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THE USE OF A TRANSMISSION SUITE WHEN DESIGNING NEW TYPES OF LIGHTWEIGHT PARTITIONS FOR USE IN STUDIO ENVIRONMENTS

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1. INTRODUCTION

1.1 The Camden

There is a common requirement within the BBC for lightweight partitions for separating studio areas. They are often needed because the maximum floor loading figures of the buildings into which the studios are to be built do not allow heavy brick or block walls to be used. A lightweight partition that is used in premises throughout the BBC is the "Camden" - so named because it was developed for use in the Camden Theatre in the 1940s.

A cross-section through a triple Camden (i.e. having three separate, independently supported Camden leaves) is shown in the Appendix (A). Double Camdens and single Camdens are also used extensively, and practical aspects of the use of the Camden in studio environments are discussed elsewhere [1]. The plasterboard provides the mass required for low frequency sound insulation. The air trapped by the fibreboard and timber battens is acoustically stiff and provides a good high frequency sound insulation. The fibreboard increases the sound insulation of the partition by four mechanisms :-

a) It adds mass to the partition.

b) It has a lower Q than the plasterboard and so it damps the motion of the plasterboard. In particular, it reduces the depth of the coincidence dip which occurs at high frequencies if the plasterboard is used alone.

c) It acts as acoustic treatment for the cavity in each leaf and so absorbs some of the sound that has leaked into it.

d) It acts as an anti-vibration mount (avm) between the plasterboard and timber battens and therefore reduces the mechanical coupling through the partition.

The Camden design has many merits which explains why it has not yet been superseded. As already explained, it is lightweight for the level of sound insulation it provides, and so allows savings in the cost of the building carcass into which studios are to be built. Studios with heavy masonry walls require strong, massive floors, and consequently the strength of the walls of the building carcass has to be considerably greater. The Camden is easier to remove than masonry walls when refurbishing studio areas, and less disruption is caused to other users of the building.

1.2 Possible Areas for Improvements to the Camden

Camdens are very costly in construction time. Builders require constant supervision as sloppiness at any stage of the construction can seriously compromise the sound insulation performance of the partition.

SOUND INSULATION OF LIGHTWEIGHT PARTITIONS

It was proposed that measurement of the sound insulation at various stages in the construction of a single and double Camden would give a valuable insight into the factors which control the sound insulation of lightweight partitions. With this insight and the above requirements in mind, design changes could then be suggested and their effects could be measured and assessed.

2. SINGLE CAMDEN

2.1 Introduction

The sound insulation between the source and receive rooms of BBC Research Department's Transmission Suite was measured at each stage in the construction of a single Camden. The purpose was to investigate how each layer of board contributes to the overall performance of the partition. The locations of the boards for each test are shown in the Appendix (B) and the results of the tests are shown in Fig. 1.

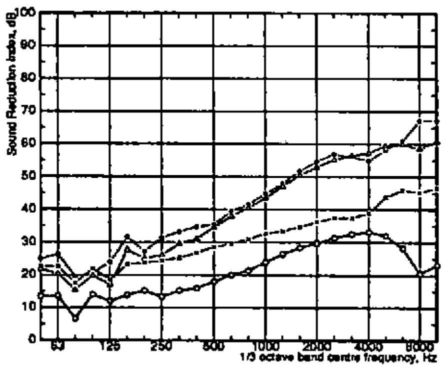

Fig. 1 - Various stages in the construction of a single Camden

- no plasterboard, one fibreboard
- one plasterboard, one fibreboard
- one plasterboard, two fibreboard
- two plasterboard, two fibreboard

2.2 Conclusions

The low frequency isolation of this type of lightweight partition is controlled by its mass. The slope of the isolation curve for a single Camden is 9 dB / octave. The coincidence frequency for 12.5 mm plasterboard is 4 kHz [2], and that for fibreboard is 8 kHz. When different types of boards are combined, the coincidence dips are shallower than those that would be observed if either type of board were used alone. Slight peaks at 160 Hz in the measured isolations of Camdens are probably caused by a system resonance involving the two double layers of boards and the 75 mm air-space.

It might be thought that the final layer of plasterboard could be omitted as it does not greatly increase the sound insulation of the partition. However the increase in isolation provided by this layer is worth having, and the plasterboard is also required for its fire-resistant properties. None of the tests so far have suggested simple ways in which the single Camden design could be improved. It is a good compromise between cost, width, weight and sound insulation.

3. DOUBLE CAMDEN

3.1 Introduction

The sound insulation between the source and receive rooms was measured at each stage in the construction of the second Camden leaf of a double Camden to investigate how each layer of board contributes to the overall performance of the partition. The locations of the boards for each test are shown in the Appendix (C)* and the results of the tests are shown in Fig. 2.

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*Note that the inner layers of plasterboard and fibreboard have to be cut to 0.6 m squares for insertion into the timber framework.

The level of vibration isolation afforded between the previously constructed single Camden and this second Camden leaf should be very high because the first leaf was built into the receive room walls, and the second leaf was built into the source room walls. The source and receive rooms are independently mounted on avms, and so the level of isolation between these two rooms and their walls is high.

