LAYERED SOUND – A NEW APPROACH TO SOUND REPRODUCTION

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1 INTRODUCTION

A patent application made earlier this year stimulated research into the effect now known as 'Layered Sound'*. The technique uses a combination of wideband conventional Pistonic based loudspeakers and Distributed Mode devices. The resultant sound is apparently more spacious and exhibits greater clarity. The object of the research reported in this paper is to investigate these claims and to carry out an investigation into the underlying potential acoustic and psychoacoustic mechanisms.

2 BACKGROUND

Although a number of implementations of Layered Sound are possible, the simplest form of the fundamental concept is based on the addition of a pair of Distributed Mode Loudspeakers to a conventional stereo set up. The DMLs are fed with exactly the same Left & Right broadband stereo signals as the conventional loudspeakers ***** but at an attenuated level, which is normally achieved by means of a second, separate amplifier. (Although, if appropriate passive attenuators are employed, a second amplifier is not absolutely necessary but it is certainly more convenient). In other words, both the conventional and DML loudspeakers play the same stereo signals but with the conventional loudspeakers operating at a higher acoustic output than the DMLs.

The DMLs are usually positioned either above or in close proximity to the conventional loudspeakers and are fed in Phase (ie Polarity) with the normal stereo signal). In the investigations reported in this paper, the DMLs were located to front of the listener and mounted directly above the stereo loudspeakers. (It is also possible to change this orientation and / or to delay the signal to the DMLs, though these variations are not reported here).

[***** Note : A high pass passive filter is usually fitted to DMLs in order to protect these devices from excessive low frequency energy, depending on their power handling and low frequency cut off characteristics. However, for the experiments reported here, wide range panels with a low frequency handling capacity down to approximately 100 Hz were employed and the filters were dispensed with in order to ensure that any anomalous phase effects were not inadvertently introduced].

3 EXPERIMENTAL RESEARCH

3.1 Preliminary Investigation

A preliminary investigation was carried out in the author's calibrated listening room. This is an acoustically well controlled, though relatively dead, domestically sized space (5.6m Long x 3.2m Wide and 2.4m high) with an average reverberation time of 0.3 sec over the range 250 – 4 kHz.

A pair of Tannoy 'Dual Concentric' NFM 6 Mk 11 monitor loudspeakers (2 way passive devices) were employed as the conventional loudspeakers together with two 500 x 700 DML panels from Amina Technologies Ltd. The panel construction comprised a resin dipped paper honeycomb core and skin with four 10 w exciters supported by an open aluminium frame. The Panels were without backs, and therefore radiated sound to both the front and rear over a wide angle, forming diffuse dipolar sources. (See previous papers by the author [1,2,] for further explanation and reference list of the DML and room interaction effects). The conventional and DML loudspeakers were fed with the same signals but from separate amplifiers. Care was taken to ensure that all the signals were in phase. The loudspeakers were placed on stands approximately 600mm in from the side walls and 700mm from the rear wall. Listening was carried out not only on the centre line between the loudspeakers at 1.5 –2m but also at a number of off axis locations.

A range of classical music recordings was used to audition the system. After setting the stereo loudspeakers to a comfortable listening level (approximately 70 - 75 dBA) the signal level of the DML panels was adjusted to produce an audible effect. Further adjustments were then made until a pleasing effect was created that not only was more spacious and involving but also seemingly with greater detail. The audible effect was immediately apparent. A fairly narrow range of desired adjustment was found to exist. Increasing the drive to the DMLs too greatly caused the effect to diminish and the sound quality to change. Equally, without sufficient drive, the effect was lost altogether. Subsequent measurement of the in room sound levels, using a wideband pink noise test signal, showed the DMLs to have been set to 4.2 dBA lower in level than the Tannoy monitors. This is in good agreement with the optimum range subsequently established for Layered Sound of –5dB ± 3dB. (The effect is also reported to exist in a wide range of rooms and conditions).

