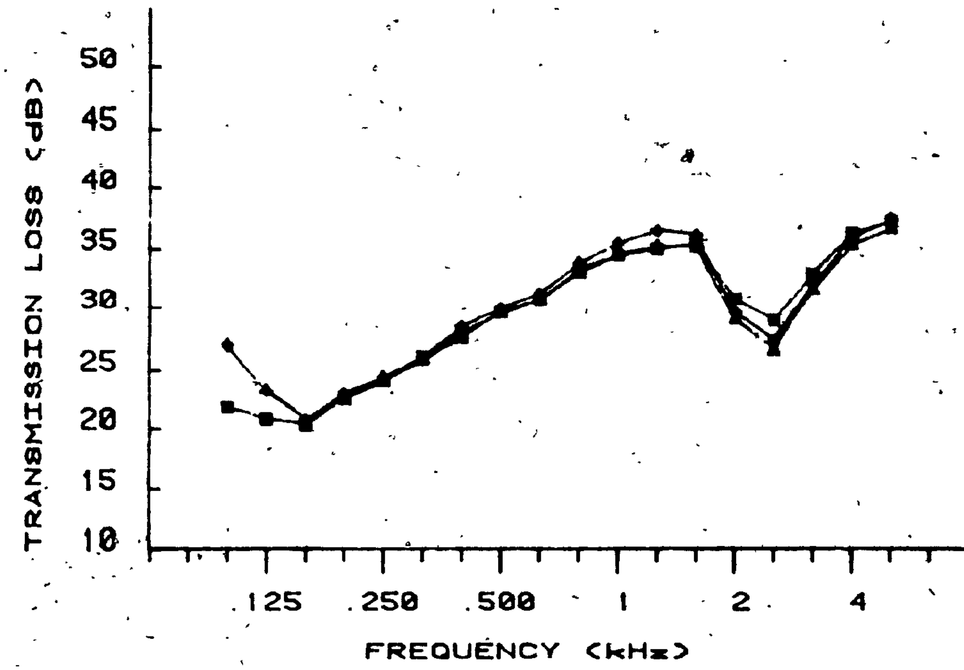
LEGEND

- NO LINING (□)
- 2.5 CM (1 in) LINING (▲)
- 5 CM (2 in) LINING (◆)

Fig. 23a: Influence of Lining the Reveal
Intensity Measured at 5 cm (2in) from Test Panel
1.14m x 1.14m Panel – No Sill

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲	◆
100	20.6	66.1	26.0
125	19.7	22.2	22.0
160	19.3	19.6	19.5
200	21.3	21.4	21.8
250	23.0	23.2	23.4
315	25.2	24.8	25.1
400	26.6	26.9	27.4
500	28.7	28.5	29.0
630	29.7	29.7	30.3
800	32.1	32.3	32.9
1000	33.5	33.7	34.5
1250	34.0	34.2	35.5
1600	34.5	34.2	35.2
2000	29.8	28.0	28.6
2500	27.9	25.6	26.3
3160	32.0	30.7	31.1
4000	35.4	34.4	35.1
5000	36.4	35.7	36.5



LEGEND

- □—□ NO LINING
- ▲—▲ 2.5 CM (1in) LINING
- ◆—◆ 5 CM (2in) LINING

Fig. 23b: Influence of Lining the Reveal
Intensity Measured at 5 cm (2in) from Test Panel
1.52m x 1.52m Panel – No Sill

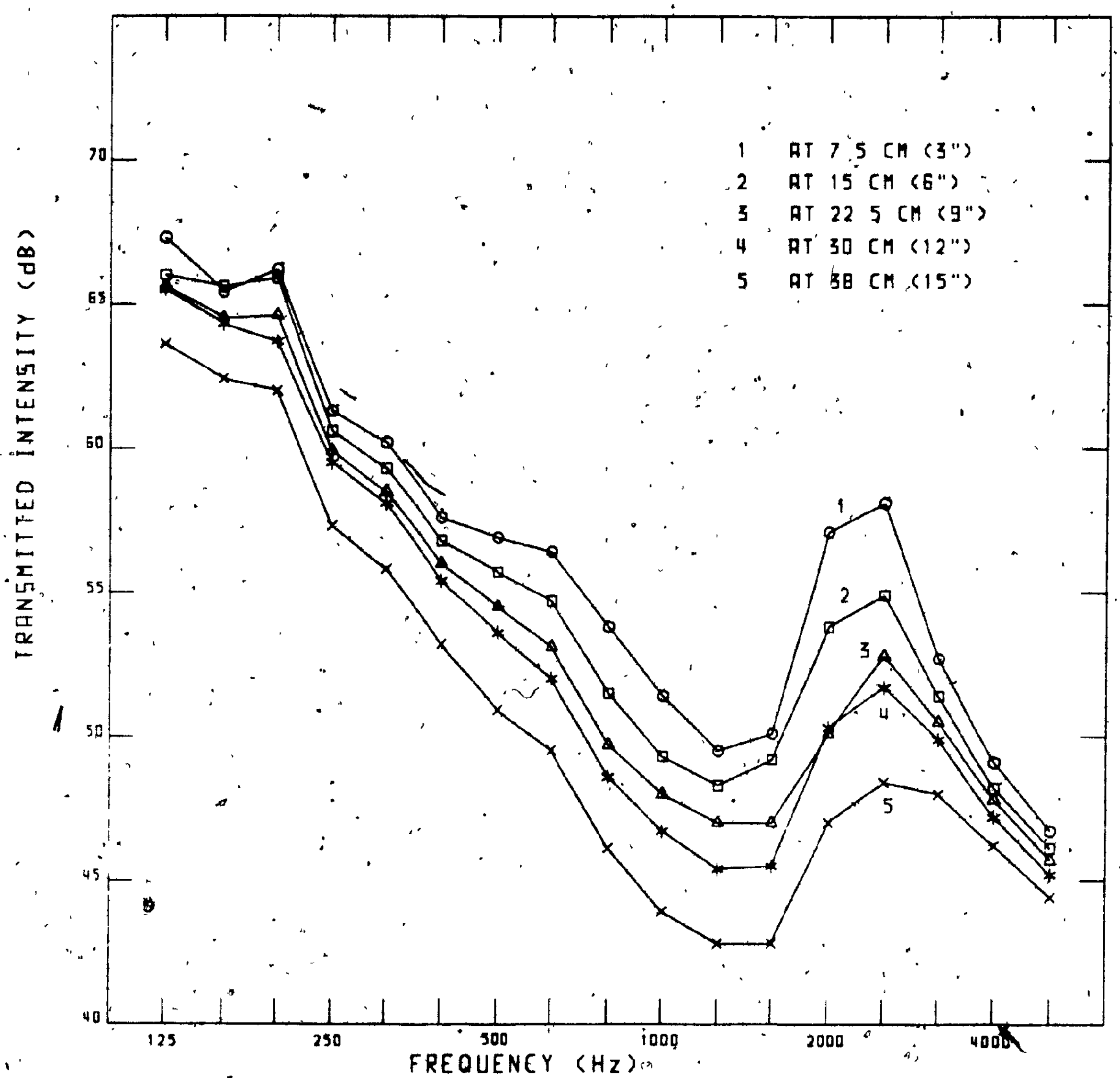


Fig. 24: Influence of the Measurement Distance.
Reveal Lined with 5 cm (2") Thick Absorbent Material.
1.14m x 1.14m (45" x 45") Panel

of energy transfer.

The tests also demonstrates the advantage of the sound intensity technique for transmission loss measurements; no room correction factors have to be applied to take the backing room's absorption characteristics into account as is the case for the standard method.

4.3.3. Optimal Depth of Lining?

In order to determine the effect of lining material depth, the transmitted sound intensity was measured at 7 cm (3") intervals, over the total depth of the reveal. This test was performed on the smaller panel size with the reveal lined with the 5 cm (2") thick material. The results are shown in Figure 24.

The decrease in the measured transmitted intensity is approximately proportional to the measurement distance. The results at 38 cm (15") indicate a slightly greater decrease, but because this set of measurements was performed at the reception room side of the reveal this change may be attributed to edge effects.

4.4. Intensity Distribution Across the Test Panel

This topic has been studied theoretically by a number of workers, for example Maidanik [4] and recently also experimentaly by Petersen [43] and Fahy [28] using the

Intensity Technique. For frequencies below coincidence, the theoretical model predicts that the wave pattern at the edges of a finite plate does cause radiation in contrast with an infinite plate. It is further argued that for these frequencies only the corners or a strip of plate around the edges effectively radiate sound energy. Above the coincidence frequency panels are said to radiate from their whole surface, although the experimental results of Fahy do not completely agree with this: according to his findings the center portion of the panel tends to radiate more strongly than the edges for those frequencies.

For the present work, the distribution of the transmitted intensity has been determined for both panel dimensions in the absence of a sill and with the reveal left bare. The radiated intensity was for this purpose measured directly behind the test panel, 5 cm (2") away from it.

The contours of equal intensity were then plotted for the whole frequency range of interest: 250 Hz up to 5000 Hz. The results are shown in Appendix D and E, respectively for the smaller and larger panel.

4.4.1. <u>1.14m x 1.14m (45" x 45") Panel (Figures D.1 to D.14)</u>

As can be seen in Figure D.1, at the very low frequencies (250 Hz), the panel is radiating predominantly through the corners. The intensity transmitted through a small portion of the center is much smaller and its contribution is therefore negligible. Differences are as high as 15 dB.

With increasing frequency, the center portion where the transmitted intensity is lowest gradually spreads out. Its contribution increases (Figure D.2 to D.4). Above 630 Hz (Figures D.5 to D.8), greater intensity is found within a strip around the panel border and the gradients are found to be much steeper than at the lower frequencies. The differences between edge and center radiation are however decreasing.

Eventually at 2000 and 2500 Hz, respectively Figure D.10 and D.11, that is within the coincidence dip, the center becomes the strongest source of radiation with the intensity even sometimes becoming negative around the perimeter.

Above coincidence (Figures D.12 to D.14), a quite uniform radiation over the whole surface of the panel can be observed.

4.4.2. <u>1.52m x 1.52m (60" x 60") Panel (Figures E.1 to E.14)</u>

The intensity distributions for the larger panel tend to be quite different compared to those encountered previously. For the larger size three regions can be observed: a center portion, a narrow concentric strip around the center, and a strip around the panel border.

At 250 Hz (Figure E.1), the corners of the panel also radiate strongly. There is a decrease in the transmitted intensity levels towards the center but this time the intensity levels at the center of the panel are comparable to those around the edges.

As shown in Figures E.2 to E.6, when the frequency increases, the center portion of the panel gradually becomes larger and the differences between the individual regions become smaller as for the smaller panel. However, gradients around the border are never as steep as in the case of the smaller panel.

Above 1000 Hz (Figures E.7 and E.8), the characteristic strip with lower intensities disappears. The radiation around the border is only slightly higher (2 to 3 dB) than at the center.

As before, around coincidence the center becomes predominant with negative intensities appearing around the panel perimeter (see Figures E.9 to E.11). Above coincidence radiation becomes uniform again (FIgures E.12 to E.14).

4.4.3. Discussion

Generally, the power flow patterns for the smaller panel agree quite well with the theoretical predictions by Maidanik [4]. This is however not true for the larger panel.

Fahy [28] has reported the existence of negative intensity in the center region of the panel. This has not been confirmed here. However, in the present study negative intensities have been found around the panel perimeter about the coincidence frequency. This might signal edge damping effects. Indeed, about coincidence, the sound transmission is high and the same holds for the vibrational amplitudes of the panel. This lends itself to effective damping, in this case around the panel border.

The differences between the two panel dimensions are believed to be caused by their modal behaviour, coupling and phase differences between the individual modes, which is dependent on the panel dimensions.

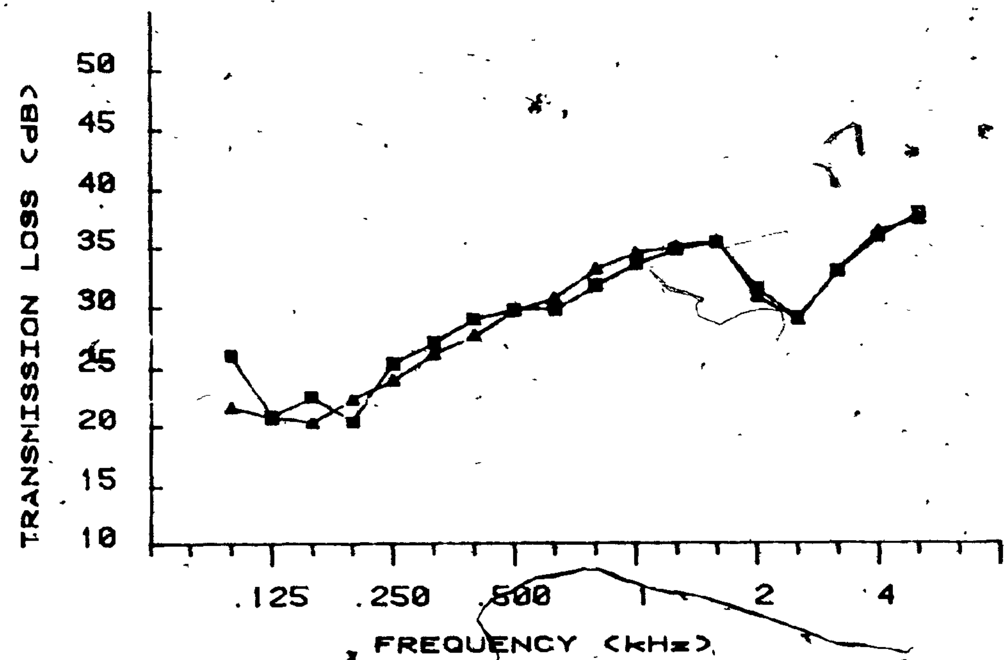
On the other hand, it is not known how the edge conditions influence the power flow distribution. Slight differences between the mounting of the two panels might have occured which in turn might have influenced the results. Verification would imply repetitive mounting and testing.

4.5. The Effect of Panel Dimensions

The transmission loss results for all test configurations are compared as a function of the panel area in Figures 25 up to 29, respectively a and b. The results at the extreme lower frequency range will not be considered because of lack of accuracy.

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	△
100	25.0	20.6
125	19.9	19.7
160	21.5	19.3
200	19.4	21.3
250	24.4	23.0
315	26.1	25.2
400	28.0	26.6
500	28.6	28.7
630	28.6	29.7
800	30.6	32.1
1000	32.6	33.5
1250	33.6	34.0
1600	34.4	34.5
2000	30.5	29.6
2500	28.1	27.9
3150	32.0	32.0
4000	34.9	35.4
6000	36.9	36.4



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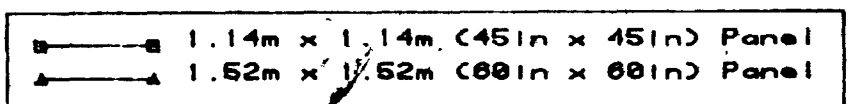
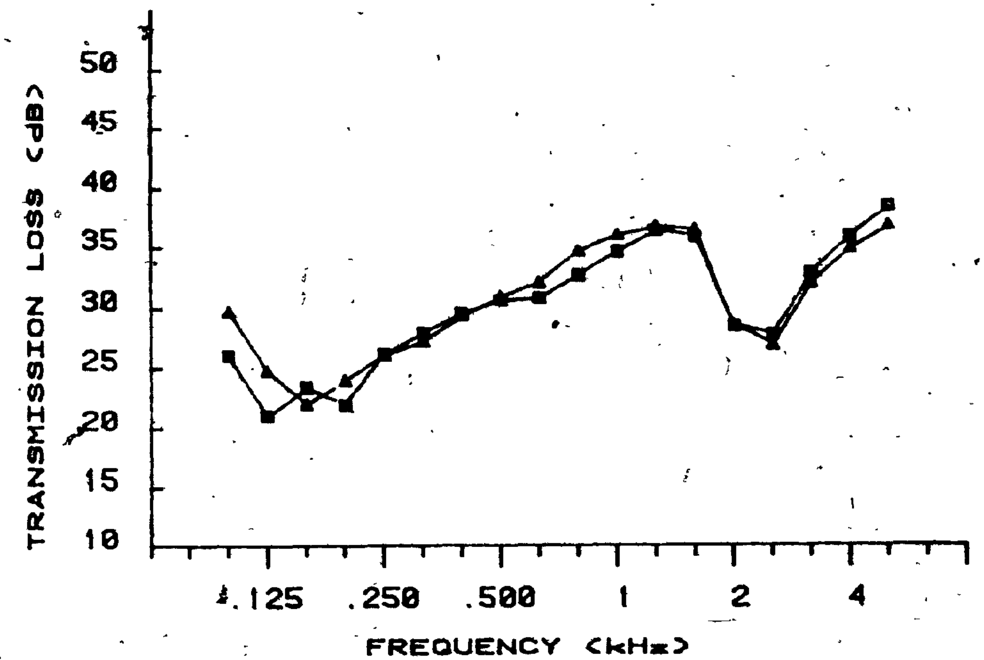


Fig. 25a: Influence of Panel Dimension
Intensity Measured at 5 cm (2in) from Test Panel
No Sill – No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	△
100	25.8	29.7
125	20.8	23.7
160	22.4	21.8
200	20.9	22.9
250	25.1	25.0
315	27.0	26.2
400	28.6	28.4
500	29.7	30.0
630	29.9	31.1
800	31.7	33.7
1000	33.6	35.0
1250	35.4	35.6
1600	34.9	35.4
2000	27.5	27.6
2500	26.7	25.8
3150	31.8	31.0
4000	34.9	33.9
5000	37.5	35.8



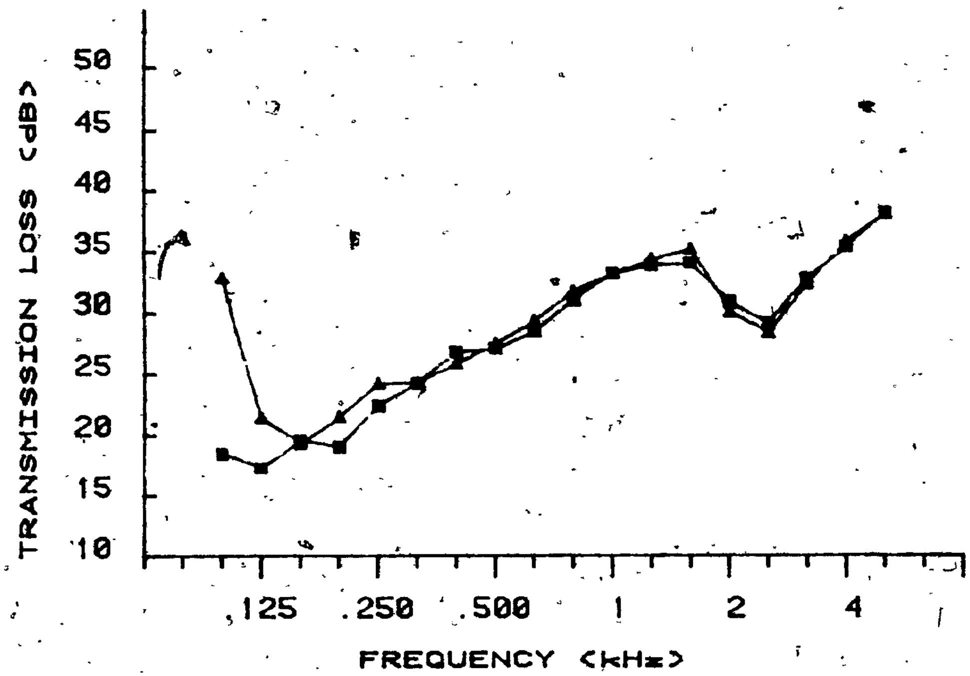
LEGEND

□——□ 1.14m x 1.14m (45in x 45in) Panel
△——△ 1.52m x 1.52m (60in x 60in) Panel

Fig. 25b: Influence of Panel Dimension
Intensity Measured at Reception Room Side of Reveal
No Sill - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	Δ
100	17.5	31.7
125	16.3	20.3
160	18.5	18.3
200	18.1	20.4
250	21.3	23.2
315	23.2	23.3
400	25.9	24.9
500	26.2	26.6
630	27.6	28.4
800	30.1	30.7
1000	32.1	32.1
1250	32.8	33.3
1600	33.0	34.2
2000	29.8	29.1
2500	28.1	27.4
3150	31.7	31.3
4000	34.4	34.9
5000	37.3	37.1



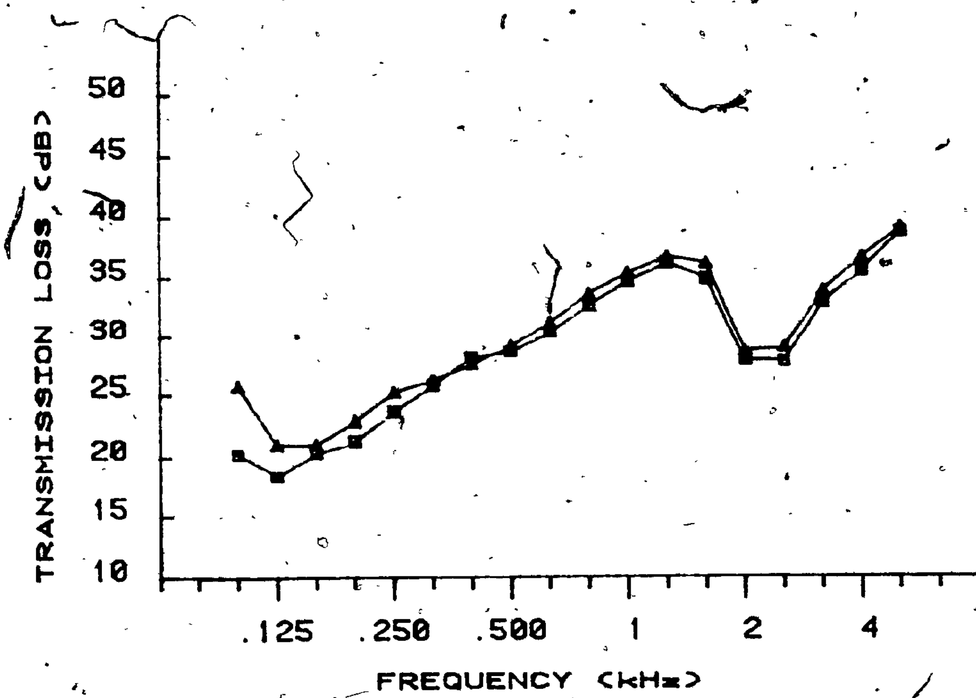
LEGEND

□ 1.14m x 1.14m (45in x 45in) Panel
Δ 1.52m x 1.52m (60in x 60in) Panel

Fig. 28a: Influence of Panel Dimension
Intensity Measured at 5 cm (2in) from Test Panel
19cm (7.5in) Sill - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	19.2	24.6
125	17.3	20.8
160	19.3	20.8
200	20.3	21.9
250	22.6	24.1
315	24.7	25.1
400	27.1	26.5
500	27.6	28.2
630	29.3	30.2
800	31.6	32.6
1000	33.7	34.4
1250	35.1	35.6
1600	33.8	35.1
2000	26.8	27.7
2500	26.7	27.9
3150	31.8	32.8
4000	34.5	35.6
5000	37.7	38.1



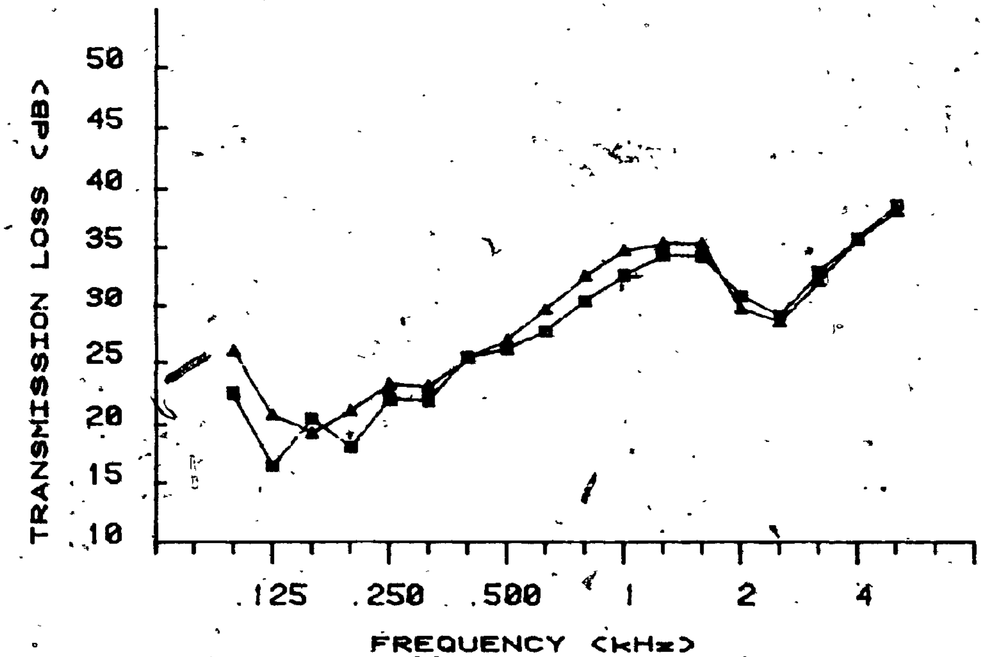
LEGEND

- □—□ 1.14m x 1.14m (45in x 45in) Panel
- ▲—▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 26b: Influence of Panel Dimension
Intensity Measured at Reception Room Side of Reveal
19cm (7.5in) Sill – No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	21.6	24.9
125	15.3	19.8
160	19.5	18.2
200	17.0	20.2
250	21.2	22.3
315	21.0	22.0
400	24.4	24.3
500	25.1	25.6
630	26.7	26.7
800	29.5	31.0
1000	31.7	33.7
1250	33.3	34.3
1600	33.2	34.9
2000	29.9	28.7
2500	28.1	27.6
3150	32.0	31.2
4000	34.6	34.6
5000	37.7	37.1



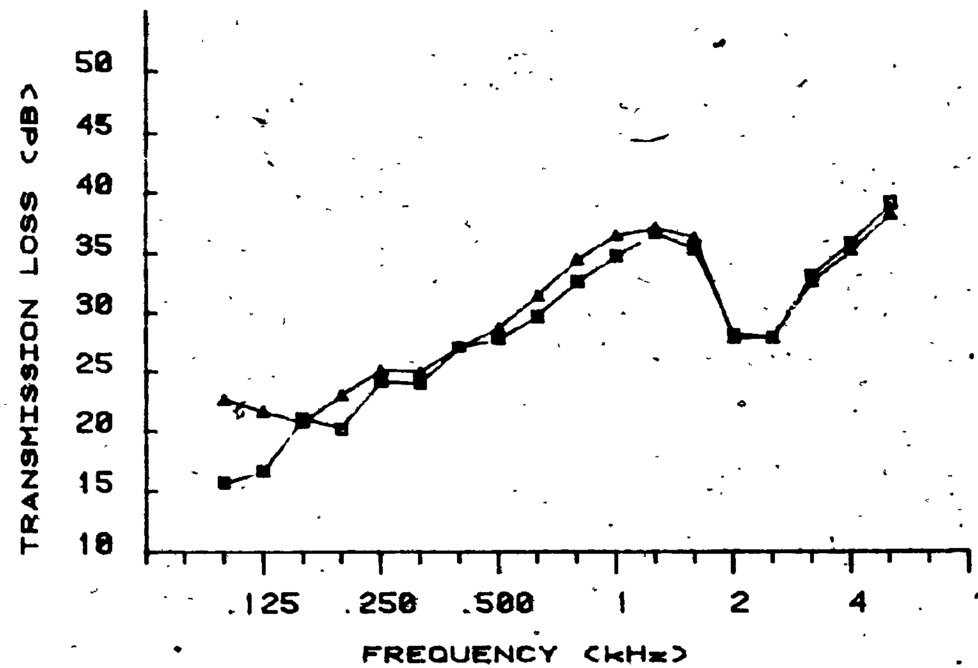
LEGEND

□——□ 1.14m x 1.14m (45in x 45in) Panel
▲——▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 27a: Influence of Panel Dimension
Intensity Measured at 5 cm (2in) from Test Panel
38cm (15in) Sill – No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	14.6	21.5
125	15.6	20.5
160	19.9	19.7
200	19.1	21.8
250	23.6	24.8
315	22.6	23.9
400	26.2	26.2
500	26.9	27.7
630	28.7	30.3
800	31.5	33.4
1000	33.7	35.5
1250	35.7	36.1
1600	34.2	35.3
2000	27.1	26.8
2500	26.9	26.8
3150	32.6	31.5
4000	34.9	34.2
5000	36.1	37.9



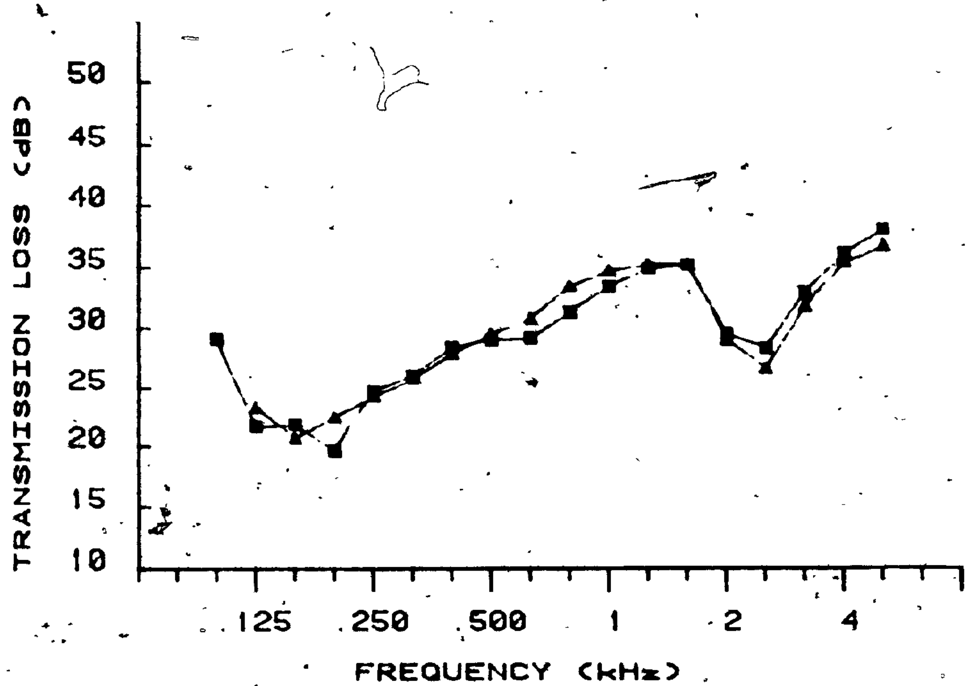
LEGEND

□——□ 1.14m x 1.14m (45in x 45in) Panel
▲——▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 27b: Influence of Panel Dimension
Intensity Measured at Reception Room Side of Reveal
38cm (15in) Sill - No Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	▫	▲
100	28.2	60.1
125	20.8	22.2
160	20.7	19.8
200	18.6	21.4
250	23.8	23.2
315	25.1	24.8
400	27.5	26.9
500	28.1	28.5
630	28.2	29.7
800	30.3	32.3
1000	32.3	33.7
1250	33.9	34.2
1600	34.2	34.2
2000	28.5	28.0
2500	27.4	25.8
3150	31.9	30.7
4000	35.2	34.4
5000	37.1	35.7



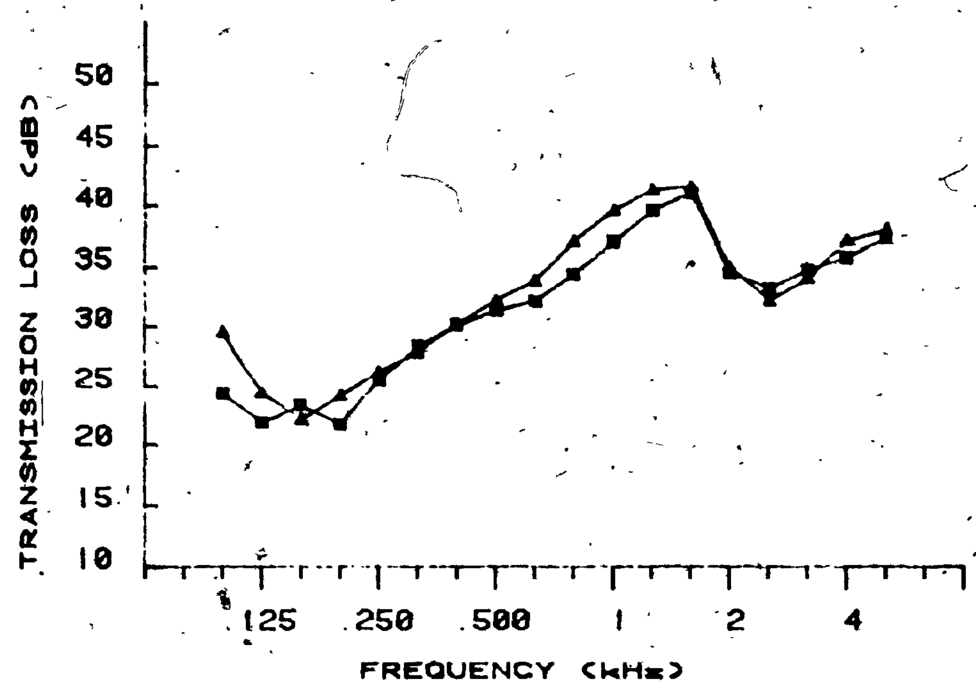
LEGEND

■——■ 1.14m x 1.14m (45in x 45in) Panel
▲——▲ 1.62m x 1.62m (60in x 60in) Panel

Fig. 28a Influence of Panel Dimension
Intensity Measured at 5cm (2in) from Test Panel
No Sill - 2.5cm (1in) Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	■	▲
100	23.4	28.5
125	20.8	23.5
160	22.3	21.1
200	20.8	23.2
250	24.8	25.4
315	27.5	27.0
400	29.2	29.3
500	30.4	31.2
630	31.1	32.9
800	33.5	36.1
1000	36.1	38.7
1250	38.7	40.4
1600	40.2	40.7
2000	33.5	34.0
2500	32.2	31.2
3150	33.8	33.2
4000	34.9	36.2
5000	36.5	37.1



