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The Active Listening Room Simulator: Part 2

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1. ABSTRACT

This paper presents the results of computer simulation of active reflectors in a reference listening room which are used to create artificial reflections in a two speaker, stereo listening configuration. This formulates the second phase of experiments in the active listening room project involving the analysis of computer modeling results and loudspeaker selection based on free field response. The aim of this project is to create a truly variable listening condition in a reference listening room by means of active simulation of key acoustic parameters such as the early reflection pattern, early decay time and reverberation time.

2. INTRODUCTION

Traditionally, experiments in the field of simulation of sound fields are carried out in anechoic chambers where 95% of the source sound energy is absorbed and is considered a completely inert acoustic environment. A reference listening room on the other hand is designed to resemble a domestic listening room with controlled acoustic characteristics. However, it is a fact that any listening environment, including a reference listening rooms, has its own acoustic characteristics, which makes it subjectively quite different from any other. Although complying with a given standard, the sound field of a reference listening room is far from being considered acoustically inert. This variation in the subjective and objective domains is the basis of the active listening room where the key acoustic features such as the reverberation time, early decay time and the early reflection pattern can be varied during specific listening tests to subjectively assess the effect of change in listening conditions on the results of the tests.

Our initial efforts in the design of an active listening room simulator are concentrated in a study of the reflection-free zone and the simulation of artificial reflections.

In part 1 of this paper [1] the core principles of this simulator and the experimental setup was described in detail. The experiment was set up in a ITU-R BS1116 [2] specification listening room at the University of Surrey. The approximate internal dimensions of the room were 7.35 x 5.33 x 2.50m. Internal room finishes were carpet on floor, lay-in grid tile absorbent ceiling and full range acoustic absorber boxes on the walls. The measured reverberation time of this room was 0.245sec at 1KHz and was found to be within the specified reverberation time window for upper and lower limits in all relevant 1/3 octave bands. The measured ambient background noise level with the ventilation system and technical power switched corresponded to NR12. The chosen source loudspeaker was an active integral amplifier, full range infinite baffle, wide dispersion, medium size studio monitor with an operational bandwidth of 60Hz – 18KHz +/-3dB. The loudspeaker was mounted on a speaker stand and the center of the cabinet was 1.25m from the floor. The deflector panels around the source loudspeaker were angled in such a way that any sound hitting these panels was forced away from the listening position. The physical size of the panels determines the wavelength of sound waves which can be reflected, therefore the lower frequency sound waves with greater wavelength compared to the panel size will not be deflected by this arrangement. The lower frequency cut-off limit was calculated to be approx. 400Hz. Each of these panels were made up of 18mm thick MDF (Medium density Fibre board) with four 600x600mm cut-outs for the flat panel DML (distributed mode loudspeaker) panels. The DMLs were embedded within the rebated recesses so that mounting was flush with the surface of the MDF panel. The DML panels were chosen because they are rigid flat panels, which can be used as deflectors to deflect sound from the source speaker away from the listener. Also, they have wide dispersion characteristics and their on-axis and off-axis responses are favorable to create artificial reflections in an angular panel arrangement[1].

3. COMPUTER MODELLING

The expanded experimental set-up for the two speaker, stereo configuration, was based on a computer model of the panel arrangement around the two source loudspeaker which was positioned as shown in figure below. The angular panel settings was optmised to create a geometric boundary setting which forces the early reflections to be directed away from the listening / measuring position. The computer model of this experiment was created in the commercially available software CATT Acoustic®. The main purposes of creating the model were:

1 - To optimise the position of the experiment set-up in terms of angles and positions of the panels to create a reflection free zone at the listener / measurement position.

2 - To predict the reflection patterns of the set-up as a whole, and from the panel arrangement in particular, within the first 20ms time window.

The model was constructed for a closed room with internal elements as floating objects. The absorption coefficients of walls ceiling and floor were adjusted to get a close match between the predicted and measured values of reverberation time. The directivity / dispersion of the source loudspeaker was accurately modeled. The positions of the source loudspeaker and the deflector panels were adjusted for maximum deflection of early reflections away from the listening / measurement position.

