DESIGN OF ROOMS FOR MULTICHANNEL AUDIO MONITORING

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This paper presents an overview of the practical aims, methods and problems of designing monitoring rooms for multichannel audio. The main problem areas encountered in practical multichannel audio monitoring room are described with a case study of a practical high quality monitoring room and with scale model measurements. The scale model is also used to investigate the effect of structural modifications to the room suggested in literature as methods to achieve better performance in multichannel audio reproduction. The design principles and methodology applied in the industry is reviewed, and some suggestions are developed to guide the monitoring room designer.

INTRODUCTION

A modern audio production facility has to be able to serve productions in a large number of different formats.

The change from mono and stereo to multichannel reproduction has produced a lot of problems, both in converting existing production facilities to multichannel format and in new installations.

The audio formats that must be handled by a modern production facility include currently

- mono, stereo
- matrixed four channel format
- five channels (later 5.0 reproduction)
- five channels with a separate Low Frequency Enhancement channel (later 5.1 reproduction)

1 MATERIAL AND METHODS

1.1 Aims of the experimental work

The properties of a multichannel monitoring system were studied in room comparable in size and construction to a medium-to-large scale monitoring facility.

The scale model was necessary to allow investigation of the effects of structural changes to the room and the loudspeaker installations.

The aim of the work is to investigate the feasibility of the methods suggested in the contemporary literature to implement multichannel audio monitoring. The particular areas of interest are

- surround loudspeaker installation methods to achieve similarity with the front loudspeaker system
- methods to achieve specified performance at low frequencies were the summation of the acoustic signals from multiple sources becomes coherent
- methods to obtain large high quality monitoring area in the room
- the frequencies of interest f < 1000Hz

