PHASED AND DIFFUSED: the problem of measuring and designing semi-reverberant, partly diffused spaces

A.S. Munro Munro Acoustics Ltd. London SE1, UK

1. INTRODUCTION

For many years a series of equations have been used to design and predict the performance of sound systems and acoustic environments based on statistically diffused soundfields and idealized directivity patterns. Although these equations have been modified for semi reverberant spaces there is a significant error produced by the strength of both early reflections and room modes. A comparison of theory and measurement applied to film mixing theatres leads to some interesting conclusions

In the course of setting up and measuring a number of large and medium sized film dubbing and mixing theatres it became apparent that the rooms were considerably less reverberant than normally accepted practice dictates. This was noticed more in the ratio of direct and early to reverberant energy than in the computed value of T_{60}, which was more or less as predicted. This effect is well known in concert halls (1) and various modifications have been made to the classical Hopkins-Stryker Equation (see equation 2) as shown in Equation 1.

This modified version attempts to correct the Critical Distance (radius) at which the direct sound falls to the same level as the diffused soundfield. An architectural modifier M_a takes into account the absorption within the coverage angle of the source (speaker system), which is usually greater than the average for the auditorium. The equation does produce more accurate results but as will be shown fails to fully describe the loss of reverberant energy. All time domain measurements and calculations are for the mid frequency band 500-2000Hz. Frequency measurements are full bandwidth.

1.1. Theatres Analyzed

Five theatres were chosen to carry out a detailed comparison of theoretical and measured data. In order to provide the widest possible picture rooms of different sizes and purpose were used and the physical data is as in Table 1.

Room	Type	Volume M^3	Nominal T_{60}	Initial Delay (ms)
A	Dubbing	237	0.35	23
B	Mixing	660	0.37	38
C	Mixing	181	0.21	20
D	Mixing	695	0.35	40
E	Preview	1411	0.42	45

Table 1

The rooms are all well known film post production theatres with the mixing (and measuring) position approximately 2/3 of the main axis length, with an initial time delay as shown in Table 1. All rooms are rectangular.

Equation 1

$$L_{act} = L_w + 10\log(\frac{Q}{4\pi D_c^{\,2}}) + (1.33.\frac{\sqrt{V}}{hT_{60}})(\log\frac{D_c}{D_x})$$

$$D_c = 0.057\sqrt{\frac{QVM_a}{T_{60}N}}$$

where

$L_{act} = actual.soundpressure$

$L_w = source.sound.power$

$Q = source.directivity.factor$

$D_c = critical.radius$

$M_a = average.absorption.coefficient / absorption.within.source.angle$

$V = room.volume$

$D_x = metres.from.source$

$h = theatre.height$

$N = total.sources / sources.within.\mathrm{cov}\,erage$

$T_{60} = reverberation.time$

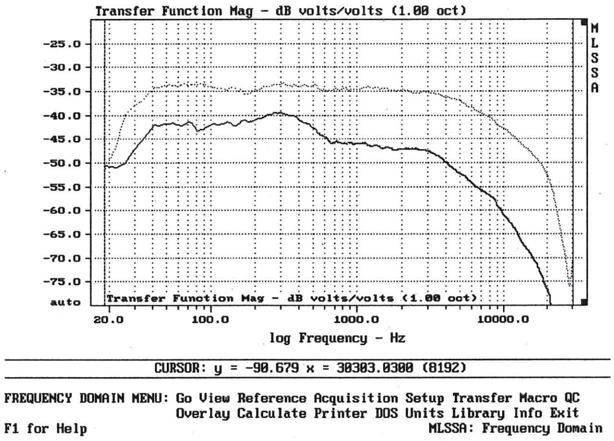
General Method

Each room was measured using an MLS analyzer to obtain the periodic impulse response for a 500ms impulse length at a sampling rate of 60KHz (20Khz bandwidth). Squaring and Schroeder Integration was then applied to obtain the Energy-Time Response and the Reverberation Time (T_{60}). FFT algorithms were used to obtain the transfer function (Energy-Frequency Response) for various Time Windows. This data is shown as Early to Late Ratio (C_{50}) and Early to Total Ratio (C_{t50}). The measured data was then compared to the predicted performance obtained using Equation 1.