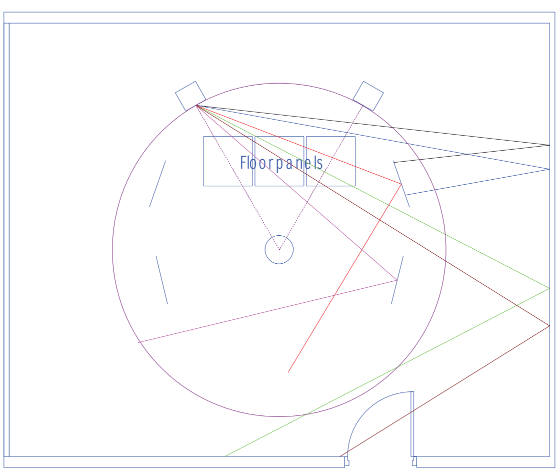

Figure 1
Ray tracing diagram of panel arrangement

Before creating the acoustic model a quick ray-tracing diagram was done to identify the main paths of significant reflections from the left speaker only in a typical, completely symmetrical, listening arrangement. The deflector panels were then arranged in such a way to deflect sound away from the listener position to maintain a reflection free zone. As the selected panel size was 600x600mm, a reflection free zone with a low frequency cut-off of 500Hz was expected. The predicted early reflection pattern is shown in the CATT Acoustic ®prediction plots below.

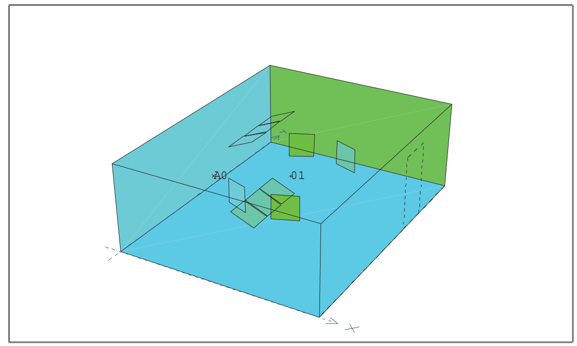

Figure 2
3D view plot of the panel arrangement in LR1
A0 = left speaker 01 = receiver

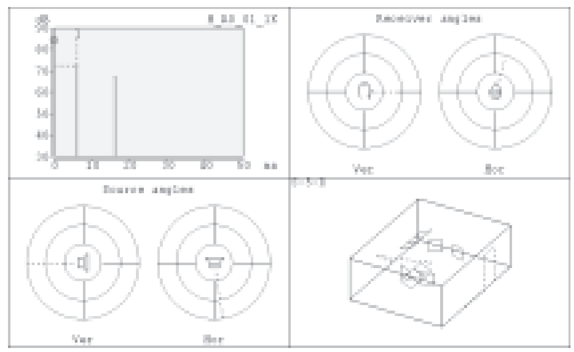

Figure 3
CATT Acoustic® model results, path and amplitude of first reflection

Time amplitude and path display of the first significant, first order reflection within the panel arrangement arriving at the listener position. This plot shows that the amplitude of the first and second, first order, reflections is well below the 15dB relative to the direct sound and the path of this reflection is from the wall behind the source loudspeaker. Additional absorption can be placed at this position to further reduce the amplitude of this reflection as this surface is not within the 2m zone around the listening position.