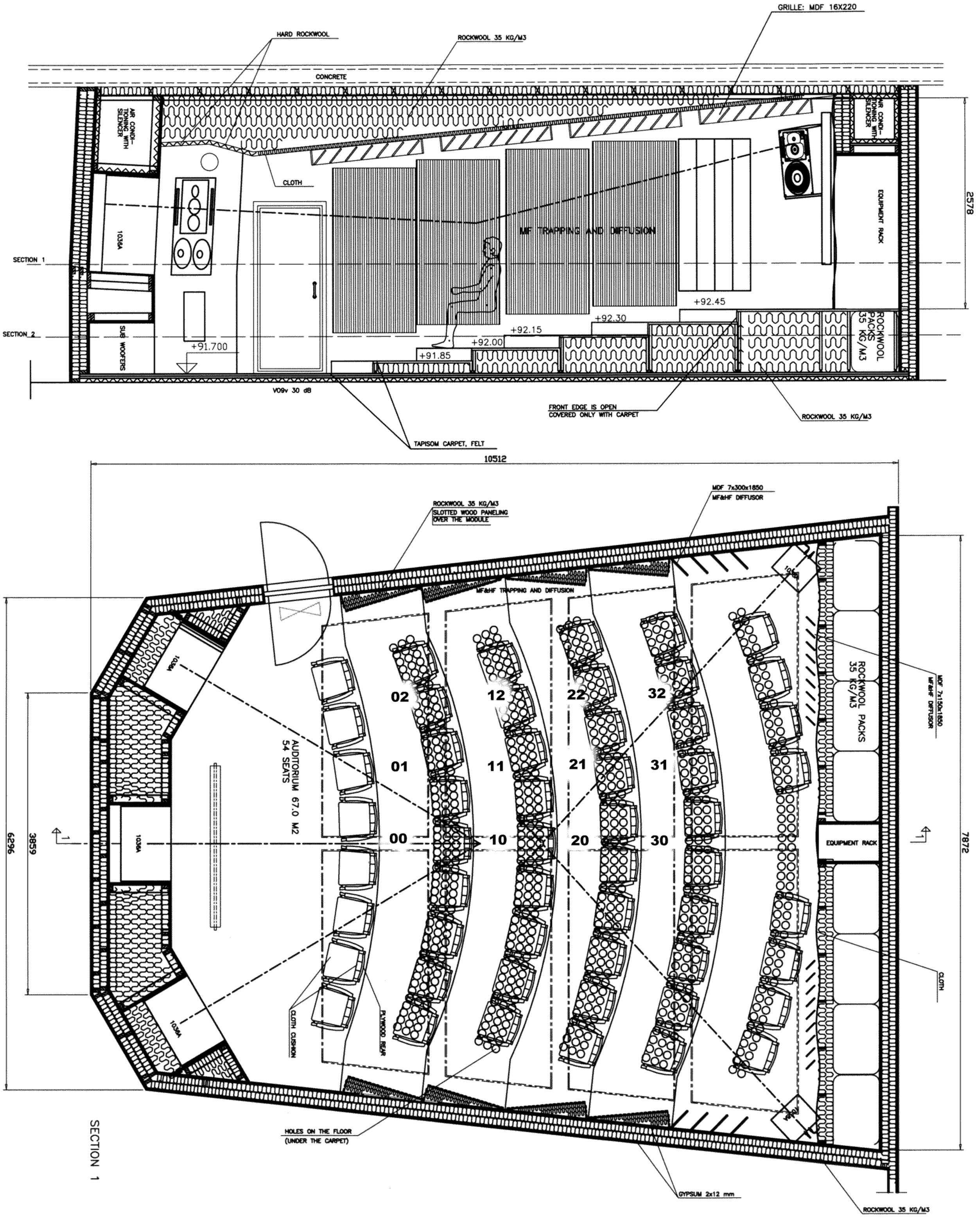

Figure 1. Monitoring room construction dimensions, and the placement of the measurement grid points.

1.2 Monitoring room and scale model

The floor area of the room is 63m^2. Free volume is 163m^3. The room was furnished as an auditorium (Figure 1). A 10:1 scale model was produced of the room, including the absorbents and the loudspeaker installations.

The loudspeaker system in the room includes three flush mounted front loudspeakers, to implement the Left, Center and Right outputs. The surround loudspeakers are installed, as they typically are, next to the rear bass trap and the side wall. Optically they are in the corner of the room, but acoustically there are reflecting boundaries close to these radiators such that their radiation to the room happens in conditions significantly differing from those of the frontal main speakers.

All loudspeakers are full bandwidth units, with acceptably low lower cut-off frequencies (front 3 pcs Genelec 1036A, surround 2 pcs Genelec 1038A).

The scale model was used to model mid-to-low frequency behaviour of the room. The radiators were 1” dome tweeters, modelling the low frequency drivers.

1.3 Measurement grid

Frequency responses were measured in the actual room in a grid of measurement points with an interval of one meter. Front-to-back there were four measurement point, from the center of the room to the right side there were three points, totalling 12 measurement points. The room is symmetrical, so only one side of the room was measured. The total floor area covered by the measurements was 12m^2. The grid interval of one meter was adequate to cover the frequencies of interest.

1.4 Data processing

The measurements were taken using a 7mm diameter microphone and the MLSSA measurement system. The impulse responses in all grid points were stored. Similar measurements were taken in the scale model.

2 RESULTS

2.1 Accuracy of the model

Measurements in the real room were compared to the scale model. A good agreement was observed.

As an example, the reflection of the front speaker sound from the back wall produces a cancellation notch which moves in frequency as the microphone moves towards the back of the room (Figure 2).

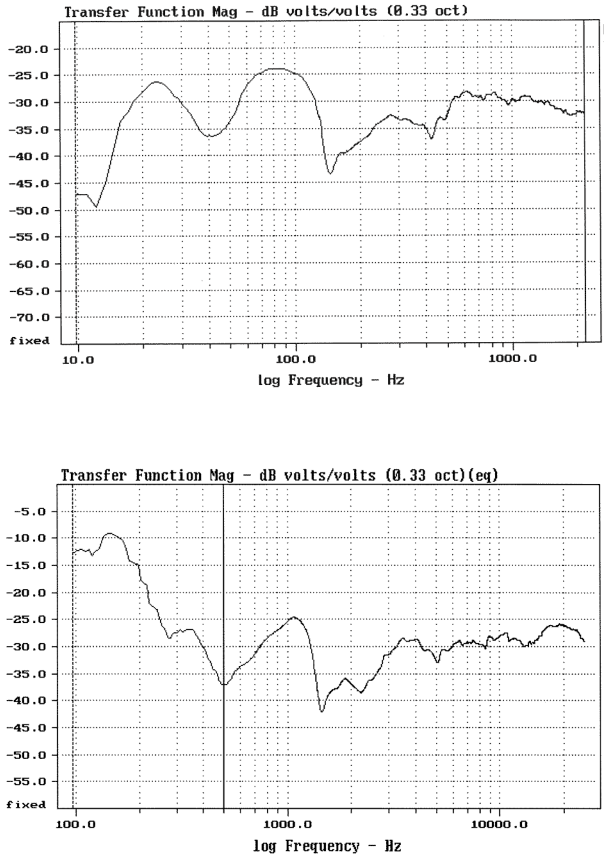

Figure 2. Cancellation of direct sound by rear wall reflection (top) in room at 50Hz, and (bottom) in model at 500Hz.