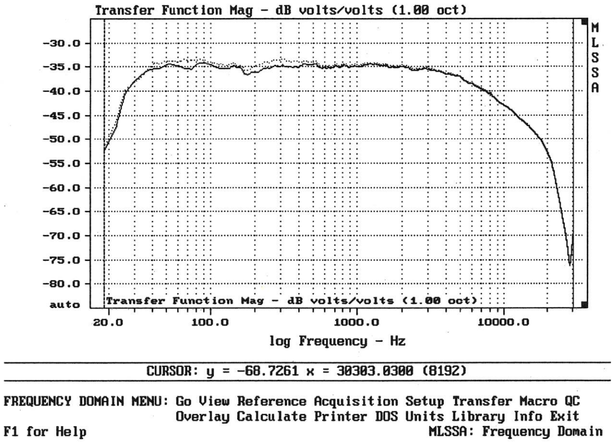
2. THEATRE A

This theatre is one of four identical rooms used for checking and re-recording foreign language versions of many internationally released productions. The measured speaker system is a fully active 4-way monitor with direct radiating drivers (no horns).

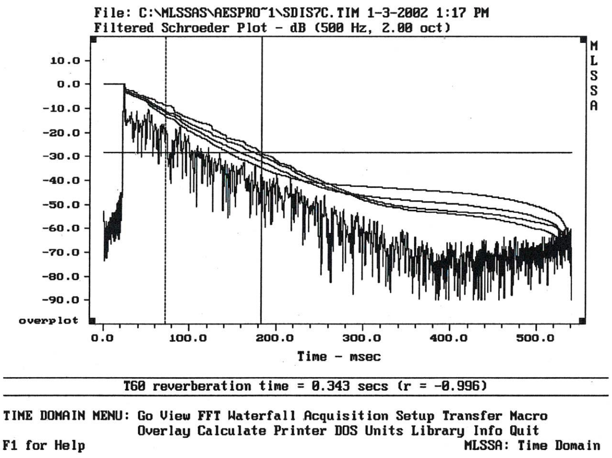
2.1. Test Results



C50



C_t50

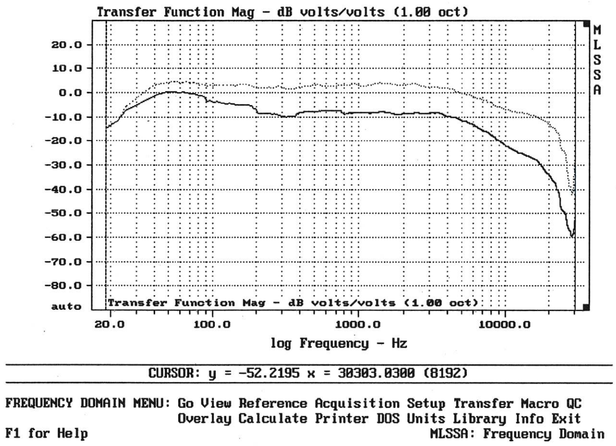


ETC and Schroeder Integration (T60)