3.2 Discussion

To investigate whether narrow gaps at the edges of the boards of fibreboard or plasterboard could impair the sound insulation of any of the partitions tested, the joints were filled with mastic, and the isolation only improved for the case of the plasterboard infill squares on the inner side of the second leaf of the double Camden. The improvement was up to 6 dB at high frequencies.

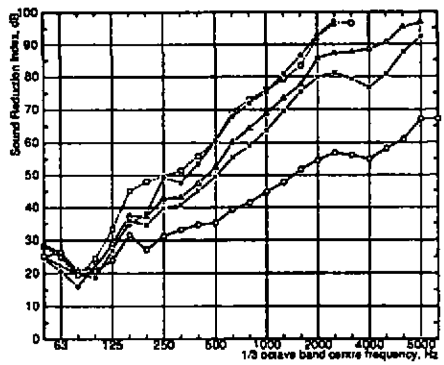

Fig. 2 - Various stages in the construction of a double Camden

3.3 Conclusions

When boards are being added to the second Camden leaf, the isolation between 50 Hz and 100 Hz seems to be controlled more by panel resonances than by the mass law. All of the curves shown in this section exhibit a dip in the isolation at 80 Hz which is thought to have been caused by the similar width air-spaces (75 mm and 50 mm). The isolation curves may be approximated by a straight line of slope 15 dB / octave from 100 Hz upwards.

Fibreboard is essential to damp the motion of the plasterboard, and the depth of the dip at the coincidence frequency for plasterboard (3.15 kHz - 4 kHz) depends upon the relative numbers of layers of plasterboard and fibreboard used. Peaks in the sound insulation curves for double Camdens at 160 Hz are thought to be caused by a resonance in the single Camden, and peaks at 250 Hz are thought to be caused by a resonance in the second Camden leaf.

When building a standard double or triple Camden, each infill square which is fitted to the 25 mm x 25 mm battens must be individually cut and filed to size. The joins at the edges of the plasterboard infill squares must be sealed with mastic. Note that mastic was not found to be necessary on the infill squares of fibreboard. Poor workmanship or insufficient supervision when the infill squares are being fitted will probably lead to an appreciably impaired sound insulation performance of the Camden.

All of the layers of boards contribute to the overall sound insulation of the double Camden and no layer can be omitted without compromising the isolation. However the contribution to the overall sound insulation made by the infill squares is out of all proportion to their cost in construction time. It was desirable to find some way of increasing the isolation of the remainder of the partition if the infill has been omitted so that the resultant isolation of the modified partition would be comparable with that of the double Camden. It is thought that because the layers of boards of the double Camden are all similar, and because the air-spaces are of similar width, that panel resonances occur which make the sound insulation curves irregular. In modifying the design of the Camden, it would be useful to introduce a degree of asymmetry to reduce the likelihood of problems caused by dips in the isolation curves at certain frequencies.

4. SINGLE CAMDEN PLUS PARAMOUNT

4.1 Introduction

It was thought that it might be possible to omit the infill layer if the plasterboard and fibreboard on the outer of the studding of the second leaf were replaced by a layer which contributed more to the overall sound insulation of the partition. It was suggested that a layer of "Paramount"* would be suitable for this purpose. Paramount consists of two 12.5 mm layers of plasterboard separated by, and bonded to a 38 mm thick cellular cardboard layer. 37 mm x 37 mm and 37 mm x 19 mm planed timber battens were used as an infill to support the edges of the sheet material, and screws were fitted through these to secure the boards to the outer face of the studding of the second leaf. Measurements were made with and without a layer of fibreboard between the Paramount and the studding of the second leaf.

4.2 Features of the Curve

The locations of the Paramount and other boards are shown in the Appendix (D,E) and the results of the sound insulation measurements are shown in Fig. 3. The curves are much smoother than that of the double Camden because of the asymmetry of the partition which discourages panel resonances.

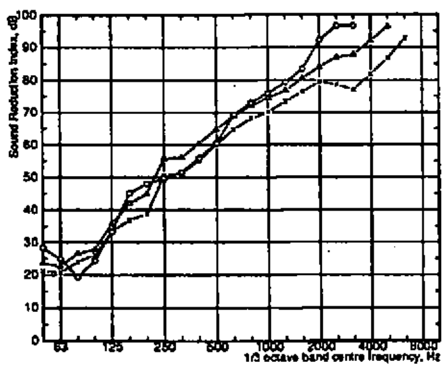

Fig. 3 - Paramount partitions compared with double Camden

- double Camden
- single Camden plus Paramount
- single Camden plus Paramount and fibreboard

4.3 Discussion

The average isolation of a partition of Paramount alone is 30 dB [3], and the previous measurement for a single layer of plasterboard and fibreboard had an average isolation of 29 dB. Other measurements not shown in this paper have demonstrated that the resultant isolation of the single Camden plus a leaf on the outer of the second stud is approximately equal to the isolation of the single Camden plus that of the second leaf (i.e. the two leaves behave independently).