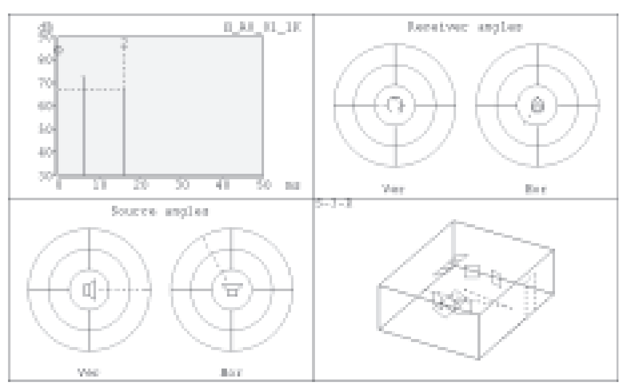

Figure 4
CATT Acoustic® model results, path and amplitude of second reflection

Time amplitude and path display of the second significant, first order reflection within the panel arrangement arriving at the listener position. This plot shows that the amplitude of the second, first order, reflections is well below the 20dB relative to the direct sound and the path of this reflection is from the wall behind the listener. Additional absorption can be placed at this position, if required, to further reduce the amplitude of this reflection as this surface is not within the 2m zone around the listening position.

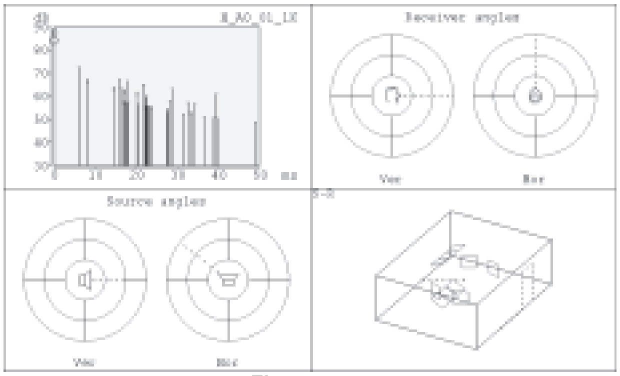

Figure 5
CATT Acoustic® model results, path and amplitude of all reflections within the first 50ms

The above figure shows the time amplitude of up to third order reflection including the diffused energy spectrum for the panel arrangement up to 50ms. It is noted that the amplitude of all reflected energy is well below –20dB relative to the direct sound.

4. ANALYSIS OF PREDICTED RESULTS

An impulse response of the source loudspeaker, with accurate directivity, and associated room reflections was acquired from the model for post processing of time amplitude and time amplitude frequency analysis i.e. ETC and ETF plots similar to the ones presented for the initial experiments in part 1[1] of this paper. It is important to understand the transformation from time domain to frequency domain, in particular the inherent limits of the joint frequency-time space. For the purposes of this experiment it is assumed that a measurement system with well-defined Fourier-Transform windows with time resolution of 1–2 ms and a frequency resolution of about 500Hz will be adequate to measure the room acoustic responses from 1KHz upwards. These are the main frequencies giving rise to the directional information which might be disturbed by early reflections[3].

The impulse response acquired from the CATT Acoustic® model for a single omni directional microphone was converted into a MLSSA compatible file and post analyzed in MLSSA analyzer.

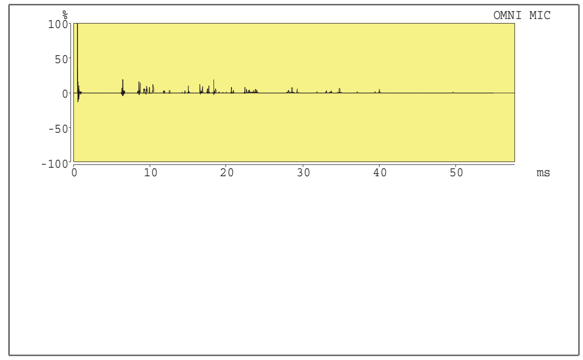

Figure 6
Impulse response acquired from CATT Acoustic® model

The impulse response acquired from the CATT Acoustic® model for a single omni directional microphone was converted into a MLSSA compatible file and post analyzed in MLSSA analyzer.