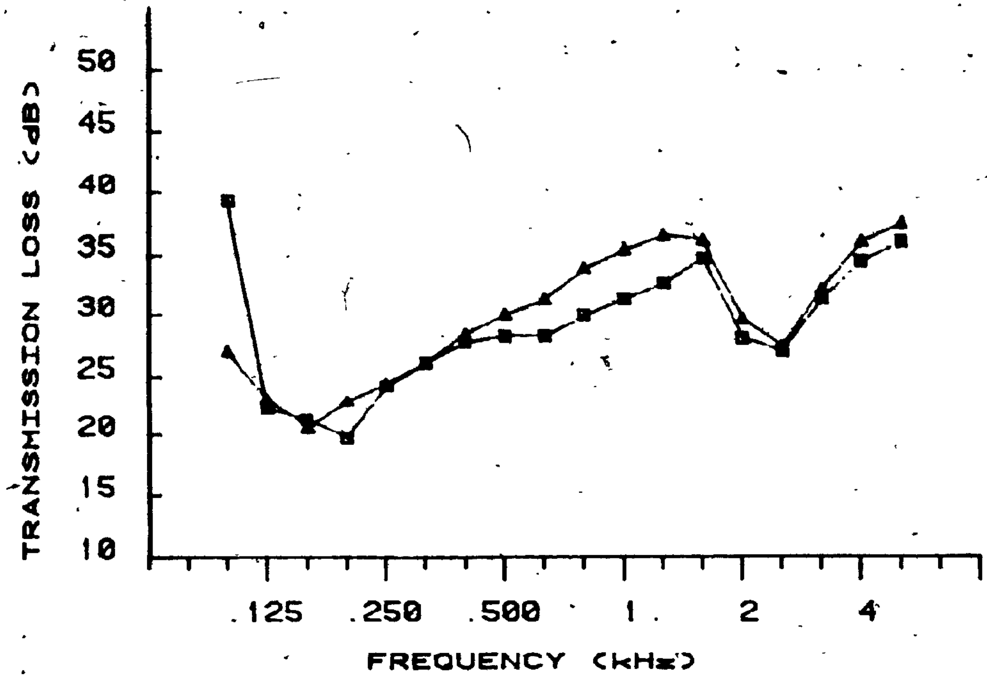
LEGEND

■——■ 1.14m x 1.14m (45in x 45in) Panel
▲——▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 28b: Influence of Panel Dimension
Intensity Measured at Reception Room Side of Reveal
No Sill - 2.5cm (1in) Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	△
100	38.3	26.8
125	21.2	22.0
160	20.2	19.5
200	18.7	21.8
250	23.2	23.4
315	25.1	25.1
400	26.7	27.4
500	27.9	29.0
630	27.2	30.3
800	28.9	32.9
1000	30.3	34.5
1250	31.6	35.5
1600	33.7	35.2
2000	27.8	28.6
2500	25.9	26.3
3150	30.9	31.1
4000	33.5	35.1
5000	35.1	36.5



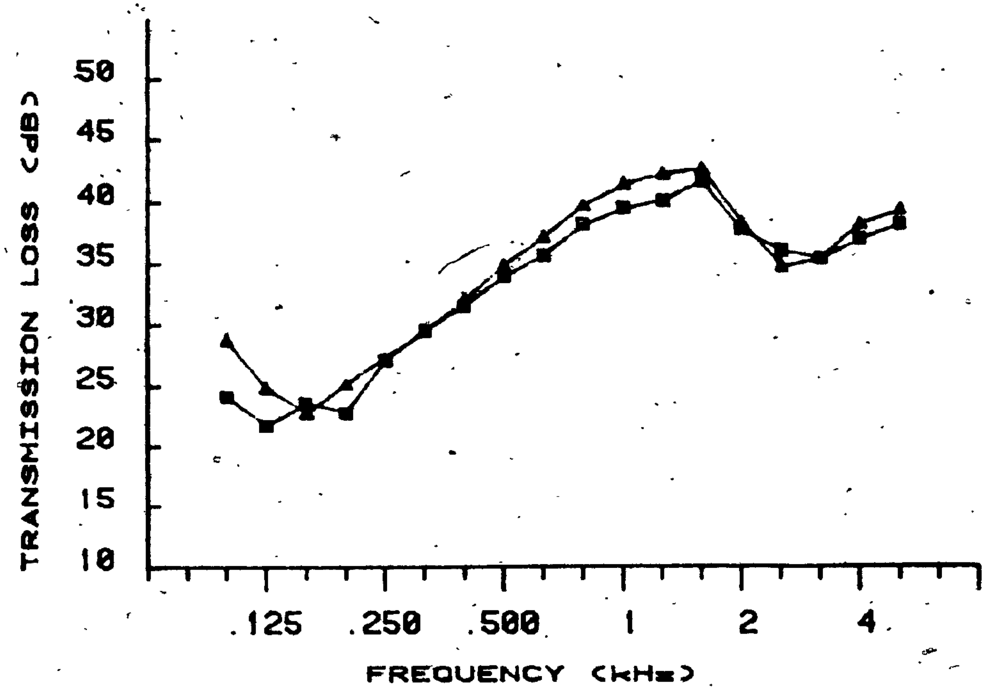
LEGEND

- ■—■ 1.14m x 1.14m (45in x 45in) Panel
- ▲—▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 29a Influence of Panel Dimension
Intensity Measured at 5cm (2in) from Test Panel
No Sill - 5cm (2in) Lining

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	▲
100	23.1	27.7
125	20.6	23.6
160	22.5	21.7
200	21.6	24.1
250	26.1	26.3
315	28.6	28.5
400	30.6	31.0
500	33.0	33.9
630	34.7	36.2
800	37.2	38.6
1000	38.5	40.5
1250	39.2	41.3
1600	40.7	41.6
2000	36.7	37.4
2500	35.0	33.6
3150	34.5	34.4
4000	36.0	37.2
5000	37.2	38.5



LEGEND

■——■ 1.14m x 1.14m (45in x 45in) Panel
▲——▲ 1.52m x 1.52m (60in x 60in) Panel

Fig. 29b: Influence of Panel Dimension
Intensity Measured at Reception Room Side of Reveal
No SIM - 5cm (2in) Lining

The conventional method to measure sound transmission loss attempts to eliminate the effect of panel dimensions by introducing a correction factor. When the intensity technique is used for sound transmission loss measurements, no corrections to account for the panel dimensions have to be made in the course of the test procedure. An energy balance between incident and transmitted energy is established and therefore the influence of the panel area is eliminated. However, the determined result will only be appropriate for that panel type under test.

From the results it can be seen that:

- For all configurations where the reveal is left bare (Figures 25, 26, 27, a and b), a general trend is apparent. Starting from the lower frequency end there is first a region where the larger panel has the highest transmission loss, then the trend reverses up to 500 Hz. Above 500 Hz and up to the coincidence dip the larger panel has again the highest transmission loss. Above coincidence differences are negligible.

- Differences generally range from about 1 to 1.5 dB in the absence of a sill (Figures 25 a and b) and 2 to 2.5 dB for a 38 cm (15 ") sill (Figures 27 a and b). They are less than 1 dB for the 19 cm (7.5") sill configuration (Figures 26 a and b).

- It is interesting to note that below 500 Hz, the frequency region where the smaller panel has the better performance reduces when sills are added on the source side. This high performance region for the smaller panel eventually almost completely disappears in case of the 38 cm (15") sill. Compare for example Figures 25.a(b), 26.a(b) and 27.a(b).

- When the reveal was lined with absorbent material (Figures 28, 29, a and b), the same global trends are observed. However, for the 2.5 cm (1") lining, differences are slighty higher above coincidence, while they are much higher below f_c for the 5 cm (2") thickness when the transmitted intensity is measured directly behind the test panel.

Previous sections have shown that:

- The effect of sills decreases with increasing panel size (see section 4.2).

- The effect of lining the reveal with absorbent material also decreases with increasing panel area (see section 4.3.1).

- The power flow through the panel is strongly influenced by the panel dimension (see section 4.4).

The present results agree with most theoretical predictions [5,6,7] in so far that, above coincidence the panel area has little or no effect on the transmission loss, while just below coincidence the transmission loss increases with increasing panel area. At the low frequency end, below

500 Hz, trends are less clear and seem to depend on the sill configuration. Panel dependency is however generally quite small, 0.5 to 2.5 dB, for almost a doubling in surface area.

However, it has to be stressed that although the same trends are confirmed for all configurations tested, the present study is limited because only two panel sizes were tested. It is therefore also difficult to compare the present results with previous experimental works [13,14].

4.6. **Fault Finding**

The capabilities of the sound intensity technique with regard to the detection of construction or material deficiencies was also examined.

For this purpose a fault was introduced by partial removal of the weather stripping on either side of one panel edge as shown in Figure 30. The fault was located on the left-hand side of the panel. The exposed portion revealed a crack approximately 9.5 cm long and 0.2 mm wide between the panel edge and its mounting frame.

Intensity measurements were made directly behind the test panel at a distance of 5 cm (2"). The intensity pattern obtained was investigated for observable irregularities (see Appendix F). From Figures F.1 to F.14, one immediately notices the location of the fault characterized by the high intensity values and steep gradients. The effect is especially visible in the mid-frequency range from 800 Hz up to 1600 Hz (Figures F.6 through F.9).

It was found that close to the fault, the values of transmitted intensities were generally higher than at the same points before the fault was introduced as might be expected. The differences in local intensity were slight at the lower frequencies, up to 3 dB at 250 Hz (compare Figure D.1 with F.1), increasing up to 14 dB at 1600 Hz (compare Figure D.9 with F.9) and falling lower again beyond this frequency.

The existence of the fault is clearly indicated by the intensity contours. However, when comparing the overall sound transmission loss before and after the introduction of the fault (see Figure 31), its influence is noticeable with a maximum difference of 3.5 dB. This could have easily been overlooked by consideration of the overall spectrum alone.

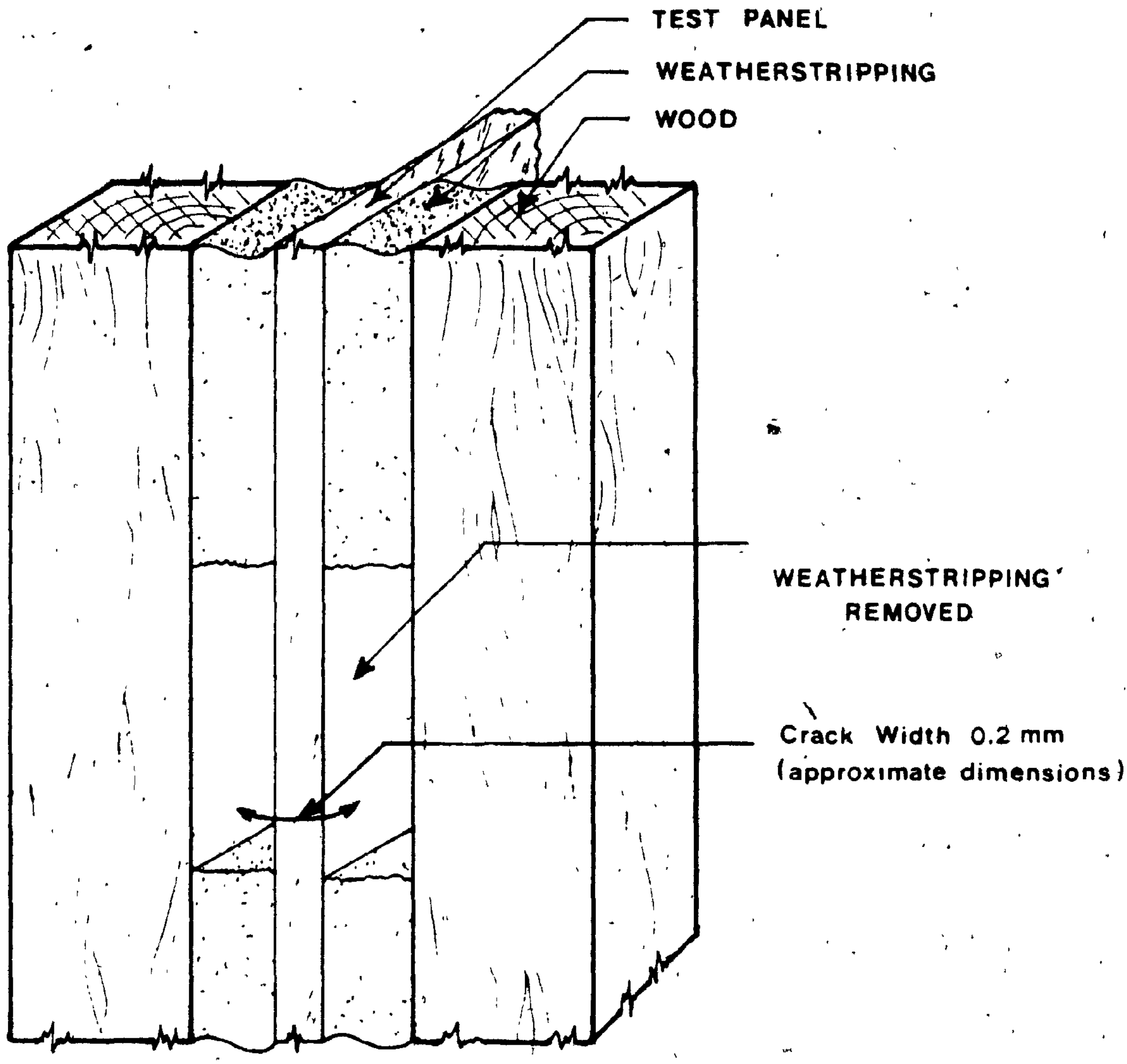
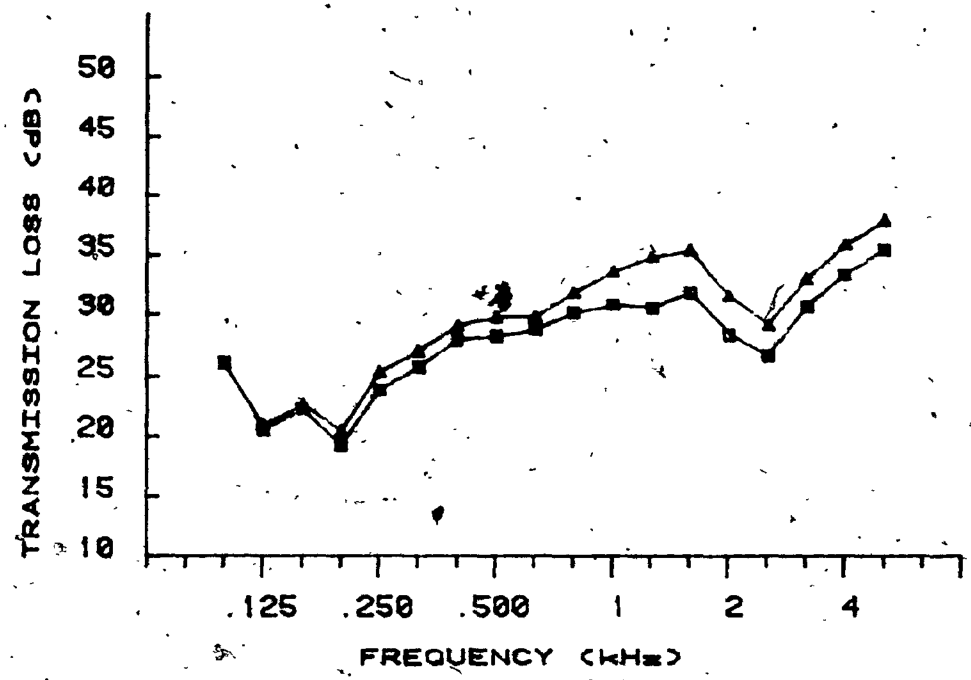


Fig. 30 Scheme of Fault Introduced by Removing Weatherstripping. Strip Length 9.5 cm; Crack Width 0.2 mm (approximate dimensions)

TRANSMISSION LOSS (dB)

FREQ. (Hz)	□	△
100	25.2	25.8
125	19.5	19.9
160	21.2	21.5
200	18.2	19.4
250	22.6	24.4
315	24.6	26.1
400	27.6	28.0
500	27.2	28.6
630	27.7	28.6
800	29.1	30.6
1000	29.7	32.6
1250	29.5	33.6
1600	30.6	34.4
2000	27.3	30.5
2500	25.7	28.1
3150	29.7	32.8
4000	32.4	34.9
5000	34.5	36.9



LEGEND

△——△ BEFORE INTRODUCTION OF FAULT
□——□ AFTER INTRODUCTION OF FAULT

Fig. 31: Comparison Between the Transmission Loss Before and After the Introduction of a Fault 1.14m x 1.14m (45in x 45in) Panel - No Sill - No Lining

CHAPTER V : CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

5.1 Conclusion

The validation of the measurement of sound transmission loss based on the intensity technique has been confirmed and a detailed test procedure has been established.

The intensity technique was used to measure the sound transmission loss as a function of: sills and reveals, lining of the reveal with absorbent material of varying thickness and panel dimensions. In addition, some of the advantages of the technique and its extended capabilities as compared to the traditional procedure have been brought forward.

It was demonstrated that in order to take into account all effects caused by the presence of the reveal, the transmitted intensity has to be measured at the reception room side of the reveal.

It was further shown that the addition of sills in the presence of a reveal always decreases the transmission loss, whether the transmitted intensity was measured directly behind the test panel or at the reception room side of the reveal. The effect was most pronounced well below coincidence.

In accordance with previous works, a symmetrically mounted panel was found to have a lower transmission loss than one with only a reveal on the receiving side.

There is however some controversy as to whether the results when the transmitted intensity is measured directly behind the test panel are equivalent to those of the no reveal configuration. Further research is necessary to establish this.

When the reveal was lined with absorbent material, the global performance was greatly enhanced and the overall transmission loss has been shown to increase with increasing thickness of the sound absorbent lining material. However the intensity measurement technique indicates that the panel radiation is not influenced by the presence of the lining. Such a conclusion would not have been possible employing the standard reverberation room method.

With regard to panel dimensions, it was found that for the panel sizes tested, the larger panel always had the highest transmission loss in the mid-frequeny region with differences of the order of 1.5 dB. At the lower frequency end the opposite was true but the effect seemed to diminish with the addition of sills. Above coincidence the effect was negligible as was the case for the other parameters.

The intensity method also allowed for the establishment of the power flow distributions through the panels. Equal intensity contours were drawn for both panel sizes. Clear and distinct patterns can be observed but they vary with panel dimensions. The exact cause for this is not known.

It was also demonstrated that the intensity technique can be used to identify the existence of untoward sound transmission paths as part of a normal measurement procedure. However, an accurate application would necessitate a better knowledge of the radiated intensity distribution as a function of panel dimensions, edge conditions and material properties.

To conclude, the intensity based method to measure sound transmission loss has proved to be simple, flexible and direct. It eliminates the use of correction factors to account for panel area and absorption in the reception room as required by the standard method. Measurements can be made in different planes, the power flow distribution through the panel can be established and consequently checked for irregularities. In addition, the technique has the added benefit that only one reverberation chamber is needed. This is important for future laboratory construction.

On the other hand, with regard to already existing and operative laboratories, the implementation of the intensity technique is expensive and its full automation relatively complex, if not impossible; consider for example the limited usefull frequency range of a particular microphone spacing. Test procedures based on the Standard measurement technique are easily fully automated. This is often the case and therefore this method requires less human attention. Another potential problem with the new technique is that, in case of a high transmission loss partition, the sound source will have to be very powerfull if one wishes to avoid signal to ambi nt ratio problems on the reception side.

8.2. Standards Concerning Sound Transmission Loss Measurements by the Intensity Technique

No standards exist yet with regard to Intensity Measurements, although recently some proposals have been brought forward concerning Sound Power Measurements [44].

Based on the experience acquired in the course of this work, suggestions will be made here with respect to standards for sound transmission loss measurements.

- **Acoustic Environment :**

In order to avoid two sided intensity measurements (respectively on the incident side of an open aperture and on the reception side of the partition), speed up the test procedure, and provide a relative and reproducible basis for measurement comparison, the transmitting room has to be reverberant as for standard requirements for sound power measurements. Thus, the ANSI/ASTM E90-75 [9] requirements still hold.

The reception room is no longer subject to stringent requirements. Its sound absorbing qualities are not critical although some absorption is required in order to reduce the reactivity of the sound field and establish the accuracy of the method. Thus the reactivity limits of the reception environment should be stated.

Background noise should also be avoided.

- **Instrumentation :**

* Sound Source and Test Signal :

The requirements as specified by ANSI/ASTM E 90-75 [9] are still appropriate.

* Microphones, Microphone Spacing and Cables :

The microphones should be specified as perfectly phase matched or their phase differences taken into account. The microphones and their spacing should be selected according to stated microphone standards, the frequency range of interest and the reactivity of the sound field in order to achieve a required accuracy.

The microphones, together with their cables, should be individually calibrated with respect to amplitude by use of a pistonphone. In addition there should be a phase calibration of the total system prior to measurement.

The reactivity of the sound field at the location of the measurements should be determined and reported after which the total error due to phase differences between the two measurement channels should be calculated.

In case of non-compliance to the accuracy requirements, the following steps can be taken : increase of sound absorption in the reception room, increase of the microphone spacing, replacement of microphones and cables.

- **Installation of the Test Panel** :

The mounting of the panel should again be in compliance with the existing standards [9].

- **Determination of the Sound Transmission Loss** :

* Incident Intensity :

This can be estimated from the diffuse field intensity, based on the measurement of the space/time-averaged sound pressure in the transmitting room.

The measurement of the sound pressure can be done according to the existing standards [9].

* Transmitted Intensity :

The transmitted intensity should be measured over the surface area of the panel. The following parameters should be considered:

- Orientation of the Microphone: The transmitted intensity should always be measured perpendicular to the panel's surface.
- Measurement Method : The measurements can be performed in two ways : by slowly scanning the panel's surface with the microphone probe, or by measuring the intensity at discrete points uniformily distributed over the surface, then averaging the results. The standard should specify scanning rates if appropriate.

  The first method gives overall results (but has not been tested here), while the second one also enables the establishment of the power flow distribution across the surface.
- Measurement grid : When using discrete measuring points, the surface has to be uniformily divided into subareas, at the center of which the measurements will be taken. These subareas should preferably be square shaped and, according to this study, about 12.5 to 16 cm wide. A finer grid will lead to higher accuracy but incurs a measurement time penalty.
- Measurement Distance : The microphone probe should always be kept at a constant distance from the panel's surface.

When only the transmission loss of the panel itself is required, the measurements should be made close to its surface. If discrete measurement points are used, a distance of half the mesh size seems appropriate. In this study 5 cm was chosen for the 12.5 cm mesh. For smaller mesh sizes attention should be paid not to exceed the near field capabilities of the microphone pair. When the scanning method is used, 5 cm also seems appropriate although this has not been tested here.

<u>Note</u> : In the event that the overall transmission loss of a partition composed of different components (sills, reveals, lining) is required, the transmitted intensity should be measured at their reception side. The same measurement grid as described above can be used.

. <u>Averaging Time</u> : The averaging is not critical although its lower limit seems to be determined by the reactivity of the sound field and should be stated by the standard.In this work 8 sec per measuring point was chosen.

5.3. **Suggestions for Future Research**

- Because of the duration and the repetitive nature of the measurements, it is strongly advised that the test procedure be automated.

- Automatic plotting of the equal intensity contours is also strongly recommended.

- Once full automation has been established the technique could be exploited to determine the transmission loss and power flow distribution through panels as a function of various physical parameters, such as:
  - edge conditions
  - material properties, including composite panels
  - panel dimensions

- It should be established whether in the presence of a reveal, the transmission loss with the transmitted intensity measured directly behind the test panel is equivalent to that in the no reveal configuration.
This could be done for example by mounting the test panel flush with the reception room side and building out the reveal.

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APPENDIX A

Other Applications of the Intensity Technique

APPENDIX A : OTHER APPLICATIONS OF THE INTENSITY TECHNIQUE

A.1. Measurement of Sound Power

A.1.1. General Background

The main application of the Sound Intensity Technique is presently the measurement of Sound Power. No standards exist that describe the test procedure, although recently some proposals have been brought forward of which the most complete is that by Brüel & Kjaer [44].

The Sound Power W of a sound source is obtained by integrating over a surface S, enclosing the sound source, the product of the intensity vector $\bar{I}$ by the surface vector $\bar{dS}$ normal to the elementary surface dS:

$$W = \oint \bar{I} . \bar{dS} \qquad (A1)$$

This is equal to:

$$W = \oint I_n . dS \qquad (A2)$$

where I_n is the intensity vector's component normal to the elementary surface dS.
In practice, when a discrete number of measuring points are

used, equation (A2) becomes:

$$W = 10\log[\sum_{i=1}^{n} I_i . S_i] \quad (A3)$$

where I_i : the intensity vector's componant normal to the surface at position i

S_i : the area associated with position i

n : the number of measuring points

The use of a discreet number of measuring points as compared to spatial averaging is recommended by Reference [44] because it allows for a more accurate positioning of the sound intensity probe. As to the number of points required, the same Reference states that the number is sufficient when double the points yields a reproducibility better than 0.3 dB.

The main advantages of using the Sound Intensity method for Sound Power Determinations are:

- The intensity can be measured in the near field of a sound source.

- There are no restrictions concerning the shape of the enclosing measurement surface. It can follow the outline of the noise source but the intensity vector always has to be measured perpendicular to the reference surface.

- The measurements can be performed even in the presence of background noise. This is explained by the fact that the sound intensity at a given measurement point is actually the net intensity at that point; sound coming from within the measuring surface is recorded as positive, while sound coming from the outside is recorded as negative. Ultimately , all the sound energy penetrating the reference surface will leave it in the assumption that there is no sound absorption within. Thus, when the ambient noise is constant, it is eventuallly eliminated in the course of the test procedure. This is actually a consequence of the definition of Sound Power (see equation (A1)) and the principle of Gauss.

According to Reference [45], a random error less than 1 dB can still be expected if the background noise does not exceed the sound level of the sound source by more than 10 dB on the reference surface. Measurements can therefore be easily and accurately performed in situ.

A.1.2. Comparison Between Sound Power Measurements Based on the Standard Reverberation Room Technique and the Intensity Technique

Numerous works have already been published concerning this topic but for additional information the results of tests performed at the Centre for Building Studies are reported here.

The sound source was a Mark Hot Thermoplus Heat Pump. It was installed in the larger chamber of the transmission loss suite and discharging into the other chamber via a high

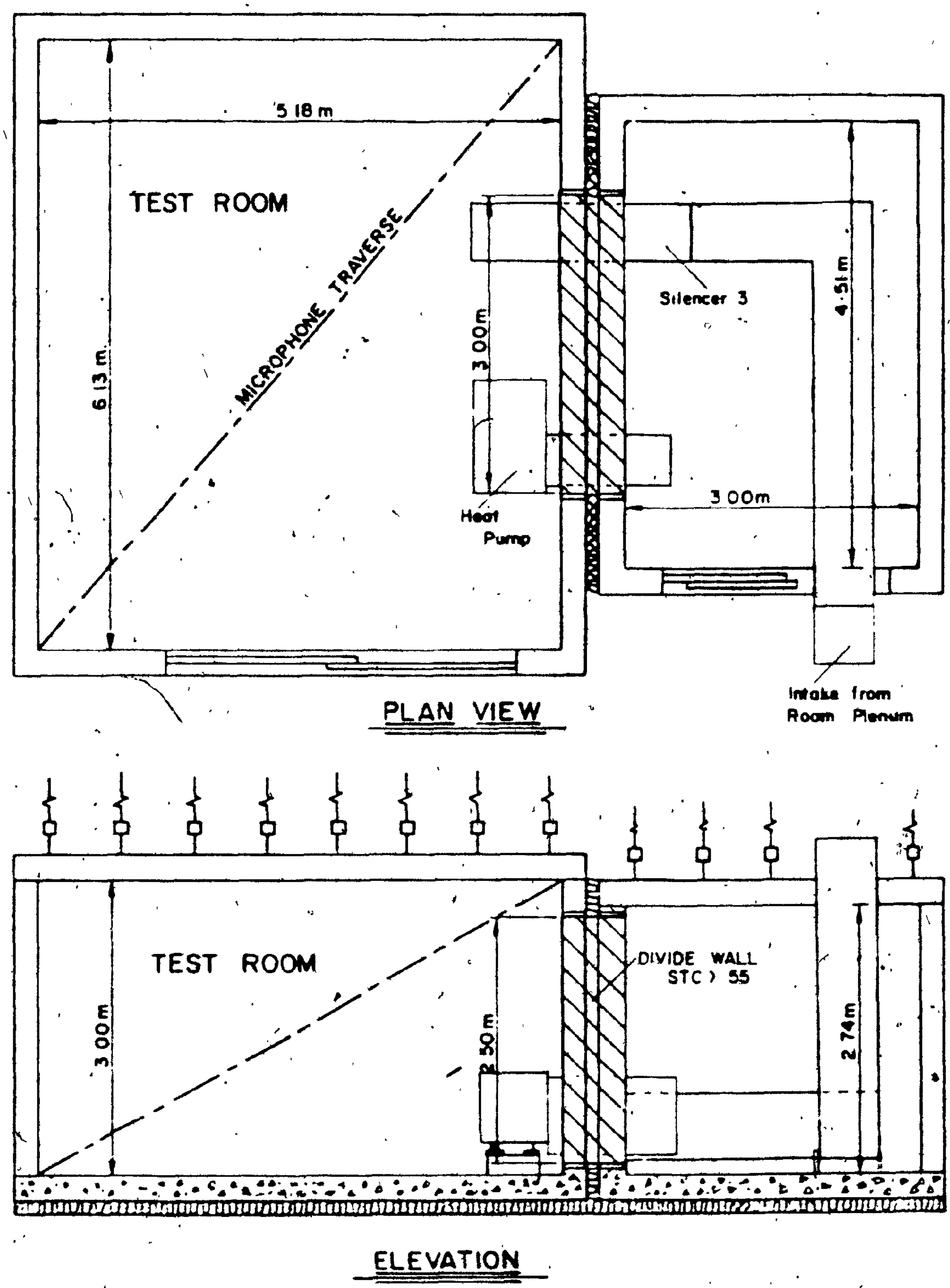

Fig. A.1 : Equipment Layout
Sound Power Measurements of Heat Pump Unit and Exhaust Side

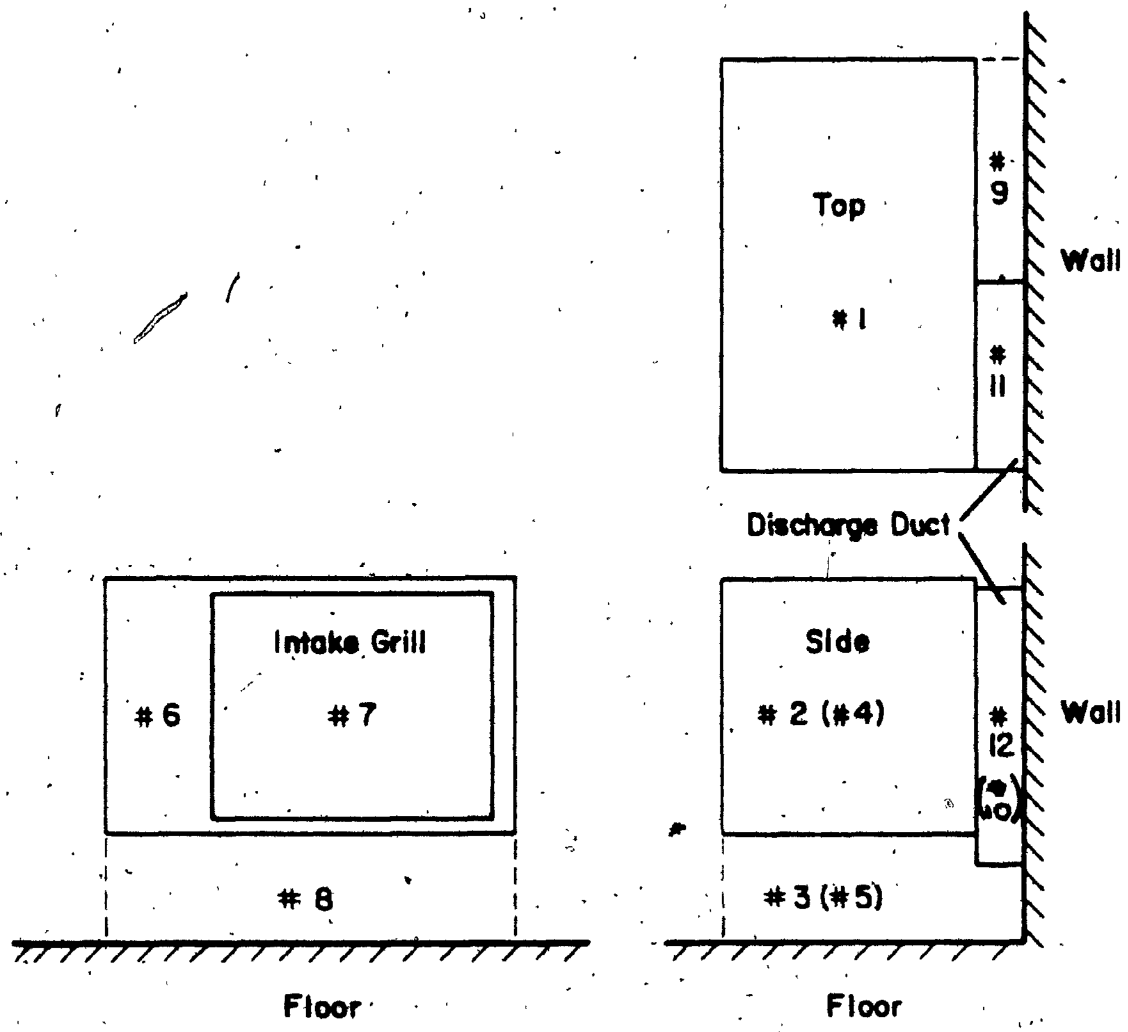

Fig. A.2 : Area Code Designations With Respect to the Heat Pump Unit transmission loss discharge duct. For actual layout of the machinery see Figure A.1.