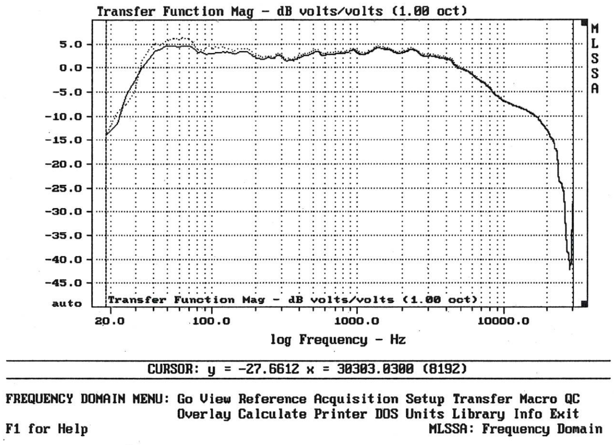
3. THEATRE B

This room is a large re-recording theatre used for major international features, including Oscar nominations. It also serves as a preview theatre with 60 permanent seats and a large seating area to the rear. The sound system is a 7.1 arrangement, based on customized 3-way units with digital control unit.

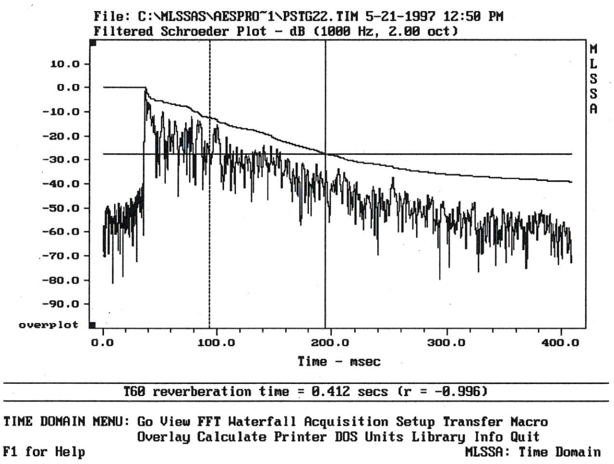
3.1. Test Results



C50



C_t50

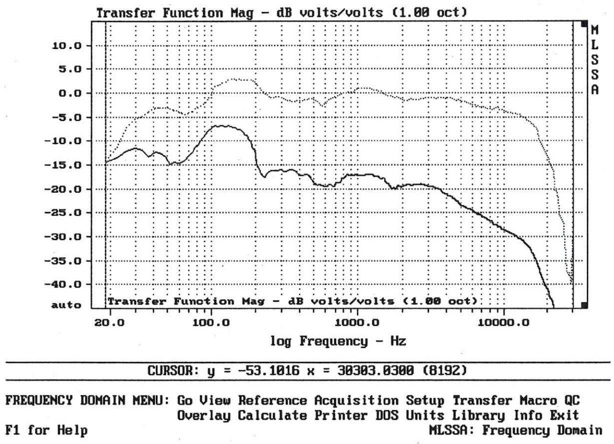


ETC and T60

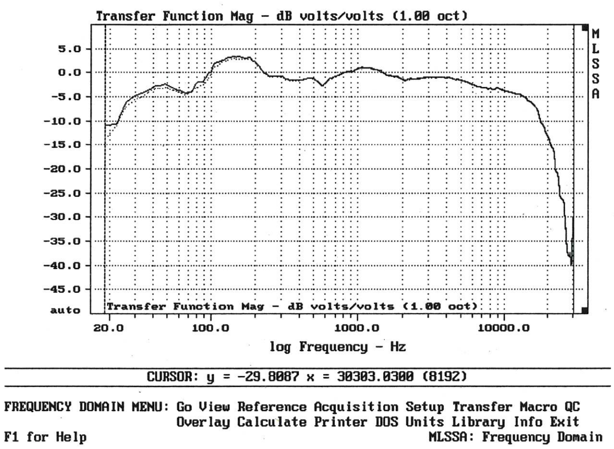
4. THEATRE C

Room C is a smaller space used for mixing and dubbing feature film and some television work. The speaker system is a standard 2-way cinema model with THX electronic crossover.

