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THE REFLECTION FULL ZONE

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INTRODUCTION

Control and listening rooms are often designed to achieve a large initial time delay gap between the direct sound from the loudspeakers and the first early reflection. This allows the listeners to listen through the system to the acoustic space being recorded. A variety of ways [1-3] have been used to achieve this based on either absorption or specially shaped rooms or walls. These methods have a variety of advantages and disadvantages in terms of absorption, region of effect, and level of artefacts away from the optimum listening position. They also have implications for the quality of sound that can be achieved if the performer wishes to be present in the control room whilst being recorded.

The purpose of this paper is to show how correctly placed diffusion structures can also be used to provide an effective initial time delay gap within control and listening rooms. This technique produces a dense series of low level reflections within the initial time delay gap, hence the title of the paper. The treatment can offer advantages, both at the optimum listening position and away from it. This can be particularly useful in smaller control rooms where it is sometimes difficult to achieve the optimum effect over a broad enough area for all the listeners involved. It also offer acoustic advantages for performers within the control room.

The paper will first review current approaches to controlling early reflections and will then look at how diffusers can fulfil the same function. It will then discuss the effect of diffusers on the early reflection energy using a simple theoretical model.

2 BACKGROUND

One of the main advances in the acoustical design of Control and listening rooms has been the realisation that, as well as reverberation time, the time evolution of the sound energy in the room is important. An idealised energy time curve for a room is shown in figure 1 and it has three major features:

- A gap between the direct sound and first reflections, this happens naturally in most spaces and gives a cue as to the size of the space. The gap should not be to long, less than 30ms, or the early reflections will be perceived as echoes. Some delay, however, is desirable as it give some space for the direct sound and so improves the clarity of the sound but a shorter gap does add "intimacy" to the space.
- The presence of a high level diffuse early reflections which come to the listener predominately from the side, that is lateral early reflections. This adds spaciousness and is easier to achieve over the whole audience in a "shoe box" hall rather than a fan shaped one. The first early reflections should ideally arrive at the listener within 20ms of the direct sound. The frequency response of these early reflections should ideally be flat and this, in conjunction with the need for a high level of lateral reflections, implies that the side walls of a concert hall should be diffuse reflecting surfaces with minimal absorption.

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- A smoothly decaying diffuse reverberant field which has no obvious defects, and no modal behaviour. This is hard to achieve in practice so a compromise is necessary in most cases. For performing acoustic music a gentle bass rise in the reverberant field is often desirable to add "warmth" to the sound but in studios this is usually less desirable.

2.1 Reflection free zones.
These conditions apply to the design of concert hall and, to a lesser extent, the design of the part of the studio that the musicians play in. However for the sound engineers in the control room of a studio the ideal is an acoustic which allows them to "listen through" the system to the original acoustic that the sound was recorded in. Unfortunately the room in which the recorded sound is being listened to is usually much smaller than the original space and this has the effect shown in figure 2. Here the first reflection the listener hears is due to the wall in the listening room and not the acoustic space of the sound that has been recorded. Because of the precedence effect this reflection dominates and the replayed sound is perceived as coming from a space the size of the listening room which is clearly undesirable. What is required is a means of making the sound from the loudspeakers appear as if it is coming from a larger space by suppressing the early reflections from the nearby walls, as shown in figure 3. One way of achieving this is to use absorption [1], as shown in figure 4. The effect can also be achieved by using angled or shaped walls [2-3]. These methods can be called reflection free zone techniques because they rely on the suppression of early reflections in a particular area of the room to achieve an apparently larger initial time delay gap. The idea is simple, by absorbing, or reflecting away, the first reflections from all walls except the furthest one away from the speakers the initial time delay gap is maximised. If this gap is larger than the initial time delay gap in the original recording space the listener will hear the original space, and not the listening room.