At off axis positions, forward of the loudspeakers but otherwise effectively throughout the room, the effect was also clearly apparent, with appreciable differences in the perceived spaciousness of the recordings being noted. Interestingly and somewhat surprisingly, the effect persisted when auditioning a single speaker (and corresponding DML) in mono.

Clearly, the addition of the DMLs was not only adding a secondary set of diffuse sound sources, but also producing additional sequences of complex reflections. From previous research by the author, it was known that such reflections would generally be diffuse and exhibit a low degree of correlation [1,2]. The combination of sources and reflections appeared to be producing an effect heard by the listener as an increase in perceived spaciousness. This suggested that additional sound (reflections) must be arriving at the listener from the sides and rear of the room. The perceived improvement in clarity and detail suggested either an alteration in the overall timbre or spectral changes to the reproduction and / or a further effect of the additional reflections. (ie the effect could be either temporal or spectral – or most likely a combination of the two).

As the effects of the sound ‘layering’ were clearly audible, it was felt that they should also respond to objective measurement. As one of the primary effects related to perceived spaciousness, it was decided to use a number of the well known and established measures and techniques relating to the assessment of spaciousness in concert halls and auditoria i.e. Inter Aural Cross Correlation (IACC), Lateral Energy Fraction (LF) as well as other measures such as EDT and Centre Time (TS). The raw impulse responses were also examined, as were the resultant frequency responses. The preliminary study showed that all these measures were clearly affected both for the stereo and to a lesser extent the mono conditions. The density of early the reflections (50mS time window) was found to have increased as to did the EDT and Centre Time.

‘Layering’ the sound, albeit that the DMLs were set 4.2 dBA lower the Tannoys, was found to increase the resultant sound level by 1.6 dBA. Whereas this may be noticeable to the critical listener, particularly when switching back and forth, the difference in perceived loudness is too small to affect the perception of spaciousness directly, particularly in view of the effect on the other acoustic parameters.

Although the above results were positive and indicated that there is a physical and measurable explanation of Layered Sound, it was thought that the author’s listening room may not be that typical of normal listening conditions and so additional sets of tests were conducted in two further rooms. These are further described in detail below and the results compared to the initial tests reported above as and where appropriate.

3.2 Layered Sound Tests – (Room 2)

The second test room was a little larger than the first measuring 5.5 x 4.5 x 2.7m. The floor was concrete covered with a thin pile carpet, the walls were of plasterboard and the ceiling was acoustic tile in a suspended grid. The test arrangement is shown in Figure 1, although a second set of tests was also conducted with the loudspeakers arranged to radiate lengthways down the room as opposed to widthways as shown.

On this occasion, Mission 780SE, two way Hi-Fi loudspeakers were employed as the conventional loudspeakers, whereas the DMLs were as per the preliminary tests. (The Tannoy units were replaced by the critically acclaimed Missions to ensure that the somewhat unusual 'point source', dual concentric nature of the Tannoys was not affecting the results).

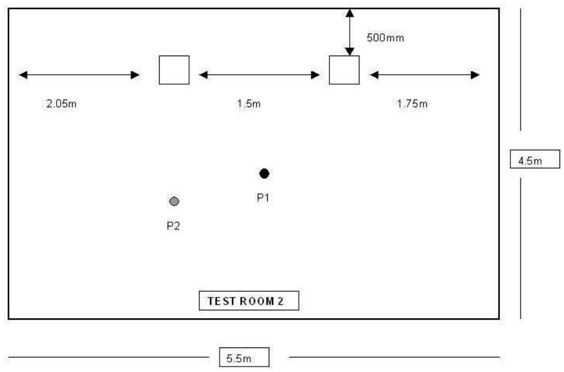


Figure 1 Test Room Layout

With the loudspeakers set up as shown in figure 1, the 'Layered Sound' effect was very evident. The spaciousness of recordings increased significantly as did the apparent clarity and detail. Adding in the DMLs also changed the stereo image. This increased in height and the overall timbre changed. On occasion, a strong, central image was perceived behind the plane of the loudspeakers. This was very obvious with pink noise and was caused by the broadband rear radiation from the DMLs reflecting off the rear wall. The image was approximately in line with the centre the DMLs, which were located on top of the Missions. It was this central reflection that was responsible for increasing the height of the stereo image – though not in an unpleasant way. As in the preliminary tests in Room 1, it was found that the sensations of spaciousness and clarity persisted throughout most of the room.