The Sound Power Measurements based on the conventional reverberation room technique complied with the requirements of the American National Standard S1.21-1972 [46].

With regard to the intensity method, measurements were performed according to the manufacturer's specifications. The heatpump unit was enclosed by a hypothetical rectangular reference surface, the sides of which were divided into different areas. Each area was again divided into n subareas. Intensity measurements were made at the center of the subarea thus created. The results were consequently integrated over the n points per area. The measurement distance was kept constant.
Measurement areas and number of measuring points for a given area are reported at the top af Table A1. Area code designations with respect to the heatpump unit are shown in Figure A.2.
Measurements were performed with two microphone spacers: 50 mm and 12 mm, giving an accuracy interval of respectively 63 to 1250 Hz and 125 to 5000 Hz.
The reactivity of the sound field was not established.

The results obtained by the conventional test procedure and the intensity method using the 12 mm microphone spacing are shown in Table A1. Further information and results for the 50 mm microphone spacing can be found in Reference [47].

Except at 315 Hz, the results by the two methods compare very well, the difference being always less than 1.5 dB.

Table A1.[illegible]: Comparison between the Sound Power Determinations by the Intensity Technique and the Traditional Method for the Mark Hot Thermoplus Heat Pump. Microphone Spacing: 12 mm.

	INTENSITY MEASUREMENTS												Total Sound Power after Corrections	
area code	1	2	3	4	5	6	7	8	9	10	11	12	Intensity	Pressure
points per area (n)	16	[illegible]	4	[illegible]	4	3	[illegible]	[illegible]	4	3	2	3		
frequency [Hz]	measured intensity level per area [dB]												Method [dB]	Method [dB]
125	60.0	0.0	[illegible]	60.7	60.0	[illegible]	[illegible]	56.9	50.0	60.9	46.0	55.1	73.4	73.5
160	57.4	62.1	70.6	61.1	61.5	59.2	63.1	70.7	53.7	58.6	46.1	60.8	76.0	77.0
200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57.4	[illegible]	64.8	44.5	51.8	0.0	54.5	70.8	71.0
250	53.3	51.4	47.0	48.4	50.8	55.7	63.1	47.6	44.6	48.1	38.2	45.0	64.9	63.5
315	[illegible]	51.0	44.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46.1	45.9	32.1	44.9	66.6	63.0
400	48.6	47.0	39.5	45.3	46.0	50.9	58.8	44.7	42.3	44.2	39.2	41.1	60.7	61.0
500	47.1	[illegible]	[illegible]	[illegible]	[illegible]	50.4	[illegible]	45.6	39.2	43.2	39.4	41.2	61.5	62.0
630	47.4	47.1	41.1	[illegible]	41.6	50.9	61.3	43.2	40.8	47.9	41.4	44.5	62.0	61.5
800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	59.7	[illegible]	33.7	42.4	37.5	40.4	60.9	62.0
1000	44.8	43.9	42.3	42.6	42.4	52.2	59.0	46.8	38.6	42.6	33.9	38.0	60.6	61.5
1250	[illegible]	[illegible]	41.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40.2	0.0	32.6	59.8	61.0
1600	42.8	40.3	38.0	39.5	[illegible]	49.5	57.2	[illegible]	35.7	33.7	26.6	31.9	58.4	60.0
2000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.0	33.4	[illegible]	24.6	32.2	57.6	59.0
2500	40.5	36.1	31.5	37.6	[illegible]	47.7	56.0	39.6	30.0	36.2	24.6	34.3	57.7	57.5
3150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28.0	32.1	24.6	[illegible]	57.0	57.0
4000	[illegible]	[illegible]	30.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.7	29.2	21.6	29.2	54.7	54.5
5000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.2	[illegible]	24.6	52.0	55.0

A.2. **Source Identification and Ranking**

Traditionally, noise source identification and ranking was carried out using the lead wrapping technique. This technique consists of wrapping an entire machine in a blanket of absorbent material with an outer layer of lead. Various components of the machine are then selectively exposed and their contribution to the total sound power is determined. However, this method is cumbersome, slow and not always accurate, in particular at the low frequencies and for weak sources.

Recently, a number of workers [48,49,50] demonstrated that the intensity technique is technically superior to the old method and has a greater flexibility although it still requires improvement. The method is based on the sound power measurements as described in section A.1. Componants of the machine are selectively enclosed by a hypothetical reference surface, after which their contribution to the total sound power is determined and they can be ranked. Measurements can be performed in situ; background noise and contamination from other sound sources is in principle eliminated because of the Gauss principle. However, Thompson [49] points out that a sufficient number of measuring points per componant is necessary in order to accurately determine the radiated sound power and eliminate the effects of comtamination from nearby sound sources.

On the other hand, because of its directional characteristics and the possibility of measuring close the the sound source, the intensity technique allows for other methods to locate specific noise sources. This can be achieved by simply recording zones of high intensity levels, changes in the intensity direction, or more accurately by contour mapping. However these methods do not imply complete enclosure of the noise source and they should therefore ideally be performed in an anechoic environment to achieve maximum accuracy.

A.3. **Measurement of Sound Absorption and Acoustic Impedance**

The use of the intensity technique for this application is new and the available litterature is extremely limited (3 articles). In addition test procedures for sound absorption contradict each other and one must conclude that further work is required to validate the intensity technique in this area.

Appendix B

Transmission Loss Spectra for Filler Wall

TRANSMISSION LOSS (dB)

FREQ.(Hz)	▫
100	44.6
125	45.8
160	46.2
200	49.3
250	50.5
315	50.3
400	53.3
500	57.5
630	61.9
800	56.7
1000	58.1
1250	63.4
1600	63.7
2000	69.2
2500	71.9
3150	72.7
4000	65.1
5000	66.1

STC 60

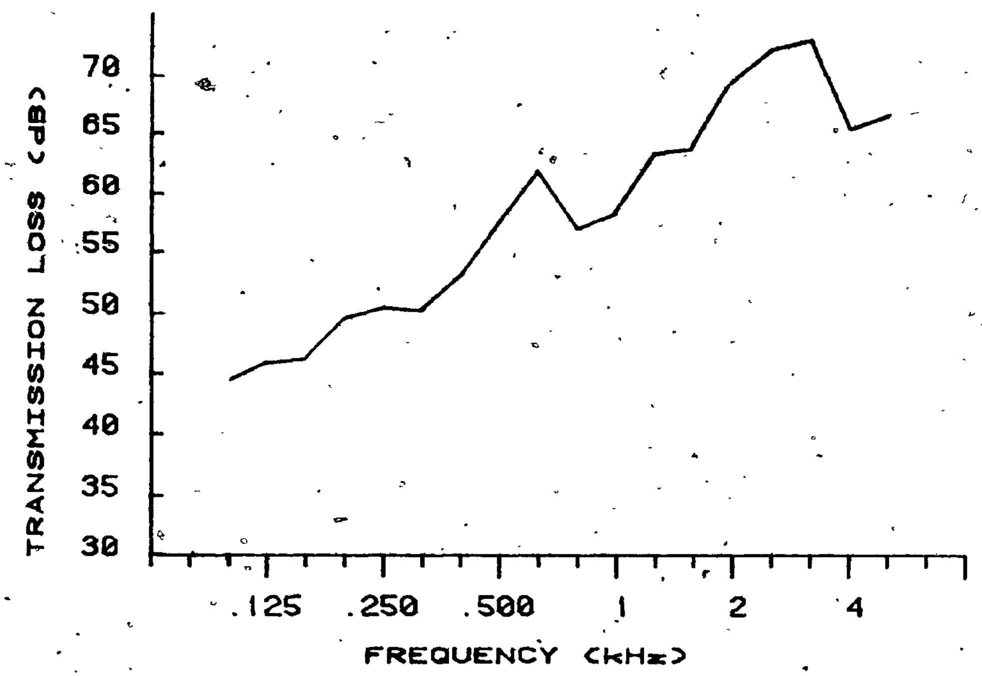

Fig. B.1: TRANSMISSION LOSS SPECTRUM OF FILLER WALL
LARGE CHAMBER IS TRANSMITTING

TRANSMISSION LOSS (dB)

FREQ.(Hz)	□
100	44.8
125	49.6
160	49.0
200	44.8
250	47.2
315	51.4
400	54.6
500	54.1
630	58.7
800	56.9
1000	59.6
1250	65.5
1600	67.0
2000	62.3
2500	63.7
3150	71.9
4000	70.4
5000	69.3

STC 57

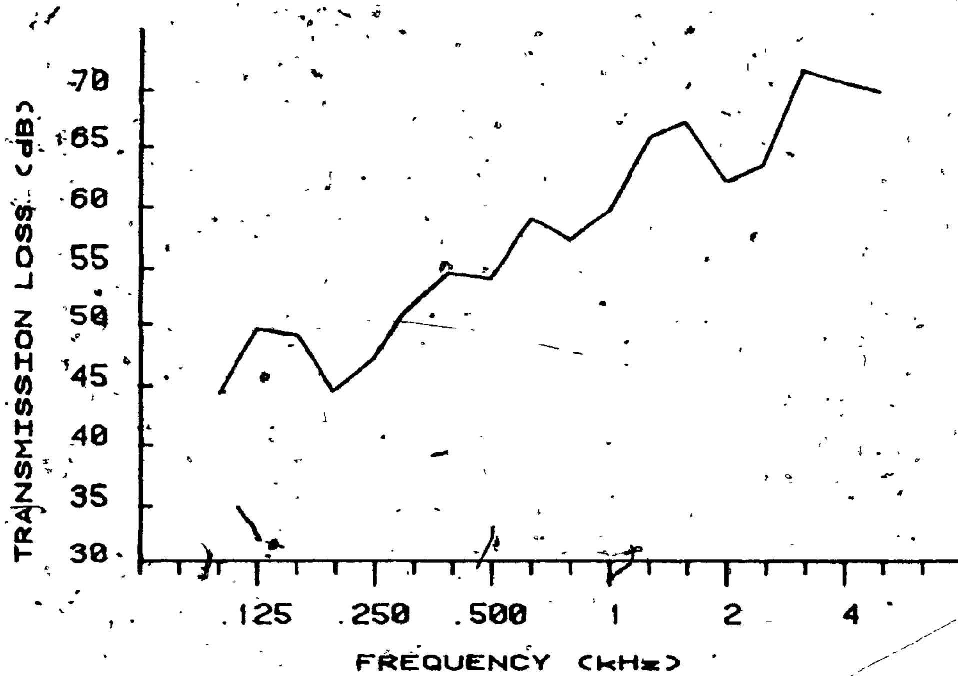

Fig. B.2: TRANSMISSION LOSS SPECTRUM OF FILLER WALL
SMALL CHAMBER IS TRANSMITTING

Appendix C

Program Listings

C.1. Measurement of the Decay-Rates and Calculation of the Reverberation Times and Room Absorption for Varying Third Octaves

```
0: dsp "*REVERBERATION TIME MEASUREMENT*";wait 100
1: dim B[18],B[18],B$[318],F[18],N$[6],S$[1],J$[8]
2: dim P[45,18],X[18],Q[18],A[18]
3: dim A$[6615],Y[18],Z[18],D$[80]
4: dim R$[1],T$[2],U$[2],S[18],T[18],L[18]
5: 100→F[1];125→F[2];160→F[3];200→F[4];250→F[5];315→F[6];400→F[7]
6: 500→F[8];630→F[9];800→F[10];1000→F[11];1250→F[12];1600→F[13]
7: 2000→F[14];2500→F[15];3150→F[16];4000→F[17];5000→F[18]
8: wrt 717,"DBN?MPL";wait 100;lcl 7;wait 1000
9: cll 'input'
10: ent "enter # of MEASUREMENT POSITIONS",Z
11: buf "in",B$,3
12: for P=1 to Z
13: dsp "POSITION MICROPHONE:position ",P;stp
14: dsp "MEASUREMENT POSITION # ",P;wait 100
15: 1→U
16: cll '?t'(U)
17: T$[1,2]→U$[1,2];650-(10+10num(U$[2,2]))→V
18: cll 'lin'
19: B$[134,280]→A$[1,147]
20: for I=1 to 18;val(A$[7I-6,7I])→T[[illegible]xt I
21: rem 7;wait 3000
22: wrt 717,"N=";wait 1000
23: "N="→T$
24: cll 'lin'
25: B$[134,280]→A$[1,147]
26: for I=1 to 18;val(A$[7I-6,7I])→L[I]
27: if L[I]+10<V;V-10→L[I]
28: next I
29: clr 7;wait 100;cli 7;wait 100
30: wrt 717,U$;wait 50;lcl 7
31: wrt 717,"04";wait 5000
32: for R=1 to 50
33: fxd 0
34: dsp R
35: cll 'time'
36: for I=1 to 18;for J=1 to 45;147J+7I-153→X;X+6→Y
37: tn^(val(A$[X,Y])/10)+P[J,I]→P[J,I];next J;next I
38: next R
39: next P
40: (R-1)*Z→R
41: dsp "STATISTICAL CALCULATION"
42: for I=1 to 18;for J=1 to 45;90I-90+2J→X;X+1→Y
43: 10log(P[J,I]/R)→P[J,I]
44: next J;next I
45: for I=1 to 18
46: 0→M→L→C→D→E→N
47: for K=5 to 43
48: if P[K,I]+5>T[I];gto 54
49: if P[K+1,I]+5>T[I] or P[K+2,I]>T[I];gto 54
50: if P[K,I]-15<L[I];gto 56
51: N+1→N
52: M+P[K,I]→M;L+.0625*N→L;E+.0625*N*P[K,I]→E
53: C+P[K,I]^2→C;D+(.0625*N)^2→D
54: next K
55: fxd 8
56: (E-M*L/N)/(D-L^2/N)→B
57: if B>=0;0→X[I];gto 66
58: (C-M^2/N-B*(E-M*L/N))/((N-2)*(D-L^2/N))→S
59: B^2→B[I];-B→X[I];N→Y[I];K-N-1→Z[I];S→S[I]
60: if K=44;43-N-1→Z[I]
61: 1.96*\S[I]/\R→S[I]
62: .921*H*X[I]/A→Q[I]
63: .921*H*S[I]/A→S[I]
```

```
64: 100*S[I],O[I]]A[I]
65: .T6*H/O[I]]O[I]
66: next I
67: U+1]U
68: ent 'ent 1 to  display spectra',r1;if r1=1;cll 'display'
69: cll 'out1'
70: set 'TLF',0,0
71: end
72: "set":
73: "N:"}T$
74: if U=1;lcl 7;wait 1000
75: wrt 717,T$;wait 1000
76: ret T$
77: "time":
78: lcl 7;wait 5000
79: for J=1 to 45
80: wrt 717,"E?"
81: buf "in"
82: tfr 716,"in",302
83: jmp rds("in")#-1
84: if J=5;rem 7
85: wrt 717,"E="
86: wait .01858.
87: B$[134,280]}A$[147J-146,147J]
88: next J
89: ret A$
90: "lin":
91: if U=1 or U=0;U+4}U
92: clr 7;wait 50;cll 7;wait 50
93: if U=-1;wrt 717,T$;wait 50;gto 95
94: wrt 717,U$;wait 50
95: if U#-1;lcl 7;wait 5000
96: wrt 717,"M?0;L?";wait 7
97: wrt 717,"E?";wait 10
98: buf "in"
99: tfr 716,"in",302
100: jmp rds("in")#-1
101: wrt 717,"E=";wait 100
102: wrt 717,"M?03L"
103: rem 7
104: if U=-1;U+2}U
105: ret B$
106: "display":
107: 1}I
108: 0}S
109: clr 7;wait 500;cll 7;wait 500
110: wrt 717,"F J?"
111: fmt 1,fz5.1
112: wrt 716.1,V-10
113: if I=0;1}I
114: if I=19;18}I
115: for J=1 to 42;wrt 716.1,F[J,I];next J
116: fxd 0;dsp "TIMEAXIS AT",F[I],"HZ.";fxd 1
117: for J=1 to Z[I];wrt 717,"D ";wait 50;next J
118: for K=1 to 3
119: if Z[I]+Y[I]>30;cll 'two';gto 123
120: for J=1 to Y[I]-1;wrt 717,"D>";wait 50;next J;wait 500
121: for J=1 to Y[I]-1;wrt 717,"D?";wait 50;next J;wait 500
122: next K
123: ent 'next 3rd octave?}press CONTINUE',S
124: if I=18;jmp 2
125: if S=0;I+1}I;gto 109
126: ret
127: "two":
128: for K=1 to 3
129: for W=1 to 29-Z[I];wrt 717,"D>";wait 50;next W
130: wrt 717,"J>"
```

```
131: for W=1 to Z[I]+Y[I]-30;wrt 717,"D";wait 50;next W;wait 500
132: for W=1 to Z[I]+Y[I]-30;wrt 717,"D";wait 50;next W
133: wrt 717,"J"
134: for W=1 to 29-Z[I];wrt 717,"D";wait 50;next W;wait 500
135: next K
136: ret
137: "input":
138: asgn "ABSDAT",1,0,X
139: setk "keys"
140: dsp "CALIBRATE & INITIALIZE SYSTEM";wait 100;beep;stp
141: fmt 4,c80
142: ent "TEST TITLE",D$;wrt 4.4,D$
143: wtb 4,10;wtb 4,10
144: ent "SOURCE ROOM A or B",S$
145: if S$="B";93.942}H
146: if S$="A";37.0722}H
147: ent "TEST PANEL AREA",G
148: ent "FINAL STORAGE FILE",N$
149: ent "TEMP. IN DEG F",F
150: ent "DATE MM/DD/YY",V$
151: fmt 5,6x,c5,2x,c8
152: dsp "source room",S$;wait 1000
153: wrt 4.5,"DATE:",V$
154: 20.06√(273.15+(5/9)(F-32))}A
155: ret
156: "out1":
157: fmt 2,8f15.5
158: fmt 3,9x,"FREQ",12x,"dB/S",11x,"T60",11x,"ABS",11x,"CL # ±%",11x,"SE"
159: fmt 4,1x,c37,f2.0
160: fmt 6,1/
161: fmt 8,1x,c15,f2.0,c25
162: wrt 4.6
163: wrt 4.8,"AVERAGE RT for ",Z,"MICROPHONE POSITIONS"
164: wrt 4.6
165: wrt 4.4,"# of decays per microphone position :",R/Z
166: wrt 4.6
167: wrt 4.3
168: wrt 4.6
169: for I=1 to 19
170: wrt 4.2,F[I],X[I],B[I],G[I],S[I],A[I]
171: next I
172: wtb 4,10;wtb 4,10;wtb 4,10
173: sprt 1,F,H,V$,D$,S$,N$,G,B[*],S[*]
174: ret
*26256
```

C.2. Standard Sound Transmission Loss Measurement

```
0: dsp '***TRANSMISSION LOSS TEST***';wait 100
1: dim A[18],B[18],C[18],D[18],E[18],F[18],G[18],H[18],J[18],K[18],L[18]
2: dim N[18],P[18],Q[18],R[18],S[18],T[18],U[18],V[30,18],W[30,18]
3: dim X[18],Y[18],Z[18]
4: dim B$[318],C$[8],D$[80],M$[12],N$[6],G$[1],R$[1],S$[1],T$[2],W$[18]
5: files ABSDAT,*
6: sread 1,F,R,C$,D$,S$,N$,S,A[*],S[*]
7: dsp 'INITIALIZE MIC IN SOURCE ROOM';stp
8: 100}F[1];125}F[2];160}F[3];200}F[4];250}F[5];315}F[6];400}F[7]
9: 500}F[8];630}F[9];800}F[10];1000}F[11];1250}F[12];1600}F[13]
10: 2000}F[14];2500}F[15];3150}F[16];4000}F[17];5000}F[18]
11: buf 'in',B$,3
12: 30}N
13: wrt 717,'O8N7L M?';wait 1000
14: fxd 0
15: for L=1 to 3
16: if L#2;jmp 10
17: rem 7
18: dsp 'SWITCH MIC TO RECEIVING ROOM';stp
19: dsp 'RECALIBRATE';stp
20: dsp 'SET'
21: wrt 717,'N=';wait 500
22: cll 'SPL READ';wait 200
23: for J=1 to 18;L[J]}B[J];next J
24: wait 5000
25: gto 43
26: if L=3;dsp 'SP MEASUREMENT IN RECEIVING ROOM';wait 2000
27: if L=1;dsp 'SP MEASUREMENT IN SOURCE ROOM';wait 2000
28: wrt 717,'O8N7L M?';wait 2000
29: dsp 'SET'
30: if L=3;lcl 7;wrt 717,'N=';wait 500;gto 32
31: if L=1;lcl 7;wrt 717,'N!';wait 500
32: for H=1 to N
33: lcl 7;wait 4000
34: cll 'SPL READ';wait 100
35: if L=1;gto 40
36: for J=1 to 18
37: if R[J]-B[J]>10;gto 39
38: cll 'BAGR'
39: next J
40: if L=3;for J=1 to 18;R[J]}V[H,J];next J
41: if L=1;for J=1 to 18;S[J]}W[H,J];next J
42: next H
43: next L
44: rem 7
45: dsp 'STATISTICAL CALCULATION'
46: for H=1 to N
47: if H=1;for J=1 to 18;0}C[J]}E[J]}G[J]}D[J]}Q[J];next J
48: for J=1 to 18
49: W[H,J]-V[H,J]}N[J];N[J]^2}T[J]
50: if A[J]=0;0}S[J];gto 52
51: N[J]+10log(S/A[J])}S[J]
52: next J
53: flt 4
54: for J=1 to 18
55: C[J]+tn^(V[H,J]/20)}C[J]
56: E[J]+tn^(W[H,J]/20)}E[J]
57: G[J]+N[J]}G[J]
58: D[J]+S[J]}D[J]
59: Q[J]+T[J]}Q[J]
60: next J
61: next H
62: for J=1 to 18
63: 20log(C[J]/N)}C[J];20log(E[J]/N)}E[J]
```

```
64: G[J]/N}G[J];D[J]/N}D[J]
65: next J
66: for H=1 to N
67: if H=1;for J=1 to 18;0}X[J]}Y[J];next J
68: for J=1 to 18
69: X[J]+tn^(V[H,J]/10)}X[J]
70: Y[J]+tn^(W[H,J]/10)}Y[J]
71: next J
72: next H
73: for J=1 to 18
74: if X[J]-N*tn^(C[J]/10)<0;0}X[J];gto 81
75: if Y[J]-N*tn^(E[J]/10)<0;0}Y[J];gto 81
76: \((X[J]-N*tn^(C[J]/10))/(N-1))}X[J]
77: \((Y[J]-N*tn^(E[J]/10))/(N-1))}Y[J]
78: 20log(1+X[J]/tn^(C[J]/20))}X[J]
79: 20log(1+Y[J]/tn^(E[J]/20))}Y[J]
80: \((Q[J]-N*G[J]^2)/(N-1))}U[J]
81: next J
82: cll 'ConfLim'
83: for J=1 to 13
84: H[J]/C[J]*100}K[J];J[J]/E[J]*100}P[J]
85: L[J]/G[J]*100}Z[J]
86: next J
87: cll '2PRINT'
88: open N$,47
89: asgn N$,2,0,X
90: fmt 1,"FILENAME :",c6
91: sprt 2,F,R,D$,S$,S,A[*],G[*],V[*],W[*],C$
92: wrt 4.1,N$
93: dsp N$
94: end
95: "SET":
96: for I=53 to 63;116-I}I;"N"}T$[1,1];char(I)}T$[2,2]
97: wrt 717,T$;wait 2000;"O"}R$;wrt 717,R$;wait 2000
98: red 717,R$;wait 500
99: if num(R$)=62;gto 101
100: 116-I}I;next I
101: ret
102: "SPL READ":
103: dsp "BACKGROUND"
104: if L=3;dsp "RECEIVING ROOM -  TEST#",H
105: if L=1;dsp "SOURCE ROOM - TEST #",H
106: wrt 717,"M?O=L?M>";wait 200
107: wrt 717,"M=";"M"}Q$
108: wrt 717,Q$;wait 500;red 717,Q$
109: if Q$=",";jmp 2
110: jmp -3
111: wrt 717,"E?";wait 200
112: buf "in"
113: tfr 716,"in",302
114: jmp rds("in")#-1
115: wrt 717,"E=";wait 200
116: for J=1 to 18;val(R$[127+7J}K,K+6])}L[J]
117: if L=3;L[J]}R[J];gto 119
118: if L=1;L[J]}S[J]
119: next J
120: ret
121: "BAGR":
122: if R[J]<=B[J]+5;dsp "ERROR : LP(r)<=BG+5";stp
123: if R[J]>=B[J];B[J]}R[J];jmp 2
124: 10log(tn^(R[J]/10)-tn^(B[J]/10))}R[J]
125: ret
126: "ConfLim":
127: 1.96/\N}D
128: for J=1 to 18
129: if X[J]=0;gto 131
130: D*X[J]}H[J]
```

```
131: if Y[J]=0;gto 133
132: D*Y[J]}J[J]
133: D*U[J]}L[J]
134: next J
135: ret
136: "2PRINT":
137: fmt 4,1/
138: fmt 1,c80
139: fmt 2,4x,c5,2x,c8
140: fmt 3,4x,c5,f4.1,c2
141: fmt 5,4x,c16,f2.0
142: fmt 6,4x,c3,2x,f4.1
143: fmt 7,5x,c4,7x,c2,7x,c2,9x,c2,8x,c2,8x,c3,7x,c3,7x,c2,7x,c3,7x,c3,7x,c3
144: fmt 8,5x,c4,6x,c4,5x,c4,27x,c4,25x,c4,26x,c4
145: fmt 9,12f10.4
146: wrt 4.4
147: wrt 4.1,D$
148: wrt 4.4
149: wrt 4.2,"DATE:",C$
150: wrt 4.4
151: wrt 4.3,"TEMP:",F," F"
152: wrt 4.3,"RH  :",R," %"
153: wrt 4.4
154: wrt 4.5,"repetition rate:",N
155: wrt 4.4
156: wrt 4.7,"FREQ","TL","NR","SD","%E","LPs","SDs","%E","LPr","SDr"," %E"
157: wrt 4.8,"(Hz)","(dB)","(dB)","(dB)","(dB)"," BG "
158: wrt 4.4
159: fxd 4
160: for J=1 to 18
161: wrt 4.9,F[J],D[J],G[J],U[J],Z[J],E[J],Y[J],P[J],C[J],X[J],K[J],B[J]
162: next J
163: wrt 4.4
164: wrt 4.4
165: fmt 0,4x,"FINAL STORAGE FILENAME:",2x,c6
166: wrt 4,N$
167: ret
*16142
```

