AN INVESTIGATION INTO THE ACOUSTIC EFFECT OF CINEMA SCREENS ON LOUDSPEAKER PERFORMANCE

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1 ABSTRACT

The advent of digital soundtracks for cinema has brought about the possibility of significant improvements in the quality of sound in cinemas. One aspect of this sound quality involves the transmission of sound through the screens, behind which the loudspeakers are almost invariably placed. The acoustic properties of the various different types of screen are currently not completely understood, and very limited data on this subject is available from the screen manufacturers. Although a number of published studies have already been undertaken relating to the acoustic performance of screens, some have had commercial interests involved, and some of the contrasting results that have been presented have not been from tests conducted under similar circumstances. This paper is concerned with investigating the acoustic properties of three different screens through detailed measurements, all carried out under the same conditions in an anechoic chamber.

2 INTRODUCTION

For the projection of motion pictures, if the perceptually important collocation of the image and sound are to be maintained, it is necessary to position an optically reflective yet acoustically transparent screen in front of the principal loudspeakers of the frontal sound stage. Materials with the desirable characteristics of both perfect optical reflectivity and acoustic transparency do not exist, and so a compromise must be found in order for films to be exhibited in public with acceptable levels of performance in both domains. Surprising as it may seem, over 80 years since the advent of films with soundtracks, relatively little definitive work has been published on the more detailed acoustic properties of screens and their interaction with loudspeakers. While some notable studies have been made on certain aspects of this subject [1, 2, 3, 4, 5. 6], much work still needs to be done before many aspects of the overall performance can be accurately predicted from the specifications of the component parts of a cinema 'B-chain' (traditionally the projector output to the ear of the listener).

Sound from a loudspeaker behind a screen can be reflected back, absorbed within or transmitted through the screen. In general, there will be degrees of all of these characteristics (although the absorption tends to be quite low), and so screens will therefore give rise to differences between the sound as would be heard directly from the loudspeaker and that which is actually transmitted to an audience. The mechanisms of sound absorption and reflexion will cause an attenuation of the transmitted sound. Also, the sound reflected from a screen will be further reflected from the loudspeaker and its surroundings, only to be re-transmitted (and re-reflected) at later times until it finally dies away. The interference between the directly transmitted sound and the subsequent reflexions produces comb filtering of the sound travelling through the screen. In this work, sound attenuation and comb filtering are investigated through measurements of the sound radiated by a loudspeaker, behind a screen in an anechoic chamber.

From an acoustic standpoint, screens form an obstruction to the passage of the sound. The degree of this obstruction depends upon the screen material, the nature and degree to which it may be perforated, the distance that it is mounted from the loudspeakers, whether the screen is flat or curved, and the angle between the screen and the front baffles of the loudspeakers. It may also be affected by the way that the loudspeakers are mounted, such as free-standing, or mounted in a baffle wall which may or may not be covered in varying degrees of absorbent material. Clearly, there are likely to be very many permutations of these variables, and thus the prediction of how a loudspeaker/screen installation can be expected to behave in a given set of circumstances is frequently no easy task. This is especially so if the combination has not been used in precisely the same way before. The problems for the system designers and installers are also not helped by the fact that the manufacturers of the screens often give little data about their acoustic performances or recommended mounting conditions. The optical specifications seem to dominate.

To some extent, the lack of published acoustic performance data may be due to the above-mentioned multiplicity of variables, but it may also have been seen as being relatively unimportant due to the tendency in the cinema industry to calibrate room installations by means of one-third-octave, real-time analysis and equalisation; a rather crude technique within which a multitude of acoustic sins can be camouflaged. However, with the movement now taking place towards more revealing methods of system analysis, including time-domain analysis, the spotlight is beginning to fall on the way in which screens may be limiting the ability of modern soundtracks to reveal their full potential. Also, during the last decade or so, woven, fabric screens have begun to be used in both professional and domestic cinemas, and have often revealed more of the fidelity that has already been inherent in soundtracks for many years, although has rarely been heard.

Many other screens, such as those made from PVC (which has good light-reflecting characteristics), need to be perforated in order the let the sound through. Un-perforated screens made of such material, at least of adequate thickness to be stable and durable, would severely attenuate the high frequencies to a point of uselessness. Placing the loudspeakers above or below the screen would both dissociate the sound from the picture and could give rise to problems of audience coverage and arrival-time integrity. The perforated screens come in the standard and mini/micro-perforated varieties, with hole diameters of around 1.2 mm to 0.5 mm respectively. The typical losses through some common, plastic, perforated screens are shown in Figure 1 (MP – mini-perforated; SP – standard perforated; MPS – super-mini-perforated). The normal proportion of hole area to solid screen for mini-perforated screens is around 1.7%, but the standard and super-mini-perforated types can reach around 5%. However, as the perforation area increases, the greater can be the tendency for the holes to become more visibly noticeable when viewing from distances of around 5 metres or less, reducing the clarity of the image, although with smaller holes, there is a risk that they can become clogged with dust and dirt unless their environment is kept clean, which can severely affect their ability to transmit the sound. Specific choices of screen material may therefore need to be made for specific conditions.

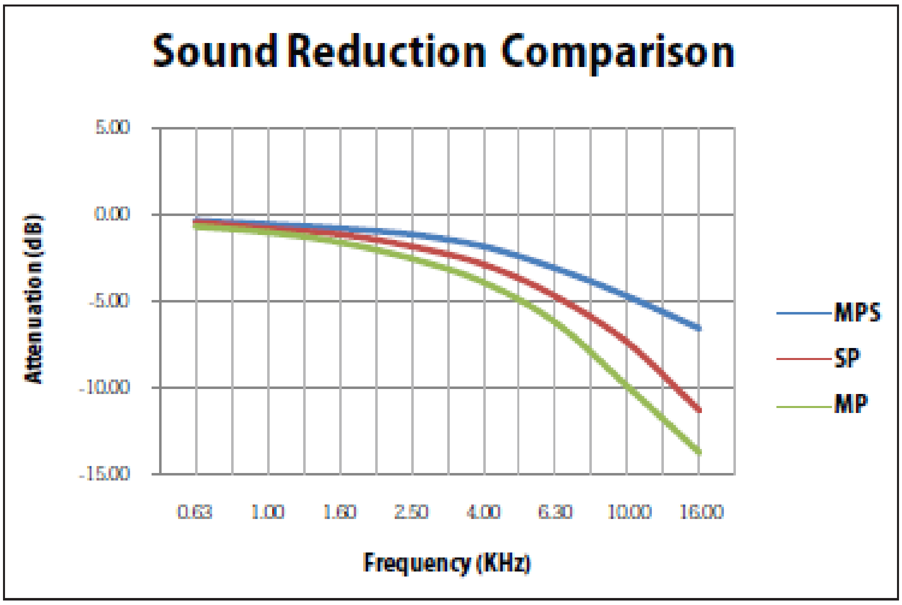


Figure 1 Typical losses through some common, plastic, perforated screens

Woven screens have a somewhat more irregular surface which tends to scatter the light and make the holes in the weave less visible, but a side-effect of this is to reduce the capacity for the screens to reflect the image back to the audience area. Less reflectivity requires a greater power from the projector lamp, requiring more power to be consumed and more heat to be produced. Ultimately, it may require a larger projector to be used. In many domestic situations and dubbing theatres, the lower reflectivity may not be a problem and the greater sound transparency of the woven screens may be seen as an advantage. However, a further problem with their use in the larger theatres is that the widths of the looms on which they are made set limits for their available sizes. Sections of woven screens cannot be seamlessly welded together as they can with the perforated PVC screens, but 6 metre-wide looms are becoming available for some of the woven screens, making screen widths of up to 14 metres feasible.