3.3 Relative Levels & Frequency Response

The opportunity was taken to carry out a brief listener based test relating to the preference range for the Layering effect. Five 'naïve' listeners were asked to set the level for the DMLs to create the Layered Sound effect. A looped, 2 minute, excerpt from a cello recording, made in a relatively live acoustic was used as the test piece. The level of the conventional stereo reproduction at the 'stereo sweet spot' listening location, was pre set to 70 – 75 dBA and remained constant throughout. The test subjects then had a free choice in setting the relative level of the DMLs and were able to readily switch back and forth to the normal stereo condition until their adjustment was complete. Each set of experimental settings was logged and the various loudspeaker drive signal levels measured electronically.

The results were remarkably consistent with a mean difference of just 1.1 dBA and a maximum variation of 1.7 dBA and 1.2 dBC. These settings were then maintained for the rest of the experiments. Later analysis showed that the DMLs had been set approximately 1 dBA / 2.5 dBC below the level of the Missions but when measured anechoically, this difference was 5.6 dBA or 4.9 dBC. (See Fig 2 Mission 780SE response is dotted curve, DML Panel is solid line).

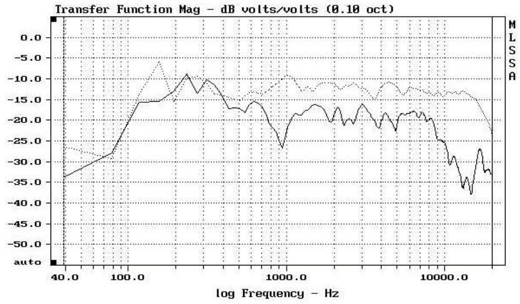


Figure 2 Anechoic Frequency Responses

Layering the sound increased the overall sound level at the listening position (over that of the stereo loudspeakers on their own) by 2.1 dBA or 0.9 dBC. Whereas, these increases are sufficient to change a listener's general perception and probably preference * they are unlikely to affect the perception of spaciousness. (*It is well known that a louder or more efficient pair of loudspeakers will nearly always be preferred to a similar quality but quieter pair). In the anechoic chamber, the corresponding increase in level of the Layered Sound over the conventional loudspeaker was just 0.4 dBA or 0.1 dBC.

Figure 3 compares the measured 'in-room' frequency responses for the Missions (solid curve) and DMLs (dotted) whilst figure 4 shows the combined Layered Sound response.

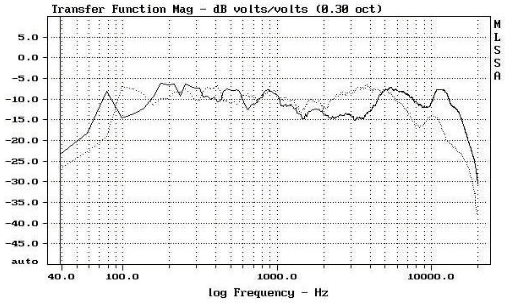


Figure 3 In-Room Frequency Responses

Figure 3 suggests that the Missions have a gradually falling mid frequency response whilst the response of the DMLs (shown at their Layered Sound relative amplitude) have a flatter overall characteristic. This is in contrast and apparent contradiction to the anechoic equivalent responses shown in figure 2, where it can be seen that the Mission 780SE has an immaculately flat response. The difference is that the responses shown in fig 3 & 4 include the early room reflections (up to 80 mS) and are a better representation of the perceived spectral balance- albeit with both channels driven. From figure 3 it can be seen that the DML is potentially 'filling in' the dip in the stereo loudspeaker response from around 1-5 kHz. This results in the very smooth and flat Layered Sound response shown in figure 4.