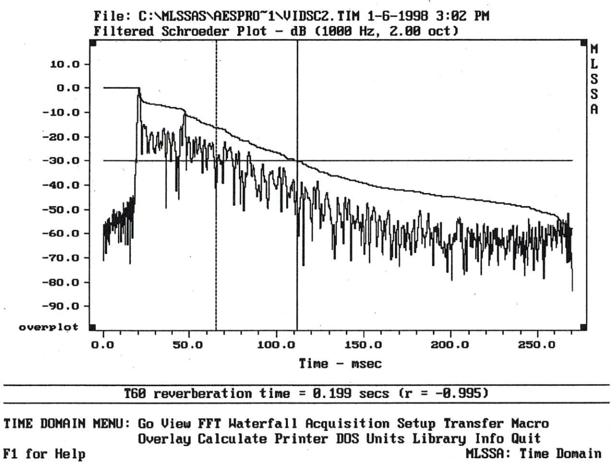
4.1. Test results



C50



C_t50

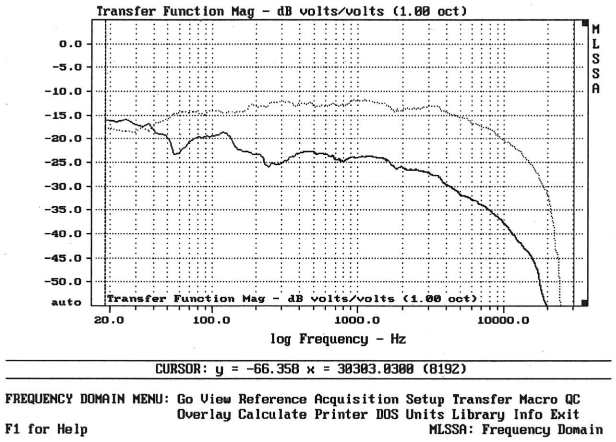


ETC and T60

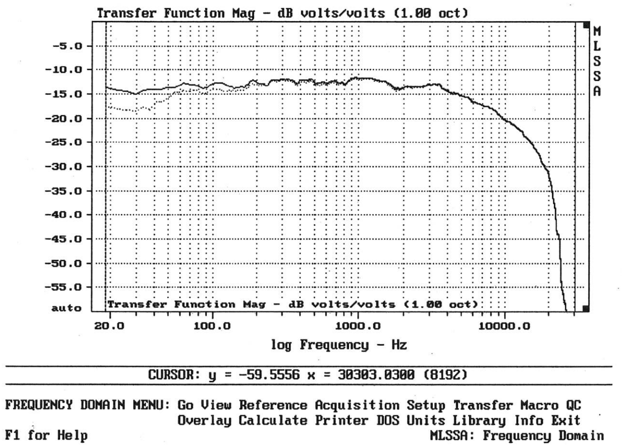
5. THEATRE D

This is a London mixing theatre with an international reputation. The speaker system is a customized 3 way model as Theatre B.