C.3. Plotting of Sound Transmission Loss Spectra (Maximum 3)

```
0: dsp '***PLOT OF TL CURVES***';wait 1000
1: dsp 'adjust TITLE & LEGEND';wait 2000
2: dsp 'LINE # 103-104 & 115-116';stp
3: dim A[18],B[18],C[18],D[18],E[18],F[18],G[18]
4: dim H[18],I[18],J[18],K[18],L[18],S[3,18],T[18]
5: dim A$[4],B$[4],C$[3,50],D$[80],E$[4]
6: dim F$[6],G$[80],H$[1],L$[6],M$[6],N$[6],S$[1],O$[80]
7: 100→F[1];125→F[2];160→F[3];200→F[4];250→F[5];315→F[6]
8: 400→F[7];500→F[8];630→F[9];800→F[10];1000→F[11];1250→F[12]
9: 1600→F[13];2000→F[14];2500→F[15];3150→F[16];4000→F[17];5000→F[18]
10: files *
11: ent 'enter # of CURVES(max 3&1 P)',C
12: dsp 'ENTER FN OF P MEASUREMENT FIRST';wait 3000
13: ent 'enter FINAL STORAGE FN',N$;asgn N$,1,0,X
14: N$[1,1]→H$;if H$≠"P";jmp 5
15: sread 1,F,R,D$,S$,S,A[*],G[*];prt D$
16: ent 'enter REFERENCE PANEL FN',F$;asgn F$,4,0,X
17: sread 4,F,R,D$,S$,D,K[*],L[*]
18: jmp 2
19: sread 1,D$,G$,I[*],A[*],G[*]
20: D$&G$→D$;prt D$
21: if C=1;jmp 8
22: ent 'enter FINAL STORAGE FN',M$;asgn M$,2,0,X
23: sread 2,D$,G$,J[*],B[*],H[*]
24: D$&G$→D$;prt D$
25: if C=2;jmp 4
26: ent 'enter FINAL STORAGE FN',L$;asgn L$,3,0,X
27: sread 3,D$,G$,T[*],C[*],D[*]
28: D$&G$→D$;prt D$
29: if H$≠"P";jmp 9
30: for I=1 to 18
31: L[I]+10log(D/K[I])→L[I]
32: G[I]+10log(D/A[I])→G[I]
33: next I
34: for J=1 to 18
35: if G[J]>L[J];0→G[J]
36: 10log(1/(D/S*10^(-G[J]/10)-((D-S)/S)10^(-L[J]/10)))→G[J]
37: next J
38: for I=1 to 18
39: if C=1;G[I]→S[1,I]
40: if C=2;G[I]→S[1,I];H[I]→S[2,I]
41: if C=3;G[I]→S[1,I];H[I]→S[2,I];D[I]→S[3,I]
42: next I
43: cll 'pss'(11,11,5.5,5.5)
44: cll 'yaxis'(0,45,5,10,5);wait 500
45: cll 'xaxis'(0,21,1)
46: 0→r2;wait 50
47: '.125'→A$;'.250'→B$;'.500'→E$
48: for G=1 to 3
49: fmt 1,c4
50: r2+3→r2
51: cll 'lablxx'(-2,2,r2)
52: next G
53: 9→r1
54: for J=11 to 19 by 3
55: fmt 1,f5.0,z
56: F[J]/1000→I
57: r1+3→r1
58: cll 'lablx'(-4,2,r1)
59: next J
60: wrt 70417,2,2
61: wrt 70421,A,B
62: cll 'space'(10);cll 'skip'(5);wrt 70412,'FREQUENCY (kHz)'
63: for I=1 to C
```

```
64: for J=1 to 18
65: if J=1;wrt 70421,A+(J+1)*U}r1,B-10+S[I,J]*V}r2;gto 72
66: if I=1 and S[1,J]=0;gto 75
67: if I=1;wrt 70420,A+(J+1)*U}r1,B-10+S[1,J]*V}r2;gto 72
68: if I=2 and S[2,J]=0;gto 75
69: if I=2;wrt 70420,A+(J+1)*U}r1,B-10+S[2,J]*V}r2;gto 72
70: if I=3 and S[3,J]=0;gto 75
71: if I=3;wrt 70420,A+(J+1)*U}r1,B-10+S[3,J]*V}r2;gto 72
72: if I=1;cll 'square'(r1,r2)
73: if I=2;cll 'tri'(r1,r2)
74: if I=3;cll 'dim'(r1,r2)
75: next J
76: next I
77: wait 3000
78: wrt 70421,A,B
79: wrt 70425,90
80: for I=1 to 5;wtb 70412,11;next I
81: wrt 70412,"TRANSMISSION LOSS (dB)"
82: wrt 70407
83: wrt 70421,A-65+(3-C),B+45
84: wrt 70417,1.7,2.2
85: wrt 70412,"TRANSMISSION LOSS (dB)"
86: wrt 70421,A-70}X,B+40}Y
87: if C=1;cll 'one'
88: if C=2;cll 'two'
89: if C=3;cll 'three'
90: wrt 70421,A-63,B+36
91: fmt 1,f10.0,f13.1,z
92: fmt 2,f7.0,f11.1,f7.1
93: fmt 3,f6.0,f8.1,f6.1,f6.1,z
94: for J=1 to 18
95: wrt 70421,X,Y-2J
96: if C=1;wrt 70412.1,F[J],S[1,J]
97: if C=2;wrt 70412.2,F[J],S[1,J],S[2,J]
98: if C=3;wrt 70412.3,F[J],S[1,J],S[2,J],S[3,J]
99: next J
100: wrt 70421,A-70}X,B-18}Y
101: wrt 70421,X+7,Y+2;wrt 70412,"LEGEND"
102: for I=1 to C
103: if I=1;"SPECTRUM #1"}C$[1];jmp 3
104: if I=2;"SPECTRUM #2"}C$[2];jmp 2
105: if I=3;"SPECTRUM #3"}C$[3]
106: next I
107: for I=1 to C;len(C$[I])}E[I];next I
108: max(E[*])}Q
109: wrt 70421,X,Y
110: wrt 70420,X+18+1.7Q,Y;wrt 70420,X+18+1.7Q,Y-3C-3
111: wrt 70420,X,Y-3C-3;wrt 70420,X,Y
112: if C=1;cll 'd1'
113: if C=2;cll 'd2'
114: if C=3;cll 'd3'
115: "COMPARISON PLOTS"}D$
116: "      "}G$
117: "       "}O$
118: wrt 70407
119: wrt 70421,A-35,B-40
120: wrt 70412,D$
121: wrt 70421,A-35,B-43
122: wrt 70412,G$
123: wrt 70421,A-35,B-46
124: wrt 70412,O$
125: end
126: "pgs":
127: (p3/p1)150}A;(p4/p2)100}B
128: ret
129: "xaxis":
130: (150-A)/(p2-p1)}U
```

```
wrt 70421,p1U+A,B;wrt 70420,150,B
A→p9
wrt 70421,p9,B;wrt 70420,p9,B-1
p9+p3U→p9
if p9<p2U+A;gto -2
if p1=0;gto +6
A-p3→p9
if p9<p1U+A;gto +4
wrt 70421,p9,B;wrt 70420,p9,B-1
p9-p3U→p9
if p9>=p1U+A;gto -2
wrt 70421,A,B
3→p3
A→p9
p9+p3U→p9
wrt 70421,p9,B;wrt 70420,p9,B-2
if p9<p2U+A;gto -2
ret
"yaxis":
fmt 1,f2.0,z
p4→H
(100-B)/(p2-p1)→V;p2V+B→Z
wrt 70421,A,p1V+B;wrt 70420,A,100
B→p9
wrt 70421,A,p9;wrt 70420,A+1,p9
for Y=1 to 4
wtb 70412.1,8;next Y
wrt 70412.1,H
p9+p3V→p9
if p9<Z;H+p5→H;gto -5
if p1=0;gto +5
B-p3V→p9
wrt 70421,A,p9;wrt 70420,A+1,p9
p9-p3V→p9
if p9>=p1V+B;gto -2
wrt 70421,A,B
ret
"lablx":
wrt 70421,A+p3U,B
cll 'space'(p1);cll 'skip'(p2)
wrt 70412.1,I
ret
"lablxx":
wrt 70421,A+p3U,B
cll 'space'(p1);cll 'skip'(p2)
if G=1;wrt 70412.1,A$
if G=2;wrt 70412.1,B$
if G=3;wrt 70412.1,E$
ret
"space":
if p1<=0;gto +2
wtb 70412,32;jmp 2((p1-1→p1)=0)
wtb 70412,8;jmp (p1+1→p1)=0
ret
"skip":
if p1<0;gto +2
wtb 70412,10;jmp 2((p1-1→p1)=0)
wtb 70412,27,10;jmp (p1+1→p1)=0
ret
"square":
wrt 70421,p1-.45,p2+.45
wrt 70420,p1-.45,p2-.45;wrt 70420,p1+.45,p2-.45
wrt 70420,p1+.45,p2+.45;wrt 70420,p1-.45,p2+.45
wrt 70421,p1,p2
ret
"tri":
wrt 70421,p1,p2+.45
```

```
198: wrt 70420,p1-.47,p2-.4;wrt 70420,p1+.47,p2-.4
199: wrt 70420,p1,p2+.45
200: wrt 70421,p1,p2
201: ret
202: "dim":
203: wrt 70421,p1,p2+.45
204: wrt 70420,p1-.45,p2;wrt 70420,p1,p2-.45
205: wrt 70420,p1+.45,p2;wrt 70420,p1,p2+.45
206: wrt 70421,p1,p2
207: ret
208: "d1":
209: wrt 70421,X+3}r1,Y-3}r2
210: cll 'square'(r1,r2);wrt 70420,r1+10}r1,r2
211: cll 'square'(r1,r2)
212: wrt 70421,r1+3,r2;wrt 70412,C$[1]
213: ret
214: "d2":
215: cll 'd1'
216: X+3}r1;Y-6}r2
217: cll 'tri'(r1,r2);wrt 70420,r1+10}r1,r2;cll 'tri'(r1,r2)
218: wrt 70421,r1+3,r2;wrt 70412,C$[2]
219: ret
220: "d3":
221: cll 'd2'
222: X+3}r1;Y-9}r2
223: cll 'dim'(r1,r2);wrt 70420,r1+10}r1,r2;cll 'dim'(r1,r2)
224: wrt 70421,r1+3,r2;wrt 70412,C$[3]
225: ret
226: "one":
227: wrt 70421,X+7,Y;wrt 70412,"FREQ.(Hz)"
228: cll 'square'(X+36.5,Y+1)
229: ret
230: "two":
231: wrt 70421,X+3,Y;wrt 70412,"FREQ.(Hz)"
232: cll 'square'(X+28,Y+1)
233: cll 'tri'(X+39.5,Y+1)
234: ret
235: "three":
236: wrt 70421,X+1,Y;wrt 70412,"FREQ.(Hz)"
237: cll 'square'(X+21,Y+1)
238: cll 'tri'(X+31,Y+1)
239: cll 'dim'(X+41,Y+1)
240: ret
*11086
```

C.4. Sound Transmission Loss Measurements by the Intensity Technique

Storage of the Incident and Transmitted Intensity on Disk

```
0: dsp '***INTENSITY MEASUREMENTS***';wait 1000
1: dsp "INPUT OF DATA TO DISK-FILE";wait 1000
2: dim A$[147],B$[318],C$[1],D$[8],E$[8],F$[6],G$[6],H$[1],I$[1],M$[3],O$[1]
3: dim R$[1],S$[2],T$[2],U$[40],V$[40],W$[2]
4: dim B[18],C[18],H[18],K[18],L[18],R[18],X[18],V[30,13]
5: files *
6: buf 'in',B$,3
7: "GEN. INPUT":
8: ent 'enter DATE (DD/MM/YY)',D$
9: ent 'enter TEMPERATURE (F)',T;ent 'enter PRESSURE (mbar)',P
10: ent 'enter 1st LINE OF TITLE (40char)',U$
11: ent 'enter 2nd LINE OF TITLE (40char)',V$
12: "P MEASUREMENTS":
13: dsp "*SOUND PRESSURE MEASUREMENTS*";wait 1000
14: dsp 'CALBRATE & INITIALIZE ROT. MIC';stp
15: 30}N
16: wrt 717,"D8N?L>M?";wait 1000
17: dsp "SET"
18: wrt 717,"N=";wait 500
19: cll 'SPL READ';wait 200
20: for J=1 to 18;L[J]}B[J];next J
21: lcl 7;wait 10000
22: 1}L
23: wrt 717,"D8N?L>M?";wait 1000
24: dsp "SET"
25: wrt 717,"N:";wait 500
26: for H=1 to N
27: cll 'SPL READ';wait 100
28: for J=1 to 18
29: if R[J]-B[J]<10;jmp 2
30: cll 'BAGR'
31: next J
32: for J=1 to 18;R[J]}V[H,J];next J
33: next H
34: dsp "STATISTICAL CALCULATION"
35: for H=1 to N
36: if H=1;for J=1 to 18;0}C[J];next J
37: flt 4
38: for J=1 to 18
39: C[J]+tn^(V[H,J]/20)}C[J]
40: next J
41: next H
42: for J=1 to 18
43: 20log(C[J]/N)}C[J]
44: if C[J]<B[J];0}C[J]
45: next J
46: for H=1 to N
47: if H=1;for J=1 to 18;0}X[J];next J
48: for J=1 to 18
49: X[J]+tn^(V[H,J]/10)}X[J]
50: next J
51: next H
52: for J=1 to 18
53: if X[J]-N*10^(C[J]/10)<0;0}X[J];jmp 3
54: \((X[J]-N*tn^(C[J]/10))/(N-1))}X[J]
55: 20log(1+X[J]/tn^(C[J]/20))}X[J]
56: next J
57: cll 'CONFLIM'
58: for J=1 to 18
59: if C[J]=0;0}K[J];jmp 2
60: H[J]/C[J]*100}K[J]
61: next J
62: "I INPUT":
63: dsp "CALIBRATE & INITIALIZE PROBE";stp
```

```
ent 'enter MICROPHONE TYPE (ih)',M$
ent 'enter SPACER IN mm FOR PROBE',S$
dsp 'SET COMMANDS for MIC TYPE&SPACER';stp
dsp 'SET INPUT ATTENUATION';stp
ent 'enter TEST AREA DIMENSIONS',A,B
ent 'enter # of COLUMNS (max 25)',C
ent 'enter # of ROWS (max 25)',R
ent 'enter FN FOR STORAGE OF GEN DATA',F$
ent 'enter FN FOR STORAGE OF I DATA',G$
open F$,1
assn F$,1,0,X
open G$,int(R*C*331/(256*3))+4
assn G$,2,0,X
'N'}H$
wrt 717,H$;wait 100;red 717,H$
sprt 1,U$,V$,D$,T,P,M$,S$,C,R,H$,N,A,B
sprt 2,C[*],X[*],K[*]
'I MEASUREMENTS':
wrt 717,'C=L?M?O;';wait 1000
dsp 'MEASUREMENTS';wait 2000
dsp 'START IN LOWER LEFT CORNER';wait 3000
dsp 'MEASURE S.I. ROW PER ROW';wait 3000
fxd 0
rprt 2,3
for I=1 to R
for J=1 to C
dsp 'SPECTRUM #;R=',I,';C=',J;wait 100
cll 'Data'
next J
next I
dsp 'FINISHED'
end
'SET':
for I=53 to 63;116-I}I;'N'}T$[1,1];char(I)}T$[2,2]
wrt 717,T$;wait 2000;'@'}R$;wrt 717,R$;wait 2000
red 717,R$;wait 500
if num(R$)=62;jmp 2
116-I}I;next I
ret
'SPL READ':
dsp 'BACKGROUND'
if L=1;dsp 'ROOM A - TEST #',H
wrt 717,'M?O=L?M';wait 200
wrt 717,'M=';'M'}Q$
wrt 717,Q$;wait 500;red 717,Q$
if Q$='>';jmp 2
jmp -3
wrt 717,'E?';wait 200
buf 'in'
tfr 716,'in',302
jmp rds('in')#-1
wrt 717,'E=';wait 200
for J=1 to 18;val(B$[127+7J}K,K+6])}L[J]
L[J]}R[J]
next J
ret
'BAGR':
if R[J]<=B[J];B[J]}R[J];jmp 2
10log(tn^(R[J]/10)-tn^(B[J]/10))}R[J]
ret
'CONFLIM':
1.96/\N}D
for J=1 to 18
if C[J]=0;jmp 2
D*X[J]}H[J]
next J
ret
```

```
131: "Data":
132: wrt 717,"L?";wait 100
133: wrt 717,"M?E=0;M>";wait 200
134: "E"→C$
135: wrt 717,C$;wait 100;red 717,C$
136: if C$="?";wait 100;jmp 2
137: jmp -2
138: buf "in"
139: tfr 716,"in",302
140: jmp rds("in")#-1
141: wrt 717,"E=M?";wait 100
142: B$[134,280]→A$[1,147]
143: for K=1 to 18
144: A$[7K-6,7K]→E$[1,7]
145: if E$[4,4]="<";"000.0"→E$[1,5];jmp 2
146: if E$[4,4]="*";"-"&E$[1,3]&"."&E$[5,7]→E$[1,8]
147: val(E$[1,8])→W
148: W*10→W
149: fti (W)→W$
150: if I=R and J=C;sprt 2,W$;jmp 2
151: sprt 2,W$,"ens"
152: next K
153: ret
*29652
```

C.5: Numerical Output of the Intensity Measurements. Calculation of the Sound Transmission Loss

```
0: dsp "NUMERICAL DATA OUTPUT ON PRINTER";wait 1000
1: dim C[18],F[18],K[18],L[18],P[25,25],T[18],X[18]
2: dim D$[8],F$[6],G$[6],I$[1],H$[1],M$[3],S$[2]
3: dim U$[40],V$[40],W$[2],Z$[6]
4: files *
5: "INPUT":
6: ent "enter FN OF STORED GENERAL DATA",F$
7: assn F$,1,0,X
8: sread 1,U$,V$,D$,T,P,M$,S$,C,R,H$,N
9: on end 1,10
10: dsp U$;wait 2000
11: dsp V$;wait 2000
12: ent "enter FN OF STORED I DATA",G$
13: assn G$,2,0,X
14: ent "enter FN OF FINAL STORAGE FILE",Z$
15: open Z$,3
16: assn Z$,3,0,X
17: 100}F[1];125}F[2];160}F[3];200}F[4];250}F[5];315}F[6]
18: 400}F[7];500}F[8];630}F[9];800}F[10];1000}F[11];1250}F[12]
19: 1600}F[13];2000}F[14];2500}F[15];3150}F[16];4000}F[17];5000}F[18]
20: "OUTPUT OF P DATA":
21: sread 2,C[*],X[*],K[*]
22: fmt 1,1x,c25,15x,c5,2x,c8
23: fmt 2,1x,c40," - ",c40
24: fmt 3,1x,c20,2x,f4.0
25: fmt 4,5x,c4,10x,c2,10x,c3,9x,c3
26: fmt 5,5x,c4,9x,c4,9x,c4
27: fmt 6,5x,f4.0,9x,f4.1,8x,f6.4,6x,f6.4
28: fmt 7,4/
29: fmt 8,"FILENAMES:",1x,c6," / ",c6," (1-2)"
30: wrt 4.7
31: wrt 4.1,"SOUND PRESSURE IN ROOM A","DATE:",D$
32: wrt 4.1,"------------------------"
33: wtb 4,10
34: wrt 4.2,U$,V$
35: wtb 4,10
36: wrt 4.3,"repetition rate =",N
37: wrt 4.7
38: wrt 4.4,"FREQ","LP","SD","%E"
39: wrt 4.5,"(Hz)","(dB)","(dB)"
40: wtb 4,10
41: for I=1 to 18
42: wrt 4.6,F[I],C[I],X[I],K[I]
43: next I
44: wtb 4,10;wtb 4,10;wtb 4,10
45: wrt 4.8,F$,G$
46: "OUTPUT OF I DATA":
47: for N=1 to 18
48: wrt 4,char(12)
49: fxd 1
50: fmt 0,2x,c42,15x,c5,2x,c8
51: fmt 1,2x,c40,1x,c1,1x,c40
52: fmt 2,2x,"R/C",2x,"|",z
53: fmt 3,2x,c16,1x,f6.1,1x,c5,15x,c16,1x,f6.1,1x,c5
54: fmt 4,2x,c13,1x,f2.0,10x,c13,1x,f2.0
55: fmt 5,7x,"|",z
56: fmt 6,3x,f2.0,2x,"|",z
57: fmt 7,1x,f5.1,1x,"|",z
58: fmt 8,/
59: fmt 9,100"-"
60: wrt 4,"NUMERICAL OUTPUT OF INTENSITY MEASUREMENTS","DATE:",D$
61: wrt 4,"------------------------------------------"
62: wtb 4,10
63: wrt 4.1,U$,"-",V$;wtb 4,10
```

```
64: wtb 4,10
65: wrt 4.3,"TEMPERATURE    :",T,"F","PRESSURE      :",P,"mbar"
66: fmt 3,2x,c16,2x,f6.2,4x,c2,14x,c16,2x,f6.2,3x,c2
67: wrt 4.3,"MICROPHONE TYPE:",val(M$),"in","SPACER IN mm  :",val(S$),"mm"
68: wrt 4.4,"# of ROWS   :",R,"# of COLUMNS:",C
69: wtb 4,10;wtb 4,10
70: fmt 3,2x,c16,1x,f4.0,1x,c2
71: wrt 4.3,"FREQUENCY      :",F[N],"Hz"
72: wtb 4,10;wtb 4,10;wtb 4,10
73: rread 2,3
74: for I=1 to R
75: for J=1 to C
76: for F=1 to 18
77: sread 2,W$
78: if F#N;jmp 4
79: itf(W$)}W
80: W/10}W
81: W}P[I,J]
82: next F
83: next J
84: next I
85: for I=R to 1 by -1
86: wrt 4.6,I
87: for J=1 to C
88: wrt 4.7,P[I,J]
89: next J
90: wrt 4.8
91: wrt 4.9
92: next I
93: wrt 4.2
94: for J=1 to C
95: wrt 4.6,J
96: next J
97: wrt 4.8
98: wtb 4,10;wtb 4,10
99: fmt 8,2x,"FILENAMES:",1x,c6," / ",c6,"(3- )"
100: fmt 9,2x,"AVERAGE TRANSMITTED INTENSITY :",1x,f5.1,1x,"dB"
101: 0}L
102: for I=1 to R
103: for J=1 to C
104: L+10^(P[I,J]/10)}L
105: next J
106: next I
107: 10log(L)-10*log(C*R)}L[N]
108: wrt 4.9,L[N]
109: wtb 4,10
110: wrt 4.8,F$,G$
111: next N
112: "OUTPUT OF TL DATA":
113: 14.94*\(459.67+T)}V
114: P*100/(287.1*(273.15+5*(T-32)/9))}D
115: rread 2,1
116: for I=1 to 18
117: C[I]+26.0206-10log(4*V*D)-L[I]}T[I]
118: next I
119: sprt 3,U$,V$,C[*],L[*],T[*]
120: fmt 1,2x,c28,15x,c5,2x,c8
121: fmt 2,2x,c40," - ",c40
122: fmt 3,5x,c4,7x,c5,7x,c5,9x,c2
123: fmt 4,5x,c4,7x,c4,8x,c4,9x,c4
124: fmt 5,5x,f4.0,7x,f4.1,7x,f5.1,8x,f5.1
125: fmt 6,7/
126: fmt 7,"FILENAMES:",1x,c6," / ",c6," / ",c6
127: wrt 4,char(12)
128: wrt 4.6
129: wrt 4.1,"SOUND TRANSMISSION LOSS DATA","DATE:",D$
130: wrt 4," ----------------------------"
```

```
131: wtb 4,10;wtb 4,10
132: wrt 4.2,U$,V$
133: wtb 4,10;wtb 4,10;wtb 4,10
134: wrt 4.3,"FREQ","LP(i)","LI(t)","TL"
135: wrt 4.4,"(Hz)","(dB)","(dB)","(dB)"
136: wtb 4,10
137: for I=1 to 18
138: wrt 4.5,F[I],C[I],L[I],T[I]
139: next I
140: wtb 4,10;wtb 4,10;wtb 4,10
141: wrt 4.7,F$,G$,Z$
142: end
*21542
```

Appendix D

Third Octave Equal Intensity Contours Normal to the Surface

1.14m x 1.14m (45" x 45") Panel

12.7cm x 12.7cm (9x9) Mesh

Measurement Distance : 5 cm

t_{av} : 8 sec

(the Numerical Values on the Figures represent the Measured Transmitted Intensity in dB)

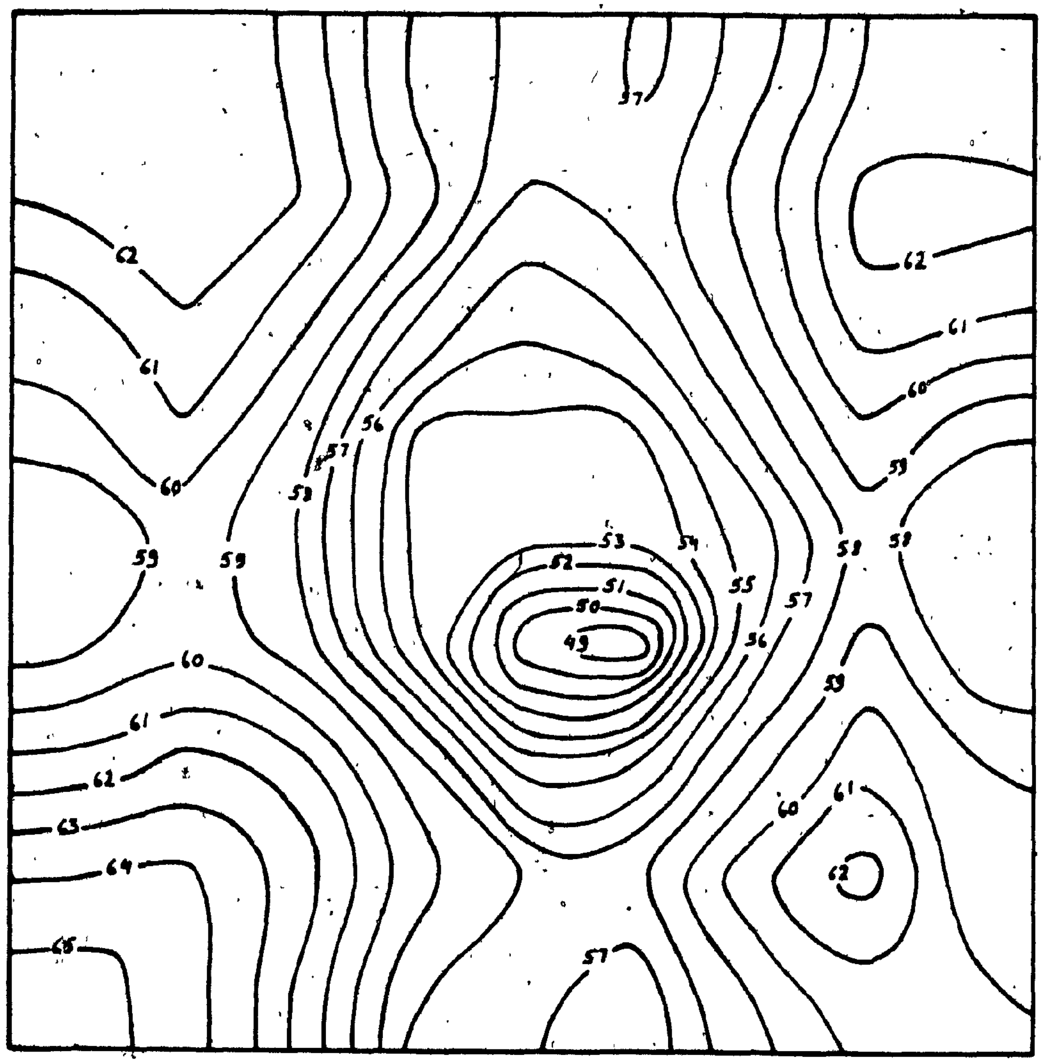

Fig. D.1: Intensity Contours Normal to the Surface at 250 Hz
1.14m x 1.14m (45" x 45") Panel

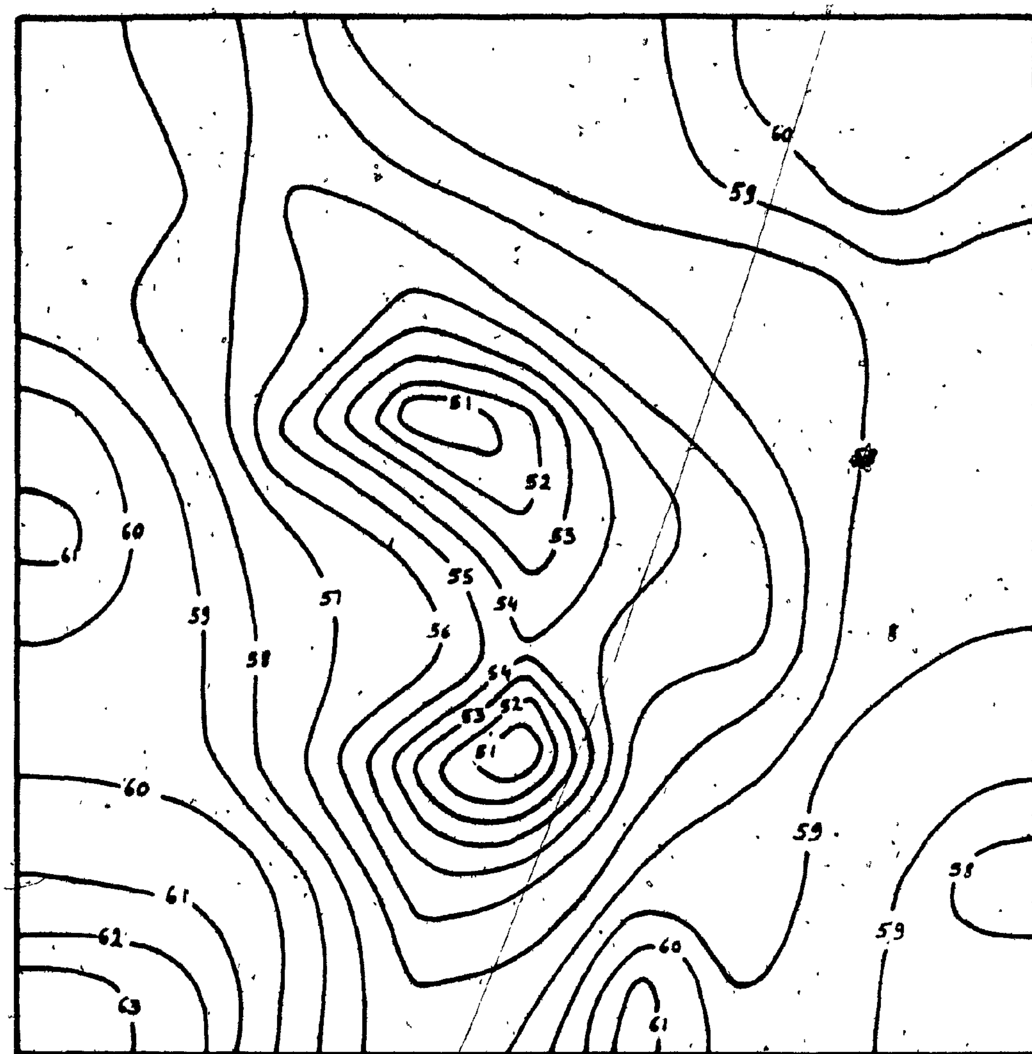

Fig. D.2: Intensity Contours Normal to the Surface at 315 Hz
1.14m x 1.14m (45" x 45") Panel

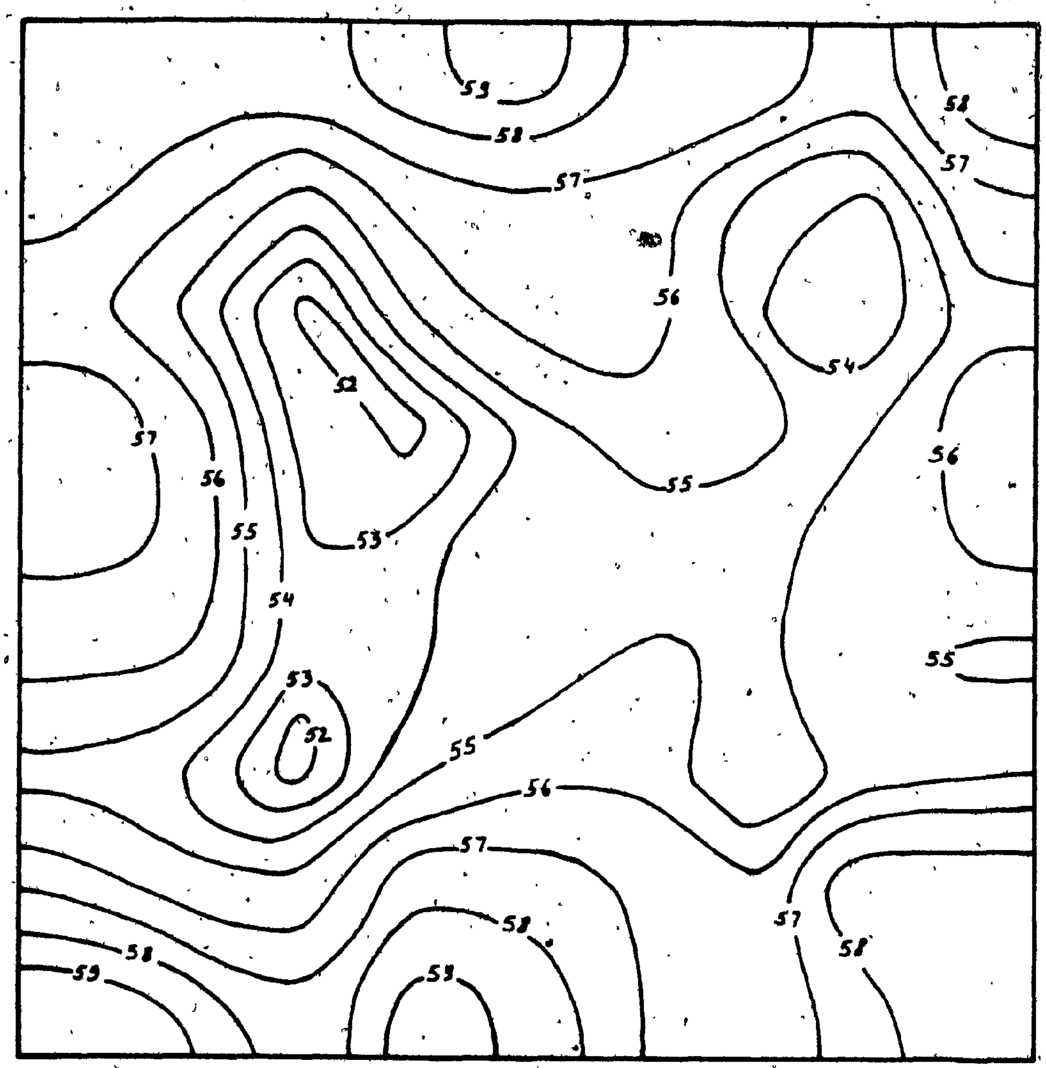

Fig. D.3: Intensity Contours Normal to the Surface at 400 Hz
1.14m x 1.14m (45" x 45") Panel

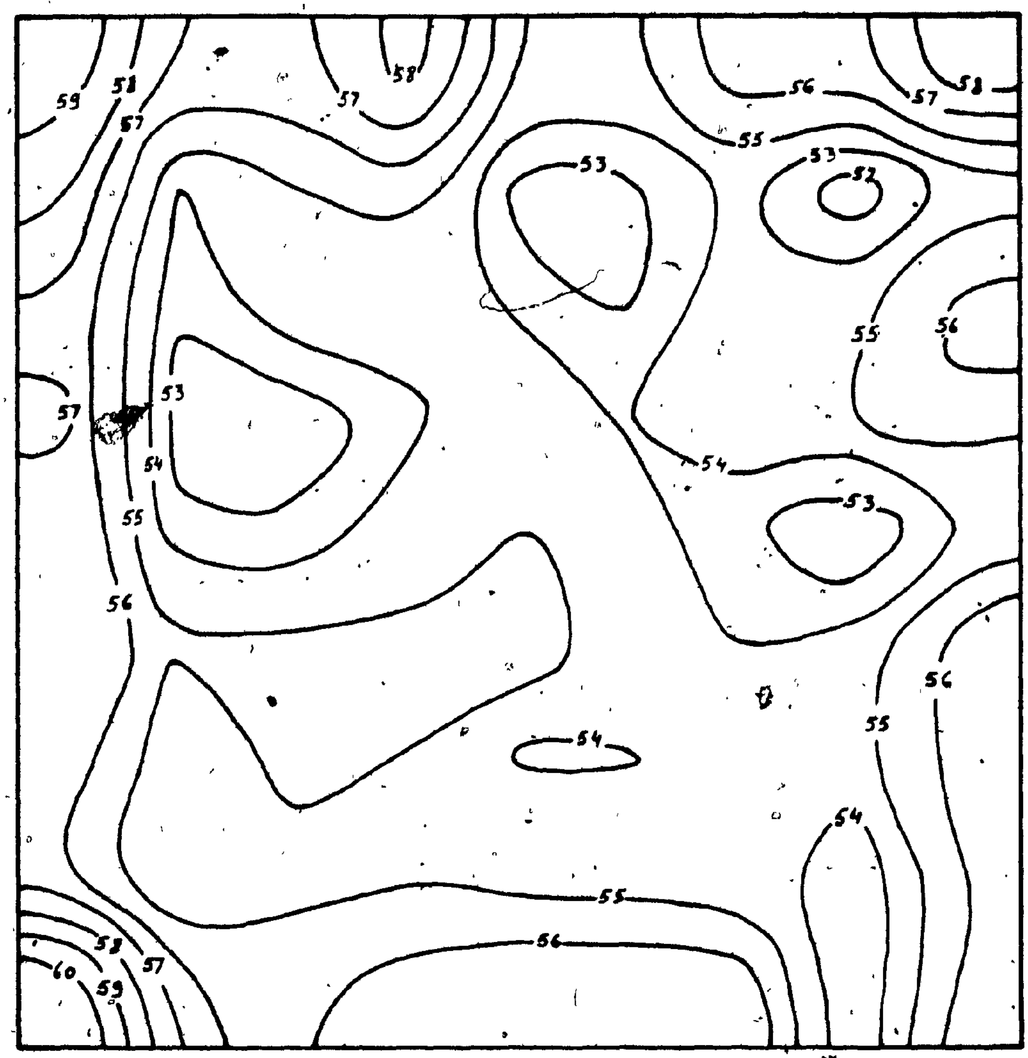

Fig. D.4: Intensity Contours Normal to the Surface at 500 Hz
1.14m x 1.14m (45" x 45") Panel.