The fact that the single layer of plasterboard and fibreboard has a similar isolation to that of the Paramount is quite surprising because the Paramount layer is almost twice as heavy, and also has a 38 mm intrinsic cavity. This observation suggests that the cardboard acoustically bridges the 38 mm cavity (the cellular cardboard is very rigid), and also highlights the beneficial effect of the fibreboard.

When fibreboard was used to damp the Paramount, the resulting isolation was comparable with that of the double Camden, although the Paramount partition had a much smoother isolation curve and did not suffer from a dip at 80 Hz.

*Paramount is a trade name registered to British Gypsum Ltd.

4.4 Conclusions

The Paramount based partition using fibreboard had a comparable isolation with that of the double Camden, but it had two serious drawbacks :-

a) The construction time and cost would probably be similar to that of the double Camden.

b) The partition is 50 mm wider than a double Camden.

Paramount was found to be unsuitable for use in this type of studio partition. Paramount is intended as simple, cheap office partitioning, but the degree of isolation it provides is comparatively poor.

5. SINGLE CAMDEN PLUS 19 MM THICK PLASTERBOARD "PLANK"

5.1 Introduction

The partition using Paramount described in the previous section did not show any great benefits over the double Camden. Therefore a similar approach was adopted, but instead of the Paramount, 19 mm plasterboard planks were used. Fibreboard was used behind the 19 mm planks because all previous measurements have suggested that the use of fibreboard with plasterboard is beneficial.

5.2 Features of the Curve

The locations of the boards are shown in the Appendix (F) and the results of the sound insulation measurement are shown in Fig. 4. Once again, the curve is much smoother than that of the double Camden because the asymmetry of the partition discourages resonances. The low frequency isolation is much better controlled than that of the double Camden. The overall isolation is comparable with that of the double Camden, although its isolation both in the range 160 Hz - 200 Hz and above 500 Hz is worse than that of the double Camden.

5.3 Conclusions

Apart from the isolations between 160 Hz and 200 Hz, the performance of the partition using 19 mm plank compares very favourably with that of the double Camden. The 19 mm plasterboard plank is more manageable and easier to fit than sheets of 12.5 mm plasterboard because of the smaller board dimensions (2.4 m x 0.6 m x 19 mm against 2.4 m x 1.2 m x 12.5 mm). However, it was felt that the design could be improved further and that the lower integrity of the second leaf at 160 Hz - 200 Hz might cause problems, especially if the design were extended to a triple leaf partition.

6. SINGLE CAMDEN PLUS TWO LAYERS OF PLASTERBOARD

6.1 Introduction

The sound insulation performance of the partition based on 19 mm plasterboard plank was marginally less than that of the double Camden. Therefore a new experiment was carried out with two layers of 12.5 mm plasterboard in place of the 19 mm plasterboard plank.

6.2 Features of the Curve

The locations of the boards are shown in the Appendix (G) and the isolations are shown in Fig. 4. The coincidence dip at 3.15 kHz is fairly pronounced which shows that the two replacement layers of plasterboard were acting independently at this frequency (otherwise the coincidence frequency would have been lower). Also they are only associated with one layer of fibreboard (so the damping effect is less) rather than two as in the second leaf of the double Camden.

SOUND INSULATION OF LIGHTWEIGHT PARTITIONS

6.3 Conclusions

The isolation curve of the partition using a double layer of plasterboard is better than that of the double Camden. There is no low frequency panel resonance, and the isolation from 250 Hz to 500 Hz is about 5 dB higher than that of the double Camden. The sound insulation curve is much smoother because of the asymmetry of the partition, and the curve is a much better fit to the general curves of sound insulation requirements between BBC studio areas than that of the double Camden.

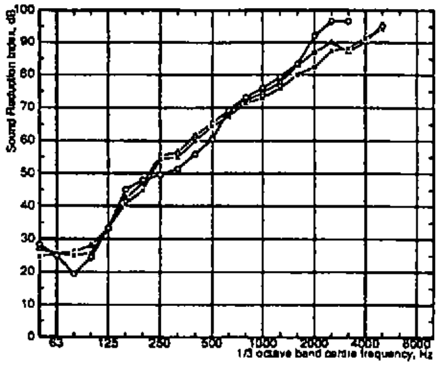

Fig. 4 - Two new types of partition

The partition uses less material (one fewer layer of fibreboard and no 25 mm x 25 mm timber battens) than the double Camden and the associated savings in labour costs are large. The partition should be more tolerant of poor workmanship and building supervision than the double Camden. Further work is being carried out to ensure that the fire integrity of the cavity is maintained.

7. OVERALL CONCLUSIONS

Several novel partition designs have been investigated with the aim of finding a cheaper alternative to the Camden. None of the tests suggested simple ways in which the single Camden design could be improved.

A new partition design has been tested and will be recommended as a replacement for the double or triple Camden when proving of the impact isolation of the partition has been completed. It requires fewer materials than the Camden, is much cheaper to build, and should be more tolerant of poor building practices. It also has a slightly higher sound isolation than the Camden, and its insulation curve is much smoother and does not suffer from dips at low frequencies.