Table 1. Similarity of frequency responses, deviation dB in band 20Hz…1kHz after 0.33 octave smoothing. “C” center loudspeaker, “L” left, “R” right, “SL” surround left, “SR” surround right.

position	C	L	R	SL	SR
00	14	10	14	21	23
10	11	8	10	20	21
20	10	12	13	21	19
30	12	15	19	19	18
01	10	15	9	20	14
11	11	13	8	16	-
21	8	13	9	17	18
31	15	24	11	17	14
02	15	23	13	18	18
12	14	17	13	23	18
22	13	20	14	18	17
32	14	22	15	16	13

2.2 Similarity of frequency responses

The similarity of the frequency responses is investigated by calculating the place dependent deviation from linear frequency response.

The frequency responses were measured at all grid points in the room. A 1/3-octave smoothing was applied. The difference between the minimum and maximum values between frequencies 20Hz…1kHz is presented in Table 1.

The variation is typical of a high quality monitoring room. It is larger for the rear channels, and caused by boundary reflections in the room.

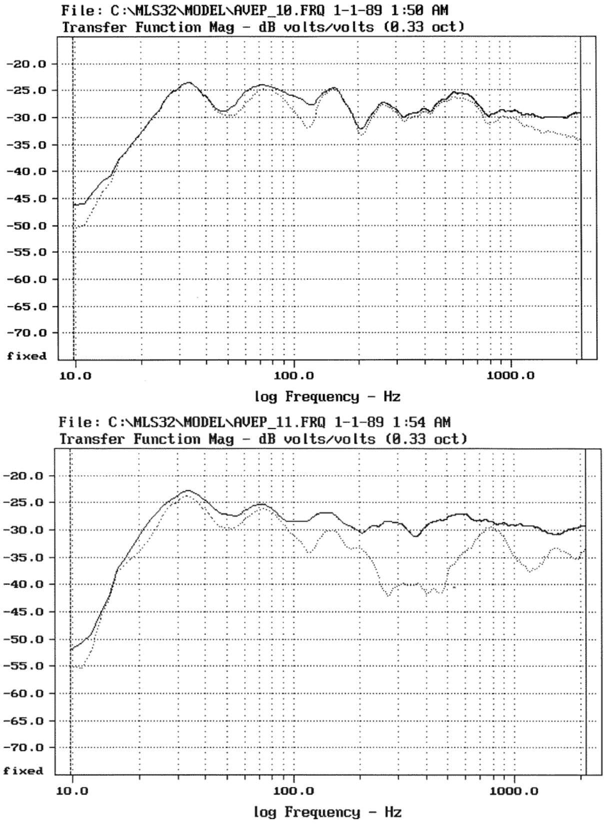

Figure 3. On-axis (top, point "10") and off-axis (bottom, point "11") signal summation for coherent (dashed) and non-coherent signals (solid).

2.3 Frequency response in the listening area

Signals from all loudspeakers combine to form sound experience at the listening point.

The signal level generated when all front loudspeakers are operating was calculated at two points, "10" on the center symmetry axis, and point "11" one meter to the side from that, for in-phase and non-coherent material.

The summation was calculated by complex averaging (non-coherent summation) and by power averaging (coherent summation).

The on-axis summation for both coherent and non-coherent signals shows good agreement, while a fairly small displacement off-axis shows a significant difference in the sound level produced for in-phase input signals (coherent summation) and other signals.

2.4 Bass response change in front-back direction

When bass frequencies are produced from radiator(s) in the front of the room, the solid rear wall behind a possible bass trap produces a reflection of the sound that interferes with the primary sound if bass trapping in the is not adequate. This is often the case.

The shape of the rear wall modifies the level of the interference. A concave rear wall is sometimes used, and this increases the amplitude of the interference at the center of the room, in the best listening area.