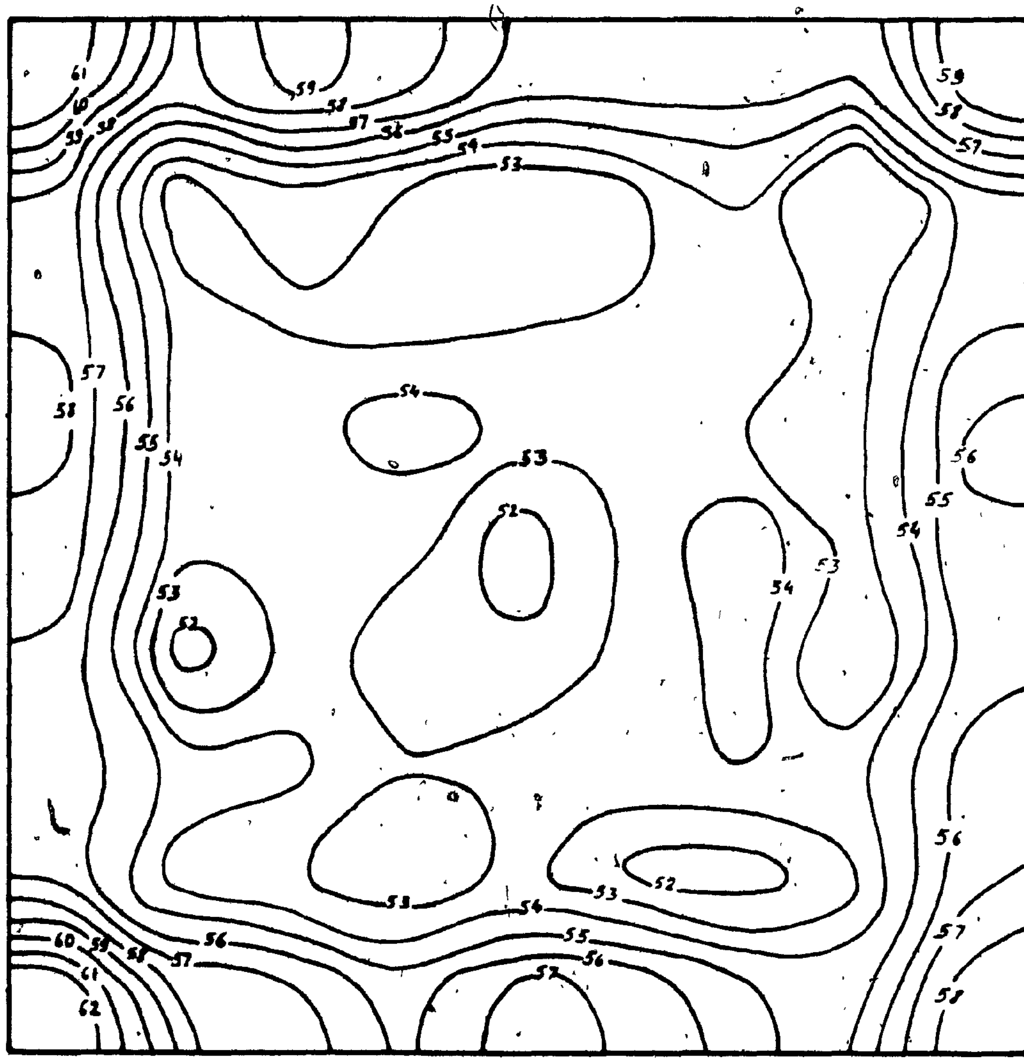

Fig. D.5 : Intensity Contours Normal to the Surface at 630 Hz
1.14m x 1.14m (45" x 45") Panel

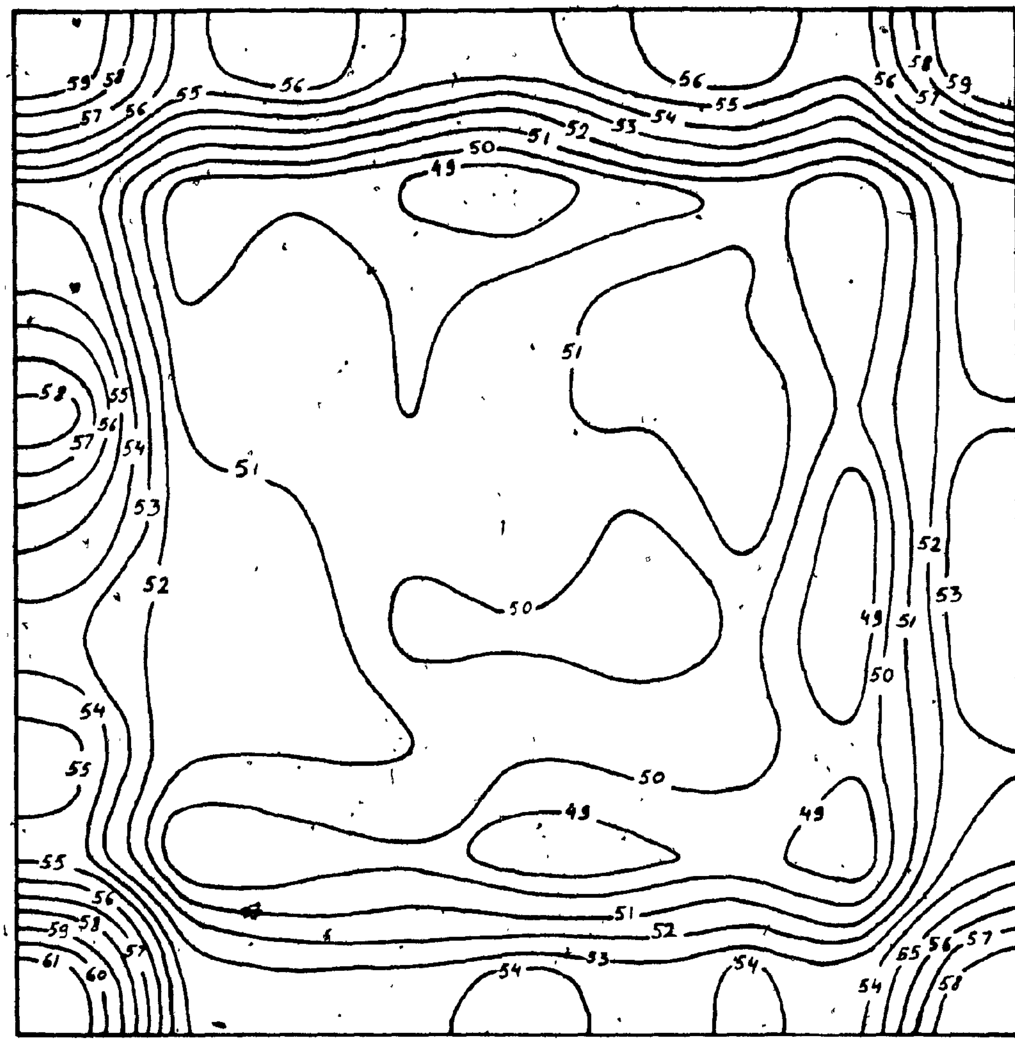

Fig. D.6: Intensity Contours Normal to the Surface at 800 Hz
1.14m x 1.14m (45" x 45") Panel

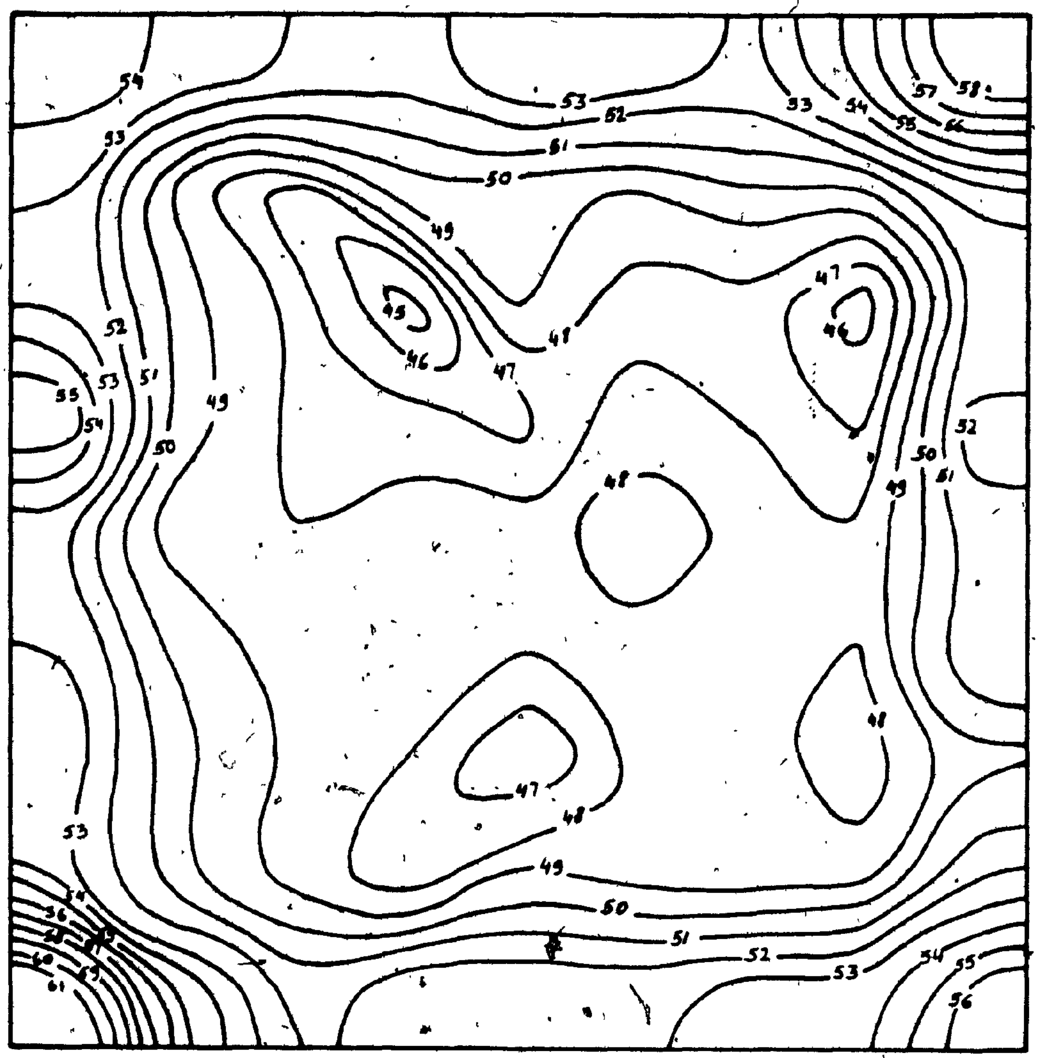

Fig. D.7: Intensity Contours Normal to the Surface at 1000 Hz
1.14m x 1.14m (45" x 45") Panel

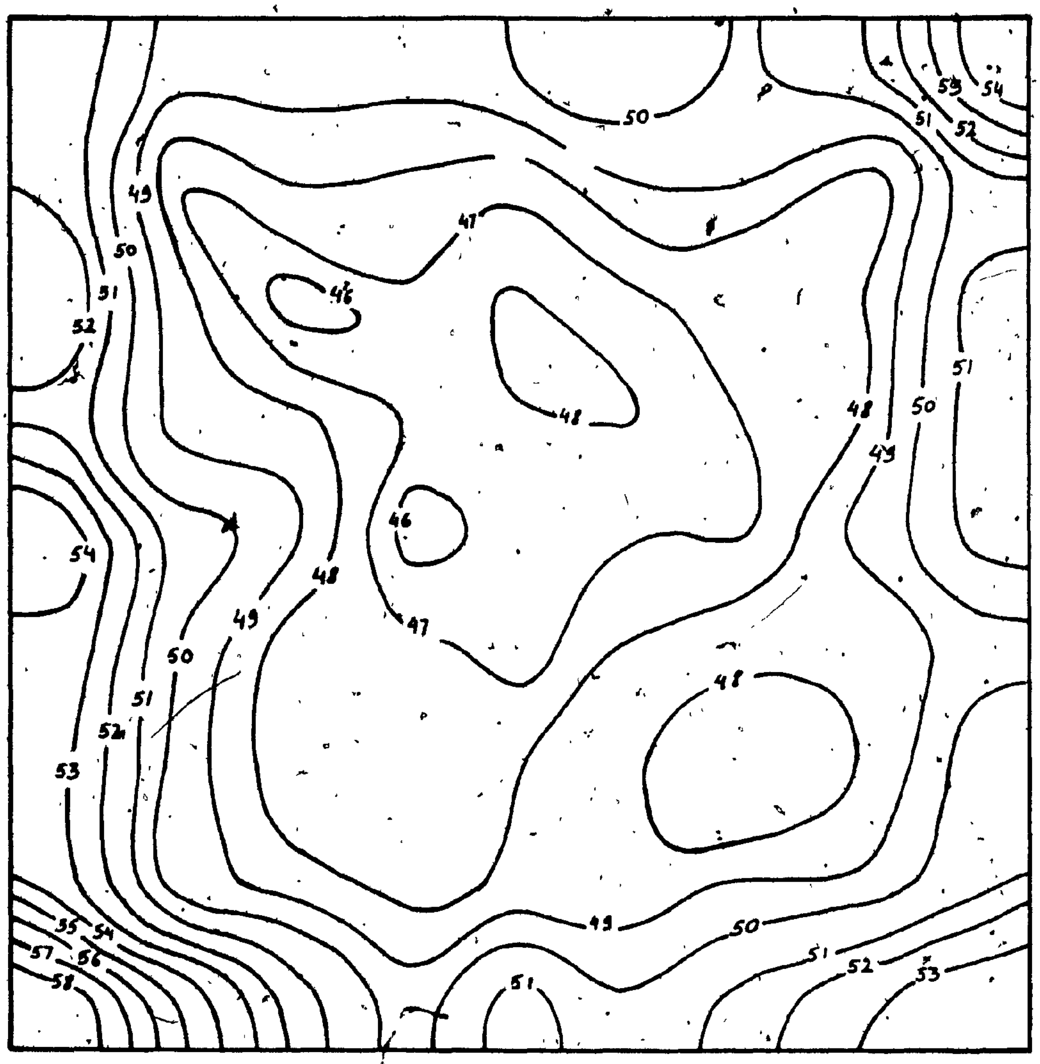

Fig. D.8: Intensity Contours Normal to the Surface at 1250 Hz
1.14m x 1.14m (45" x 45") Panel

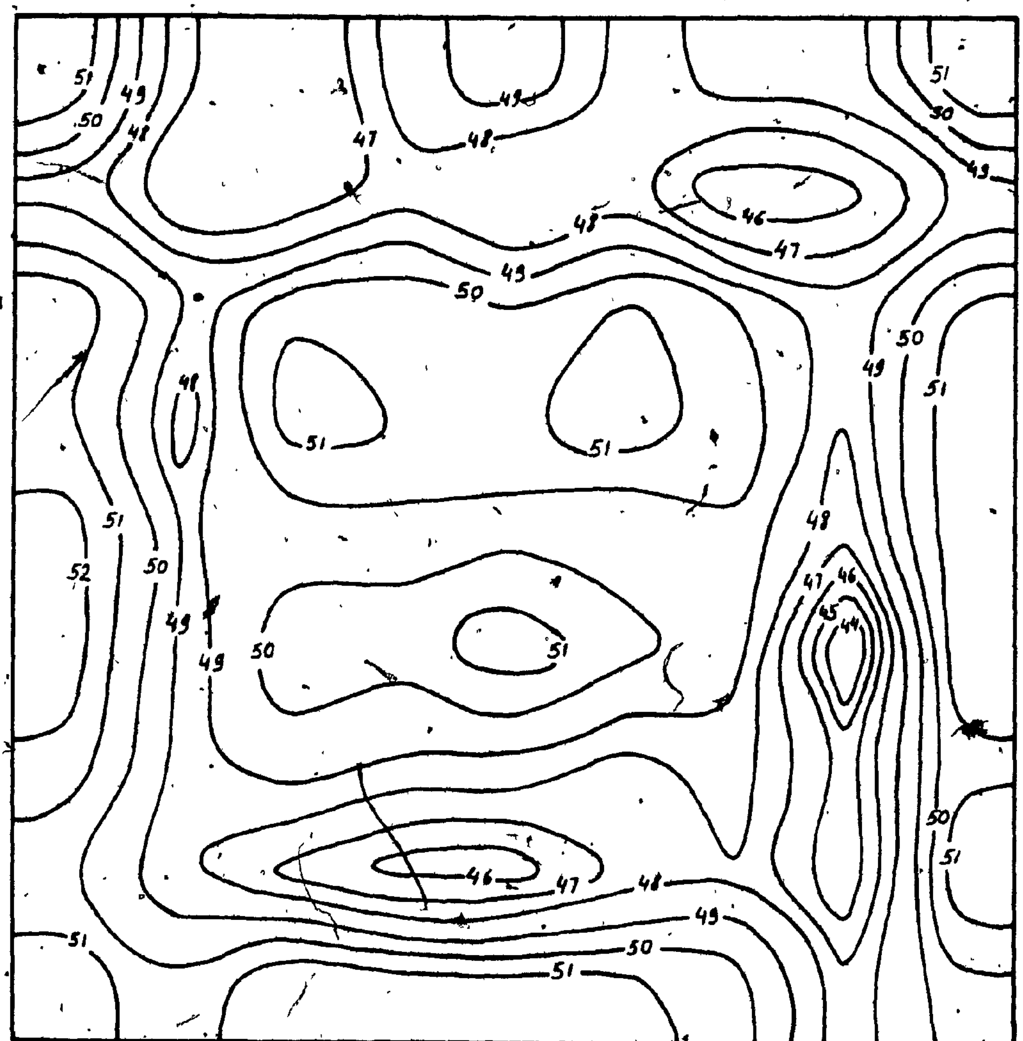

Fig. D.9: Intensity Contours Normal to the Surface at 1600 Hz
1.14m x 1.14m (45" x 45") Panel

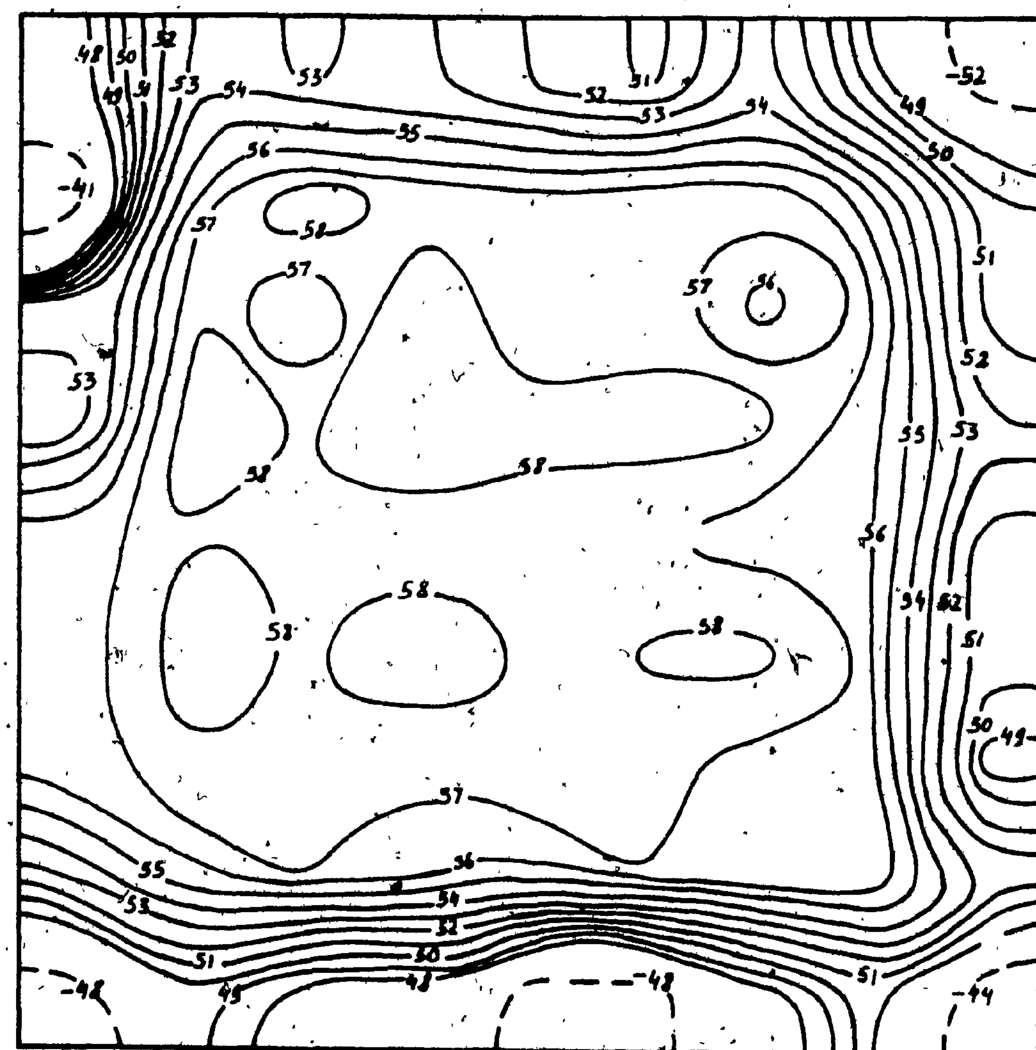

Fig. D.10: Intensity Contours Normal to the Surface at 2000 Hz
1.14m x 1.14m (45" x 45") Panel

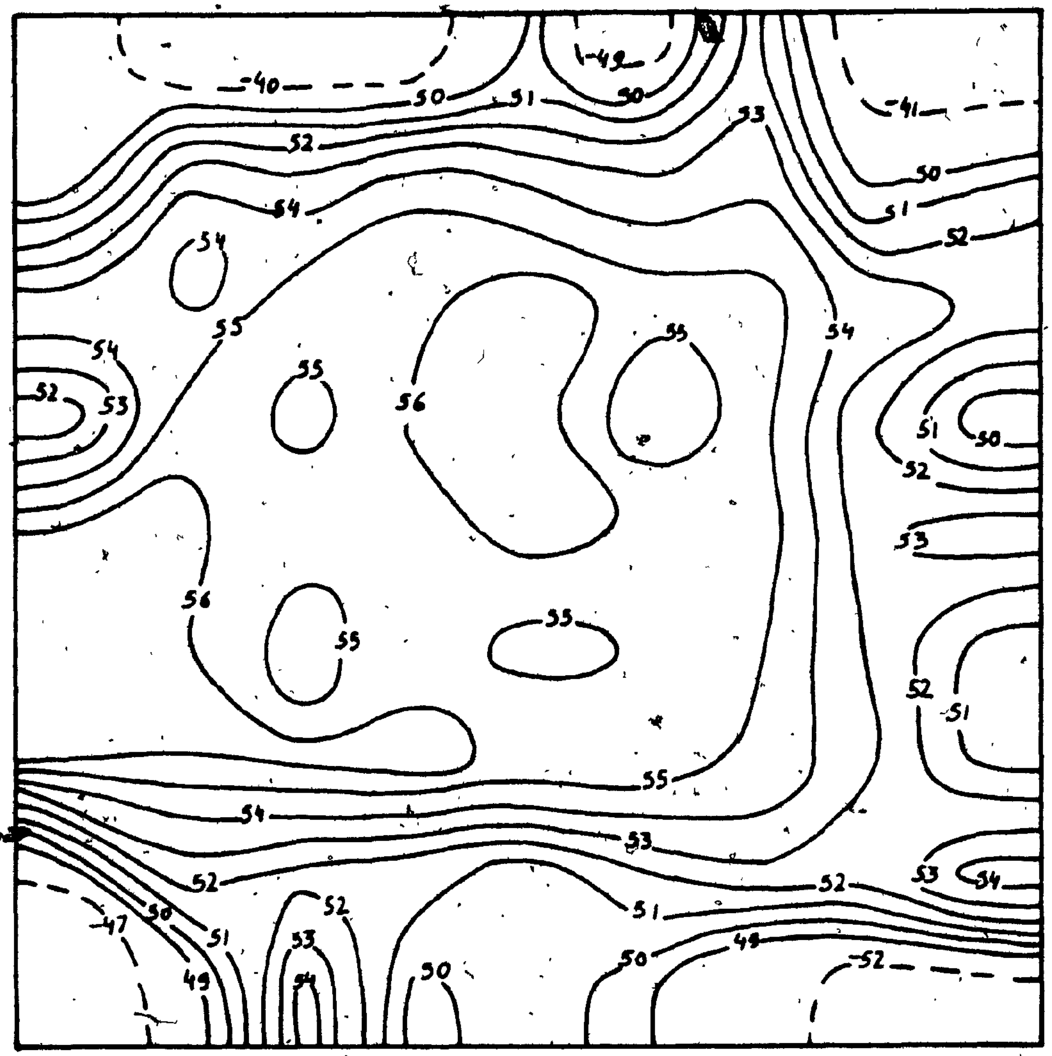

Fig. D.11: Intensity Contours Normal to the Surface at 2500 Hz
1.14m x 1.14m (45" x 45") Panel

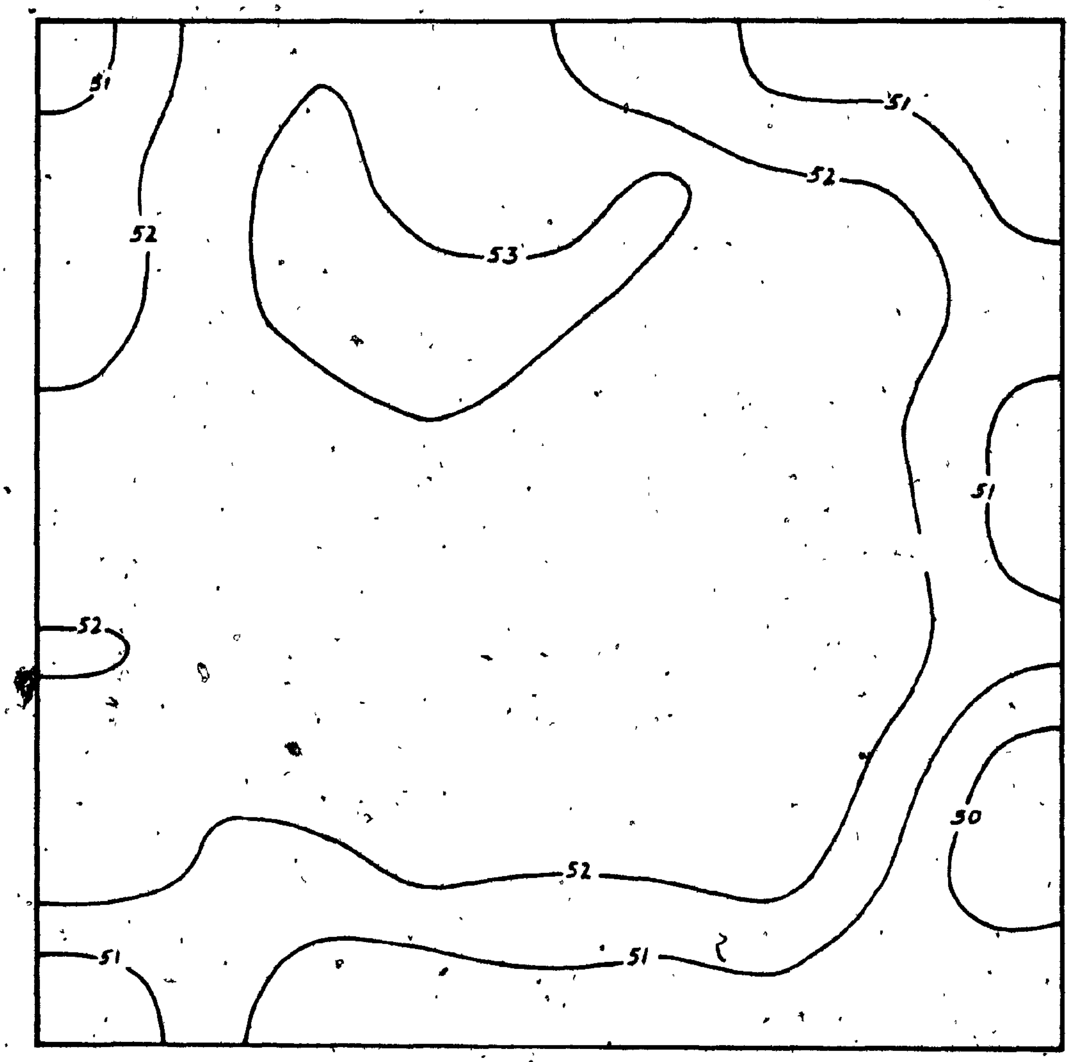

Fig. D.12: Intenisty Contours Normal to the Surface at 3150 Hz
1.14m x 1.14m (45" x 45") Panel

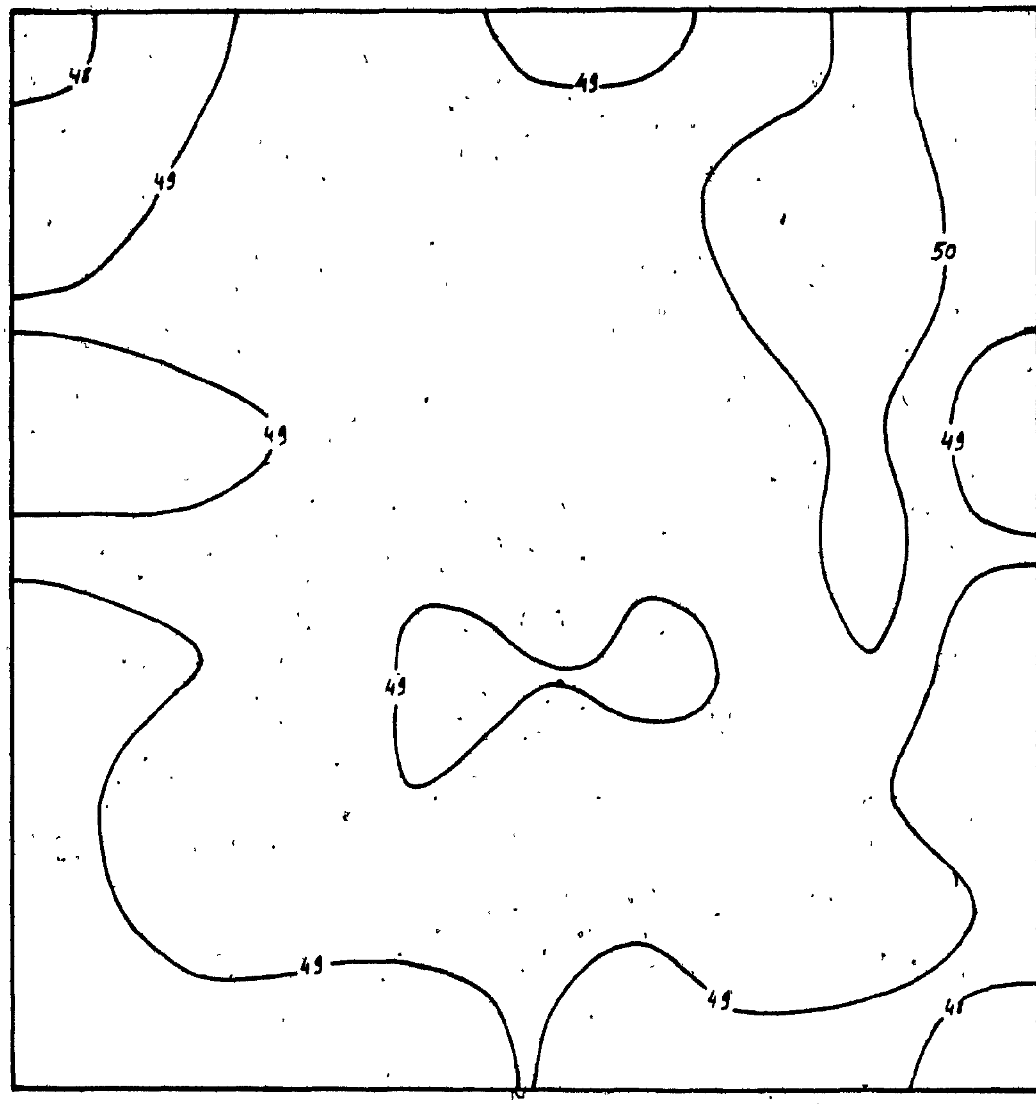

Fig. D.13: Intensity Contours Normal to the Surface at 4000 Hz
1.14m x 1.14m (45" x 45") Panel