The sound insulation curve of the double Camden is thought to be irregular and to suffer from low frequency dips because of panel resonances caused by the high degree of symmetry (the same type of layer is repeated each time and is separated from the next by a similar width air-space).

Fibreboard has been shown to provide large increases in sound insulation in proportion to its mass because of its ability to damp the motion of the plasterboard. It also reduces the depth of the coincidence dip for plasterboard by resonating at a higher frequency and by adding damping.

8. REFERENCES

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2. GILFORD, C. Acoustics for radio and television studios, p62. Peter Peregrinus Ltd. 1972.

3. *ANON.* 1984. British Gypsum White Book, p172. Hutton & Rostron. 1984.

ACKNOWLEDGEMENT

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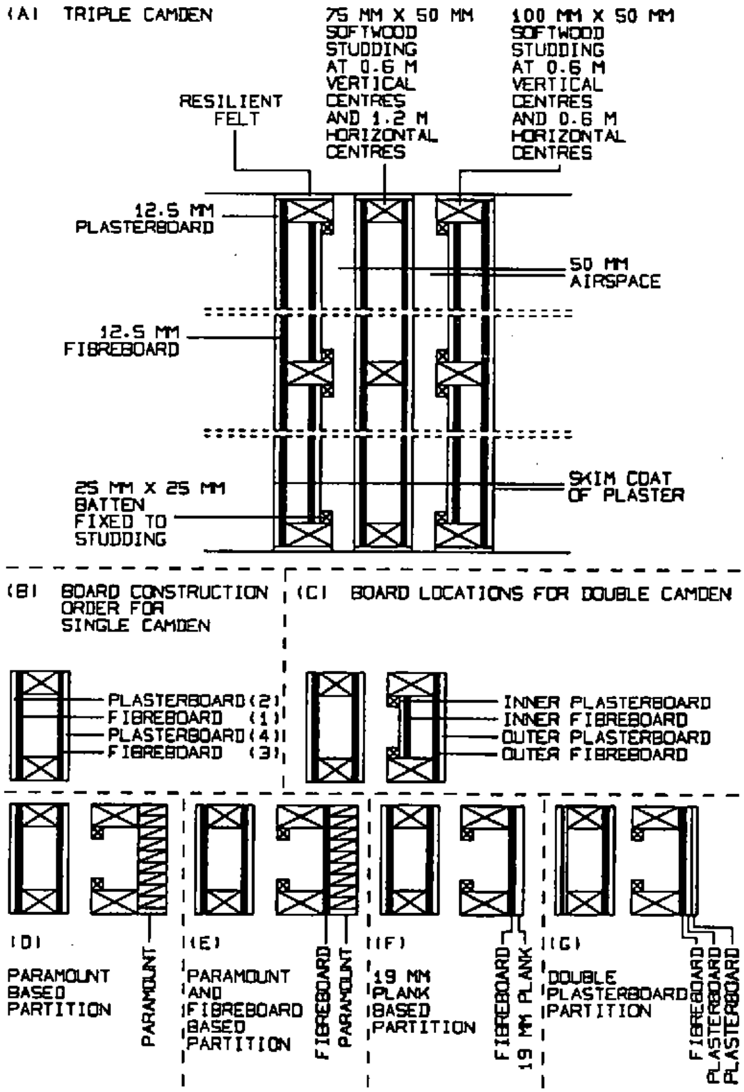
APPENDIX


(A) TRIPLE CAMDEN
75 MM X 50 MM SOFTWOOD STUDDING AT 0.6 M VERTICAL CENTRES AND 1.2 M HORIZONTAL CENTRES
100 MM X 50 MM SOFTWOOD STUDDING AT 0.6 M VERTICAL CENTRES AND 0.6 M HORIZONTAL CENTRES
RESILIENT FELT
12.5 MM PLASTERBOARD
50 MM AIRSPACE
12.5 MM FIBREBOARD
25 MM X 25 MM BATTEN FIXED TO STUDDING
SKIM COAT OF PLASTER
(B) BOARD CONSTRUCTION ORDER FOR SINGLE CAMDEN
PLASTERBOARD (2)
FIBREBOARD (1)
PLASTERBOARD (4)
FIBREBOARD (3)
(C) BOARD LOCATIONS FOR DOUBLE CAMDEN
INNER PLASTERBOARD
INNER FIBREBOARD
OUTER PLASTERBOARD
OUTER FIBREBOARD
(D) PARAMOUNT BASED PARTITION
PARAMOUNT
(E) PARAMOUNT AND FIBREBOARD BASED PARTITION
FIBREBOARD
PARAMOUNT
(F) 19 MM PLANK BASED PARTITION
FIBREBOARD
19 MM PLANK
(G) DOUBLE PLASTERBOARD PARTITION
FIBREBOARD
PLASTERBOARD
PLASTERBOARD

A CROSS CORRELATION METHOD FOR MEASURING THE SOUND REFLECTED FROM DIFFUSING SURFACES

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1. INTRODUCTION

It is well known that the effects of reflecting surfaces on sound generally follow simple empirical rules depending on the wavelength of the sound and dimensions of the surface. There are many surfaces in auditoria - such as overhead reflectors, balcony fronts and walls which subdivide audiences - which are small enough to diffract sound at the lower end of the audible frequency range. At the moment there is little experimental data on how these surface reflect sound in both the near and far fields. Yet such surfaces are crucial in determining the sound field received by the audience, particularly the early sound field.