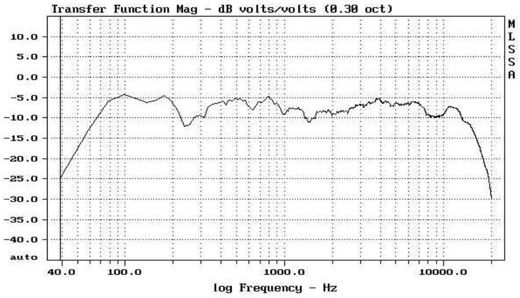


Figure 4 In-Room 'Layered Sound' Response

From an examination of the above frequency responses, it is not surprising that a difference in the overall timbre was perceived together an impression of greater clarity & detail. This is also supported by the responses shown in figure 6, which show how layering the sound of the Tannoy NFM (with the DML set 4.2 dBA lower) resulted in increases of around 2.5 - 3.5 dB at mid and high frequencies. The overall level however only increased by 1.6 dBA / 2 dBC.

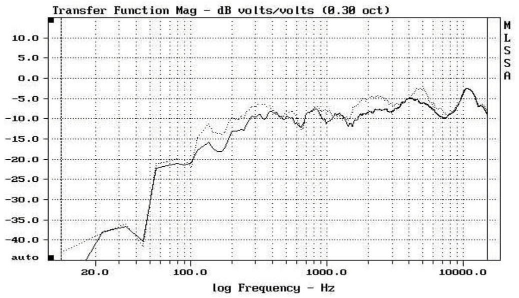


Figure 6 Tannoy & DML Responses (Room 1)

It is interesting to compare the in-room Layered Sound response of figure 4 with that measured in the anechoic chamber shown in figure 5. In the latter case, the response is not as smooth or so well extended, though it should be noted that this is a mono, single Mission & DML anechoic measurement. At the lower frequencies, there would appear to be a noticeable interaction occurring between the loudspeakers.

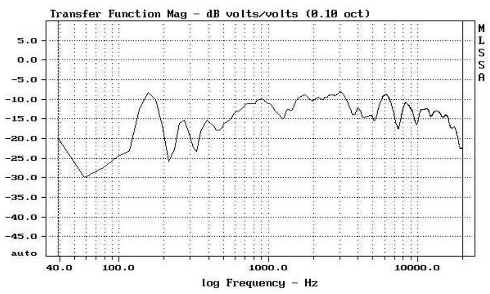


Figure 5 Anechoic Layered Sound Response

3.4 Temporal Aspects

Examination of both of the test room impulse responses showed the early reflection densities to have increased significantly under the Layered Sound condition. As has been previously described by the author [1,2] the room responses and interaction of DMLs as compared to conventional Loudspeakers with room boundaries are very different. It was therefore anticipated that Layered Sound would produce either an intermediate effect or combination of both sets of features. A number of temporally based parameters were investigated for both on and off axis positions. These included Inter Aural Cross Correlation, Lateral Energy Fraction, Centre Time , EDT and early reflection density and direction of arrival.

IACC measurements were made using a Neuman Dummy Head initially located at the stereo sweet spot. The test signal (a maximal length sequence - mls) was fed simultaneously to both Left and Right loudspeakers and with various combinations of the Mission and DML devices. IACC values were computed for the first 80 mS of the received signal. Figure 7 shows plots of IACC for the Stereo loudspeakers DMLs and Layered Sound.