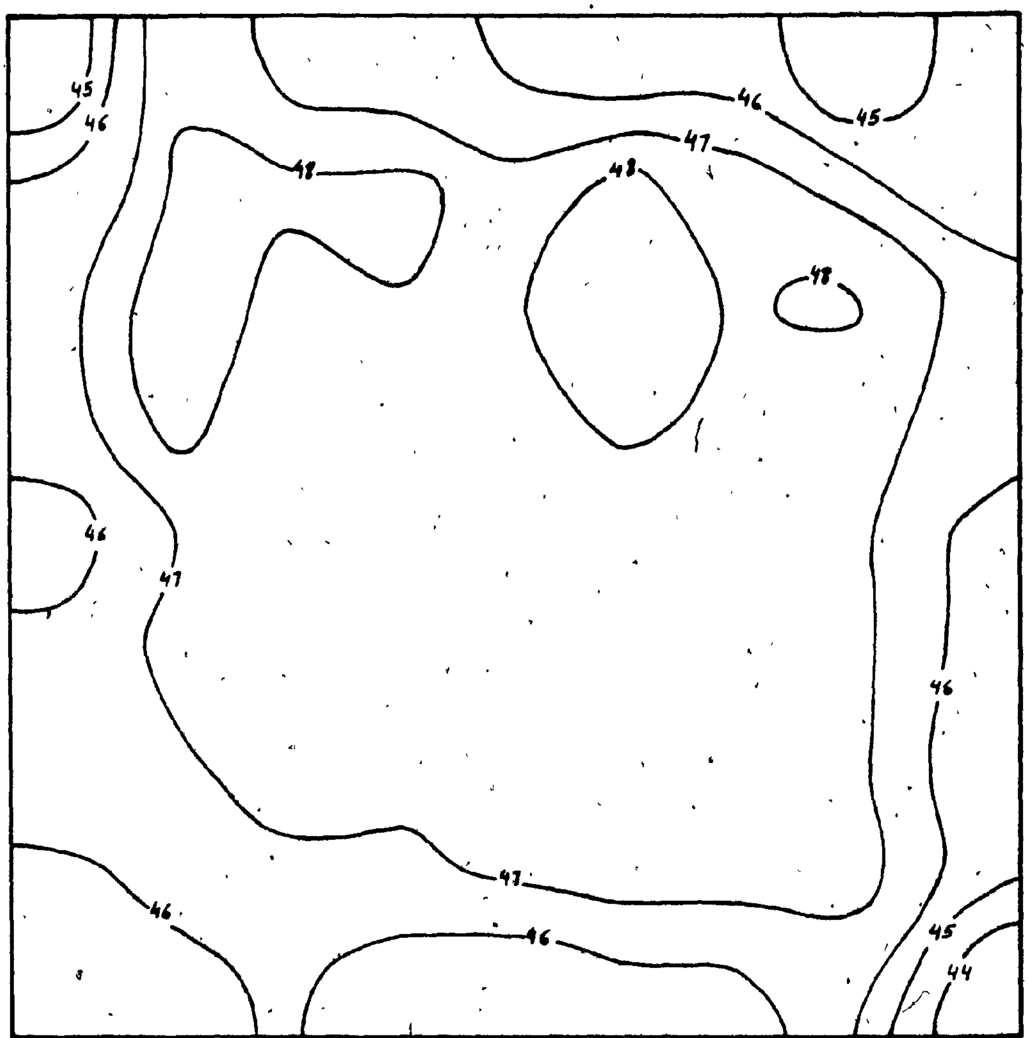

Fig. D.14: Intensity Contours Normal to the Surface at 5000 Hz
1.14m x 1.14m (45" x 45") Panel

Appendix E

Third Octave Equal Intensity Contours Normal to the Surface

1.52m x 1.52m (60" x 60") Panel

12.7cm x 12.7cm (9x9) Mesh

Measurement Distance : 5 cm

t_{av} : 8 sec

(the Numerical Values on the Figures represent the Measured Transmitted Intensity in dB)

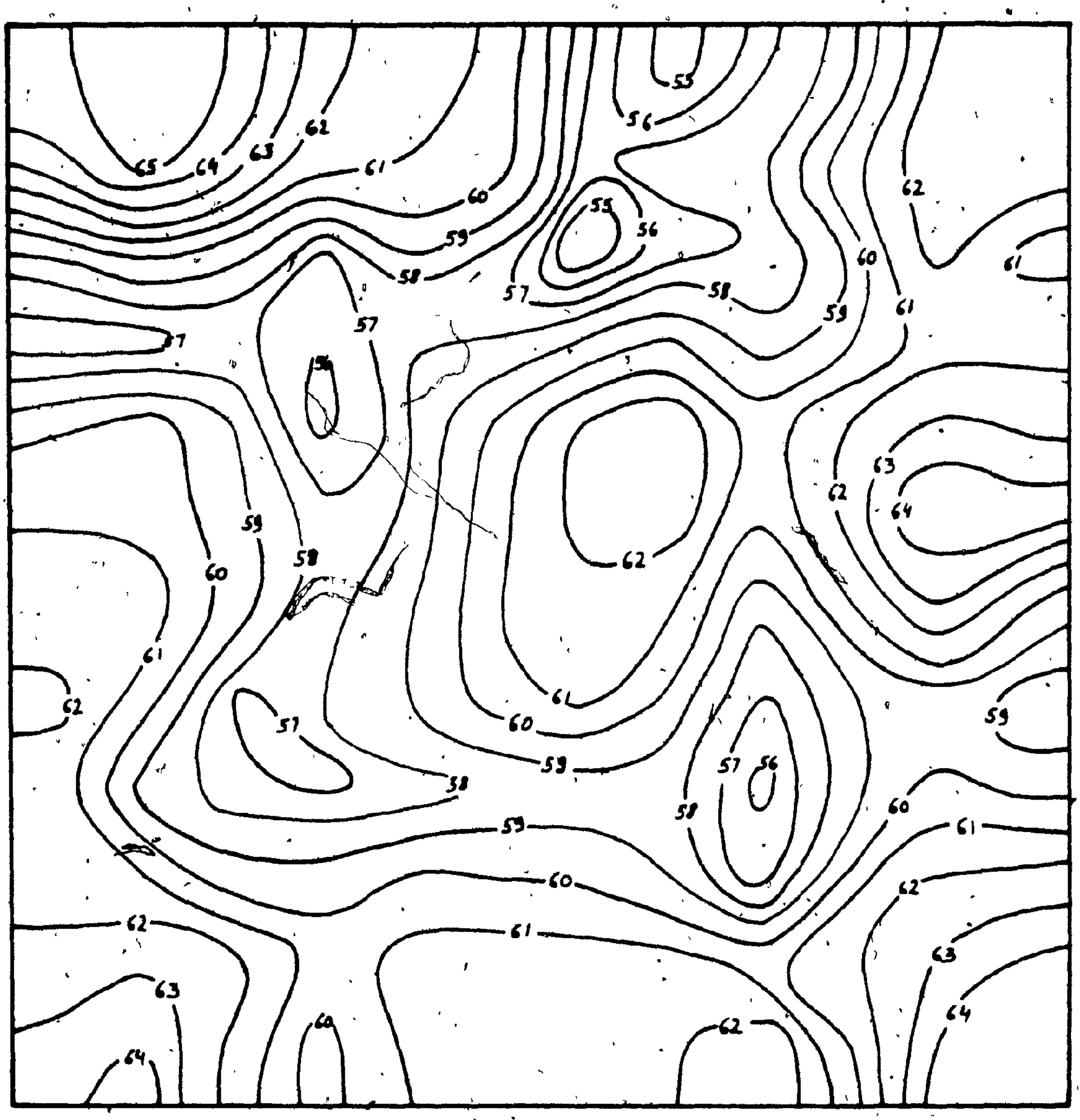

Fig. E.1: Intensity Contours Normal to the Surface at 250 Hz
1.52m x 1.52m (60" x 60") Panel

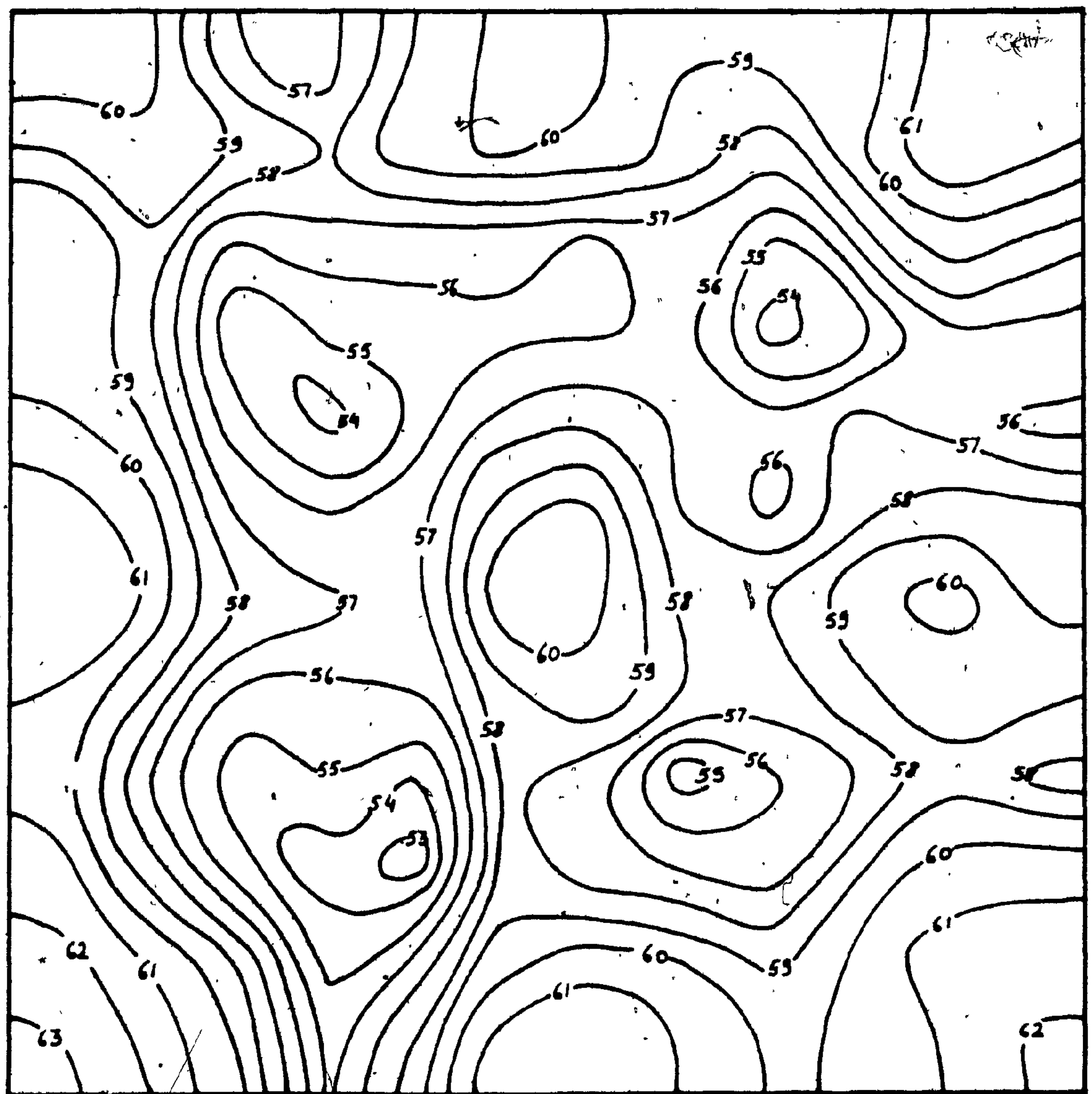

Fig. E.2: Intensity Contours Normal to the Surface at 315 Hz
1.52m x 1.52m (60" x 60") Panel

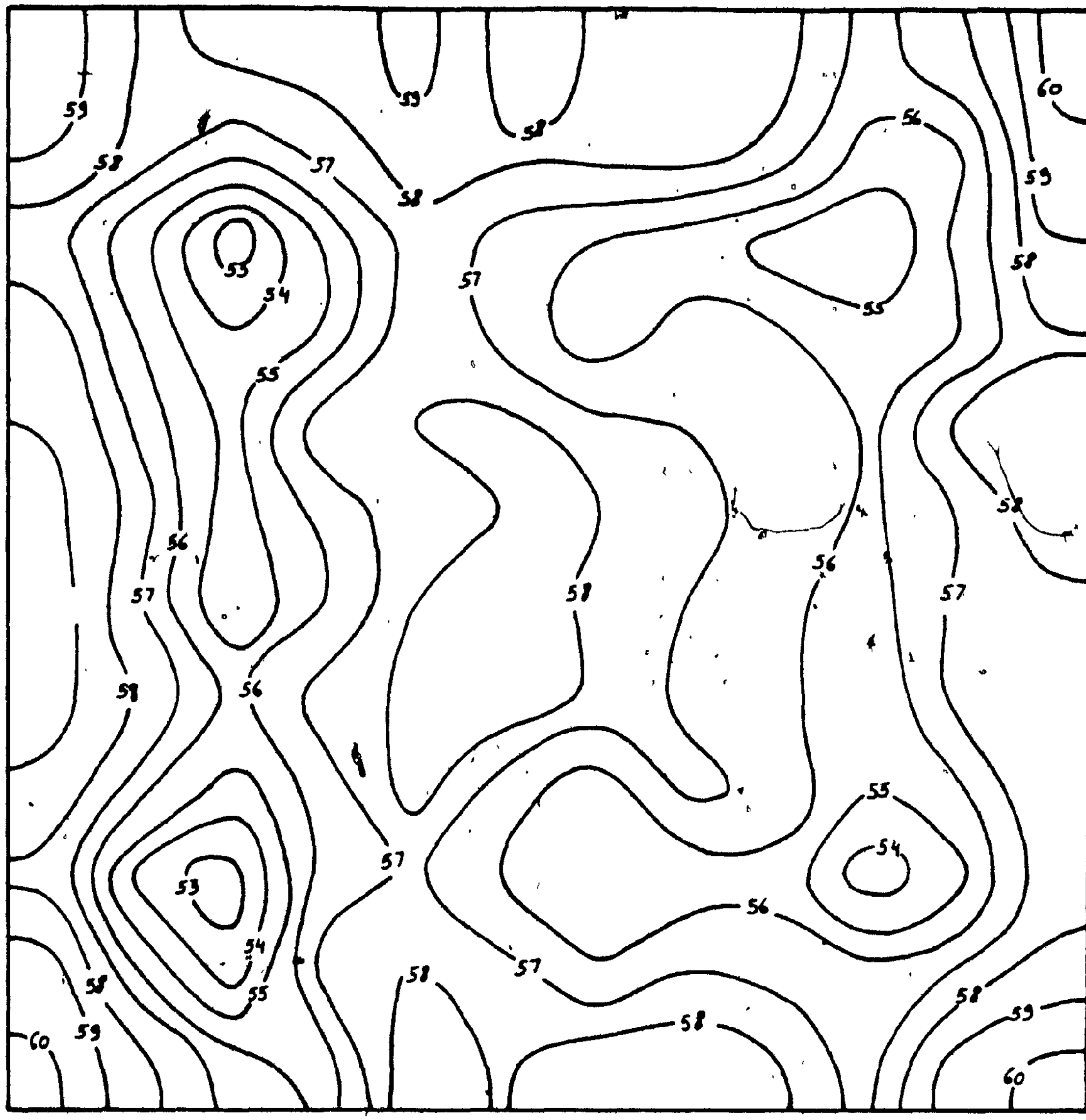

Fig. E.3: Intensity Contours Normal to the Surface at 400 Hz
1.52m x 1.52m (60" x 60") Panel

Fig. E.4: Intensity Contours Normal to the Surface at 500 Hz
1.52m x 1.52m (60" x 60") Panel

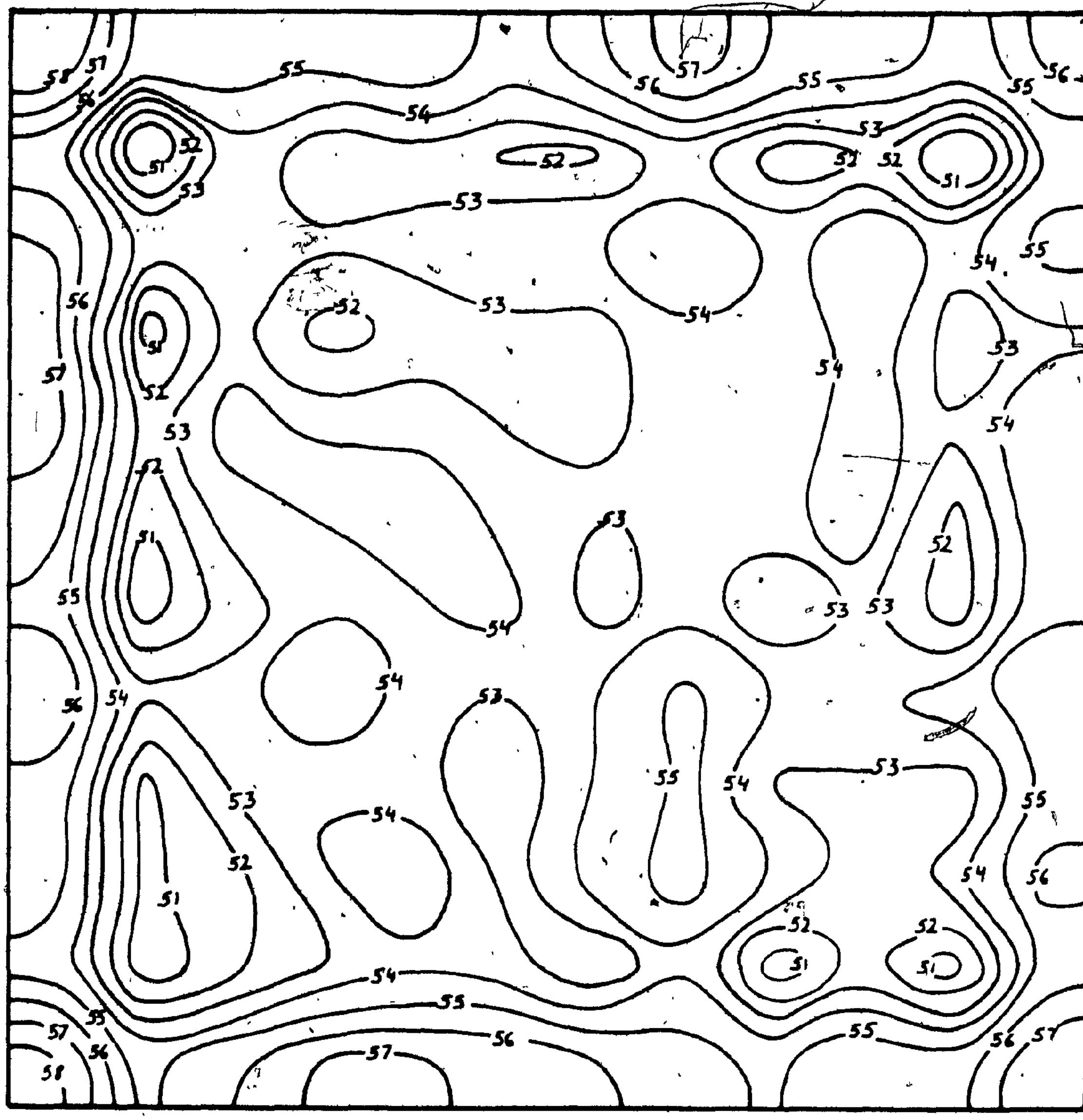

Fig. E.5: Intensity Contours Normal to the Surface at 630 Hz
1.52m x 1.52m (60" x 60") Panel

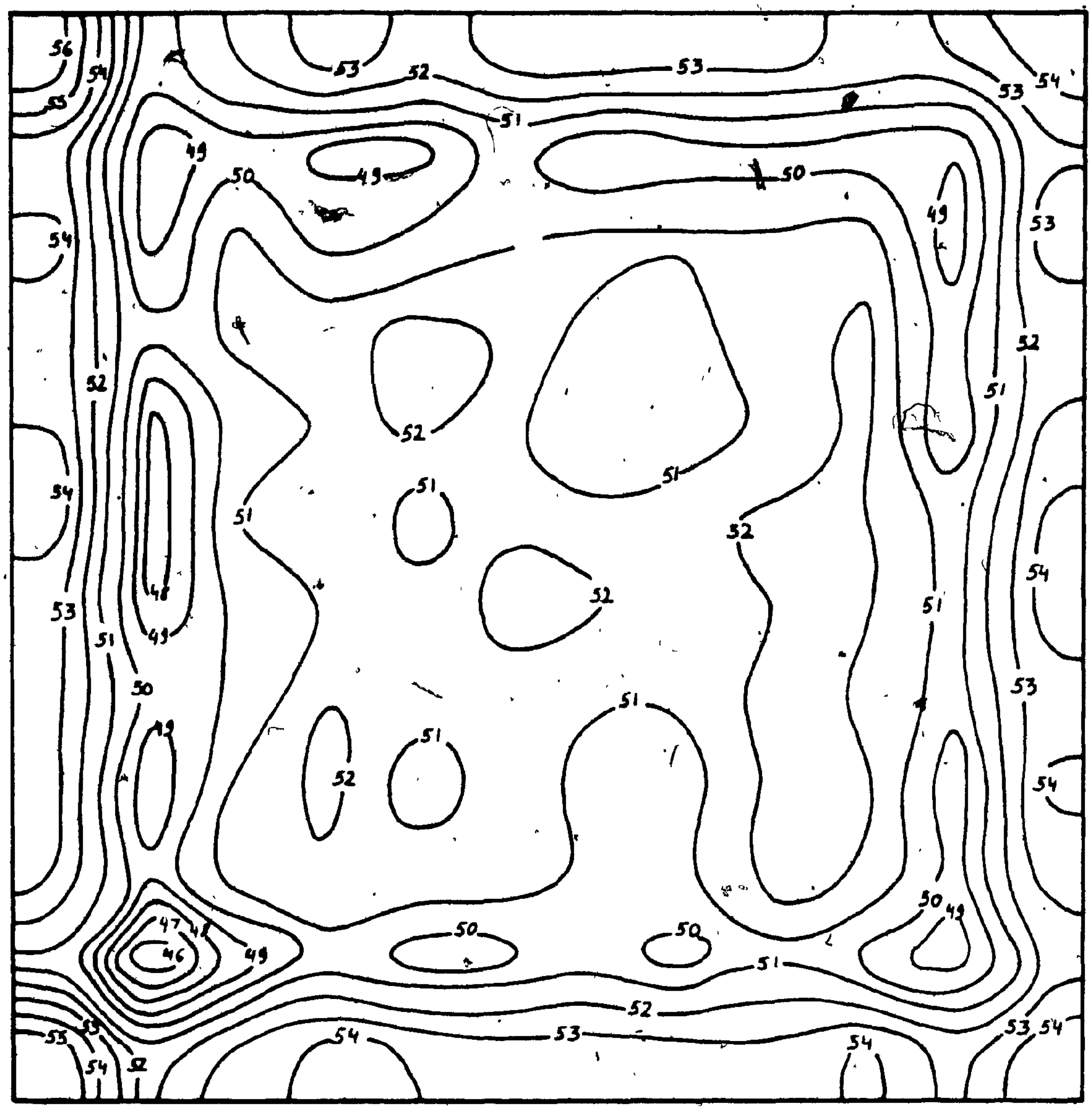

Fig. E.6: Intensity Contours Normal to the Surface at 800 Hz
1.52m x 1.52m (60" x 60") Panel

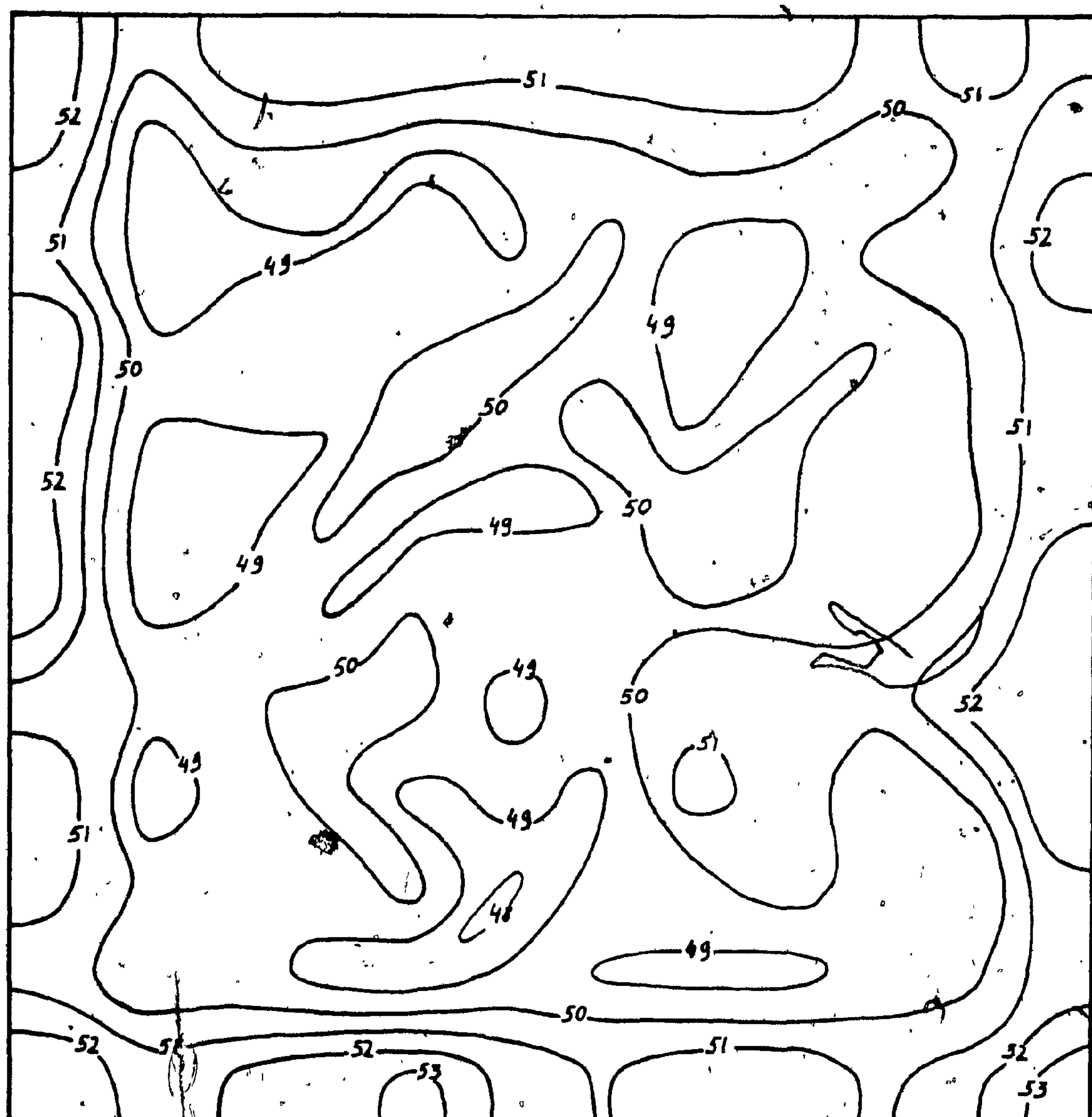

Fig. E.7: Intensity Contours Normal to the Surface at 1000 Hz
1.52m x 1.52m (60" x 60") Panel

Fig. E.8: Intensity Contours Normal to the Surface at 1250 Hz
1.52m x 1.52m (60" x 60") Panel

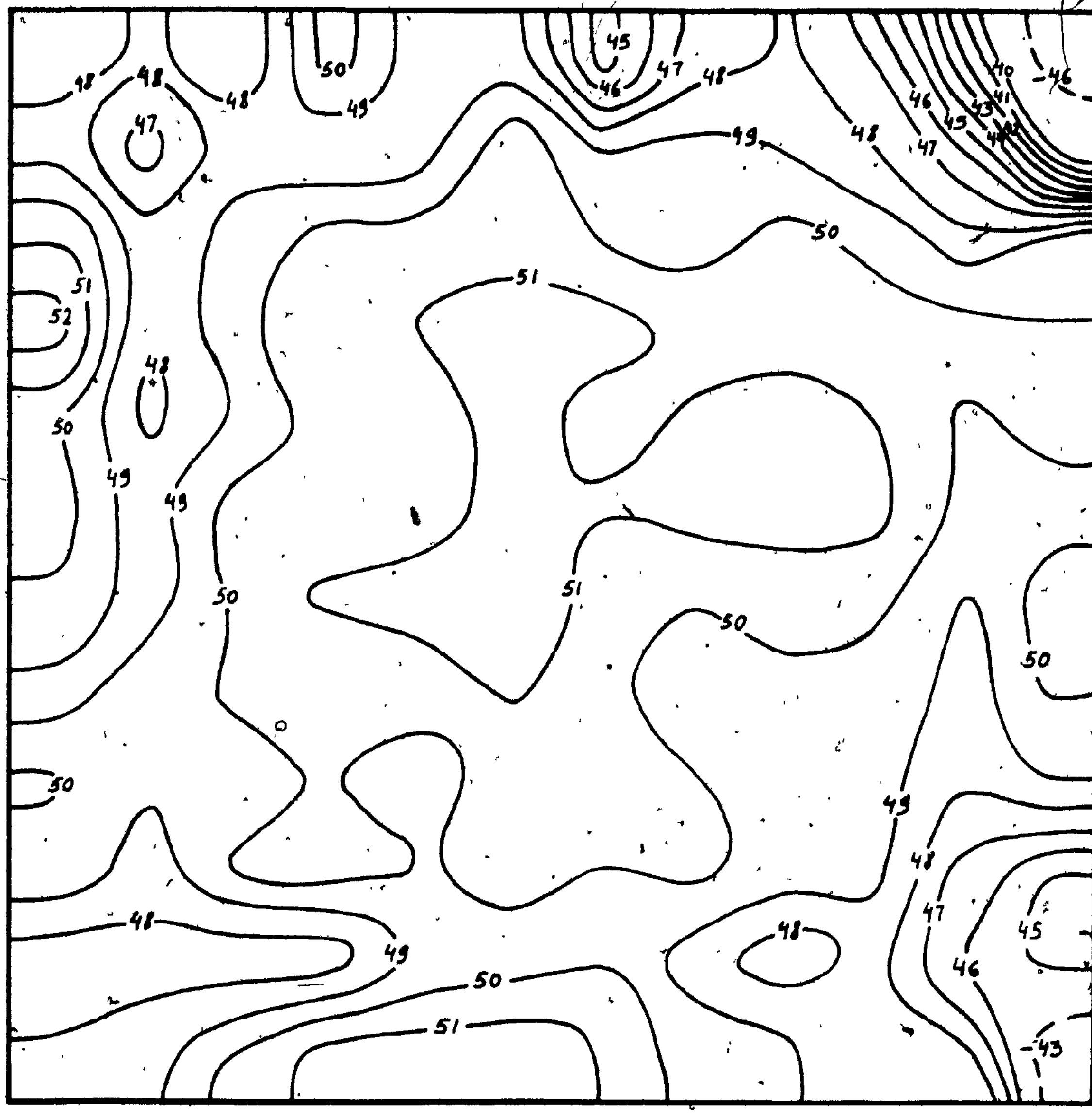

Fig. E.9: Intensity Contours Normal to the Surface at 1600 Hz
1.52m x 1.52m (60" x 60") Panel

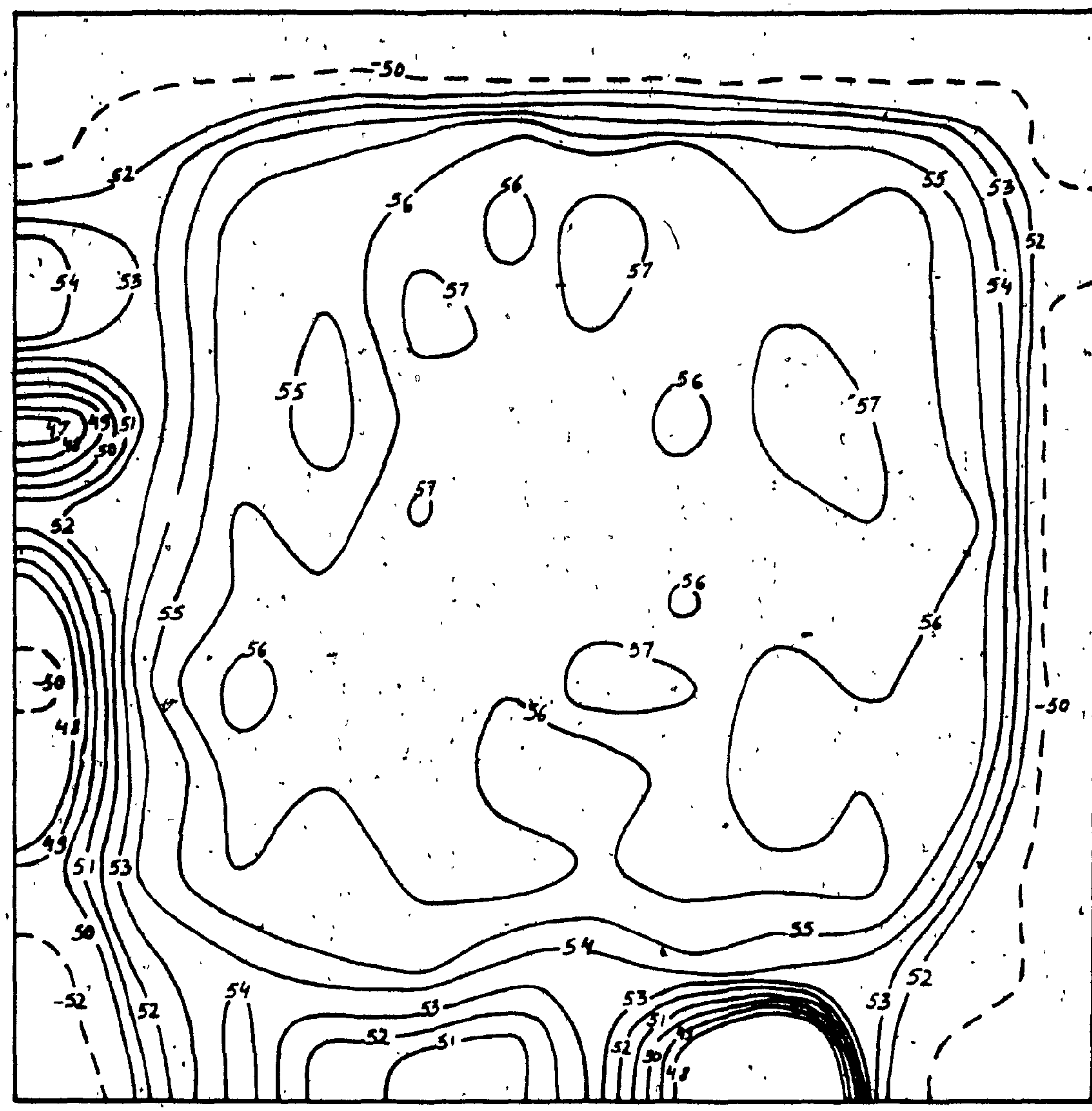

Fig. E.10: Intensity Contours Normal to the Surface at 2000 Hz
1.52m x 1.52m (60" x 60") Panel