3. MEASUREMENT METHOD AND AIMS

For the purposes of the investigations outlined in this paper, two different types of woven screens and one mini-perforated screen of 1.7% open area were mounted on a wooden frame of two metres square, in accordance with the basic principles of Appendix 1 of BS5382:1976 'Specification for Cinematograph Screens', following the outline of '*Appendix A. Method of measuring attenuation of sound (Not applicable to un-perforated screens). Stretch the screen under test, which is to be not less than 2 m x 2 m, on a suitable frame and place it vertically and symmetrically 150 mm in front of the mouth of the speaker. Place the sound level meter with its microphone concentric with the axis of the speaker and 2 m distant. The attenuation of sound due to the presence of the screen is the difference between the respective readings of the sound level meter* [Taken with and without the screen in place.] *These differences when plotted on a graph should produce a fair curve*.' Interestingly, it also states that '*Attenuation of sound pressure due to the presence of a perforated screen in front of a loudspeaker shall not exceed 3 dB at 6 kHz and 6 dB at 12 kHz, compared with the attenuation of the sound pressure at 500 Hz'*, but we will return to this matter at the end of Section 5.

The basic measurement set-up is shown in Figures 2 and 3 and was conducted in the large anechoic chamber (611 cubic metres, total) of the Institute of Sound and Vibration Research, at Southampton University, UK. The loudspeaker was an Electrovoice T251, as shown in Figure 4, which was deemed to be of a size and nature both suitable for the test conditions and representative of the basic component style of most cinema loudspeakers. Note, though, that it was decided for these tests, in anechoic conditions, to place the microphones at 3 metres from the loudspeakers in an attempt to capture a more integrated response from the displaced drivers.

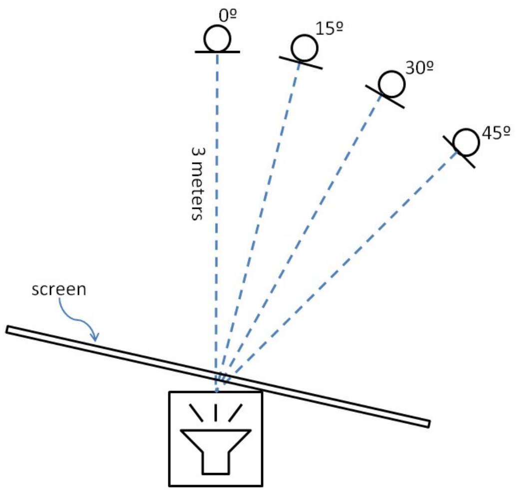


Figure 2 Geometric layout of loudspeaker, screen and microphones

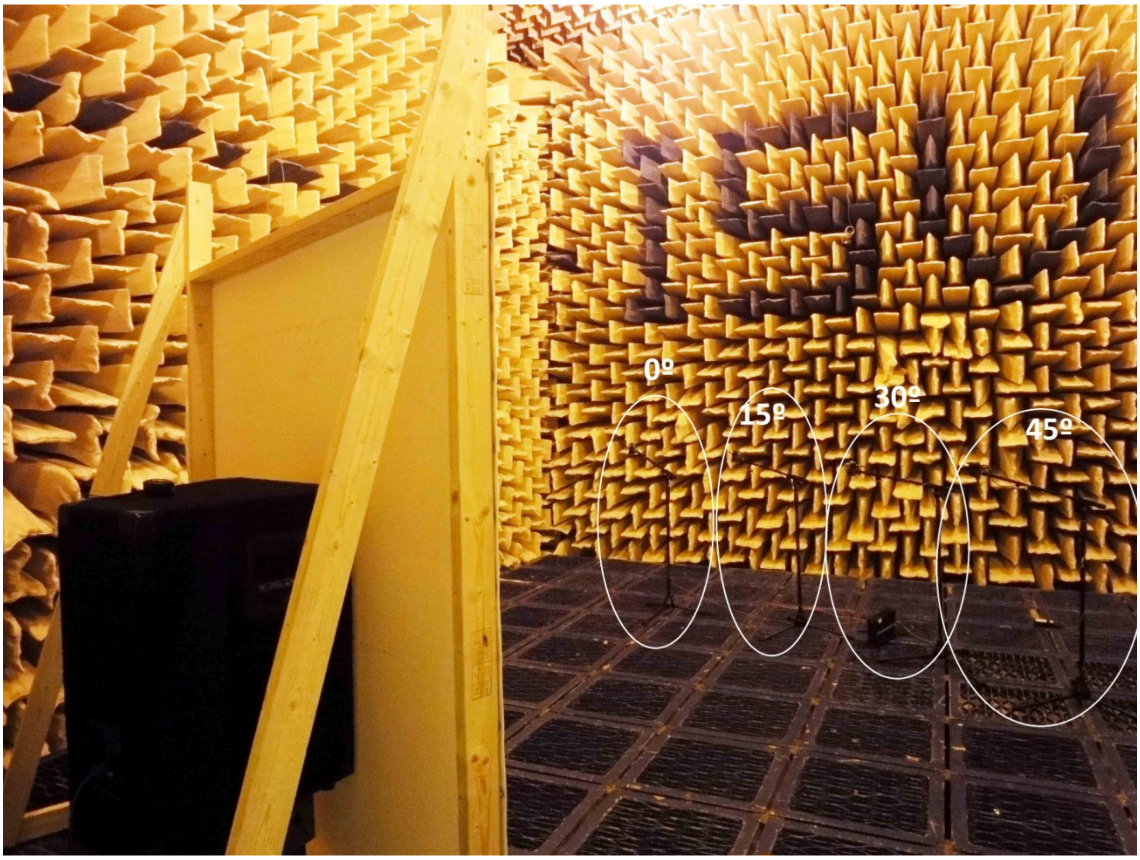


Figure 3 Photograph of loudspeaker, screen and microphones

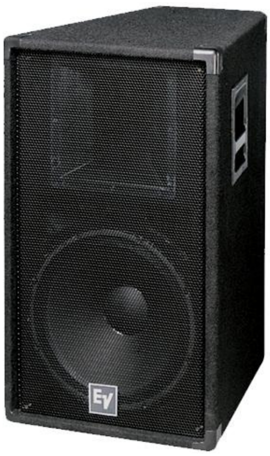


Figure 4 Electrovoice T251 used in measurements

The first tests were made with the loudspeaker alone, with the geometry shown in Figure 2 but without the screen, at angles of 0º, 15º, 30º and 45º to the central, vertical axis of the loudspeaker, with a microphone height judged to be reasonably representative of the combined output of the low and high frequency drivers. After the direct measurements had been made, a screen was introduced between the loudspeaker and the microphone, initially mounted perpendicular to the loudspeaker, and measurements were taken at different loudspeaker/screen distances and different angles.

As well as the afore-mentioned recommended measurements at 15 cm, others were taken a 2 cm, 7 cm, 30 cm, 45 cm and 60 cm. Furthermore, two additional measurements were taken with the screen at horizontal inclinations of both 10º and 25º to the loudspeaker baffle, with the screen almost touching one side of the loudspeaker, as shown in Figure 2. All of these are representative of mounting conditions found in both professional and domestic practice.

Figures 5 and 6 show the enlarged general nature of the types of screen material investigated here. The screens will be henceforth referred to as Screens A, B and C, the first two being woven materials and the other one mini-perforated.