For example, it is becoming more and more common for audiences to be subdivided into smaller blocks, as in St David's Hall, Cardiff. The main principle behind this is to provide more early lateral energy to the listener and so increase the feeling of spatial impression. This has resulted in quite large numbers of people being near to reflecting surfaces. But there is little data on how these surfaces reflect sound in the near field. Neither can computer ray tracing models deal satisfactorily with the diffraction effects. Consequently, an exact measurement of the effects of such surfaces could aid auditoria design.

Before dealing with the surfaces in situ, an experimental method has been devised to measure the sound field reflected from the surfaces alone. Initial experiments have been carried out on a quadratic residue diffusor (QRD). This is described below.

2. THE MEASUREMENT SYSTEM

A schematic representation of the experimental set up is shown in figure (i). The source signal is white noise played through a loudspeaker; this approximates to plane waves in the region around the microphones and diffusor. Two microphones measure the resulting sound pressure levels: the one nearest the loudspeaker is stationary, the second rotates about the diffusing surface to produce polar plots. The two microphone signals are fed to the dual channel FFT analyser (Ono Sokki) which calculates all the necessary cross correlation and spectral functions. The cross correlation function calculated between the two microphone signals is at the heart of the measurement system.

A cross correlation between the two microphones produces four peaks, as each microphone signal consists of incident and reflected sound. An example is shown in figure (ii). (The fourth peak is missing as it is outside the time limits used for the cross correlation). Once the reflected sound peak has been isolated, see later, a Fourier transform of this impulse response is taken. Corrections are then made for the response of the source and pick-up systems, as well as for the difference in the two microphone responses. This then gives the transfer function for the panel.

The reflected sound peak is separated from the other three peaks by two processes:
(1) A measurement of the system with no panel present produces a cross correlation with a single peak, figure (iii). This then can be subtracted from the cross correlation with the diffusor present. Subtraction is necessary for measurements close to the panel as the tail of the incident sound peak may overlap the reflected sound peak. It also has the advantage of removing any unwanted reflections from apparatus - such as the boom arm - provided these are common to both measurements. A typical result for the subtraction of the cross correlations is shown in figure (iv).
(2) A consideration of arrival times allows the blanking off of any remnant of the incident sound peak after subtraction, as well as removing the two smaller 'secondary' peaks. See figure (iv).

The measurement system can be summarized by the following equation for the transfer function of the test panel:

$$H(w) = \frac{FFT\,[Rxy_{1-2}(\tau)].\exp(iw\tau_0)}{Sxx_2(w).\Gamma(w)}$$

where $Rxy_{1-2}(\tau)$ is the cross correlation after processing by subtraction and time elimination.
$Sxx_2(w)$ is the autospectrum measured by the loudspeaker microphone with no diffusor present. This normalizes for the response of the source and microphone systems.
$\Gamma(w)$ is the transfer function between the two microphones;
$\exp(iw\tau_0)$ is a phase factor to compensate for time delays.

The calibration of the microphones is done by placing the two microphones a few centimetres apart and several metres from the loudspeaker in the anechoic chamber. White noise is played through the loudspeaker and the transfer function between the two microphones is given by the cross spectra.

The major draw back of the system is the large amount of time needed for the measurement. As the sound source is white noise, a large number of averages of the cross correlations have to be taken to reduce the random error to acceptable levels; typically 1024 averages are used. A graph of random error verses frequency shows a series of minima and maxima, see figure (v) - a result for 128 averages. (As the incident and reflected sound interfere with each other a series of sound pressure level minima and maxima are produced at the diffusor microphone. At frequencies where the sound pressure level is a minimum the signal to noise level is reduced and consequently the random error increases.) For 1024 averages the mean error is about 7%, but this fluctuates between 14% and 3.5% with frequency. The measurement takes about 24 hours in total for a resolution of 2°, and consequently the measurement process is fully automated. A computer (Compaq IBM-compatible portable) controls both the FFT analyser and the rotating boom arm carrying the diffusor microphone. The apparatus was found to be stable enough over this time period not to significantly affect the accuracy of the experiment.

Due to the size of the anechoic chamber, scale models of the diffusors have to be used. So far a 1:5 scale model of a single period quadratic residue diffusor (QRD) has been tested. It is based on the prime number seven and is similar to those used by A.H Marshall in Wellington Town Hall, New Zealand [1]. Most QRDs installed in recording studios have a large number of very deep and narrow wells. In auditoria such a design would cause too much absorption and so the diffusor is designed with a smaller number of much shallower wells. The main body is constructed from hardwood, the fins from plywood; the dimensions are given in figure (vi).

3. RESULTS

Polar plots of the transfer function of the QRD at three different frequencies for normal incident sound are given in figures (vii) - (ix). These are for a diffusor - microphone distance of 1.01m scale size, 5.05m full size. (The microphone is normal to the diffusor.) The average standard error is about 7%, the resolution is 2°.