The solid back wall in the studied room was straight, but still the effect of the back wall reflection is clearly visible as loss of level in the low bass frequencies.

The interference notch moves up in frequency as the microphone approaches the back wall (Figure 4). A distinct cancellation notch becomes visible at measurement point "30" at 40Hz. This bass cancellation was visible for all front loudspeakers, and resulted in loss of bass output and then a change in tonality when the listener moves towards the back of the room.

Any subwoofer placed in the front would suffer the same loss in its radiating energy. Experience with many monitoring room designs shows that the rear wall reflection is a common cause of a lack of bass performance in rooms designed according to high standard established design methods.

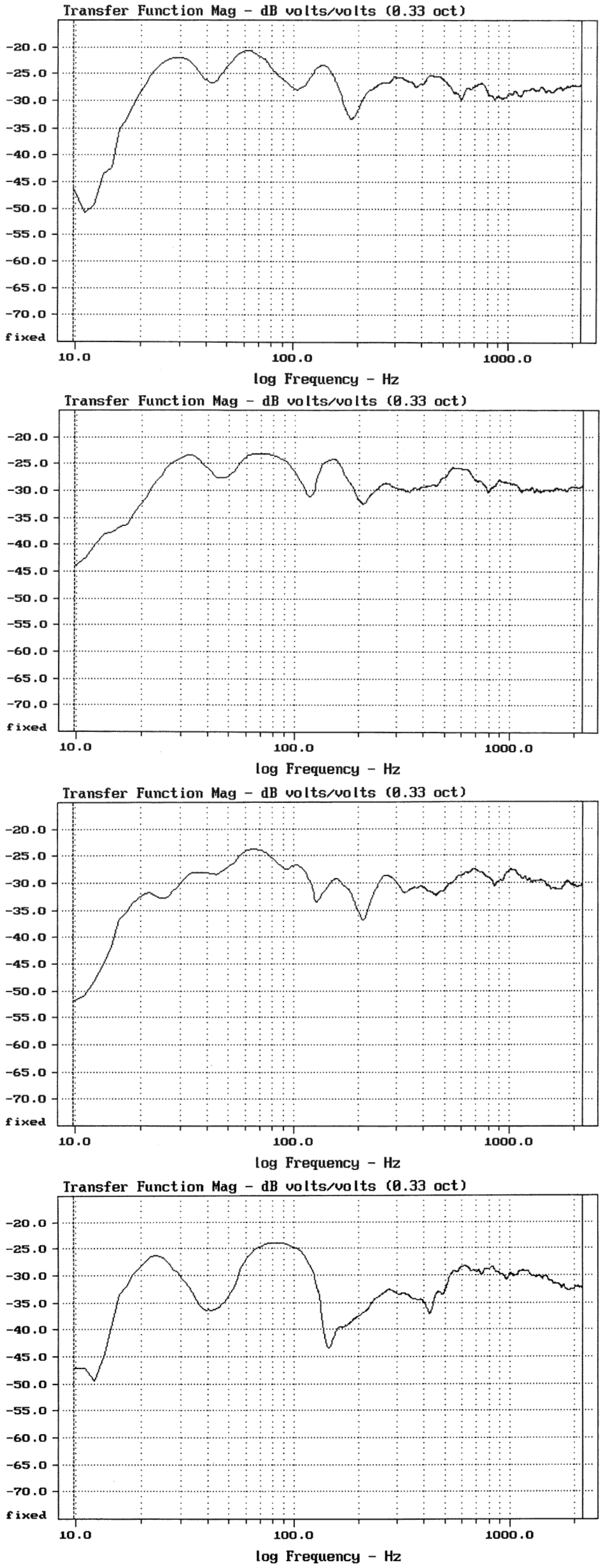

Figure 4. First order reflection modifies the bass level of the Right loudspeaker as the microphone moves back on the center symmetry axis of the room. From top to bottom: measurement point "00"," 10", "20","30".

2.5 Surround loudspeaker installation

The wall installation of the surround loudspeakers typically significantly differs from that of the front loudspeakers. It is typical to see surround loudspeakers installed close to the side walls of the room. Because of radiating angles defined in current standards [1,2], they become placed in a position where a significant amount of energy is radiated to the side wall.