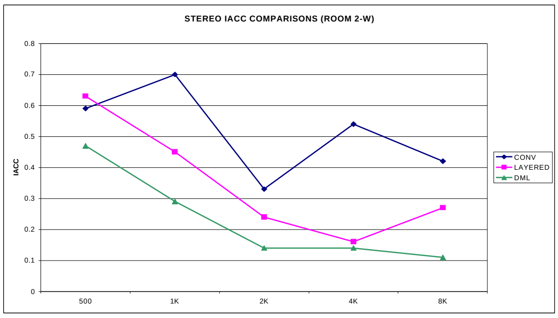


Figure 7 IACC Comaprisons

As would be expected, the IACC for the conventional stereo loudspeakers (upper curve) - where effectively each ear receives the same acoustic signal when the loudspeakers are fed with identical stimuli, is fairly high – though this does reduce with increasing frequency. By contrast the IACC characteristic for the DMLs (lower curve) produces consistently lower values. The mid curve shows the IACC characteristic for Layered Sound and as can be seen this sits between the two, though more closely tracking the DML than the conventional loudspeaker.

Measurements of the Lateral Energy fraction were made using an AKG C34 stereo microphone with switchable polar responses thus enabling the total sound field (omni directional microphone) and lateral sound field (figure of 8 microphone) to be simultaneously captured. Figure 8 shows the resultant plot. This clearly shows that at high frequencies, the Layered Sound exhibited greater lateral energy than the conventional stereo set up.

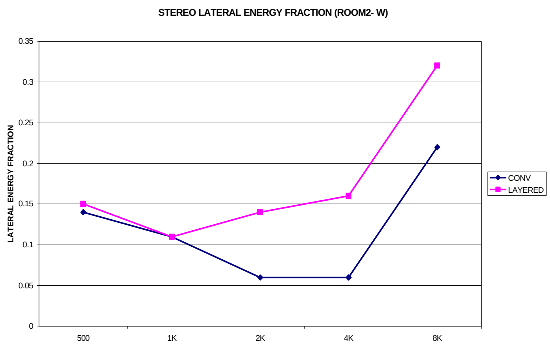
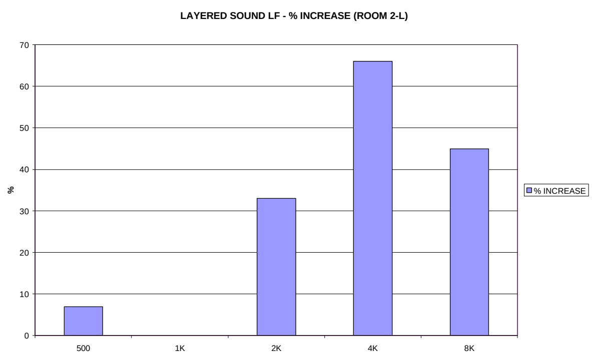


Figure 8 Lateral Energy Fractions Stereo & Layered Sound

Figure 9 shows this data in the form of the percentage change.



When the radiation characteristics of the conventional loudspeakers and DMLs are considered, together with their location within the room and the relative levels employed, then this is a very logical result.

Measurements of Centre Time (TS) showed this to increase from 14.5 mS for the Missions to 17.9 mS for Layered Sound (23 % increase). The EDT averaged over the range 500Hz – 4 kHz did not change from 0.31 seconds.
The above results suggest that for the IACC and LEF to change so significantly, the reflection sequence at the listening position must be notably different for Layered Sound as compared to conventional stereo. Measurements of reflection density and direction of sound arrival were therefore undertaken to throw further light on this. Figure 10 shows a polar reflectograph indicating the direction and strength of the early reflections attributable to the normal stereo set up. The graph includes all the reflections occurring within 20 dB of the direct sound over a period of the first 50 mS.

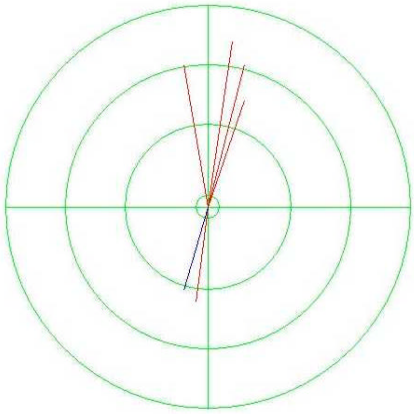


Figure 10 Polar Reflectograph - Stereo LS

The frequencies involved cover the range from 850 Hz to 2500 Hz, though the energy of the test signal is biased slightly towards the higher frequencies. As the figure shows only six reflections fall into this category, with four frontal ones and two from the rear. This is in contrast to figure 11, which is the equivalent polar reflectograph for the Layered Sound condition.