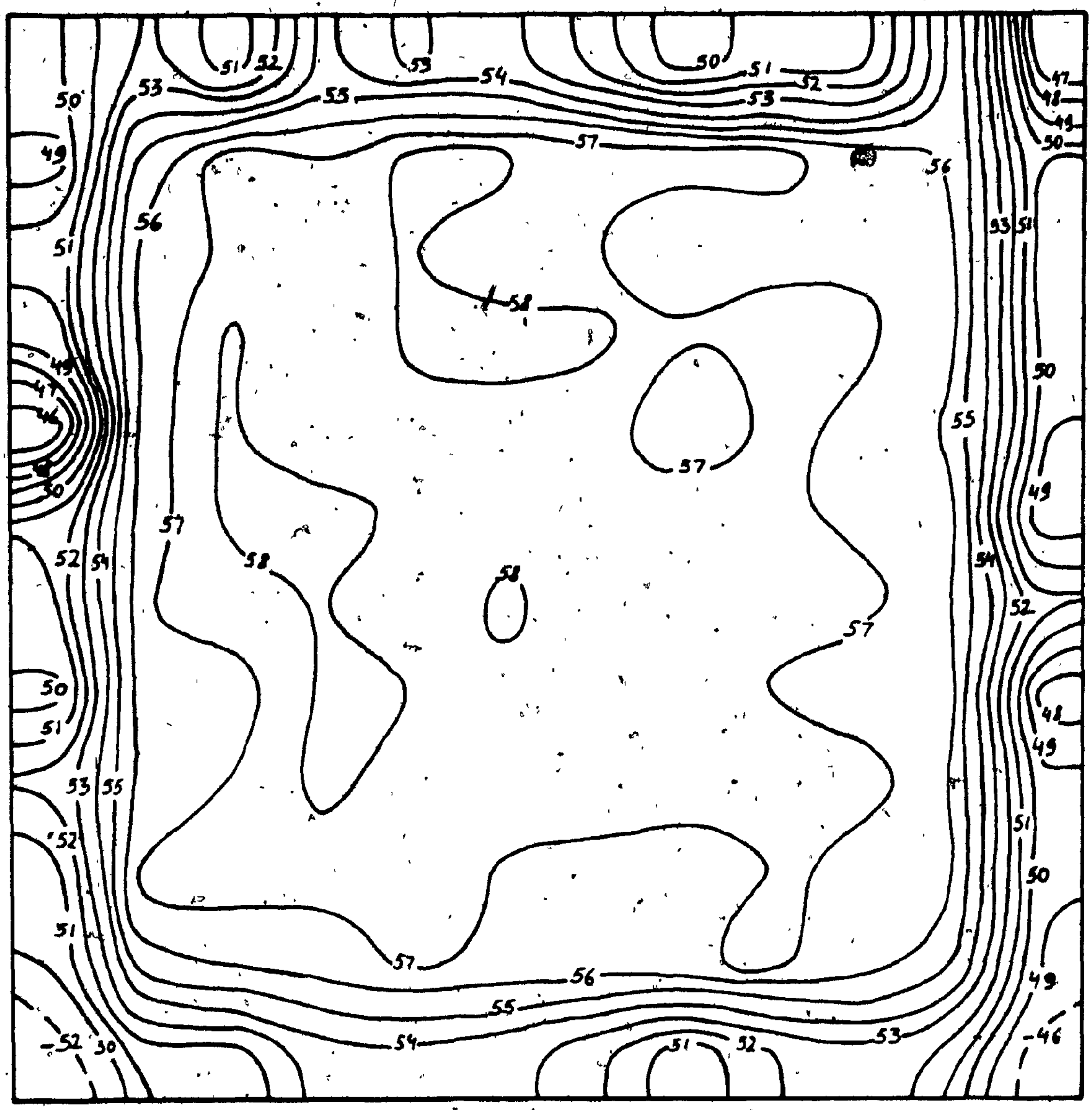

Fig. E.11: Intensity Contours Normal to the Surface at 2500 Hz
1.52m x 1.52m (60" x 60") Panel

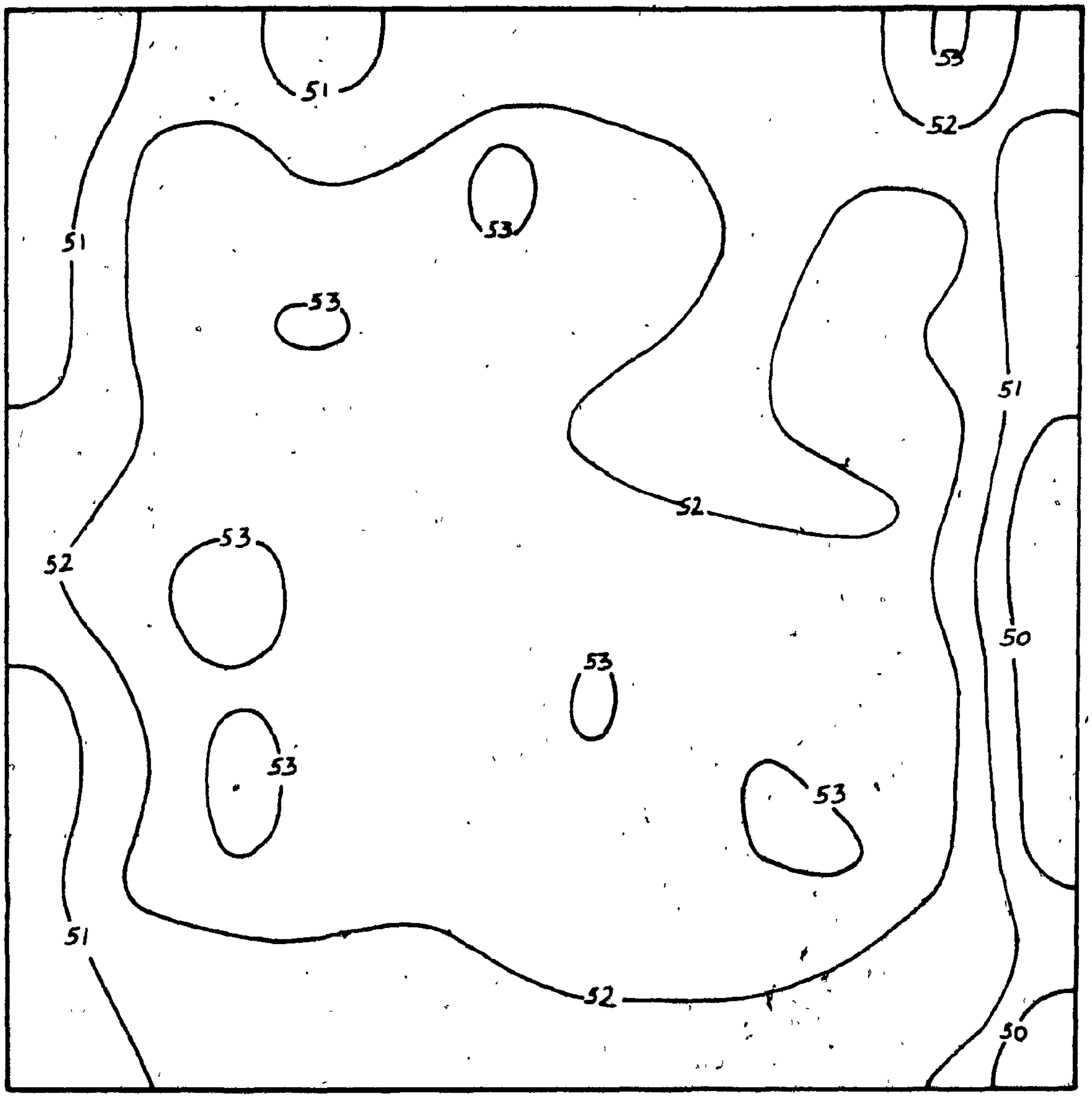

Fig. E.12: Intensity Contours Normal to the Surface at 3150 Hz
1.52m x 1.52m (60" x 60") Panel

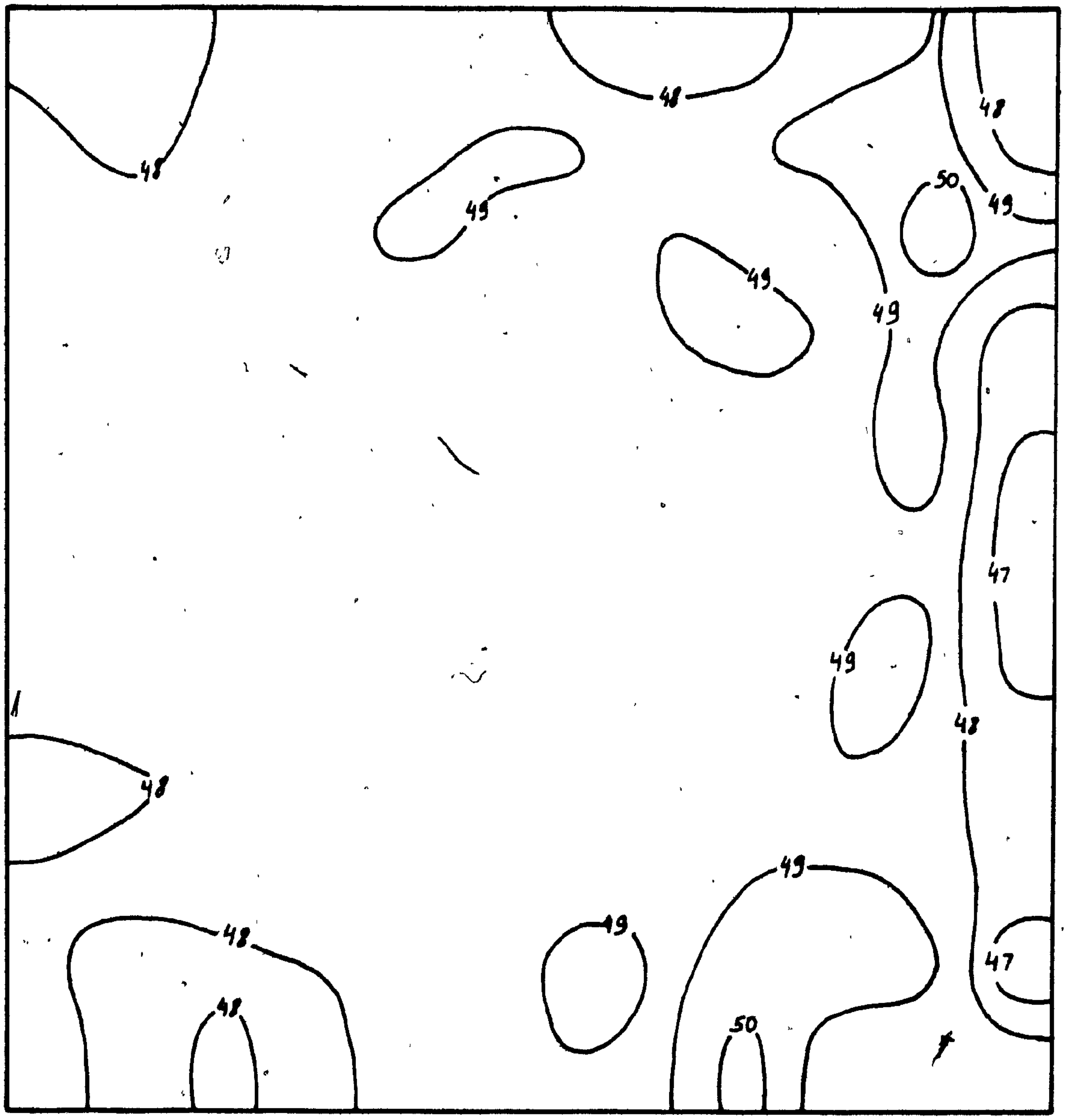

Fig. E.13: Intensity Contours Normal to the Surface at 4000 Hz
1.52m x 1.52m (60" x 60") Panel

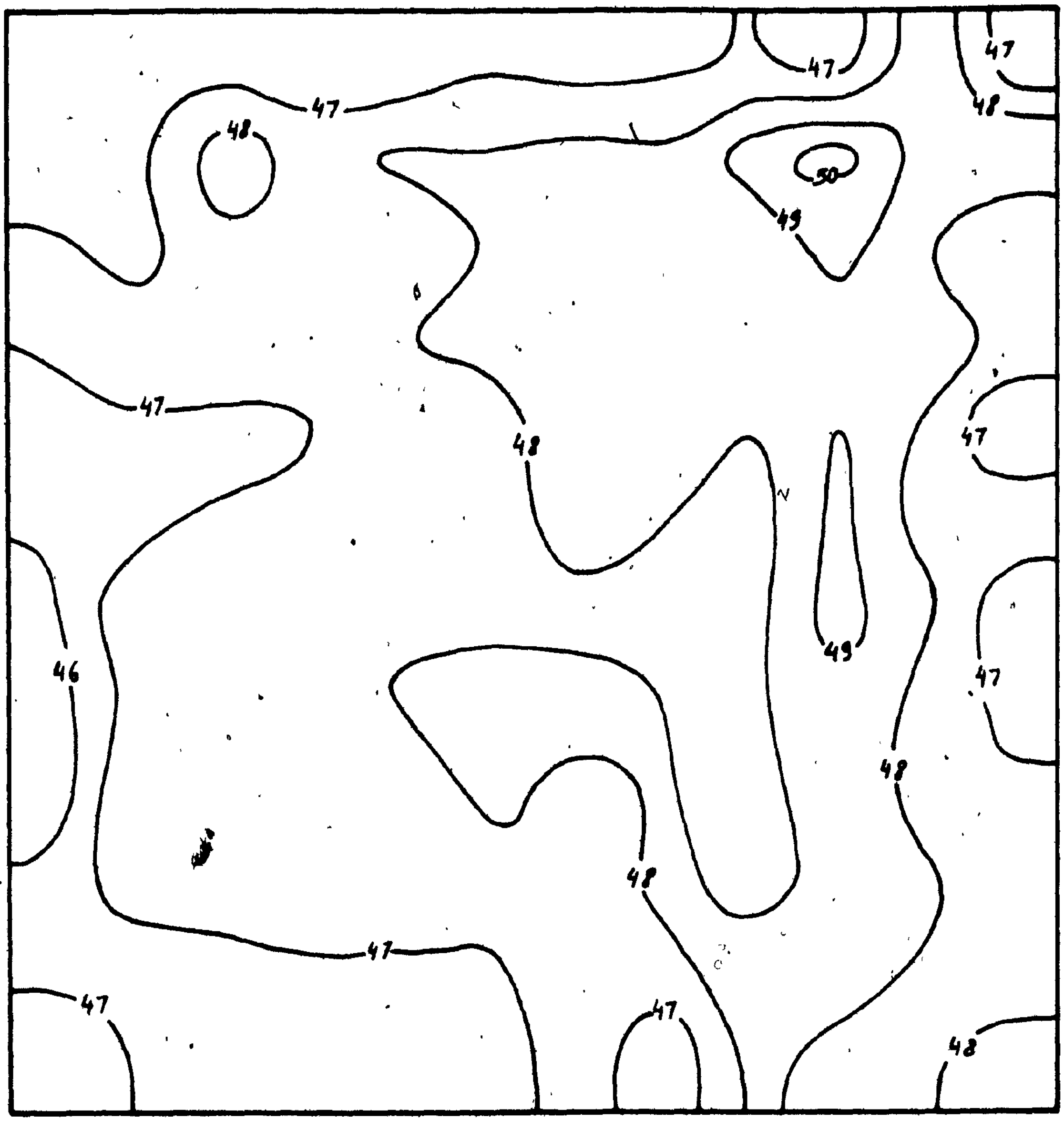

Fig. E.14: Intensity Contours Normal to the Surface at 5000 Hz
1.52m x 1.52m (60" x 60") Panel

Appendix F

Third Octave Equal Intensity Contours Normal to the Surface when the Weatherstripping is Partially Removed

1.14m x 1.14m (45" x 45") Panel

12.7cm x 12.7cm (9x9) Mesh

Measurement Distance : 5 cm

t_{av} : 8 sec

(the Numerical Values on the Figures represent the Measured Transmitted Intensity in dB)

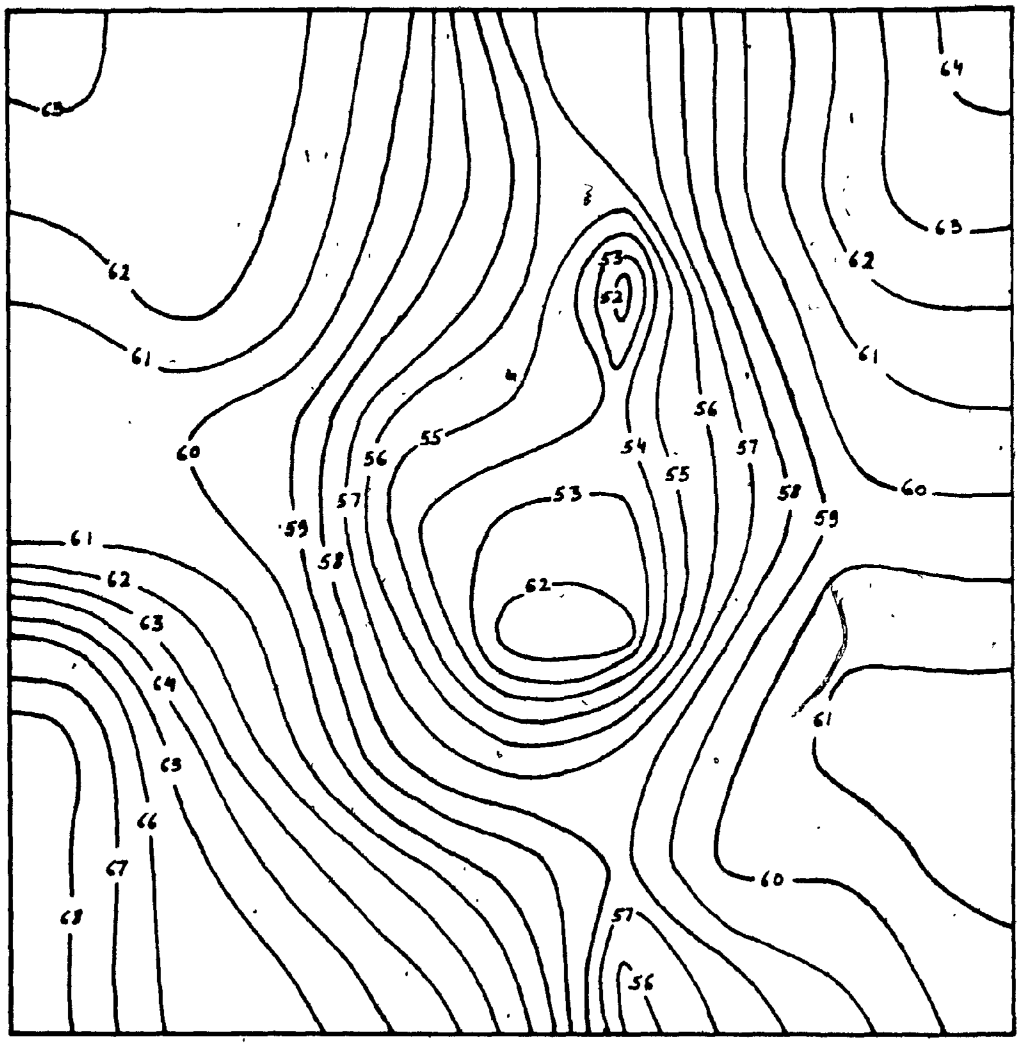

Fig. F.1: Intensity Contours Normal to the Surface at 250 Hz
Weatherstripping is Partially Removed
1.14m x 1.14m (45" x 45") Panel

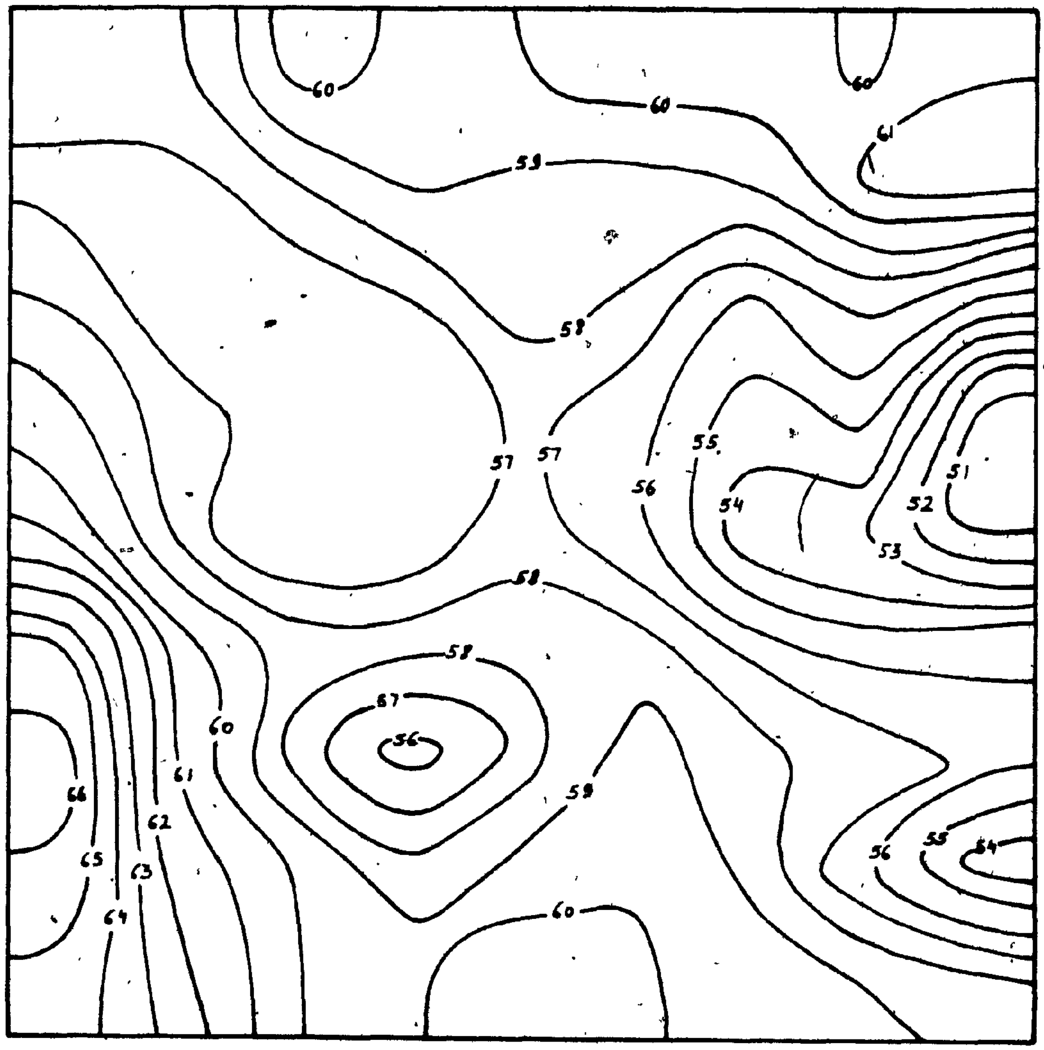

Fig. F.2: Intensity Contours Normal to the Surface at 315 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

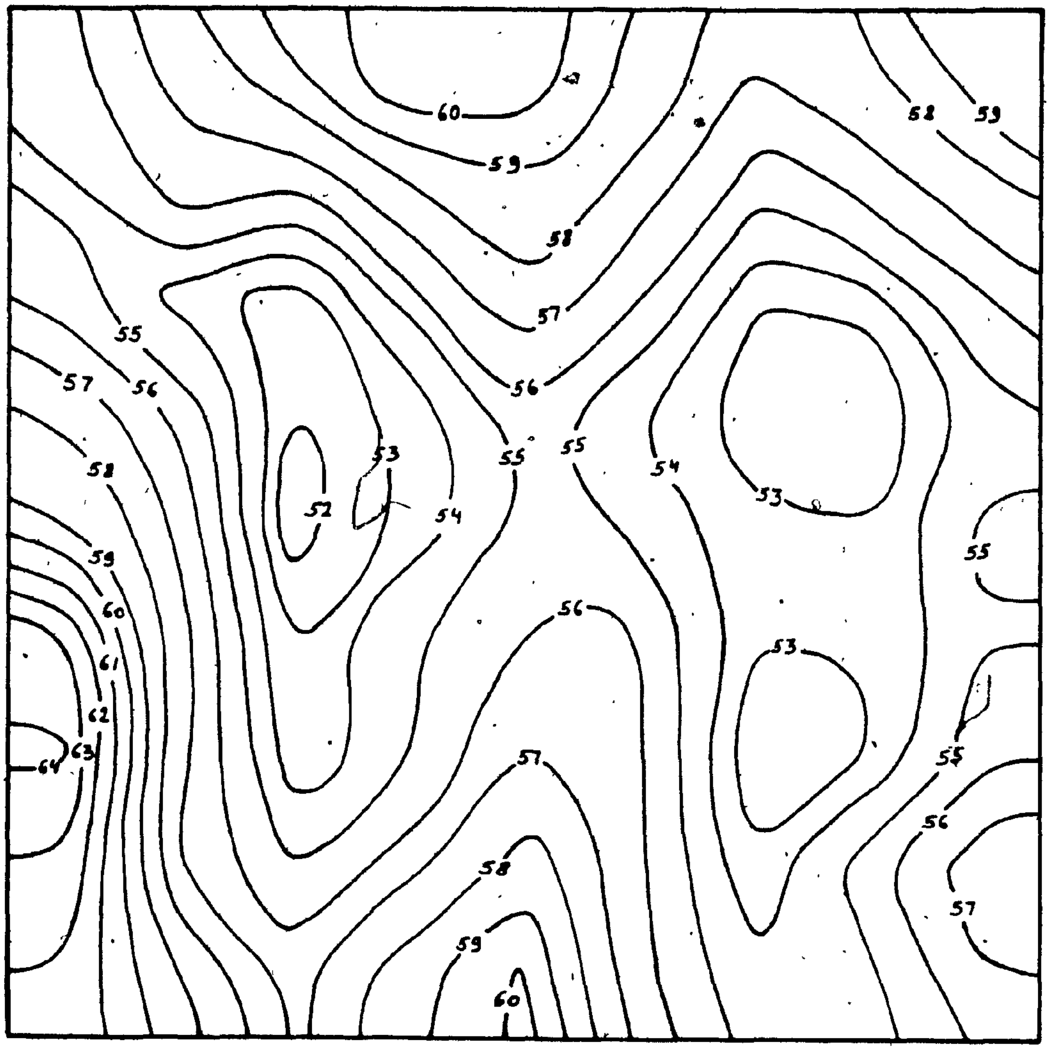

Fig. F.3: Intensity Contours Normal to the Surface at 400 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

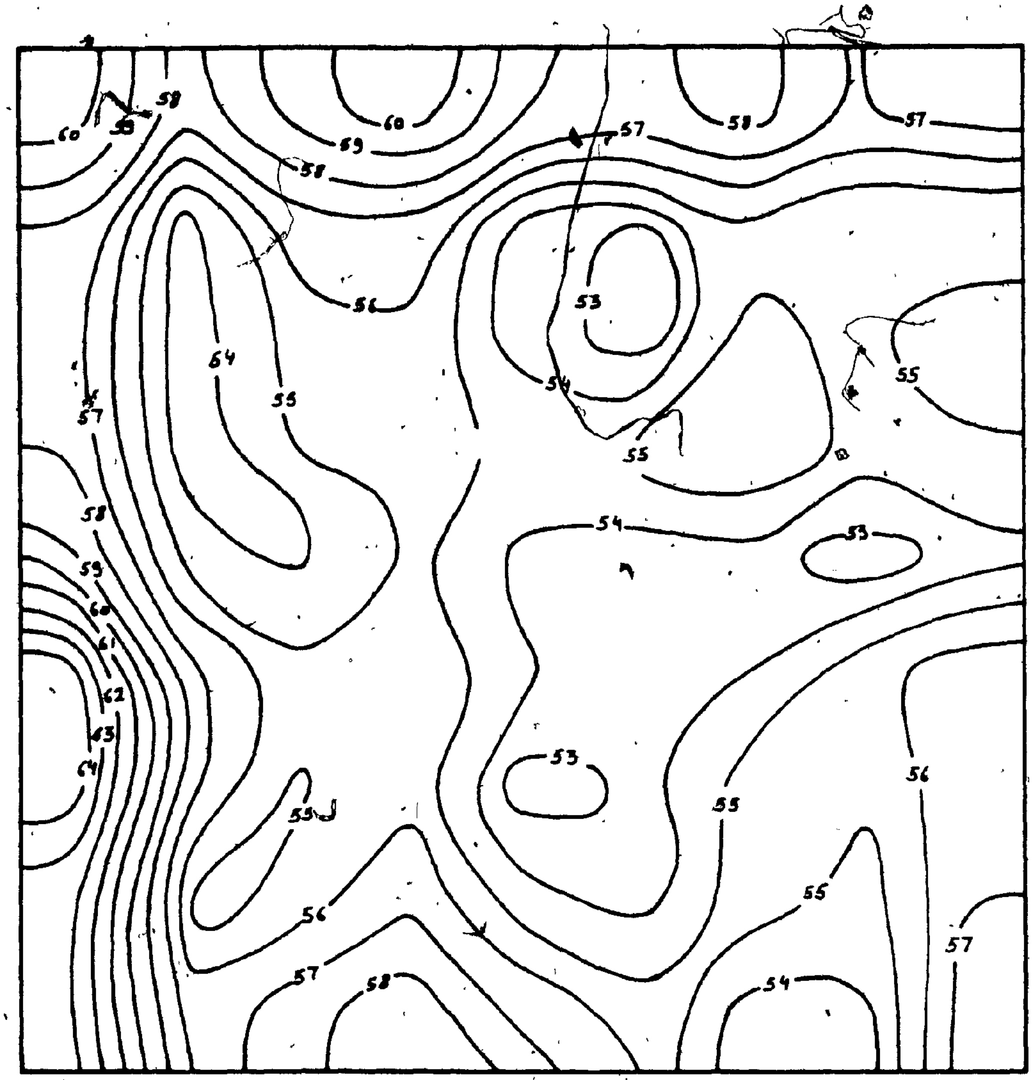

Fig. F.4: Intensity Contours Normal to the Surface at 500 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

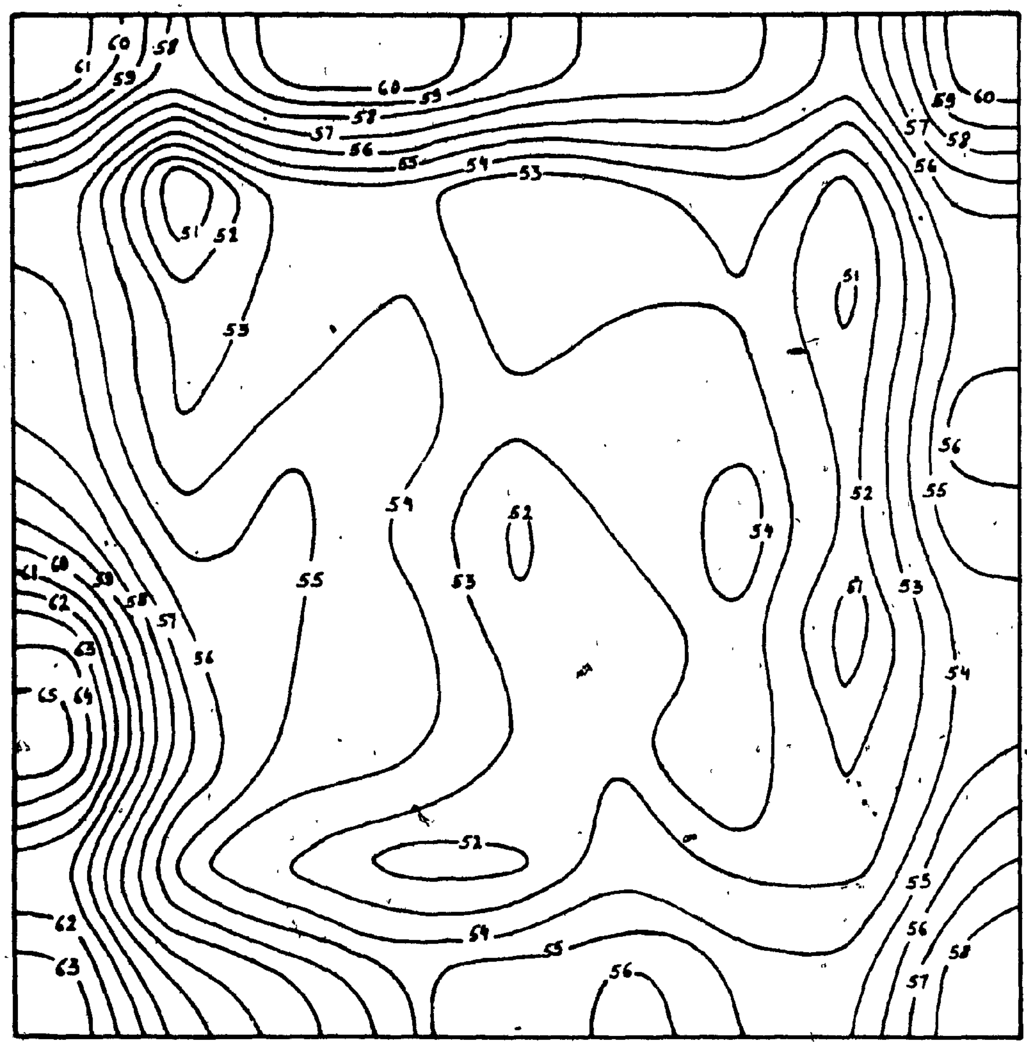

Fig. F.5: Intensity Contours Normal to the Surface at 630 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