Figure 1 shows the placement of the surround loudspeakers in the room used in this study. The scale model was used to investigate the effect various possibilities to install the surround loudspeakers. Both fully absorbing (free field) and soffit installations have been proposed in the literature.

A baffle around the surround loudspeaker (Figure 5) appeared to reduce the notch produced by a secondary image radiator produced by the side wall on which the surround loudspeaker was installed. The absorbing material around the surround loudspeaker seemed to have minimal effect and failed to produce free field radiating conditions for the surround loudspeaker.

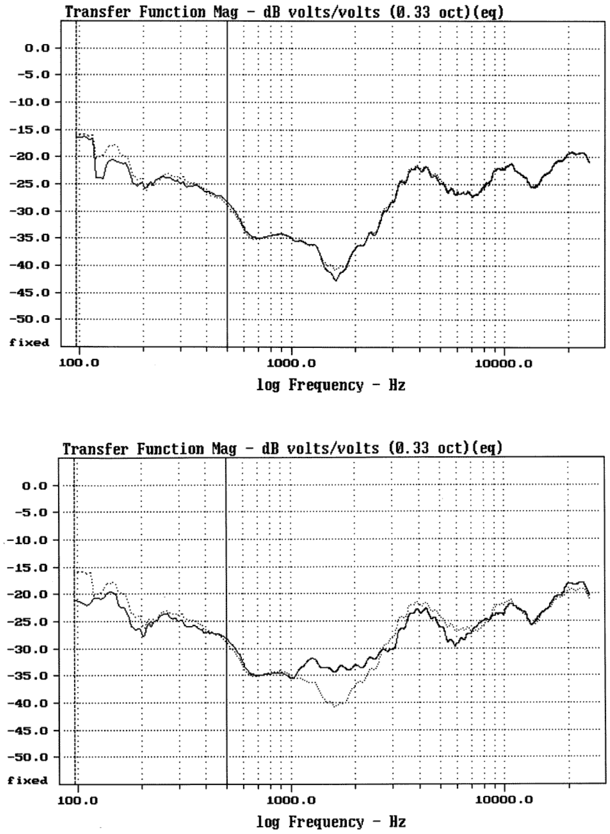

Figure 5. Effect of fully absorbing (top, solid) and baffle (bottom, solid) installation relative to the actual (dotted).

Loudspeaker radiation can also be analysed by using energy-time curves that more specifically provide information about the individual reflections that contribute to the measured frequency response.

The scale model was used to investigate the effect of modifications to the absorbance of the surfaces in the room.

If the baffles around surround loudspeakers are implemented, they will reflect some sound energy from the front loudspeakers, increasing the level of early reflections associated with the front sound (Figure 6). This radiation is coming from the back of the listener, so it is likely to be discerned as a separate sound event [3].

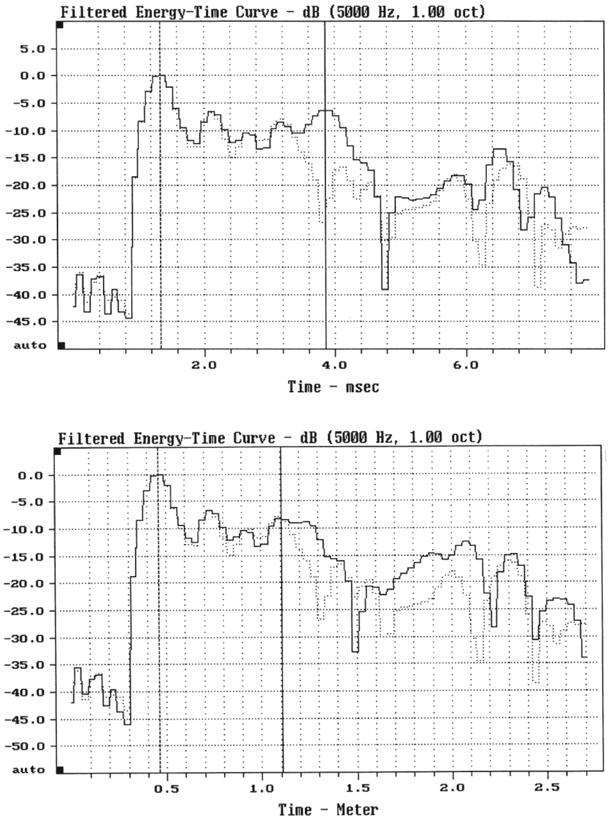

Figure 6. Reflection from the Left (top, solid) and Right (bottom, solid) surround loudspeakers in baffles, standard installation without baffle (dashed).