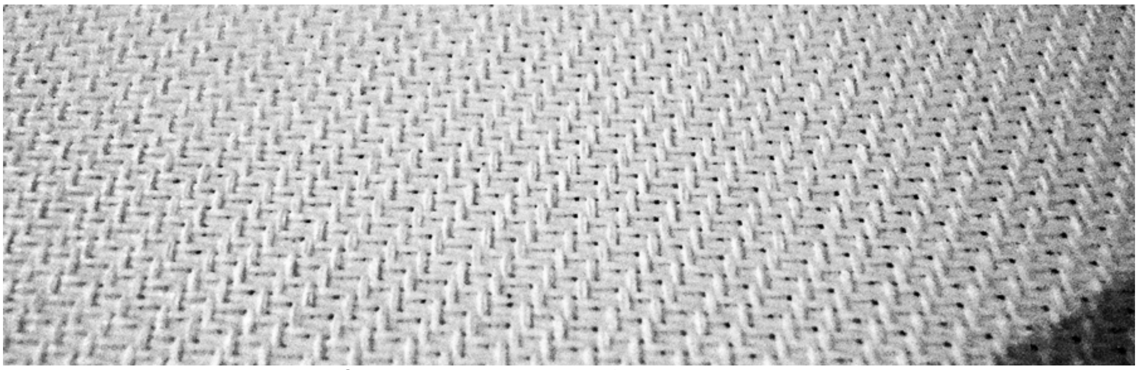


Figure 5 Close-up photograph of a woven screen material

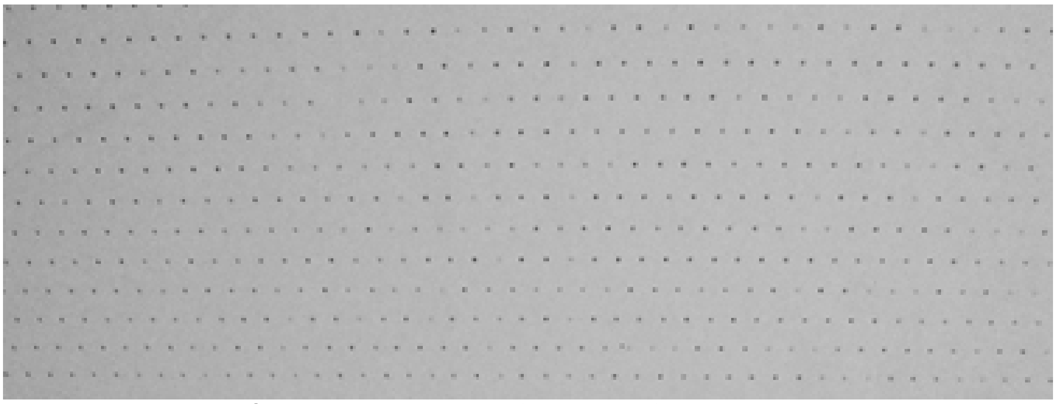
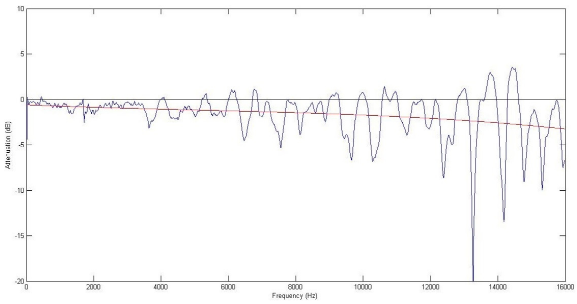


Figure 6 Close-up photograph of a mini-perforated screen material

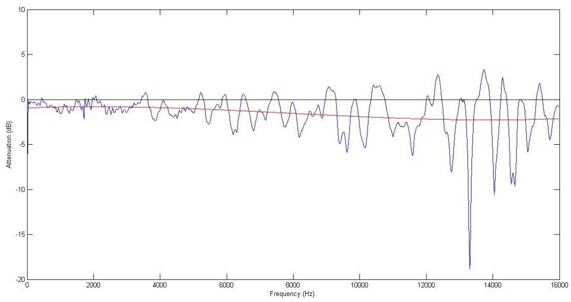
4 RESULTS

4.1 Frequency response and attenuation at different mounting distances and angles of incidence

Data related to attenuation and comb filtering was obtained by looking at the frequency responses of the loudspeaker/screen combinations when the screens were placed at different distances from the loudspeaker and at different angles. The results showed that there is little significant loss in the screens below 1 kHz, so the responses are displayed on a linear frequency scale, rather than the more usual logarithmic scale, to more clearly show the comb-filtering and attenuation at high frequencies.



2 cm spacing



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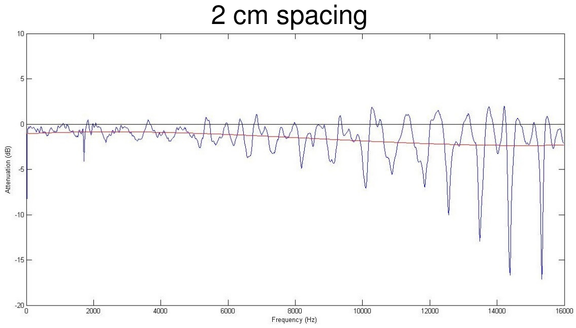

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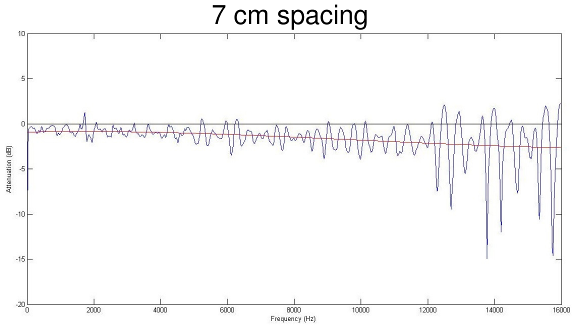

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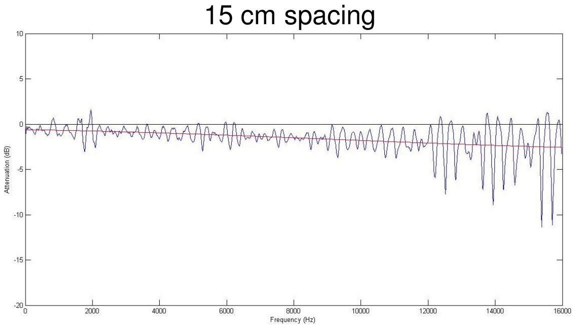
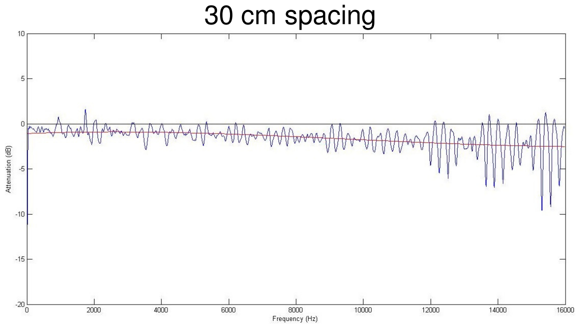


45 cm spacing



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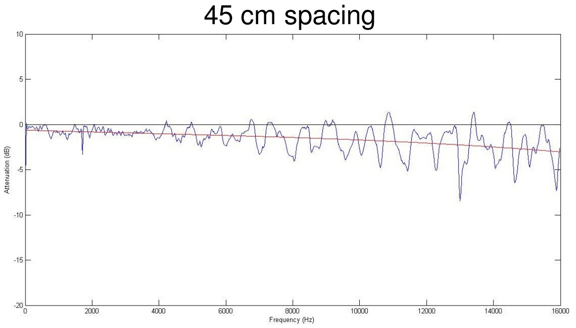
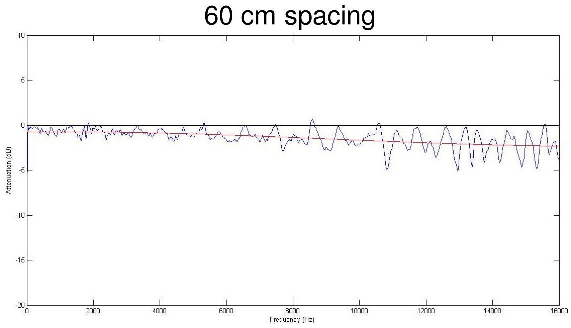