The frequency response of the panel roughly divides into three regions. At low frequencies - below about 600 Hz model scale, 120 Hz full scale - the diffusor reflects sound uniformly in all directions, and there is little fine detail, figure (vii). The main influence on the sound field is the total size of the diffusor, the wells being too small relative to the wavelength to have much effect. At high frequencies, above about 8000 Hz (1600 Hz full scale), the polar plot shows great variation with a large number of peaks and troughs, yet the underlying distribution is uniform, figure (viii). In the mid frequency range, however, the distribution is not so uniform; there are many wide peaks and troughs, figure (ix).

Also included is a comparison between the experimental result for 1000 Hz (200 Hz full scale) and a theoretical prediction based on a simple Fraunhoffer diffraction model, figure (x). The Fraunhoffer theory predicts the reflection field to be the Fourier transform of the diffusor's surface [2,3]. The result is typical; the theory succeeds in predicting the overall gross structure of the reflection pattern, but nothing of the fine detail which can be as much as +- 8 dB. The failure of the theory is to be expected as it is an over-simplified model; for example it assumes measurement in the far field.

4.CONCLUSIONS

A system has been successfully set up to measure the reflection of diffusing panels as a function of angle and distance from the panel. The use of a cross correlation technique has allowed simple separation of the incident and reflected sound, leading to an accurate measurement of the surface's transfer function.

5.FUTURE WORK

Further investigations into the properties of QRDs will be done. Other surfaces such as plane and curved panels will be tested. These results should allow the validation of theories concerning all three reflector types. The measurement technique is being adapted to use a maximum length sequence signal instead of white noise. As the maximum length sequence is a determinant signal this will remove the necessity for time-consuming averaging without a loss in accuracy.

5.REFERENCES

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[2] M.R.Schroeder, "Binaural Dissimilarity and Optimum Ceilings for Concert Halls: More Lateral Sound Diffusion", J.Acoust.Soc.Am., Vol. 65, 1979, 958-963.
[3] P. D'Antonio & J.H.Konnert, "The Reflection Phase Grating Diffusor: Design Theory and Application", J.Audio Eng.Soc., Vol 32, 1984, 228-240.

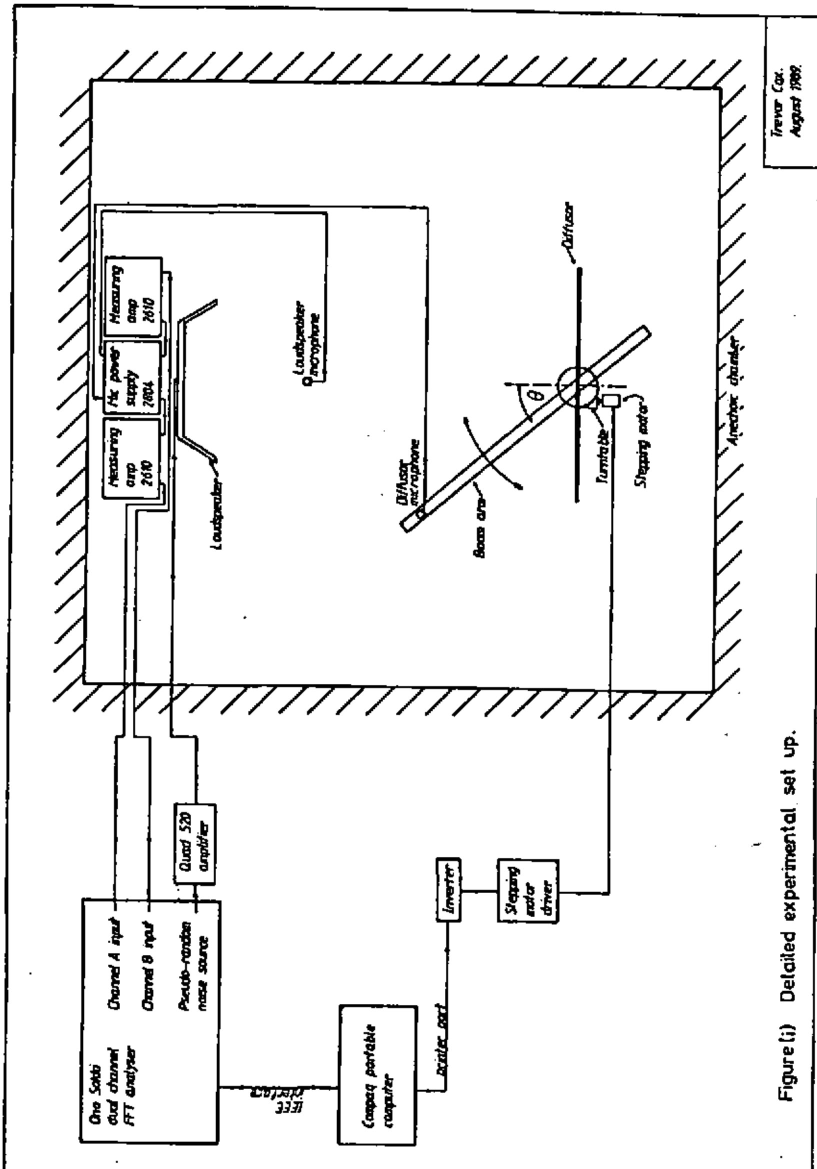


Figure (i) Detailed experimental set up.