2.6 Control of reflections by additional absorbing material on walls

Because the loudspeakers are calibrated for on-axis listening, they are normally aimed towards the listeners. In our case, the loudspeakers were to optimise the monitoring quality at point "10".

For front radiation, additional absorbance on the same wall with the loudspeaker produced more reduction in early reflection level than if the absorbing material was placed on the opposite wall (Figure 7).

The surround loudspeaker radiation can also reflect off the wall opposite to it, and from the faces of the front loudspeakers (Figure 8).

If the front wall is made absorbing, the loudspeakers in the front can still contribute significantly to the surround audio reflections from the front.

2.7 Coherence of front bass radiators

Griesinger [8] recommends a constant phase difference for reproduction of bass frequencies from multiple front speakers to increase the envelopment. Other authors [9] have advocated the use of a single subwoofer instead of multiple sources to minimise loudspeaker-room interaction and the problems of coherent summation of the energy at low frequencies from multiple sources.

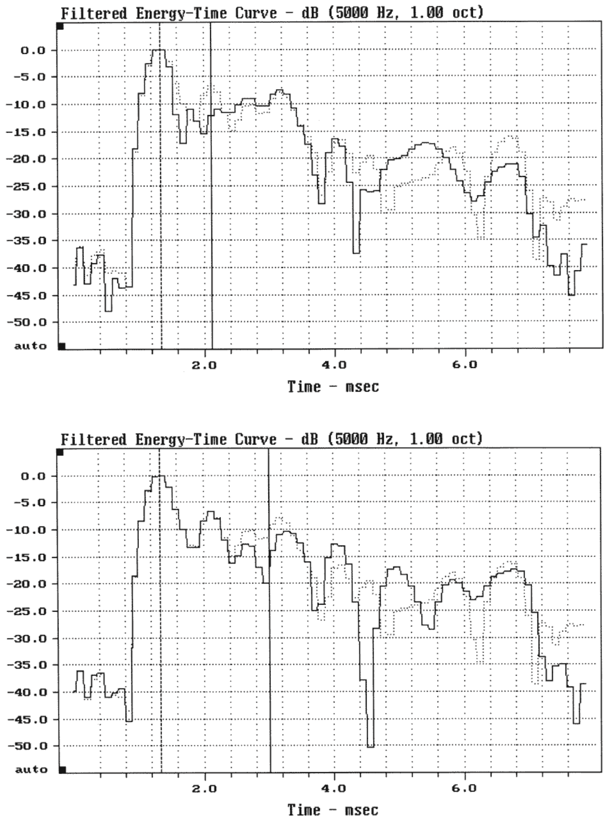

Figure 7. Effect of absorbing material on the same wall (top, solid) or opposite wall (bottom, solid) of the Right loudspeaker; no added absorption (dashed).