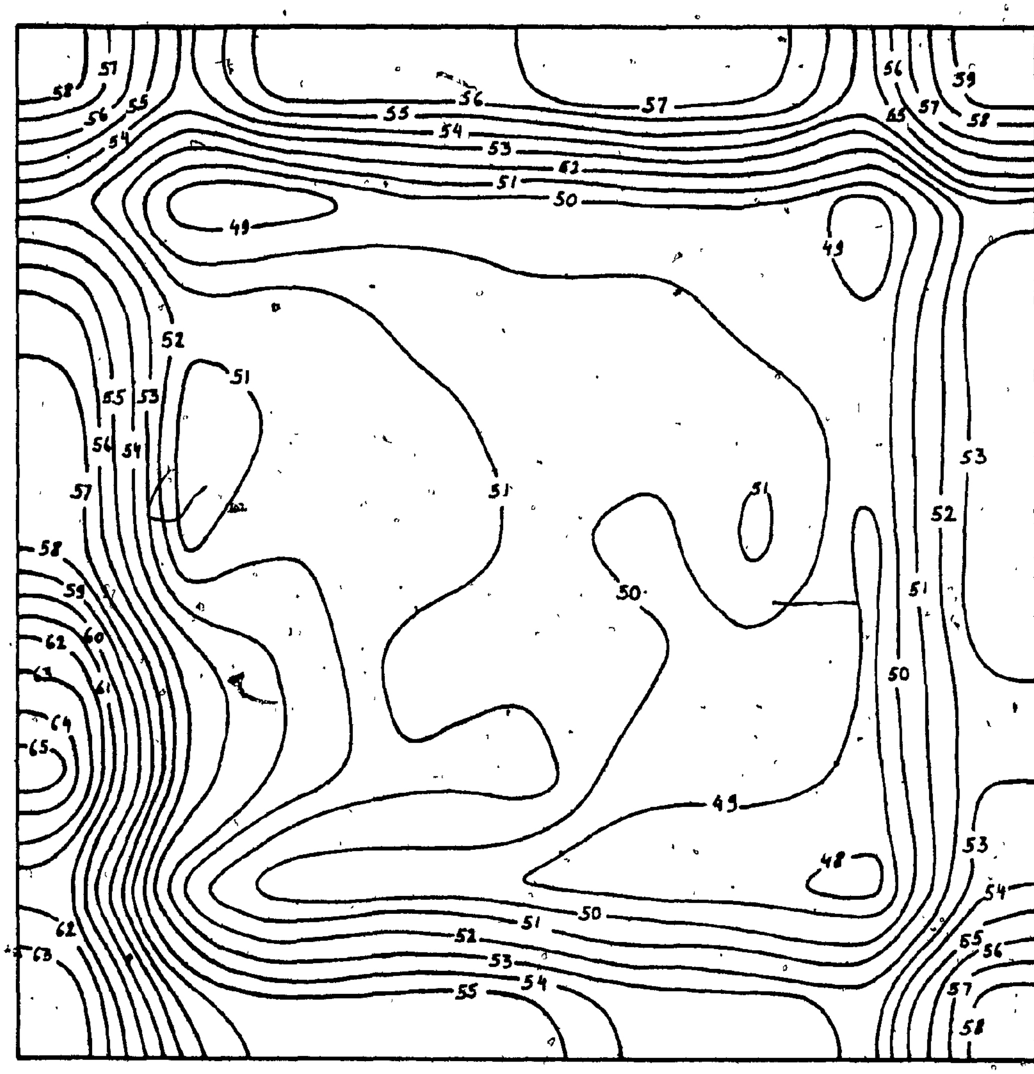

Fig. F.6: Intensity Contours Normal to the Surface at 800 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

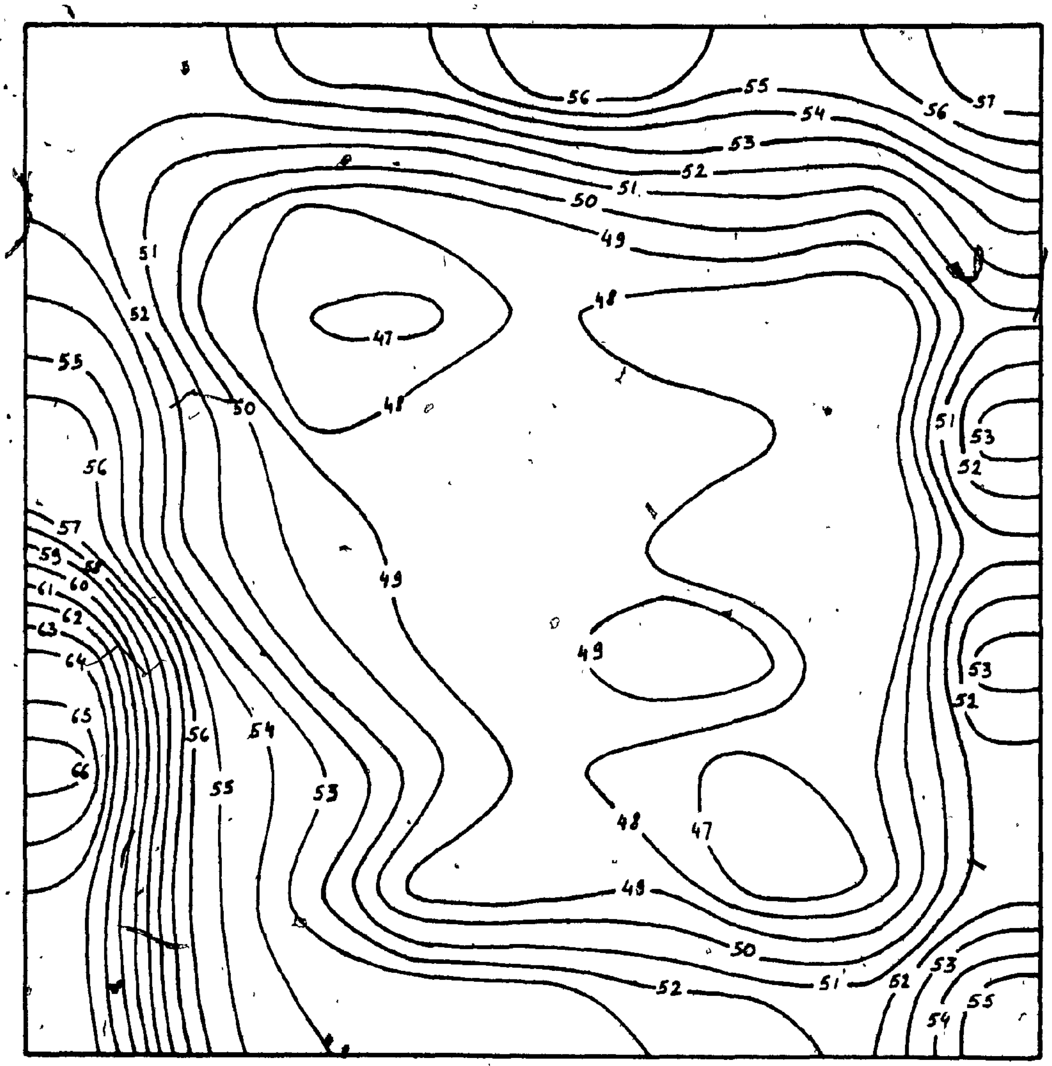

Fig. F.7: Intensity Contours Normal to the Surface at 1000 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

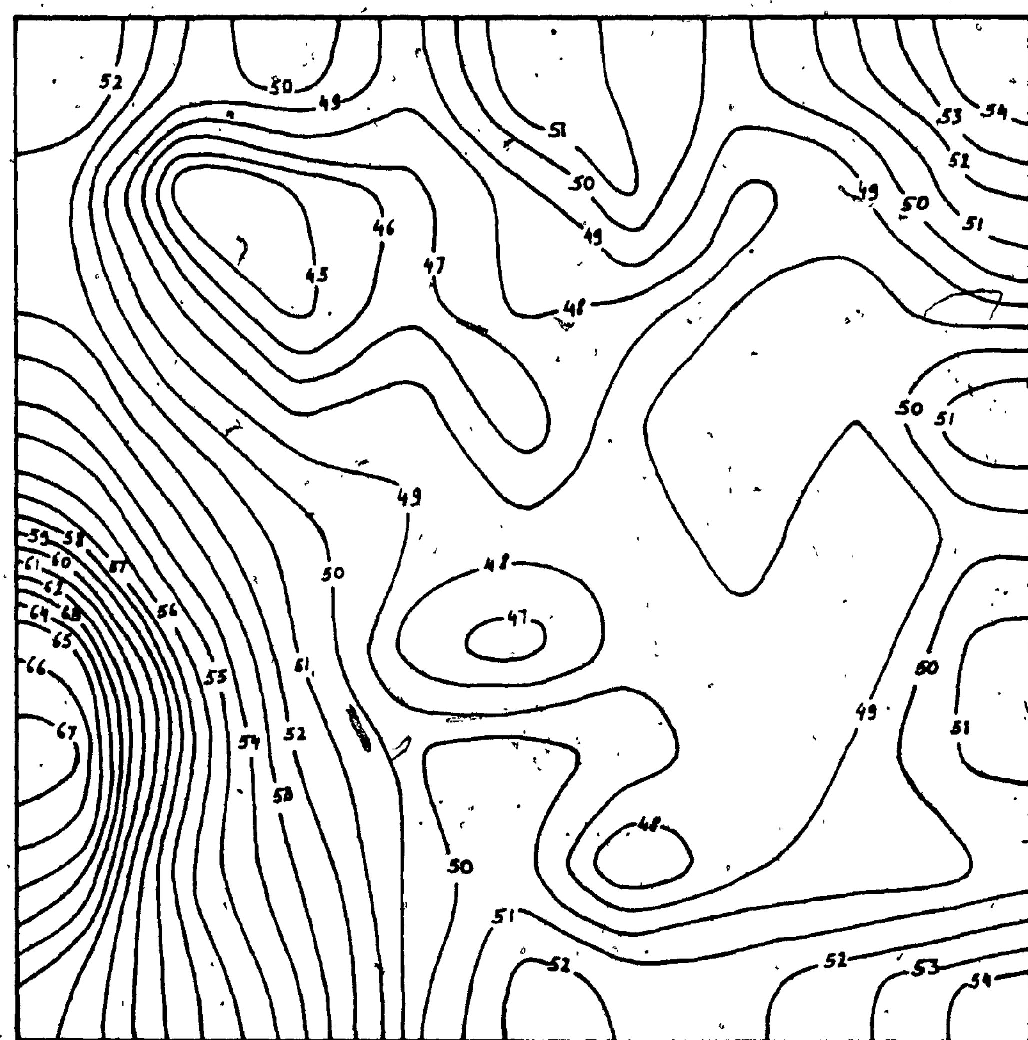

Fig. F.8: Intensity Contours Normal to the Surface at 1250 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

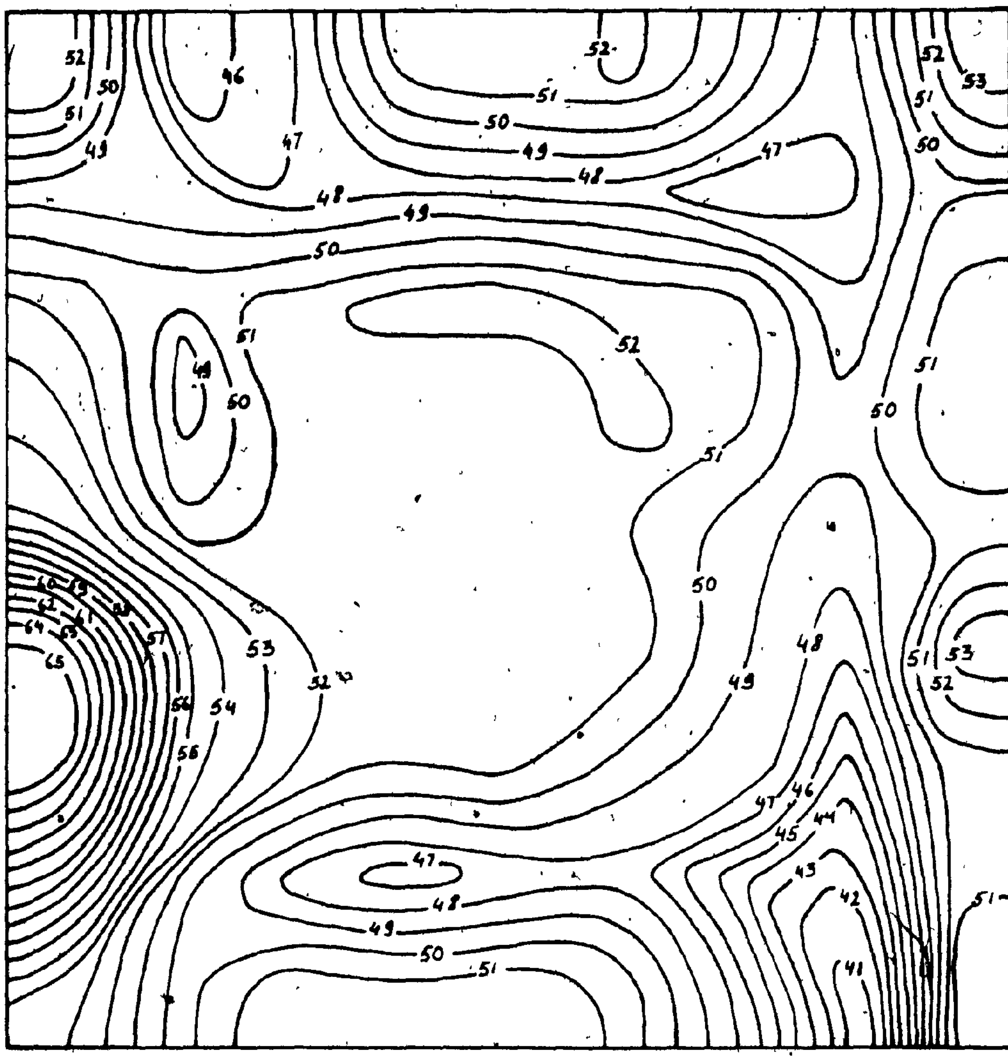

Fig. F.9: Intensity Contours Normal to the Surface at 1600 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

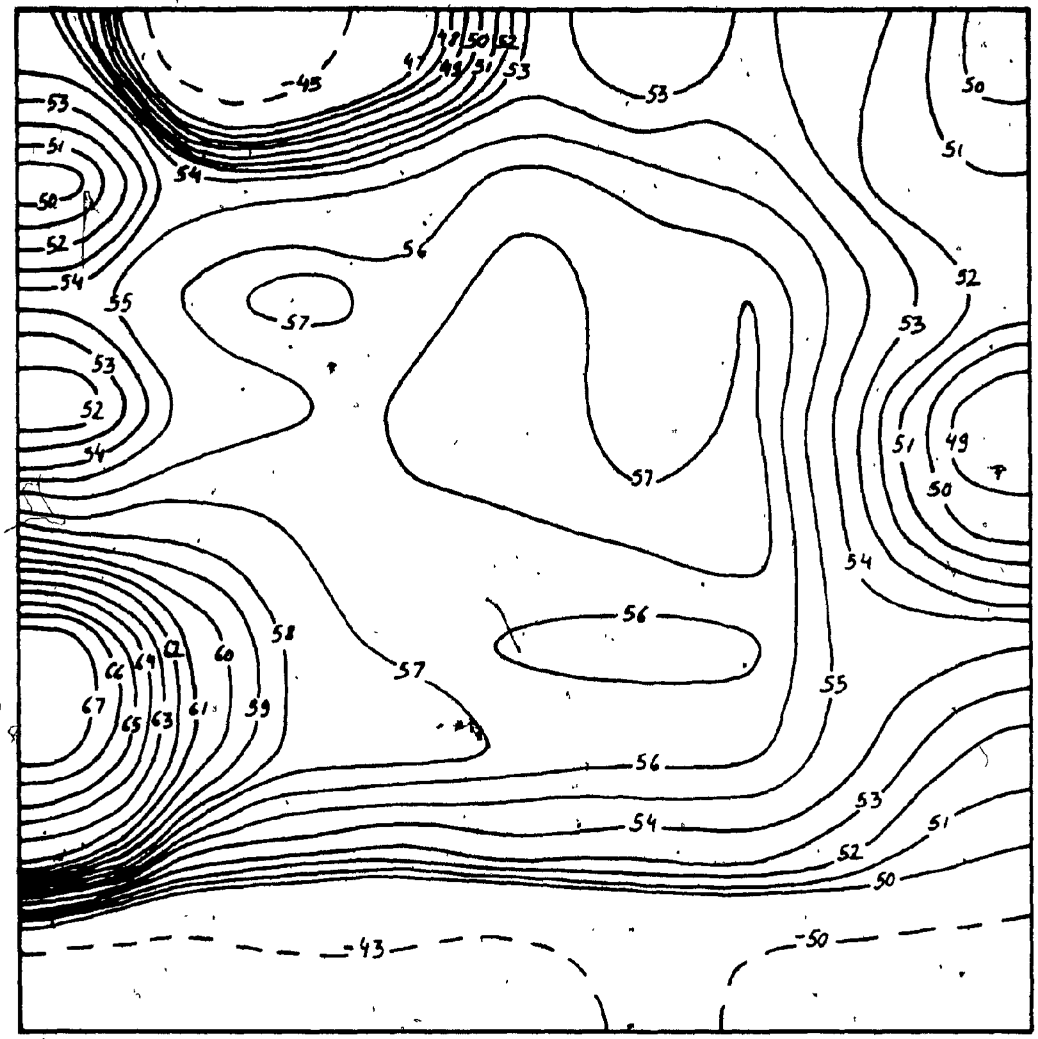

Fig. F.10: Intensity Contours Normal to the Surface at 2000 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

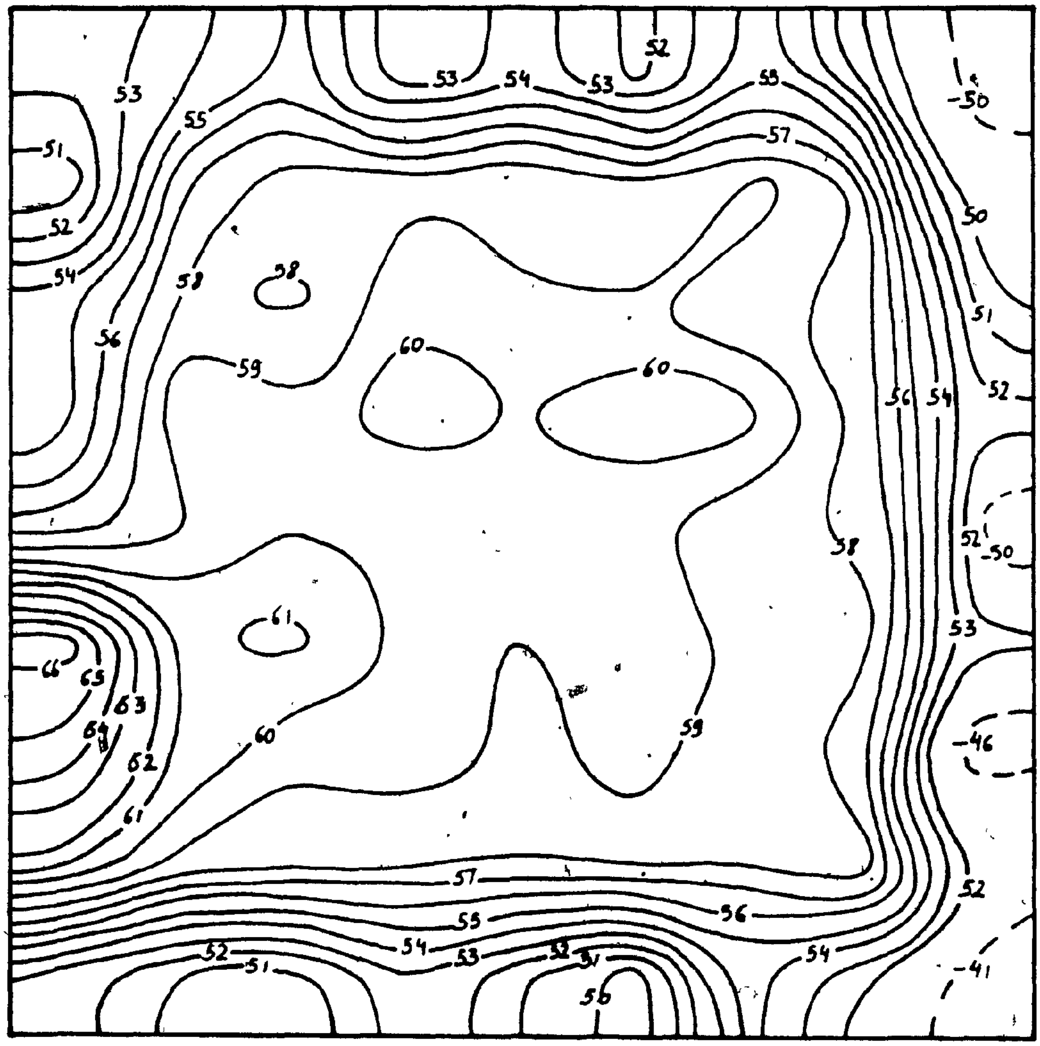

Fig. F.11: Intensity Contours Normal to the Surface at 2500 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

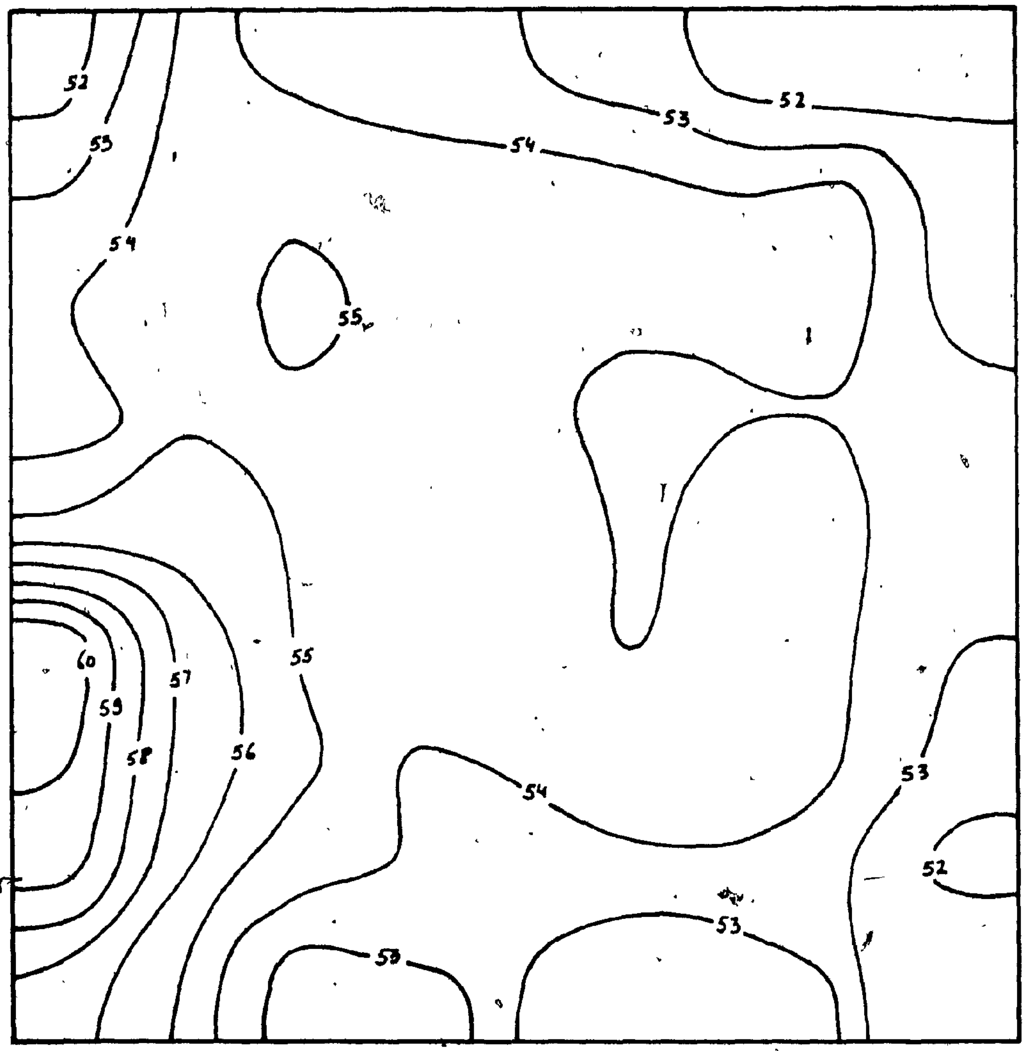

Fig. F.12: Intensity Contours Normal to the Surface at 3150 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

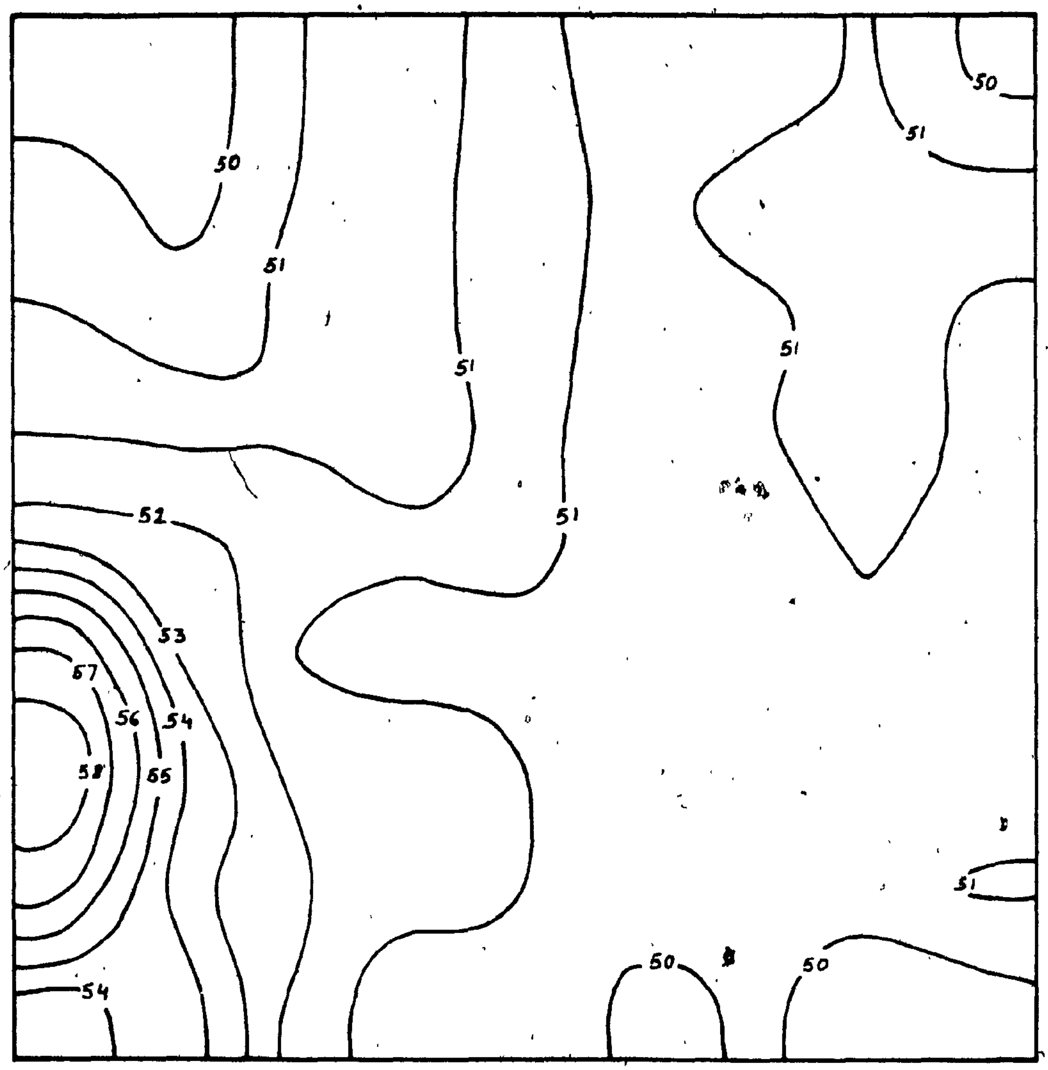

Fig. F.13: Intensity Contours Normal to the Surface at 4000 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel

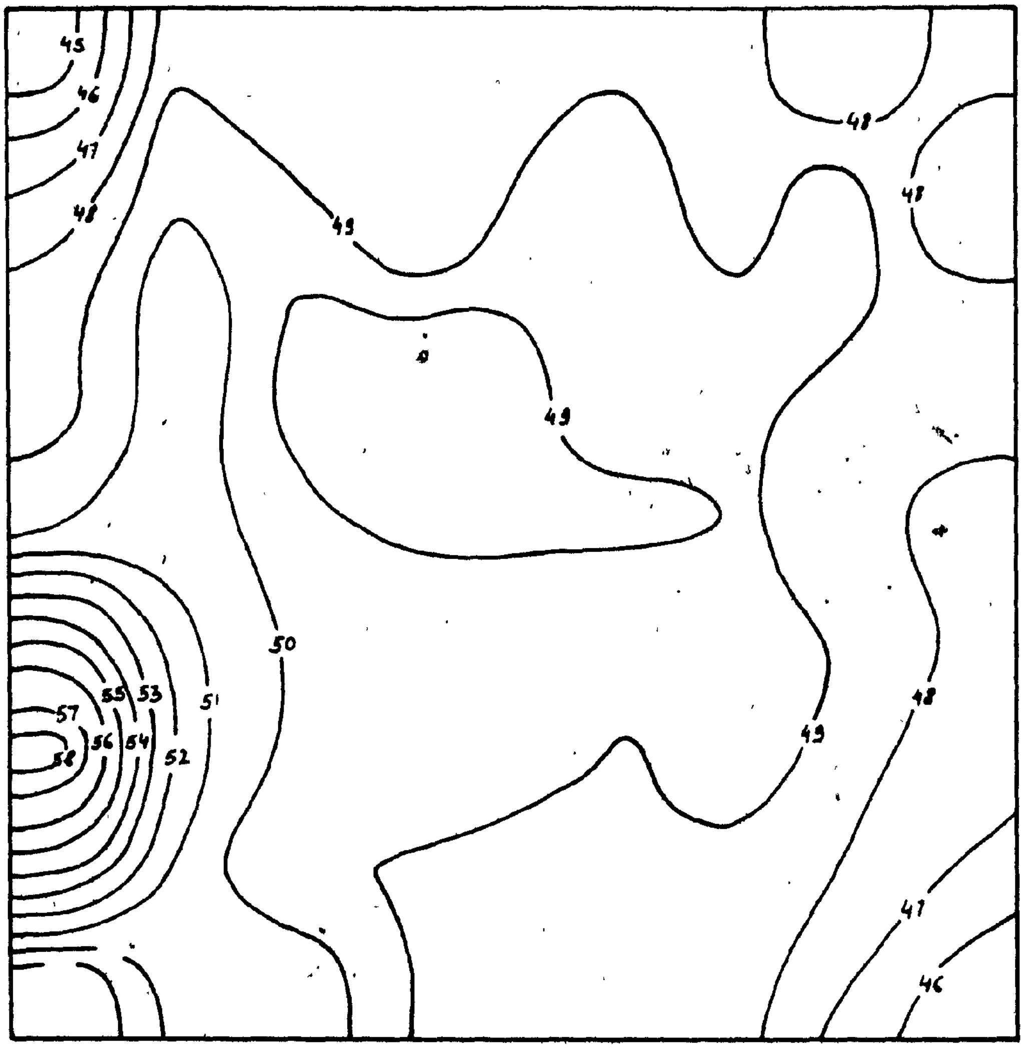

Fig. F.14: Intensity Contours Normal to the Surface at 5000 Hz
Weatherstripping Partially Removed
1.14m x 1.14m (45" x 45") Panel