Angled 10 degrees



Angled 25 degrees

Figure 7 Normalised attenuation plots at 0 degrees for Screen A

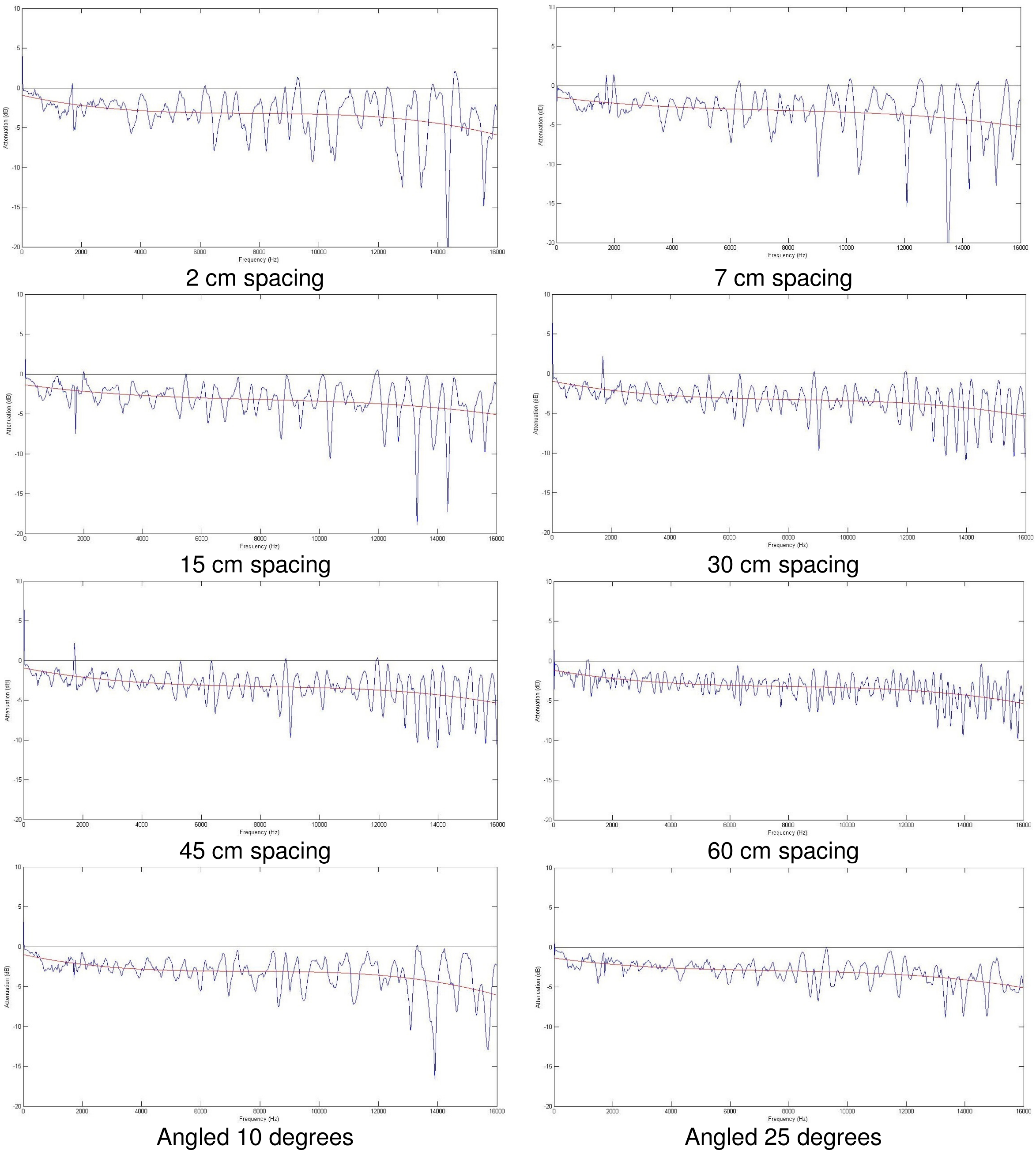


Figure 8 Normalised attenuation at 0 degrees for Screen B

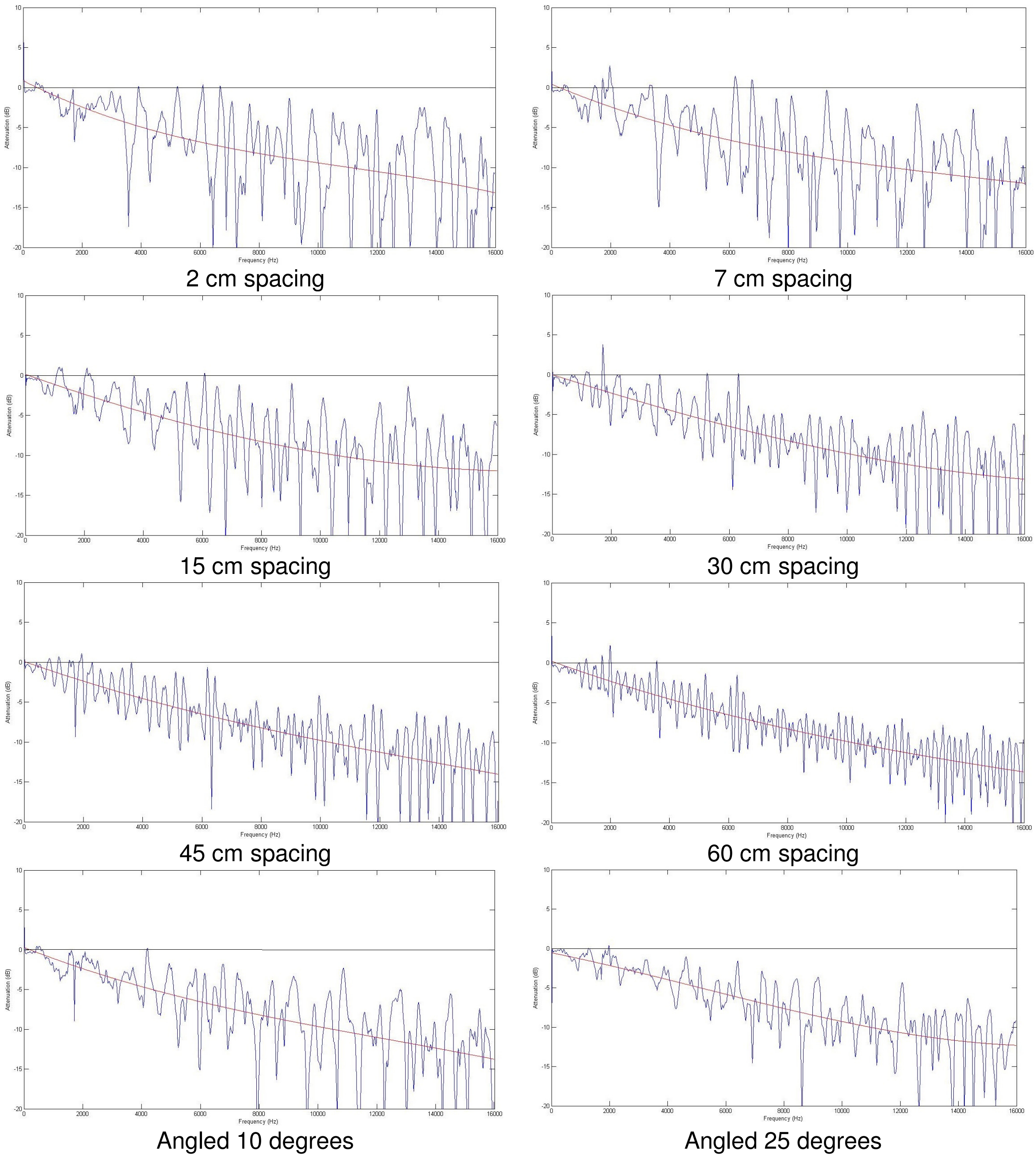


Figure 9 Normalised attenuation at 0 degrees for Screen C

The normalised attenuation at 0 degrees can be seen in Figures 7 to 9, and show the reflexion patterns and overall transmission losses for the various screens and mounting configurations. The lines drawn through the responses are based on a low-order polynomial curve-fit procedure to separate the general attenuation from the comb filtering. [Attenuation is here the decibel difference between the incident and transmitted sound. As the sound incident on the screen was not directly measured, the attenuation introduced by the screen was approximated as the difference between the measurements taken with and without the screen in the absence of comb filtering.]