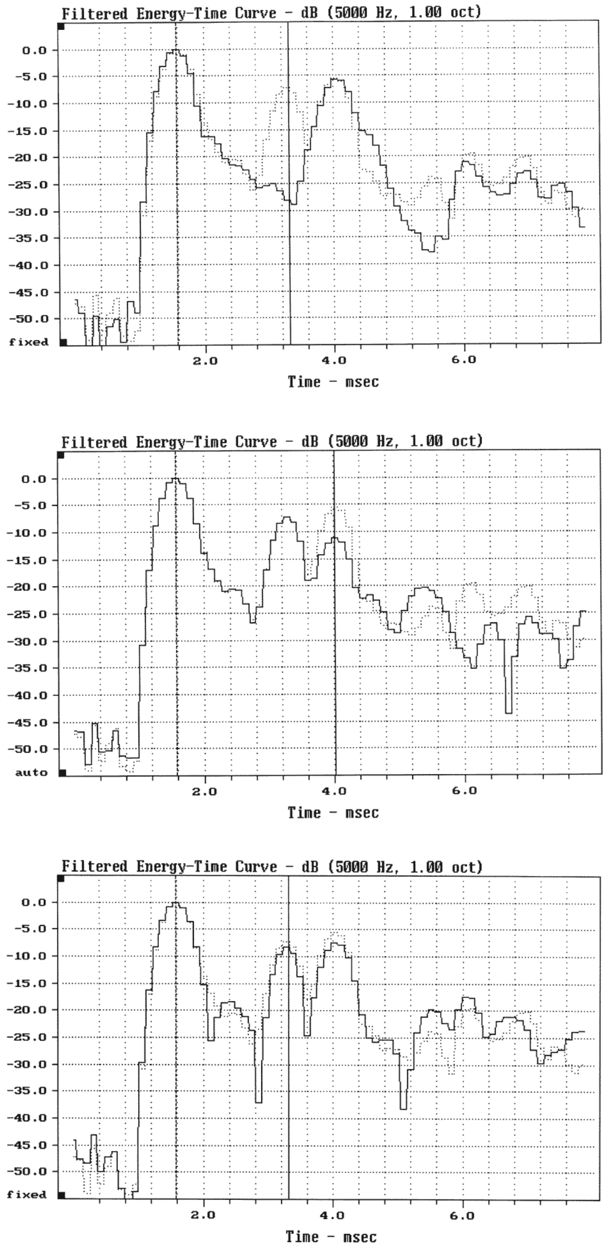

Figure 8. Right surround loudspeaker radiation with (top, solid) absorbing material on the opposite left wall, over the left front speaker (middle, solid) or around the left front speaker (bottom, solid), relative to standard surround loudspeaker installation (dashed).

To model an additional subwoofer in our configuration, a low pass filtered version of the Right loudspeaker response to point "11" was calculated and summed to the response of the Right loudspeaker, modelling an non-symmetrically placed front subwoofer radiating with excellent coherence in the passband (Figure 9). The subwoofer signal is band limited, and the filtering associated with this band limitation is implemented in practical applications as electrical filtering as well as mechanical and acoustical filtering.

The phase difference on the transition band caused by the band limiting filter relative to other sound radiators may actually decrease the sound level and the system efficiency.

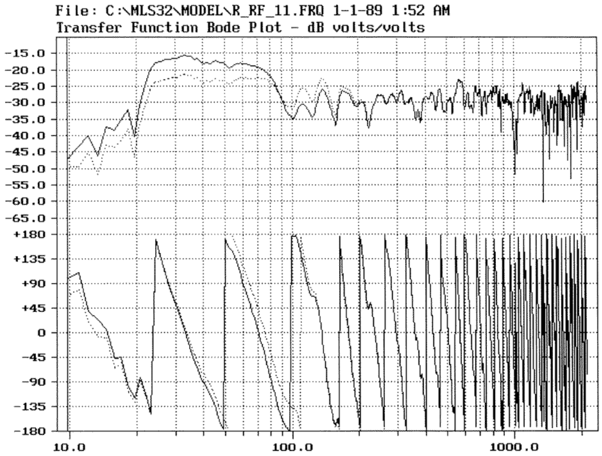

Figure 9. Effect of an additional off-axis subwoofer, Right loudspeaker with additional subwoofer (solid), Right speaker alone (dashed).

3 DISCUSSION

3.1 Design aims

Volker [6] summarises the development of the monitoring room performance specification over some 60 years. The design aims of a modern day reproduction system can be structured into [1,2,7]

- wide listening area
- equality of sound level at all frequencies in the listening area (flatness of frequency response)
- similarity of frequency responses of all full bandwidth loudspeakers (similarity of frequency responses)
- equal times-of-flight of the audio signal from all full bandwidth sources
- faithful reproduction of the standardised loudspeaker angles of the full bandwidth sources
- sound sources at the listening height
- good integration of low frequency sound sources, including the Low Frequency Enhancement Channel, to produce an even frequency response, in-line with the frequency response at higher frequencies

There are several reasons why the design aims for multichannel monitoring room can frequently not be fulfilled. These arise when old production facilities are converted for new audio systems, or newly designed facilities face design limitations that hinder these aims to be respected. Majority of problems can be grouped to

- properties of the loudspeaker(s)
- room geometry and loudspeaker — room interaction
- use of subwoofer(s)

3.2 Properties of the Loudspeakers

The assumptions of the current standards for 5.0 and 5.1 reproduction [1,2] call for similar loudspeakers to be installed. Often, this recommendation is difficult to fulfill. The surround loudspeakers may differ in size and implementation from the front loudspeakers. The center loudspeaker may be different from the left and right loudspeakers. The calibration of frequency responses is frequently overlooked.