Unfortunately this effect can only be achieved over a limited volume of the room, unless the room is made anechoic, which is undesirable or very large, which is often impractical. If the technique of using shaped walls is used the one often finds that the area away from the optimum listening area has stronger early reflections than normal because the act of directing the reflections away from one area of the room concentrates them in other areas. It must also be achieved while satisfying the need for even diffuse reverberation and therefore the rear wall in such situation must often have some explicit form of diffusion structure on it to assure this. The initial time delay gap in the listening area should be as large as possible, but is clearly limited by the time it takes sound to get to the rear wall and back to the listener, ideally this gap should not be much greater than 20ms or the reflection will be perceived as an echo. In most practical rooms this requirement is automatically satisfied and initial time delay gaps in the range of 8ms to 20ms can be achieved.

2.2 Absorption level required for reflection free zones.
In order to achieve a reflection free zone it is necessary to suppress early reflections, but by how much? Figure 5, data from [4], shows a graph of the average level that an early reflection has to be in order to disturb the direction of a stereo image and from this we can see that the level of the reflections must be less than about 15dB to be subjectively inaudible Allowing for some reduction due to the inverse square law, this implies that there must at least 10dB, or $\alpha = 0.9$ of absorption on the surfaces contributing to the first reflections. However it is important to realise that this technique is only applicable at mid to high frequencies where small patches of treatment are significant with respect to the wavelength.

2.3 The level of early reflections relative to the direct sound.
The intensity of the direct sound is given by:

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$$I_{direct\ sound} = \frac{QW_{Source}}{4\pi r^2}$$

where $I_{direct\ sound}$ = the sound intensity (in Wm^{-2})

Q = the directivity of the source (compared to a sphere) (1)

W_{Source} = the power of the source (in W)

and r = the distance from the source (in m)

Equation 1 shows that the intensity of the direct sound reduces as the square of the distance from the source, in the same way as a sound in free space.

The intensity levels of the early reflections are affected by both the distance and the surface from which they are reflected. The intensity of the early reflections, in the absence of absorption, can be calculated from the extra path length due to the reflection and using that distance in place of r in equation (1). by considering the "image" of the loudspeaker, also shown in figure 6, and by using Pythagoras' theorem. Given the intensity level at 1m the intensity of the early reflection can be calculated because the reflected wave will also suffer from an inverse square law reduction in amplitude:

$$I_{early\ reflection} = \frac{W_{Source}}{4\pi\left(r^2 + (2d)^2\right)} \quad (2)$$

Because there is a direct correspondence between, delay, distance from the source, and the reduction in intensity due to the inverse square law we can plot all this on a common graph, as shown in figure 7, which shows the maximum bounds of the intensity level of reflections, providing there are no focusing effects.

In general most surfaces absorb some of the sound energy and so the reflection is weakened by the reflection. Therefore the level of direct reflections will be less than that which would be predicted by the inverse square law due to surface absorption. The amount of energy, or power, removed by a given area of absorbing material will depend on the energy, or power, per unit area striking it. As the sound intensity is a measure of the power per unit area this means that the intensity of the sound reflected is reduced in proportion to the absorption coefficient. That is:

$$Intensity_{reflected} = Intensity_{incident} \times (1 - \alpha) \quad (3)$$

Because a multiplication of sound levels is equivalent to adding the decibels together, equation 3 can be expressed directly in terms of the decibels as:

$$I_{absorbed} = I_{incident} + 10\log(1 - \alpha) \quad (4)$$

Which can be combined with equation 2 to give a means of calculating the intensity of an early reflection from an absorbing surface:

$$I_{early\ reflection} = I_{1m} - 20\log_{10}(Path\ length) + 10\log(1 - \alpha) \quad (5)$$

From the above equations it is clear that the intensity reduction of an specular early reflection is inversely proportional to the distance, and hence the time, squared.