The mini-perforated Screen C quite clearly gives rise to more comb filtering and high-frequency transmission loss. Nevertheless, as stated previously, where greater optical reflectivity than can be achieved by the woven screens is required, and in larger theatres which require taller screens than can be made on current looms, perforated PVC screens are usually the most practical option. The characteristics of perforated screens are therefore of vital interest to the cinema industry.

The manufacturer of one of the woven screens claims that the maximum loss for that screen is 2.5 dB; however, it does not say at what distance the screen was located or at which frequency this loss was found, which could be information of great help to the users. As can be seen in Table 1, the maximum loss varies both with frequency and the distance between the loudspeaker and screen.

Table 1: Attenuation measured with Screen A at different distances, angles and frequencies

Distance/Angle	Attenuation (dB) at 100 Hz	Attenuation (dB) at 5 kHz	Attenuation (dB) at 10 kHz	Attenuation (dB) at 16 kHz
2 cm	0,74	0,90	1,39	2,40
7 cm	0,60	0,78	1,57	1,60
15 cm	0,56	0,95	1,41	2,32
30 cm	0,78	0,82	1,44	1,71
45 cm	0,58	0,90	1,41	1,92
60 cm	0,66	0,90	1,41	1,86
10 degrees	0,23	1,07	1,52	3,46
25 degrees	0,96	1,13	1,88	2,37

It is evident with this screen that the losses are not significant, and would be swamped by other characteristics in a room the size of a small dubbing or exhibition theatre. The other woven screen, Screen B, showed losses of the same order, but the losses shown for the mini-perforated Screen C, shown in Table 2, are more significant.

Table 2: Attenuation measured with Screen C at different distances, angles and frequencies

Distance/Angle	Attenuation (dB) at 5 kHz	Attenuation (dB) at 10 kHz	Attenuation (dB) at 16 kHz
2 cm	2,53	5,50	10,04
7 cm	3,21	6,57	9,44
15 cm	2,86	7,17	9,17
30 cm	4,27	8,01	11,94
45 cm	4,34	8,30	11,86
60 cm	4,40	8,40	11,34
10 degrees	3,87	7,04	11,64
25 degrees	3,93	7,40	13,52

The attenuation measurements taken at 0º angle of incidence show a general tendency for the level of the comb filtering to reduce as the distance from the loudspeaker to the screen increases. At 500 Hz, the attenuation introduced by each screen was in the order of 1 to 2 dB, but the characteristic slope of the attenuation of the higher frequencies is different for each screen type. At 5 kHz and a distance of 15 cm, the attenuation introduced was around 1 dB for Screen A, 2.5 dB for Screen B and 4 dB for Screen C. However, at 12 kHz, the corresponding attenuations were in the order of 2, 3.5 and 8 (at least) dB respectively.

As the measurements were taken progressively further off axis, still keeping the loudspeaker-to-screen distance at 15 cm, neither the attenuation nor the comb-filtering patterns changed to any consequential degree from the zero to the 30º position, but at the 45º angle the responses became somewhat more erratic, with perhaps a slight tendency towards response pattern widening for

Screens B and C (see sub-Section 4.3). The measurements taken with the screens angled horizontally at 10º and 25º to the loudspeaker indicate that the general trends were the same. With all three screens, there was a slightly less tendency to suffer disturbance at the 15º measurement angle.

Measurements were then taken with the screen at closer distances to the loudspeaker. Mounting the screen as close as 2 cm to the loudspeaker is recommended in certain proprietary documents used by the cinema industry, especially when free-standing loudspeakers are used, and 7 cm is very representative because ‘not more than 10 cm’ is a widely-followed industry recommendation. In general, although the patterns clearly changed, no visibly significant trends were noticeable in the attenuation plots at the shorter distances when compared to the 15 cm position, other than that the 45º responses became somewhat more ragged. At the greater distances of 30, 45 and 60 cm, a gradual reduction in the level of the comb filtering was apparent, accompanied with a more uniform, more clearly defined sinusoidal pattern of the comb-filtered responses.

The responses with the screens mounted at an angle of 10º to the loudspeakers showed less mid-range comb-filtering on the 0º and 15º axes, as compared to the 15 cm screen-distance measurement, but were otherwise reasonably consistent with the 7 cm and 15 cm measurements. This type of inclination is common for the toe-in of the left and right loudspeakers at the edges of the screens. The 25º angle was measured for comparison, as it is sometimes used in smaller post-production rooms. The tendency (principally for the mini-perforated screen) was for less comb-filtering at the narrower angles of measurement but more at the wider angles.

From a merely visual assessment of the responses it is difficult to conclude that either of the angles of incidence is either beneficial or detrimental compared to the 15 cm parallel mounting of the screen. Changes occurred in different frequency bands in different ways, making it very difficult to globally compare one response with another. In fact, although the 45º responses were rather different in the way that they related to the responses at other angles, there was no significant general trend.

No attenuation change with distance of anything more than about 2 dB was evident in any clearly discernible way, but this could have been related to other aspects of the mounting conditions, such as reflected-wave expansion and driver loading, as opposed to being purely distance related.

4.2 Power Cepstrum

The power cepstrum is a signal post-processing technique that is useful for revealing echoes in responses [7]. Figures 10 to 12 show the power cepstra of the measurements on the 0º axis. These power cepstra are the result of post-processing the attenuation frequency responses in Figures 7 to 9 after removal of the mean (curve-fitted) attenuation. As the distance from the loudspeaker to the screen increases it can be seen that the reflexions become fewer, later and lower in level. The reflexions from Screen B are marginally stronger than those from Screen A, but those from Screen C are significantly stronger. The 10º and 25º measurements show early reflexion groups of similar delays to the 7 and 15 cm responses, but of a lower level than at the corresponding times from the parallel screens.

4.3 Directivity

The (smoothed) directivity plots for the three screens at the different distances and angles are shown in Figures 13 to 15. They are normalised to the corresponding 0º measurements. The loudspeaker is actually only rated by its manufacturer as having 60º horizontal directivity, so the anomalies at the 45º off-axis position should be expected. Other than frequency response irregularities, particularly for the perforated screen at close distances, no significant effect seems to be apparent in terms of any directivity changes due to the screens; at least not with these screens or this form of loudspeaker mounting. This finding therefore is not in agreement with some of the other published data, for example in the ‘Summary’ of Reference 4.