3.3 Room geometry and loudspeaker – room interaction

The stereophonic reproduction has generated few fairly stabilised and accepted principles of design such as a reflection free zone in front of the room, the Live End-Dead End principle, left-right symmetry of the monitoring room, symmetrical placement of the Left and Right loudspeakers. The stereophonic design principles do not directly extend to multichannel reproduction, and the current lack of clear design approach is generating a lot of debate. Proponents of traditional design approach attempt to extend the traditional approach to multichannel rooms, claiming that this would be possible although they at the same time recognise many problems [4,5].

The traditional approach installs the front loudspeakers flush with the hard front wall, generating an extended baffle in the front. The back wall typically contains a thick soft bass trap. The surround loudspeakers are typically installed either free-standing or embedded flush with the surface of the bass trap material, resulting in conditions similar to a free-standing placement at low frequencies and a variable, undefined boundary condition at higher frequencies.

It may be difficult to maintain the angles defined in the standards for the surround loudspeakers and to maintain equidistant placement of all full bandwidth radiators in small rooms and retrofit installations.

The need to produce similar radiating conditions for all full bandwidth loudspeakers has been recognised [4,5]. Various solutions have been suggested to ensure similar radiating conditions for all loudspeakers

- rooms with sound absorbing material around all walls, including the front
- some additional baffling around surround loudspeakers

We demonstrated potential problems in applying either of these approaches.

3.4 Use of subwoofer(s)

One or more subwoofers are typically used because of (1) the reproduction of a separate Low Frequency Enhancement Channel [1], and because (2) the output capability of the main loudspeakers is compromised at low frequencies even though the recommendations call for full bandwidth loudspeakers. This is typical in small room installations, where the physical size of the main loudspeakers is limited, and thereby the low frequency handling capability is not adequate.

The frequency band of the Low Frequency Enhancement channel overlaps with the bandwidth of main loudspeakers. If a subwoofer is used to reproduce the Low Frequency Enhancement channel without proper bass management, a possible consequence is non-coherent radiation of the same programme content by the subwoofer and the main loudspeakers. This may result in unpredictable summing of audio (Figure 10).

Although the standard [1] assumes that the Low Frequency Enhancement is carrying additional sound information, such as sound effects, in practice it is likely that similar material appears on the main channels. When this happens, and the bass management does not account for this possibility, there may actually be a reduction at some frequencies in the bass level because of an additional subwoofer, not an increase.

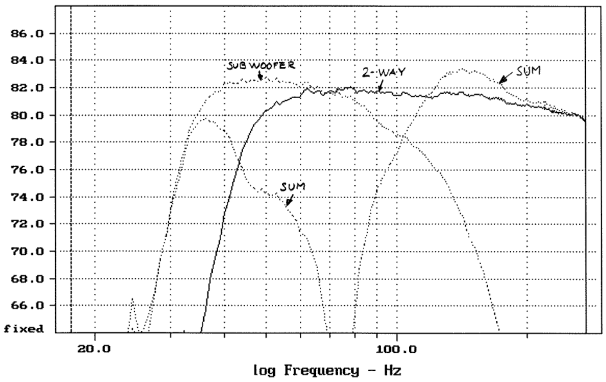

Figure 10. Anechoic acoustical sum of a full bandwidth loudspeaker (solid) and a subwoofer with 33…120 Hz passband. Severe signal cancellation occurs because of phase mismatch in overlapping frequencies caused by acoustical design.

The management of low frequency information under the limitations above has not been specified in standards and recommendations, making it an implementation dependent property.

The contemporary implementations can be divided into

- single subwoofer
- several subwoofers to increase output capability
- surround subwoofer to enhance the surround loudspeakers' low frequency capability
- distributed bass reproduction from Left and Right main loudspeakers
- distributed bass reproduction from frontal loudspeakers
- distributed bass reproduction from all loudspeakers

The problems seen in installations, both big and small rooms, are

- low order reflection induced place dependent interference (notably the back wall reflection)
- dissimilar frequency response characteristics from several low frequency radiators because of differences in the method of room installation and radiation characteristics
- wrong management of low frequency signal sources

4 CONCLUSIONS

A descriptive study of an implemented multichannel monitoring facility demonstrated the problems of multichannel monitoring environment acoustical design. Surround loudspeaker installation, low frequency sound integration and the control of low order reflections were discussed.

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