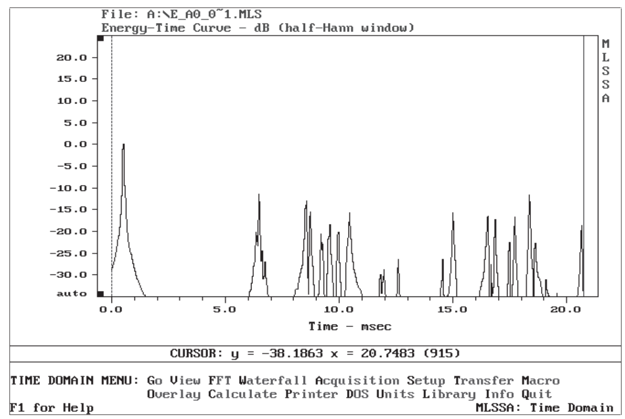

Figure 7
ETC plot of the predicted reflected energy by CATT Acoustic® model

MLSSA ETC of the CATT Acoustic® impulse showing all the amplitude and time distribution of reflections within 22ms. It is clear that the amplitude of the first significant reflection, as predicted by the model is below the –10dB mark and the following reflections are also below is level.

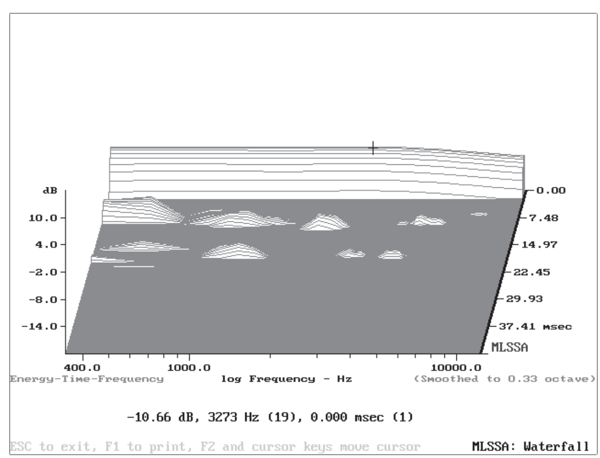

Figure 8
ETC plot of the predicted reflected energy by CATT Acoustic® model

MLSSA ETF of the CATT impulse showing all reflections within a 40ms time window from 400Hz to 12kHz. The spectral profile of the reflected energy is noted to be well controlled and well below the critical –10dB mark relative to the direct sound.

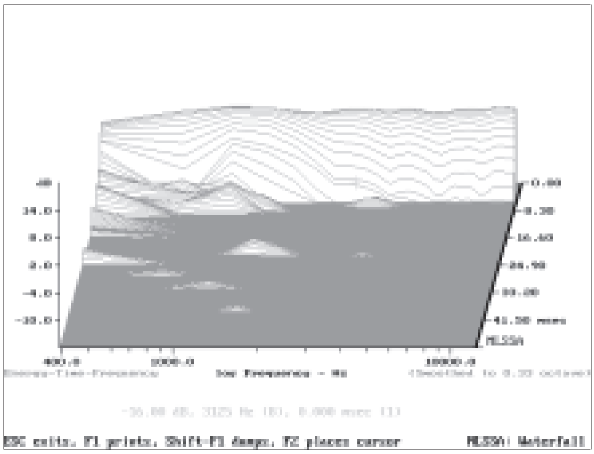

Figure 9
ETF plot of the measured reflected energy within the basic panel arrangement[1]

For comparison, MLSSA ETF plot of the reflection free zone crested by the panel arrangement in the initial experiments reported in part 1 [1] of this paper.

5. PROPERTIES OF DML LOUDSPEAKER

As mentioned in section 2, one of the main reasons for using the DML type loudspeaker panels for this application was based on their assumed radiation characteristics which resembles a broadband surface reflection from a room surface. The key feature of this type of radiator was considered to be the "diffused" nature of dispersion characteristics when compared with a conventional cone loudspeaker which normally is considered as a point source radiator. This characteristics it is well documented in published papers that DMLs have a much diffused reflection pattern when compared with a conventional loudspeaker [4] [5][6].