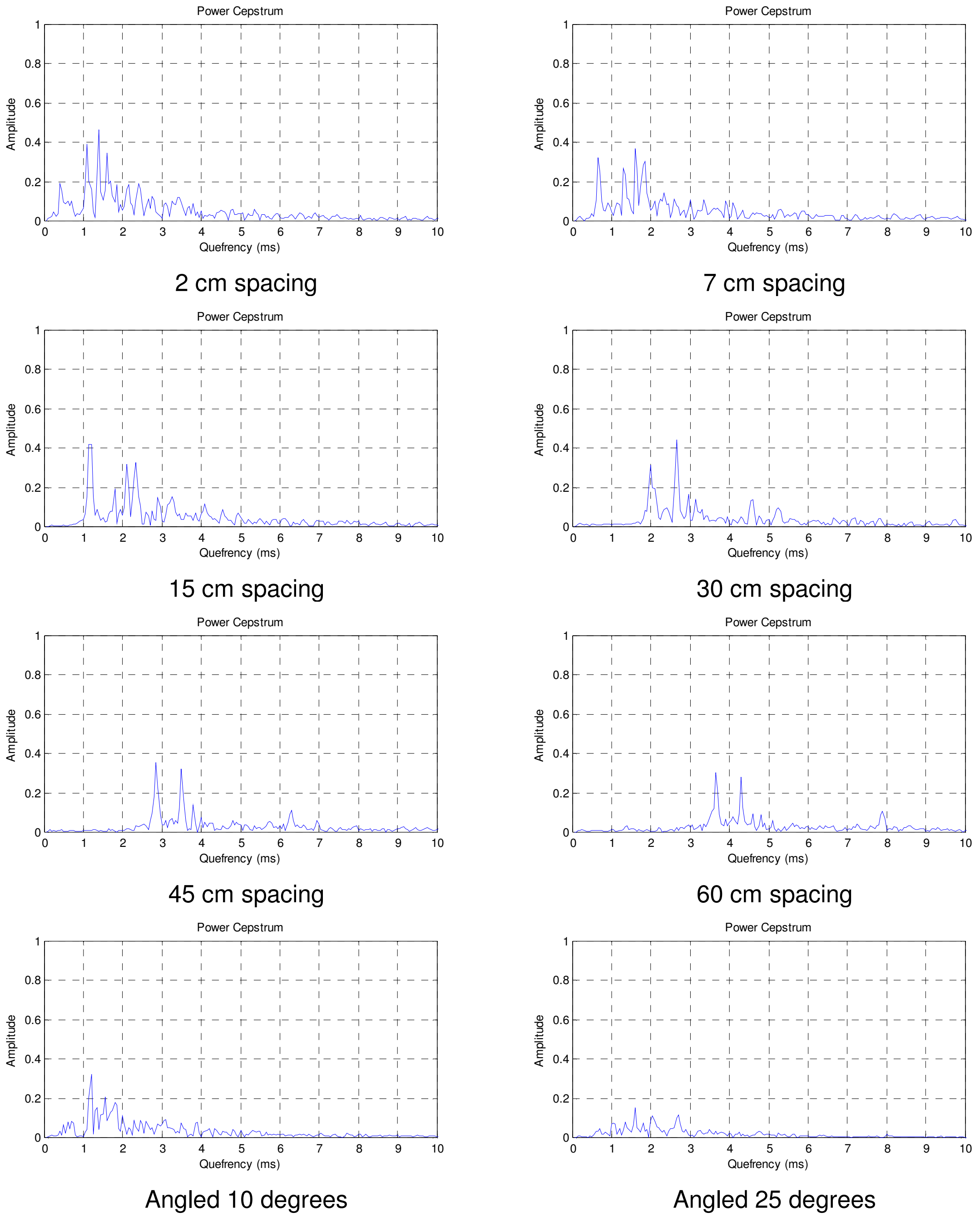


Figure 10 Power cepstrum at 0 degrees for Screen A

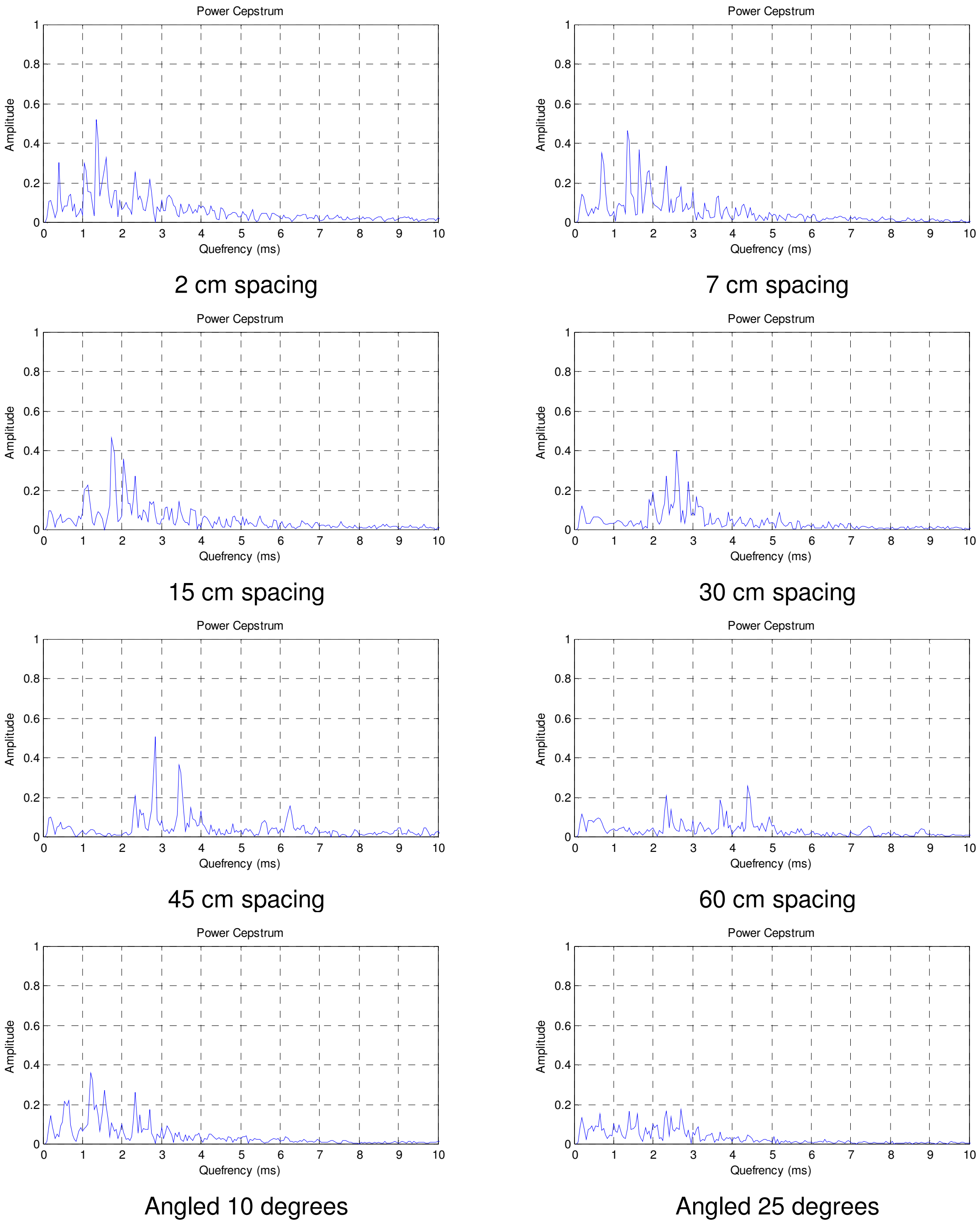


Figure 11 Power cepstrum at 0 degrees for Screen B

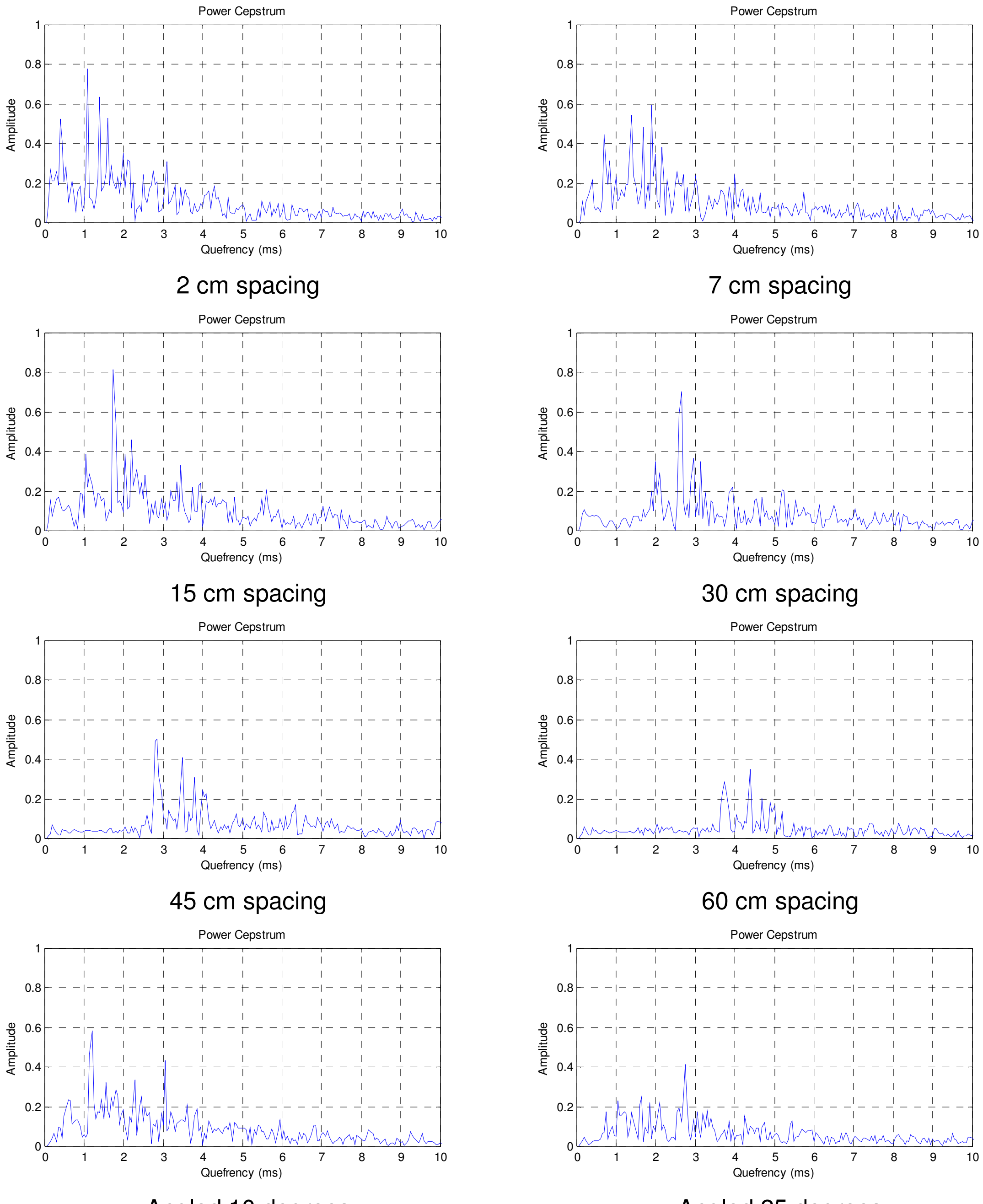
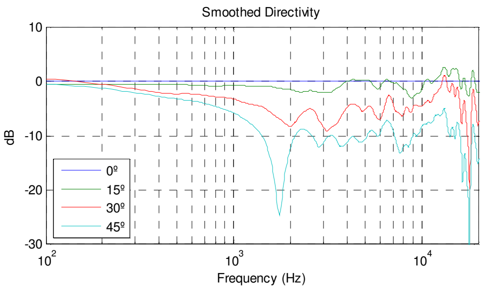
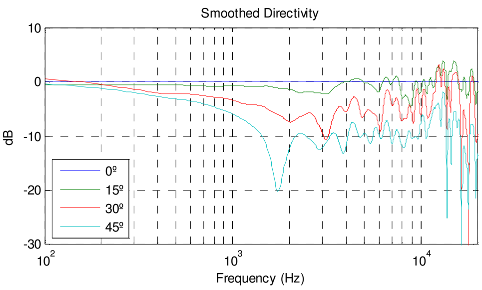


Figure 12 Power cepstrum at 0 degrees for Screen C



No screen



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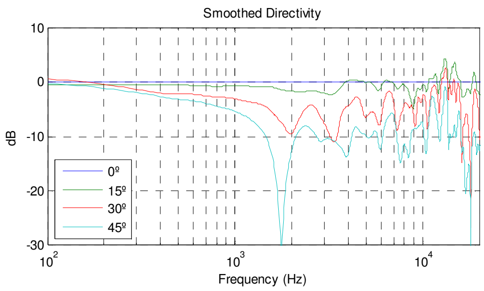