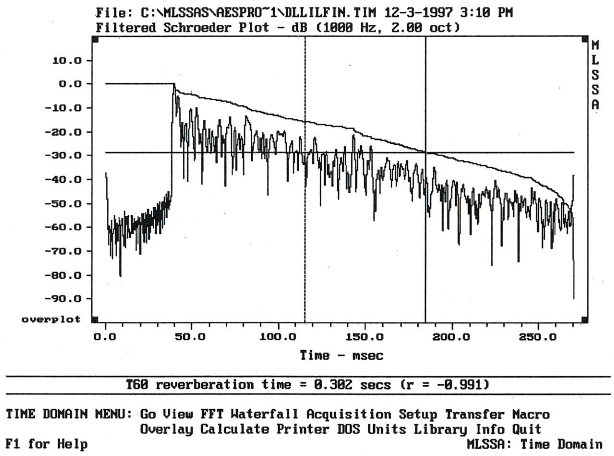
5.1. Test Results



C50



C_t50

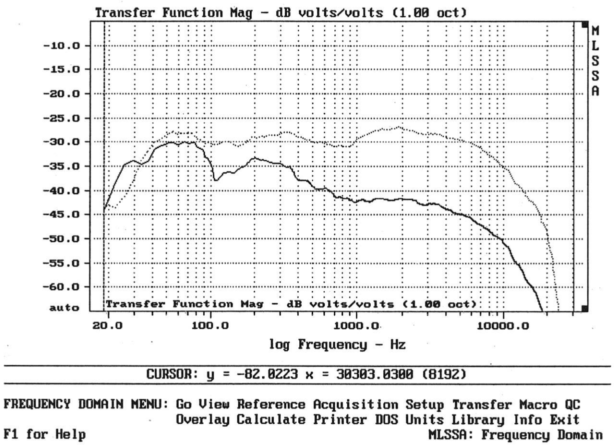


ETC and T60

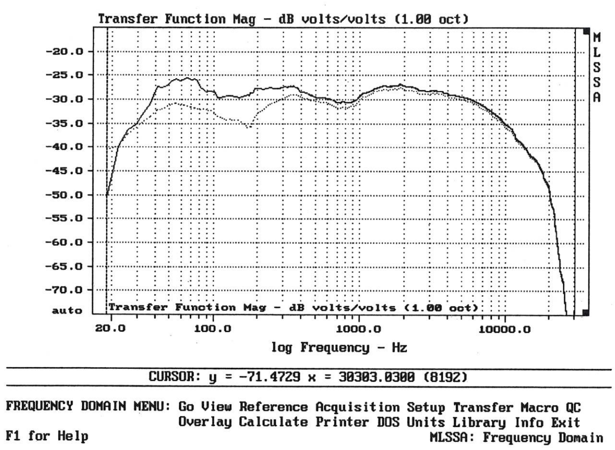
6. THEATRE E

Theatre E is the largest in this survey and is one of the few preview and presentation rooms used for viewing final mixes of major feature films. The sound system is a standard 2-way cinema system (as C).

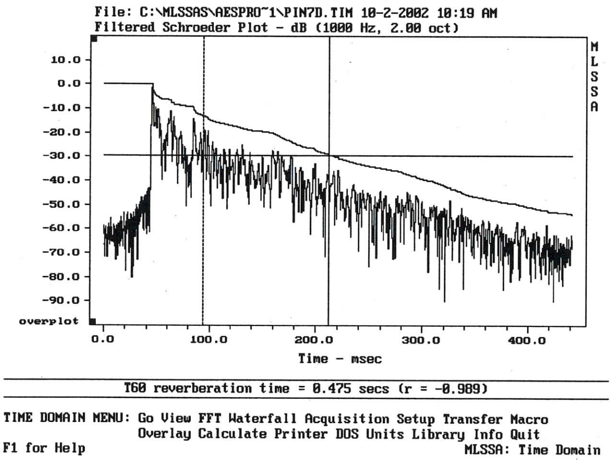
6.1. Test Results



C50



C_t50



ETC and T60

7. THEORETICAL DATA

Each room was analyzed using the available acoustic data and the known physical properties inserted into the classical (old) Hopkins Striker Equation (Equation2) and the Modified version (Equation 1). The results are shown as a chart and then compared with the measured data. The same frequency band has been used (500-2KHz) for the calculations.