In this case numerous reflections are received at the listening position from all around the room with over 50 % of them arriving either laterally or from behind the listener. These latter reflections also tend to be the later arriving ones. Comparing the two polar reflection plots, it is not hard to envisage why the Layered Sound set up sounded more spacious. Although that being said, it is unusual for small rooms to sound spacious !

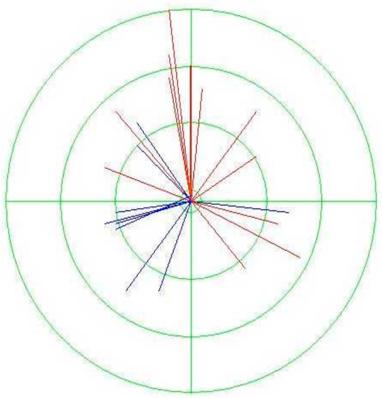


Figure 11 Polar Reflectograph Layered Sound

As noted earlier, the increased sense of spaciousness was also perceived at off axis locations. The IACC was therefore measured at position 2, which although off axis to the stereo seat was on axis to the LHS loudspeaker as indicated in figure 1. Figure 12 compares the IACC data for this position.

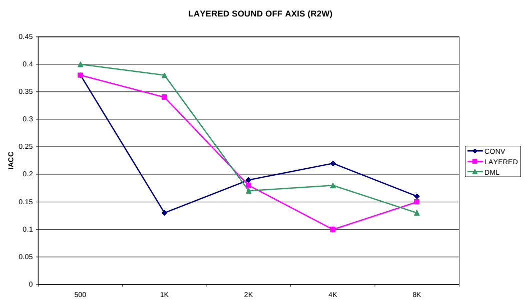


Figure 12 IACC Comparisons - Off Axis

As would be expected from this asymmetrical position, the IACC graphs are very different to those measured on axis. Their precise interpretation however still requires some further study.

The corresponding frequency response plots are shown in figure 13. Again the Layered Sound spectrum is shown to peak around 2-5 kHz which would doubtless explain the apparent improvement in clarity & detail.

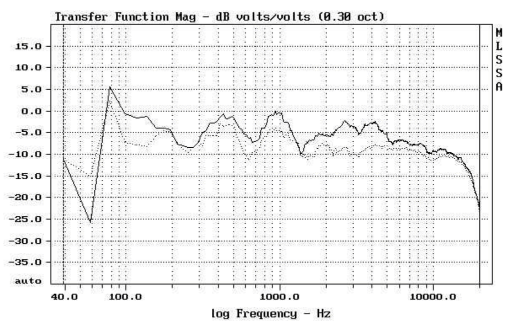


Figure 13 Off Axis In-Room Frequency Responses

In order to gain some further insights into the underlying acoustic mechanisms, the experimental set up was reconfigured so that the loudspeakers faced down the length of the room. The loudspeaker spacing was kept constant at 1.5m and again measurements were primarily made at the stereo seat. The same Layered Sound ratio was also maintained with respect to the loudspeaker drive voltages.

Figure 14 shows the resultant IACC plots. The graphs are a little different to the widthways configuration but follow the same basic trend with the stereo set up exhibiting the highest correlation and the DMLs the lowest.

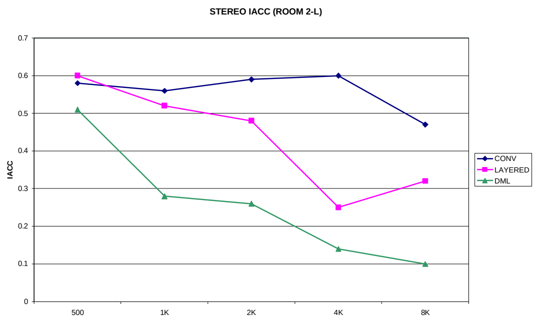


Figure 14 IACC Comparisons Lengthways set up

As before, the IACC for the Layered Sound system followed an intermediate curve between the Stereo and DML values but the overall mean is 23 % higher than for the widthways condition.