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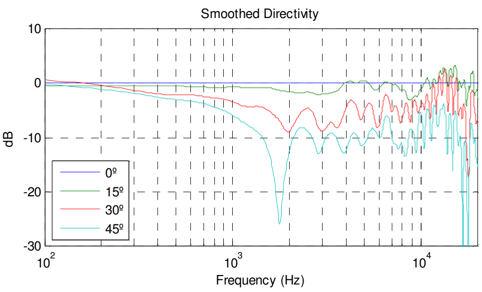

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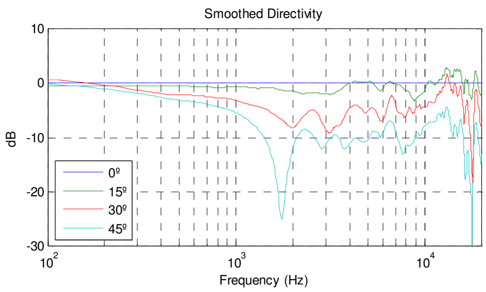

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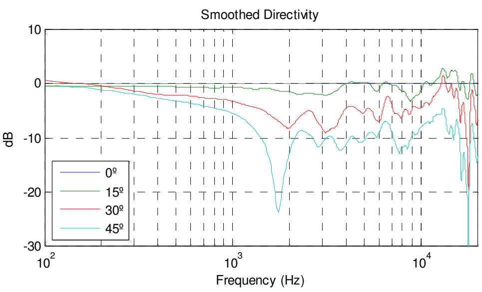

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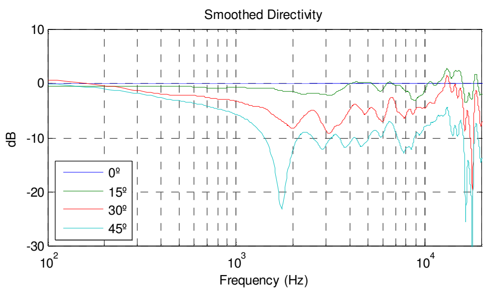

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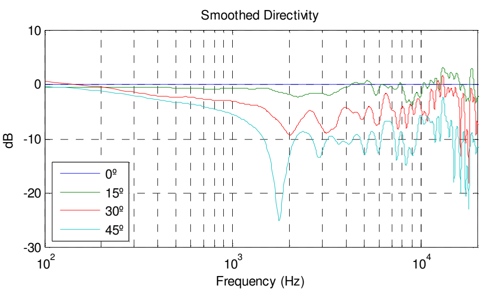
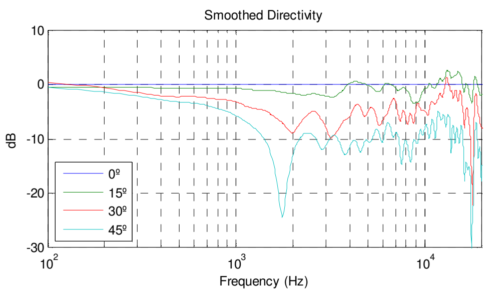
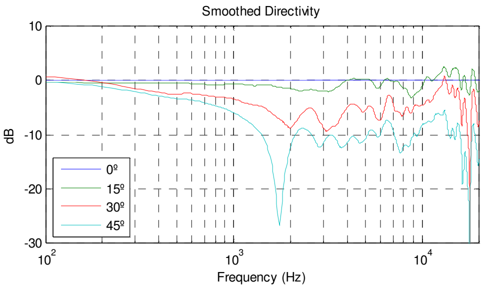