Equation 2

$$Lp = L_w + 10\log(\frac{Q}{4\pi D_c^{\,2}}) + (\frac{25TN}{VM_a})$$

$$D_c = 0.057\sqrt{\frac{QVM_a}{T_{60}N}}$$

where

$Lp = calculated.soundpressure$

$L_w = source.sound.power$

$Q = source.directivity.factor$

$D_c = critical.radius$

$M_a = average.absorption.coefficient / absorption.within.source.angle$

$V = room.volume$

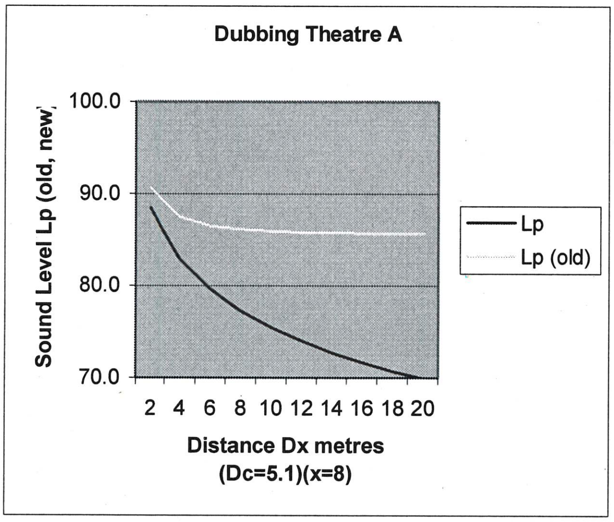
$D_x = metres.from.source$

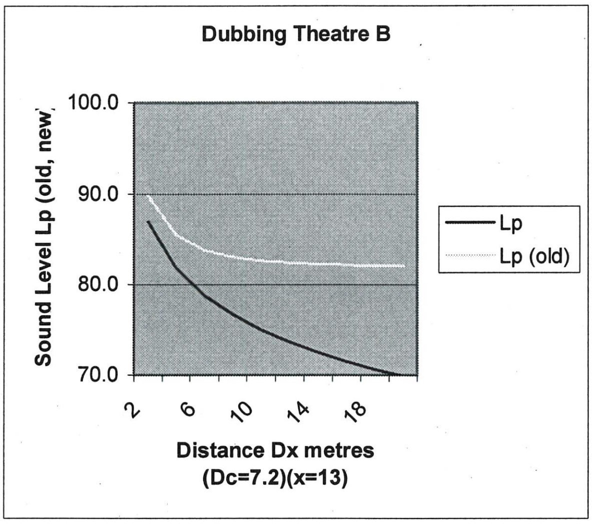
$h = theatre.height$

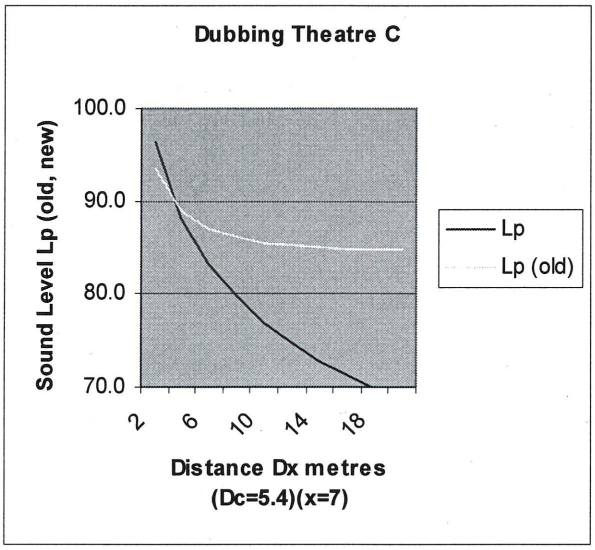
$N = total.sources / sources.within.coverage$