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THE SOUND INTENSITY FROM A DIFFUSING SURFACE

Diffuse surfaces on the other hand scatter sound in other directions than the specular [5-10]. In the case of an ideal diffuser the scattered energy polar pattern would be in the form of hemisphere. In the case of a typical diffuser which only scatters in one dimension then the polar pattern would be in the form of a cylinder. The effect of this can be calculated by modelling the scattered energy as a source whose initial intensity is given by the incident energy. Thus, for an ideal scatterer, the intensity of the reflection is give by the product of the equation describing the intensity from the source and the one describing the sound intensity radiated by the diffuser. For the geometry shown in figure 8 this is given by:

$$I_{diffuse\ reflection} = \left(\frac{W_{Source}}{4\pi r_s^2}\right)\times\left(\frac{2}{4\pi r_d^2}\right) \qquad (6)$$

For a two dimensional diffuser. The factor 2 in the second term represents the fact that diffuser only radiates into half a hemisphere. For a one dimensional diffuser, which radiates into a half cylinder equation (6) becomes:

$$I_{diffuse\ reflection} \approx \left(\frac{W_{Source}}{4\pi r_s^2}\right)\times\left(\frac{2}{2\pi r_d^2}\right) \qquad (7)$$

For the geometry shown in figure 8 equations 7 and 8 reduce to:

$$I_{diffuse\ reflection} = \frac{W_{Source}}{8\pi^2\left(\sqrt{\left(\left(\frac{r}{2}\right)^2+d^2\right)}\right)^4} \qquad (8)$$

For the two dimensional diffuse and approximately:

$$I_{diffuse\ reflection} \approx \frac{W_{Source}}{4\pi^2\left(\sqrt{\left(\left(\frac{r}{2}\right)^2+d^2\right)}\right)^4} \qquad (9)$$

For the one dimensional case.

Equations (8) and (9) show that diffusion offers a twofold advantage over a specular reflection. Firstly there is an initial drop in intensity due to the fact that the energy incident on the surface is being re-radiated into directions other than the specular. Secondly there is a stronger reduction in intensity as a function of distance due to the re-radiation pattern. The effect of this is more obvious if we consider the ratio of the early reflection to the direct sound which is given by:

$$I_{early/direct} = \frac{\left(\frac{W_{Source}}{4\pi\left(r^2+(2d)^2\right)}\right)}{\left(\frac{W_{Source}}{4\pi r^2}\right)} = \frac{r^2}{\left(r^2+(2d)^2\right)} \qquad (10)$$

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in decibel form this becomes:

$$I_{early/direct(db)} = 10\log(r^2) - 10\log\left(r^2 + 4d^2\right) \quad (11)$$

For the two dimensional diffuser the ratio of the early reflection to the direct sound becomes:

$$I_{early/direct(db)} = 10\log(r^2) - 20\log\left(\left(\frac{r}{2}\right)^2 + d^2\right) - 10\log(2\pi) \quad (12)$$

In decibel form and this can be further simplified to:

$$I_{early/direct(db)} = 10\log(r^2) - 20\log\left(\left(\frac{r}{2}\right)^2 + d^2\right) - 8dB \quad (13)$$

For the one dimensional diffuser the corresponding equations are:

$$I_{early/direct(db)} = 10\log(r^2) - 20\log\left(\left(\frac{r}{2}\right)^2 + d^2\right) - 10\log(\pi) \quad (14)$$

And

$$I_{early/direct(db)} = 10\log(r^2) - 20\log\left(\left(\frac{r}{2}\right)^2 + d^2\right) - 5dB \quad (15)$$

Comparing equation (11) with equations (15) and (13) shows that a the reflection from a diffuser has an excess loss of 5dB or 8dB, depending on whether the diffuser is one or two dimensional. Furthermore there is a faster rate of sound intensity reduction with distance compared to the specular case, although there is a break even point as one gets close to the diffusing surface. For example if r=3m and$d$=1.5m then the level of early to direct energy for the specular, one dimensional diffuser, and two dimensional diffuser, would be -3dB, -8.6dBand -11.6dB respectively. If d=2m the ratios become -4.5dB, -11.4dB and -14.4dB respectively. This level of performance approaches that of an absorber of α=0.9 but without absorption.