Figure 15 shows the corresponding graphs for the Lateral Energy Fraction. Again the curves are different to the widthways condition, with a generally increased LEF.

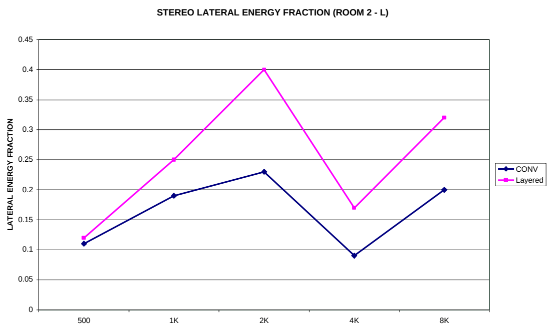


Figure 15 Lateral Energy Fraction Lengthways.

The reason for this is clearly shown by the polar reflectographs. Figure 16 shows the graph for the normal stereo condition.

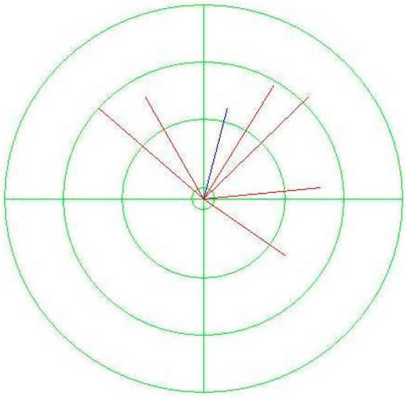


Figure 16 Polar Reflectograph - Stereo Lengthways

Seven reflections occur within the first 50 mS that are within 20 dB of the direct sound, whereas with Layered Sound (figure 17) this increases to twenty. Around 25% of these reflections also occur after 20 mS, including the rearmost arrivals. The proportion of rearwards arriving energy however is lower than for the widthways condition.

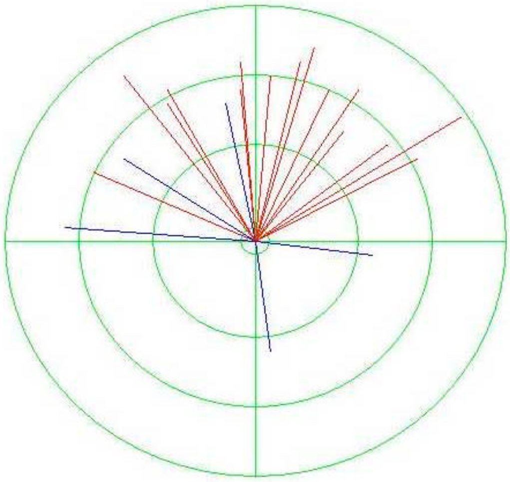


Figure 17 Layered Sound Lengthways Polar Reflectograph

The averaged Centre Time over the range 500 Hz – 4kHz again increased under the Layered Sound condition from 17.7 mS to 21.7mS. The Averaged EDT over this range also increased from 0.35 to 0.39 seconds. (Compared to 14.5 > 17.9 mS and 0.31 Sec EDT for the widthways equivalent set up).

4 DISCUSSION

The experiments reported above, show that Layered Sound is a different commodity to either of its constituent components. However, by adjusting the ratio of the DML to conventional sound, it is possible to traverse between the two extremes.

In all the cases experienced, it was noted that Layered Sound exhibited an enhanced or emphasised upper mid / high frequency response. This could very well account for the perceived improvement in clarity and detail, though the accompanying temporal changes may also play a part.

It was also found that the Layered Sound was generally around 2dBA louder than the conventional stereo set up. Further subjective experimentation is required in order to establish and isolate these effects.