Figure (ii) Cross Correlation Function With Diffusor Present.
Microphone normal to QRD, normal incident sound, 1024 averages.

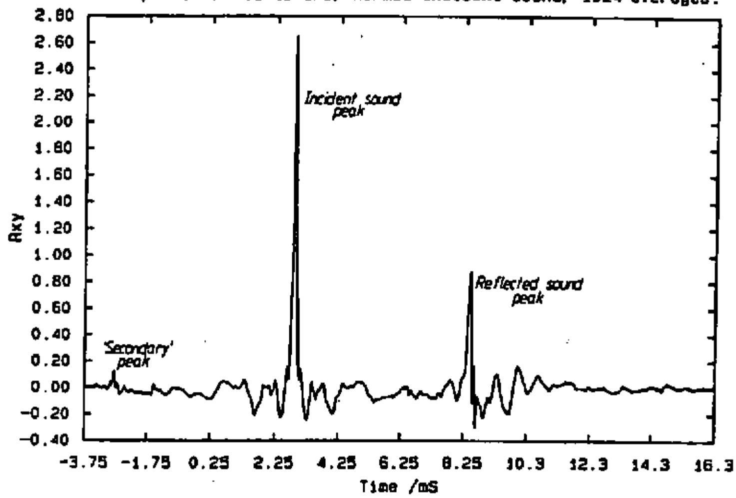


Figure (iii) Cross Correlation Function, No Diffusor Present.
Microphone normal to QRD, normal incident sound, 1024 averages.

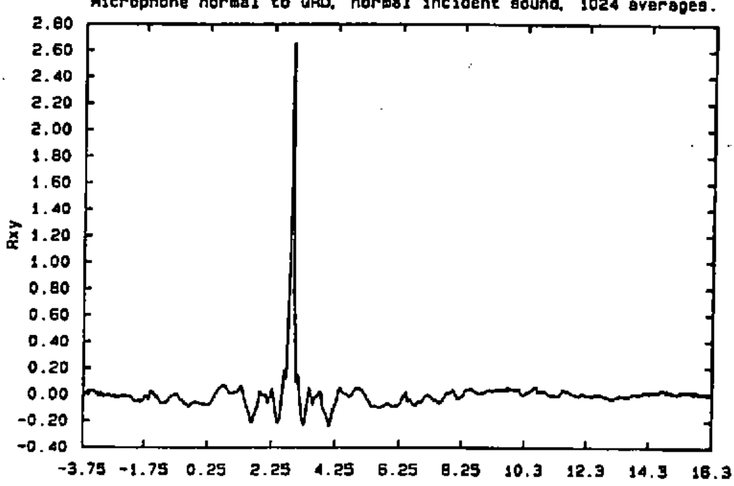


Figure (iv) Processed Cross Correlation Function.
Processed cross correlation produced by blanking off region shown

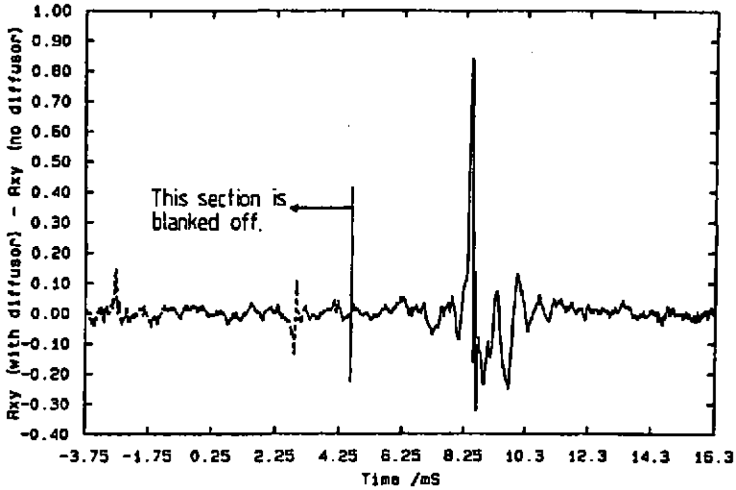
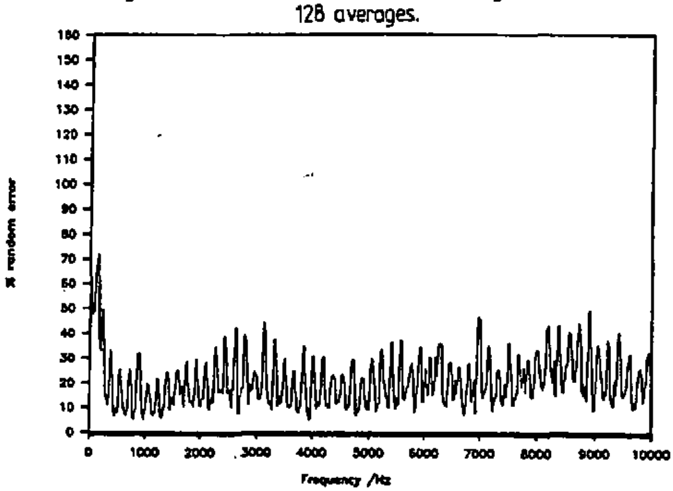


Figure (v) Error in transfer function magnitude
128 averages.