DISCUSSION

So diffusion can result in a reduction of the amplitude of the early reflection from a given point. However there will also be more reflections, due to the diffusion, arriving at the listening position from other points on the wall, as shown in figure 9. Surely this negates any advantage of the technique? A closer inspection of figure 9 reveals that although there are many reflection paths to the listening point they are all of different lengths, and hence time delay. Furthermore the phase reflection diffusion structure will add an additional temporal spread to the reflections. As a consequence the initial time delay gap will be filled with a dense set of low-level early reflections instead of a sparse set of higher level ones, as shown in figure 10. The effect of this is a large reduction of the comb filtering effects that high level early reflections cause. This is due to both the reduction in amplitude due to the diffusion and the smoothing of the comb filtering caused by the multiplicity of time delays present in the sound arriving from the diffuser. As these comb filtering effects are thought to be responsible for perturbations of the stereo image [] one should expect improved performance even if the level of the early reflections are slightly higher than the ideal. The fact that the reflections are diffuse also results in an absence of focusing effects away from the optimum listening position which should result in a more gradual degradation of the listening environment away from the optimum listening position.

CONCLUSION

A method of achieving an equivalent effect to a reflection free zone using diffusion, instead of shape or geometry, has been described. In this technique the initial time delay gap is filled with dense low-level reflections, due to the effect of the diffusion on the wall, which reduce the comb filtering effect that would otherwise occur. Due to the diffusion the performance is less critical of the listener's position in the room.

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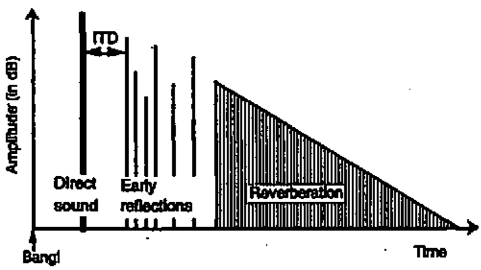

Figure 1 An idealised energy time curve.

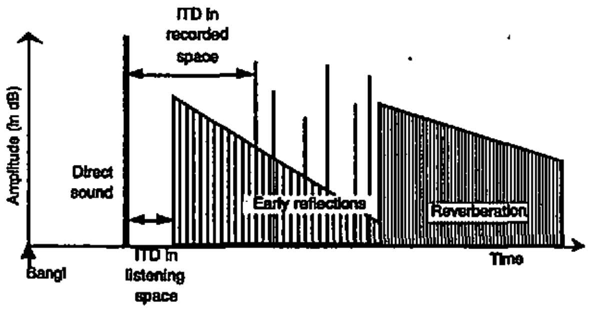

Figure 2 The effect of a shorter initial time delay gap in the listening room.

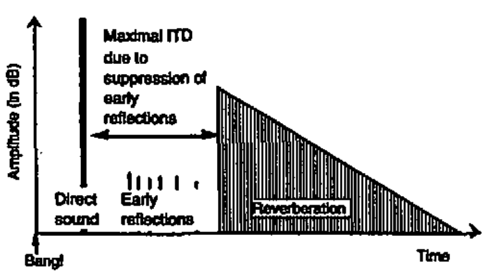

Figure 3 Maximising the initial time delay gap by suppressing early reflections.

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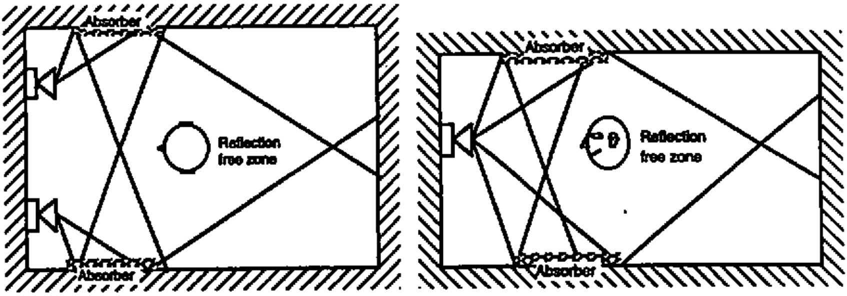

Figure 4 Achieving a reflection free zone using absorption.