A new method involving the evaluation of the Cross-Correlation Function has been developed to describe the diffusivity of direct sound radiation which illustrates how a DML may produce an output with a diffuse character, stemming from the fluctuation in output with both angle and frequency [7] .The measure by which the diffuseness is characterized should therefore account for the similarity of the responses at different angles, over a given band of frequencies. A natural approach towards this goal is to take two responses, either impulse or frequency responses, and calculate their correlation.

The dependence of the spatial correlation of the radiation field on sound source properties and frequency is an important measure. In order to characterise the diffusivity of a particular source, the correlation measure is applied to a polar data set in the following way. A single reference angle is decided upon, for example the on-axis position, and the *CCF* (cross correlation function) is calculated between the response at the reference position and another position of the polar data set. This procedure is repeated for every measured response of the polar data set to form a set of *CCF* responses. In the *CCF* polar plot the maximum value of the *CCF* is plotted as a function of angle. An example of this method is presented here for a typical DML panel and cone loudspeaker. The two *CCF* polar plots below exhibit strikingly different behavior.

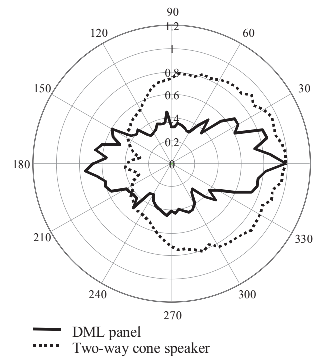

Figure 10
Maximum Cross-Correlation polar plot
On-axis response is compared with all other responses of the polar data set [7]

Both traces have a value of 1 on-axis, corresponding to the correlation of the reference position with itself. As the angle from the on-axis increases, the correlation of the cone loudspeaker remains high and only decreases significantly for positions behind the front face of the loudspeaker. The DML on the other hand is characterised by a narrow set of angles where the output remains well correlated to the reference position, and outside which the correlation falls off rapidly. In summary, the cone loudspeaker represents a source with a broad angle directivity and correlation, whereas the DML exhibits a broad angle directivity but a correlation that falls off rapidly with angle[7].

Some more conventional measures, such as the sound power response and polar response of DML type loudspeaker are also presented in the figures below.