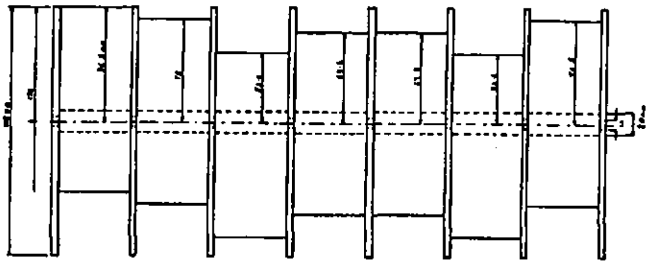


Figure (vi) The quadratic residue diffusor tested.

Figure (vii) Measured Transfer function magnitude of QRD.
500 Hz model scale, 100 Hz full size.
Each circle is 10 dB

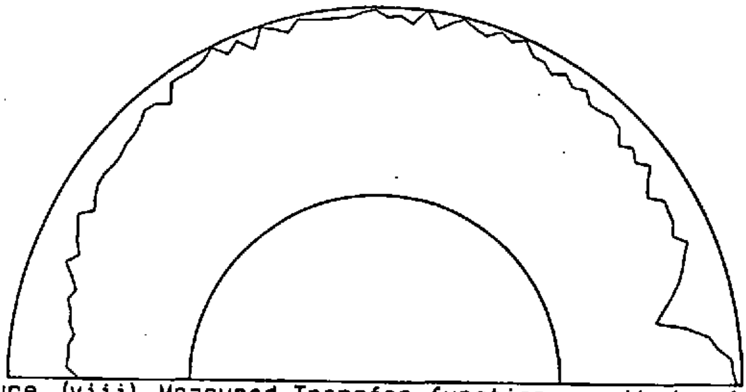


Figure (viii) Measured Transfer function magnitude of QRD
17500 Hz model scale, 3500 Hz full size.
Each circle is 10 dB

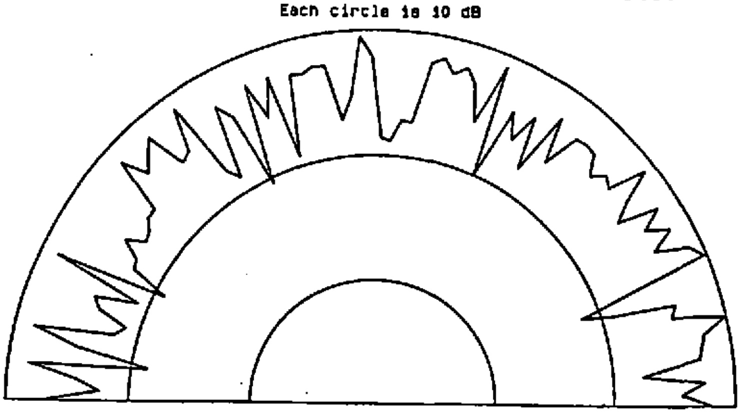


Figure (ix) Measured Transfer function magnitude of QRD 1000 Hz model scale, 200 Hz full size.

Each circle is 10 dB

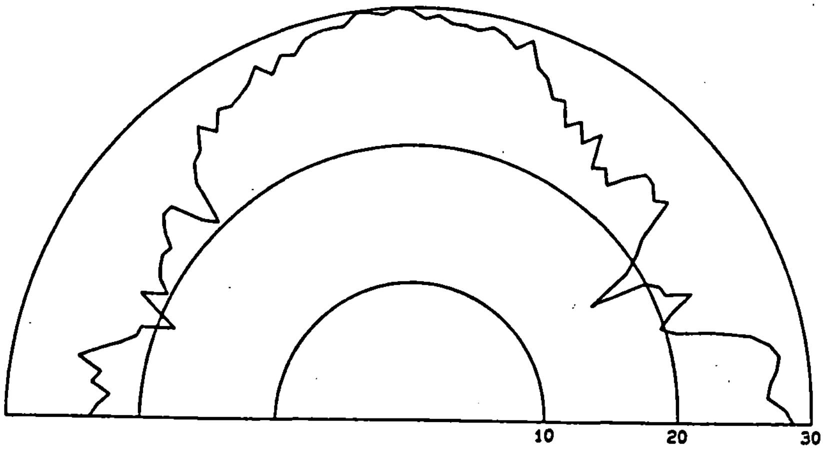


Figure (x) Transfer function magnitude of QRD
Measured values (1) compared to theoretical prediction (2)
1000 Hz model scale, 200 Hz full scale