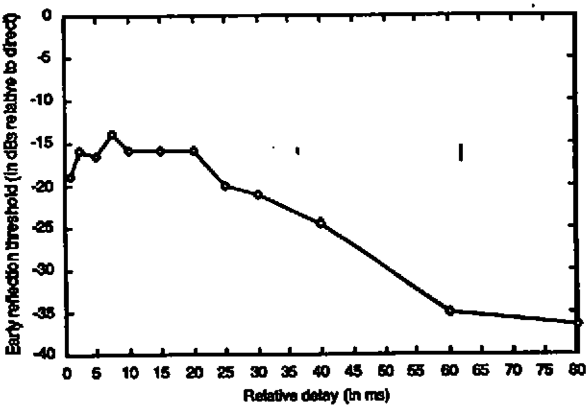

Figure 5 The minimum amount of reflection suppression required for a reflection free zone

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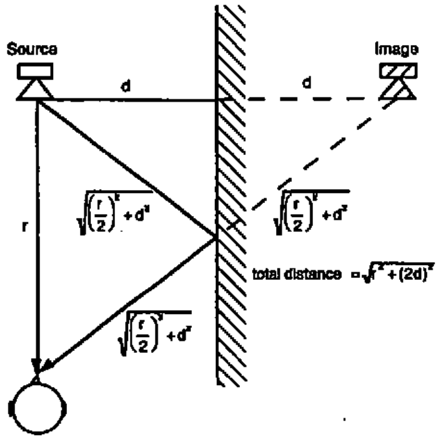

Figure 6 The geometry for calculating the intensity of an early reflection.

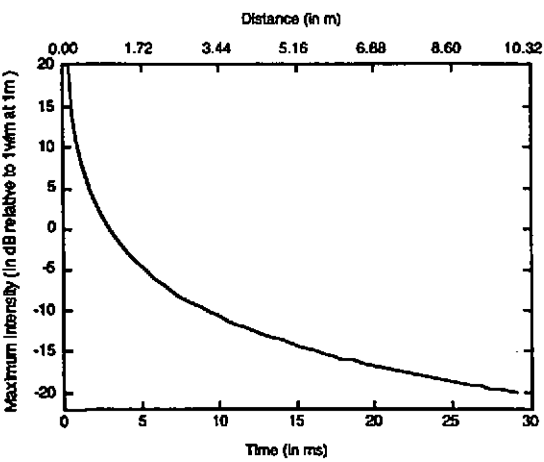

Figure 7 The maximum bounds for early reflections assuming no absorption or focusing.

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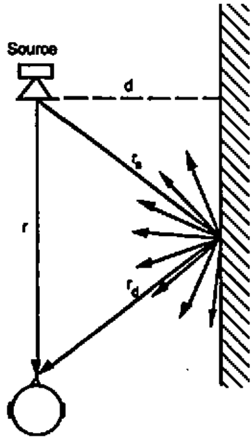

Figure 8 The geometry for calculating the intensity of an early reflection from a diffuse surface

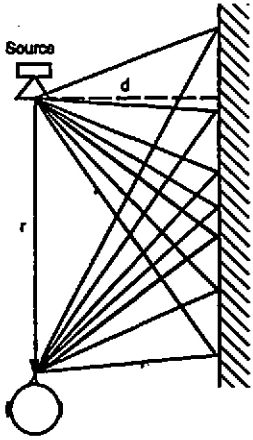

Figure 9 Additional early reflection paths due to a diffuse surface.

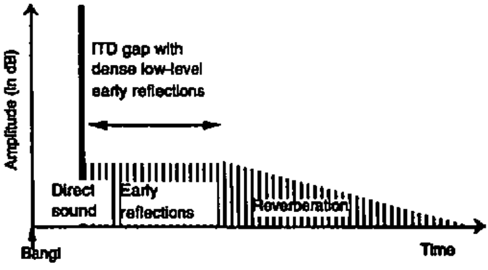

Figure 10 The initial time delay gap due to diffusion of early reflections.