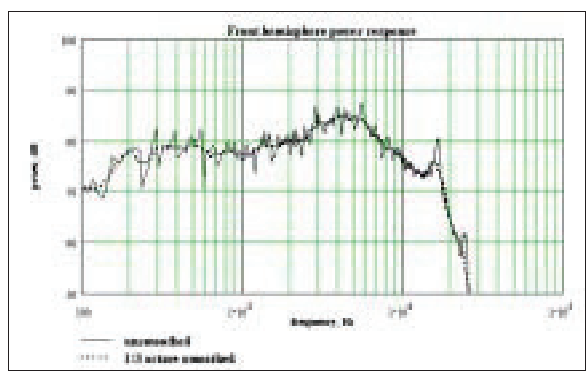

Figure 11
Total power response of DML calculated from 5 degree polar responses

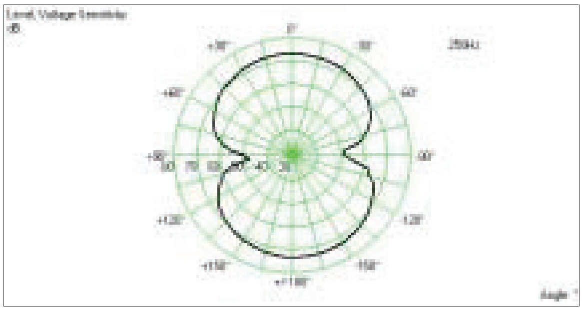

Figure 12
DML polar response at 250Hz with octave smoothing

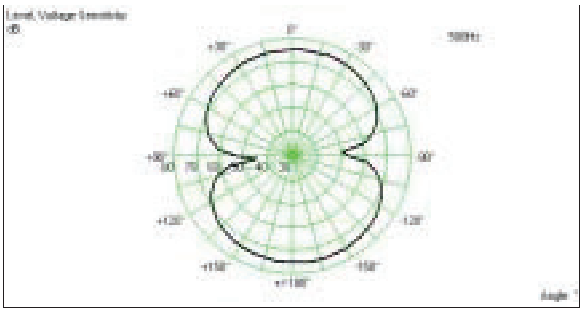

Figure 13
DML polar response at 500Hz with octave smoothing

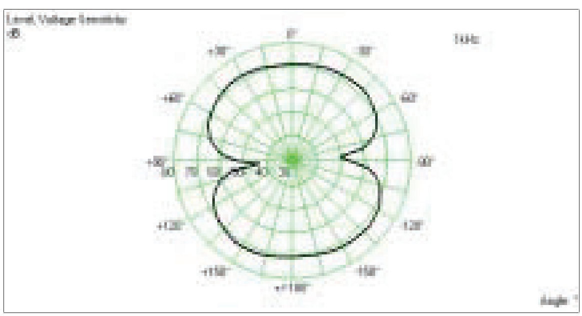

Figure 14
DML polar response at 1kHz with octave smoothing

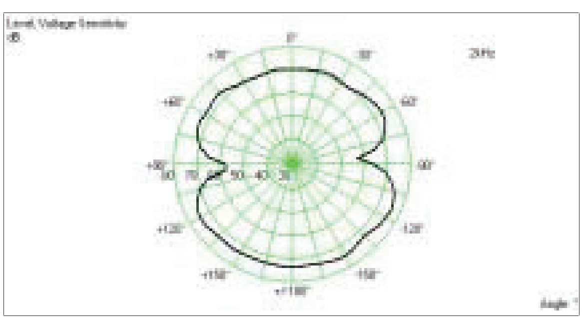

Figure 15
DML polar response at 2kHz with octave smoothing

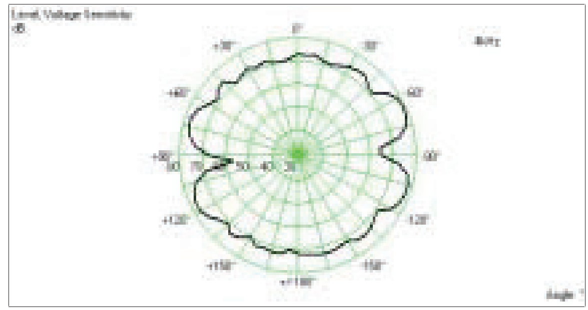

Figure 16
DML polar response at 4kHz with octave smoothing

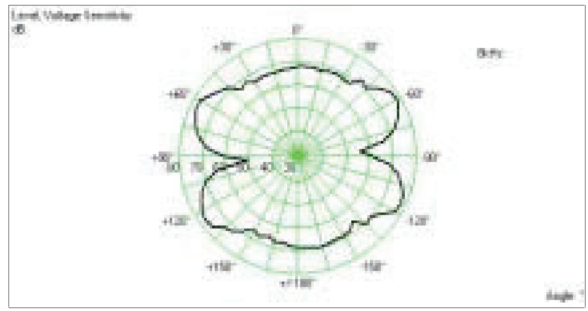

Figure 17
DML polar response at 8kHz with octave smoothing

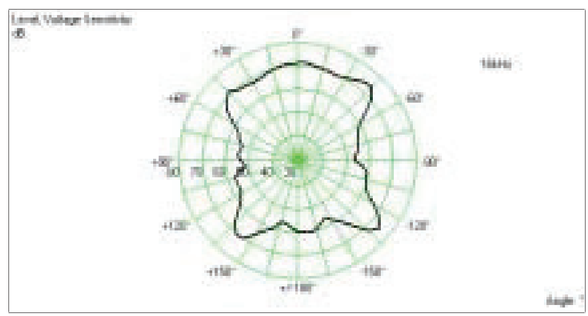

Figure 18
DML polar response at 16kHz with octave smoothing

6. COMPARISION OF LOUDSPEAKER RESPONSES

In this section the results of a comparative study is presented which involved a detailed analysis of on and off axis free field frequency responses of DML panels compared with conventional cone loudspeakers and real room reflections. The key objective of this exercise was to establish the suitability of DML panels to reproduce the spectrum of real room reflections in the angular panel arrangement of the simulation setup. A complete set of 5 degree free field measurements were taken at 1m from a 600x600mm panel in an anechoic chamber. Some key results are presented in the figures below.