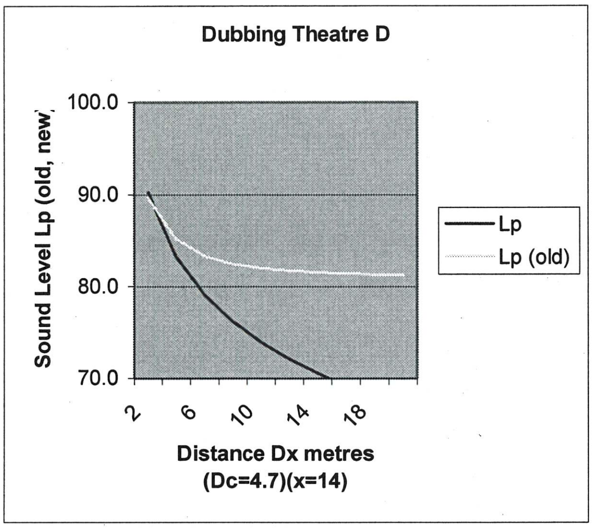
$T_{60} = reverberation.time$

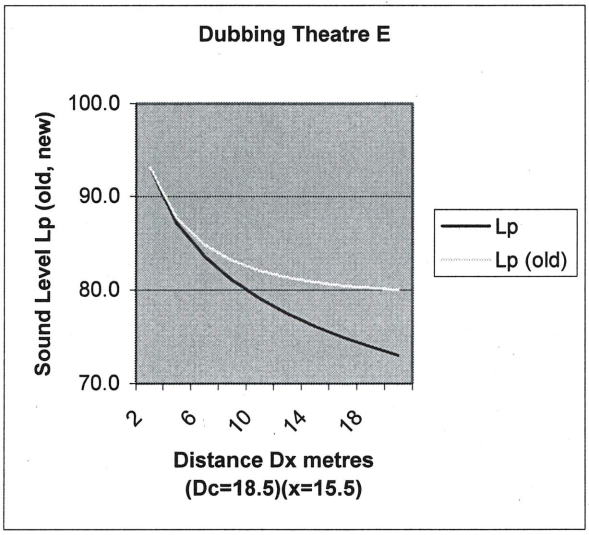
7.1. Calculated Data




Dubbing Theatre B
Sound Level Lp (old, new)
100.0
90.0
80.0
70.0
2
6
10
14
18
Lp
Lp (old)
Distance Dx metres
(Dc=7.2)(x=13)


Dubbing Theatre C
Sound Level Lp (old, new)
100.0
90.0
80.0
70.0
2
6
10
14
18
Lp
Lp (old)
Distance Dx metres
(Dc=5.4)(x=7)





8. COMPARISONS

The actual test results show a C50 equivalent value at the point of measurement. It is clear that the value is well above the figure that would have been obtained if the measurement point were beyond the true Critical Distance (at which C50 would be zero). The ratio is positive, even at low frequencies, where D_c is usually expected to be short. It is also clear that the total energy in each room consists almost entirely of the first 50ms (or less) so that the reverberant energy has little or no effect on the steady state loudness of the sound that is received at the mixing position in each theatre. The only exception is Theatre E, the largest by far, at low frequencies, where significant energy arrives after 50ms.

The theoretical charts show the first 58ms of sound travel from the screen speaker, which covers the length of the largest theatre (20m). The distance Dx that was used in each test is indicated together with the Dc calculated using Equations 2. In every room except E it can be seen that the listening (or mix) location is roughly twice the traditionally calculated Dc. However the modified equation 1 shows that there is a 10dB difference in the reverberant sound level, resulting in a similar drop in the resulting total sound level.

9. CONCLUSIONS

The following conclusions can be made from the results

1. The mixing position in most rerecording and dubbing theatres is well within the critical distance and that consequently the reverberant energy has little or no effect on the loudness of the sound.

2. Larger theatres have even greater values of Dc and the mixing position is well within the direct soundfield. It follows that the sound system will be up to 20dB lower than at the front of the theatre and this has serious implications for theatres with audience seating.

3. The designer of cinemas needs to consider the implications of such potentially large variations in positional sound level.

4. The design of the speaker system can influence the resulting soundfield in a significant way, by controlling directivity and coverage, especially as the first 50ms was found to contain all the useful energy.

5. The existing formulae do not specifically address the discrete reflections within the first 50ms and the methods proposed by Mankovsky (3) and others should be given more credence. It is intended that further analysis be carried out for a future paper.

10. REFERENCES

[1] Barron M. JASA Issue 84 pp618 and Auditorium Acoustics (E. & FN Spon) pp32

[2] Davis D. 72nd AES Convention Anaheim 1982

[3] Mankovsky V.S. Acoustics of Studios and Auditoria, Focal Press 1971