It was noted that at low and lower mid frequencies, interaction took place between the DML and conventional loudspeaker, giving rise to both peaks and notches in the combined (Layered Sound) frequency response. This was particularly noticeable in the anechoic measurements. Such interactions would be quite audible and for critical listeners could lead to perceived changes in timbre. From previous research, it is anticipated that such interactions would be dependent on the construction, bandwidth, diffusivity and correlation characteristics of the DML.

It was surprising to find the consistency with which listeners set the relative levels between the Stereo and DML loudspeakers. Whilst the experiment reported was extremely limited, it follows the trend of observations made in several other rooms and with different loudspeakers.

The IACC, Lateral Energy Fractions and polar reflectographs indicate that the sensation of spaciousness is different for Layered Sound as compared to either the DMLs or the conventional stereo loudspeakers on their own. The small increases in apparent loudness accompanying the creation of the Layered Sound effect, could potentially affect subjective preference but are unlikely to be the cause of the perceived increase in spaciousness.

The wall or boundary immediately behind the DMLs would appear to be an important factor as not only does this generate an additional central image, located at the height of the DMLs but is also responsible for the creation of many of the early reflections. When the boundary behind the DMLs was hard and reflecting, the resulting central reflection was clearly audible and affected the perceived height of the central Stereo image. The acoustic properties of this surface and the rear radiation characteristics of the DML panels themselves are worthy of further study in order to optimise the desired effect. It is anticipated that slightly delaying the signals feeding the DMLs may help minimise disturbance to the conventional stereo image whilst still enabling the other desirable effects associated with Layered Sound to be maintained.

It was surprising to discover that an additional set of loudspeakers located in the same plane as conventional stereo loudspeakers and forward of the listener, could provide such a striking sense of spaciousness. The effect would appear to be strongly associated with the unique properties of Distributed Mode Loudspeakers, both in terms of their wide dispersion and power response and the decorrelated, diffuse nature of their radiation. In a previous paper [1] the author has shown that the majority of the reflections associated with DMLs in relatively small rooms, tend to be diffuse and decorrelated. It is suspected that these properties may well affect or heighten the perception of increased spaciousness.

Other experiments, not reported here, in different rooms and employing different loudspeakers indicate that the Layered Sound effect can occur under a range of conditions and that the effect also works well in multi-channel / surround sound systems.

A series of separate experiments was also conducted to establish the frequency limits and bandwidth associated with the Layered Sound effect. In summary it was found that the minimum range required extended from 500 Hz to 2,000 Hz but ideally a range extending from 200 Hz to at least 5 kHz was required for optimal performance. Extending the range below 200 Hz was also found to be beneficial, as it generally improved the low frequency sound distribution within the listening room, but it did not add to the 'layering' effect or increased spaciousness.

5 CONCLUSIONS

The reported research shows that Layered Sound is an interesting form of sound reproduction in its own right. The enhanced perception of spaciousness and involvement with the reproduced sound

are surprising, though understandable when viewed in terms of the changes in Frequency Response, IACC, LEF and reflection arrivals / density.
It is concluded that one of the major reasons for the apparent success of the technique is due to the decorrelated and diffuse nature of the sound radiated by the DMLs

Although changes to the primary stereo image are apparent, the effect is not unpleasant and the improved sensation of involvement throughout the listening area can be considered to compensate for this.

It is not clear at this stage whether the perception of improved clarity is due entirely to the small changes in frequency response and level that occur or are also in part due to the increased density of the early reflections and their spatial characteristics.

Much further work is required in order to fully understand and optimise the Layered Sound effect. In particular the optimal geometry of the arrangement, local boundary characteristics and properties of the auxiliary DML devices need further investigation as does the potential for delaying the DML radiation.

6 REFERENCES

[1] P. Mapp, H. Azima, V. Gontcharov, The Complex Loudspeaker – Room Interface, Some Further Insight. AES 107th Convention New York 1999

[2] H. Azima & P. Mapp, Diffuse Field Distributed Mode Radiators and their Associated Early Reflections. AES 104th Convention Amsterdam 1998. [