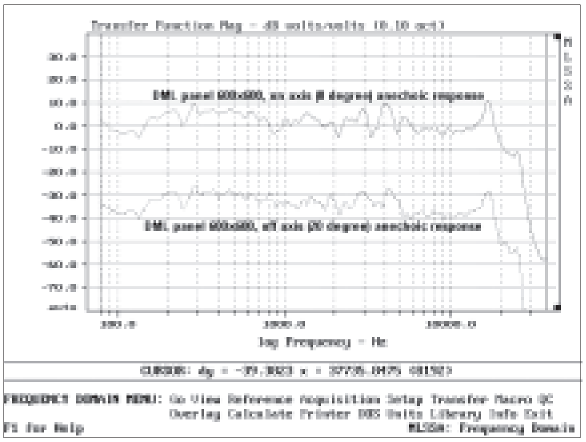

Figure 19
DML panel, on and off axis, free field response (dB level of compared plots are offset by 30dB)

One of the most characteristic features of the anechoic response of the above mentioned DML panels is the dip in response at around 800Hz which is due the diffraction cancellation in the given size of these panels. Also, a significant boost in the sound pressure and sound power response between 2kHz – 5kHz region was noted. This is due to the coincidence effect and the boost is due to the coupling of sound waves inside and outside the panel. A sharp peak at around 18kHz was noted in all measurement which is due to a voice coil interferences within the panel surface. In general, it was noted that the off axis, 20 – 30 degree, free field response of the DML panels is much smoother than the on axis response. This maybe favorable to the application as the deflector panel arrangement with embed DMLs are angled in the same region in relation to the listener position.

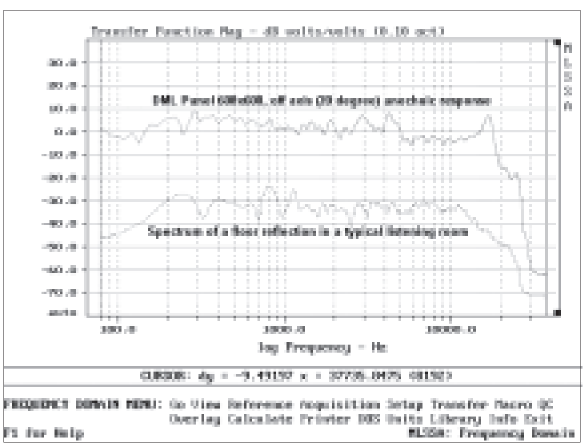

Figure 20
DML panel, off axis response compared with the spectrum of a typical floor reflection (dB level of compared plots are offset by 30dB)

It was considered necessary to investigate into the spectral properties of real early reflections in listening rooms before setting up the simulator for listening tests and also evaluate the performance of the DML panels to establish their suitability in terms of timbral properties. In the above figure, the DML off axis frequency response is compared with the measured spectrum of floor reflection from a typical. It is apparent that the DML will require careful equalization to match the spectrum of this given reflection.

7. CONCLUSION

It is clear from the predicted results from the acoustic model that that the concept of deflector panels with embedded DML in the angular panel arrangement around a source loudspeakers in a stereo listening setup fulfils the key requirements of the reflection free zone around the listener position in the proposed simulation set-up.

With regards to the suitability of DML panels as acoustic radiators used for the re-production of “artificial” room reflections in the angular panel arrangement, it is apparent from the measurement data that this type of loudspeaker has the potential to simulate the diffused nature of real room reflections. The off axis frequency response of DML panels also looks favorable to re-produce the spectral and timbral properties of real room reflections when used in conjunction with a broadband equalization network.

8. REFERENCES

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