Angled 10 degrees

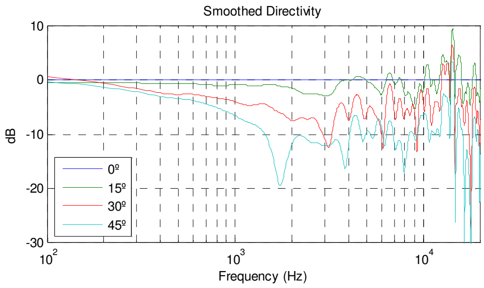


Angled 25 degrees

Figure 13 Directivity for Screen A



No screen



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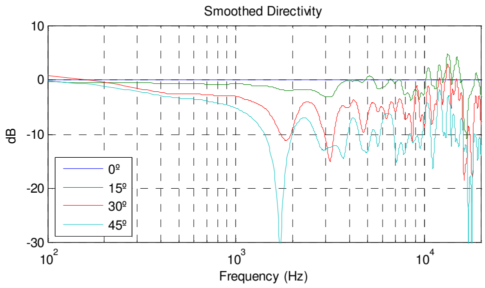
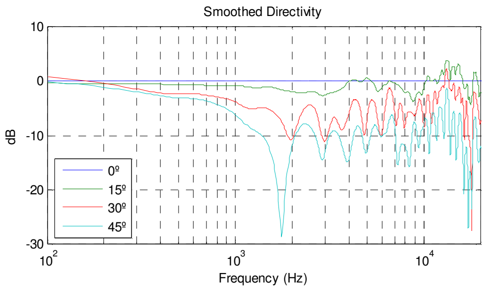


7 cm spacing



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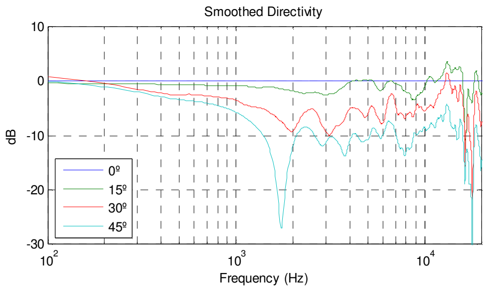

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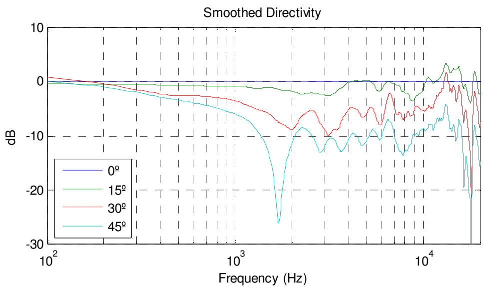
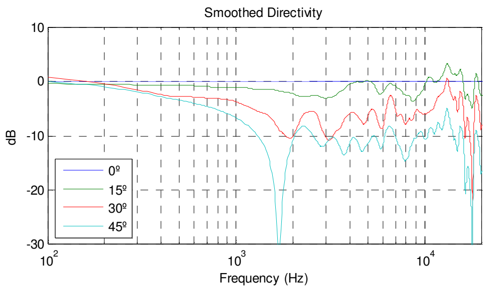
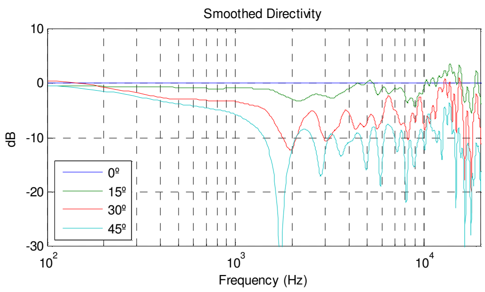


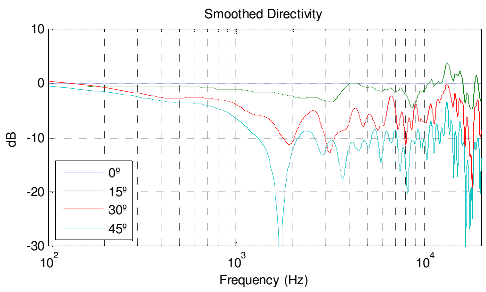
45 cm spacing



60 cm spacing

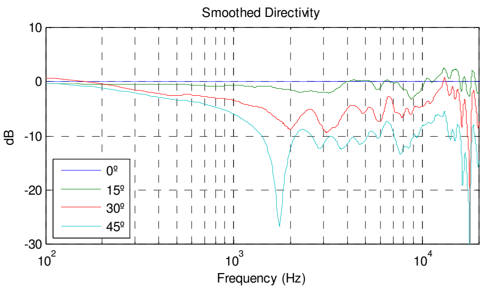


Angled 10 degrees

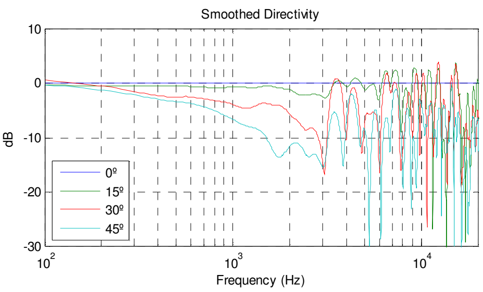


Angled 25 degrees

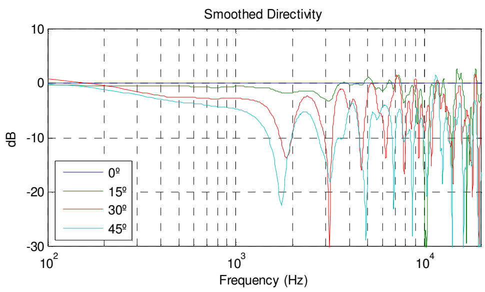
Figure 14 Directivity for Screen B



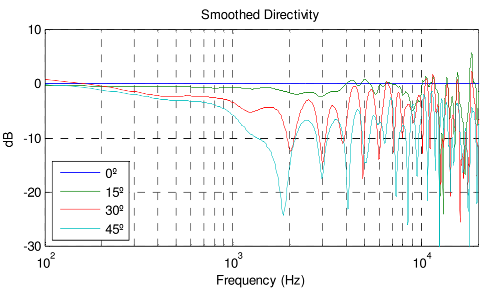
No screen



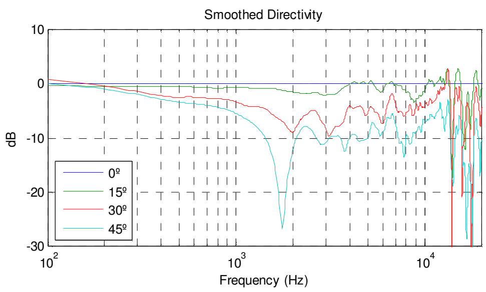
2 cm spacing



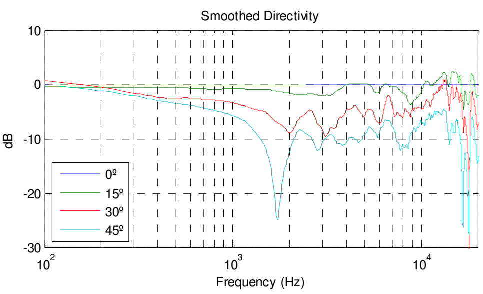
7 cm spacing



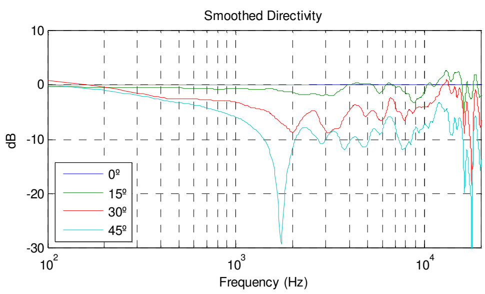
15 cm spacing



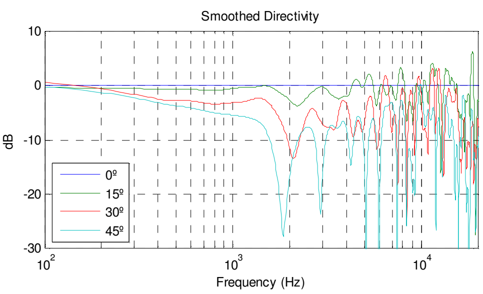
30 cm spacing



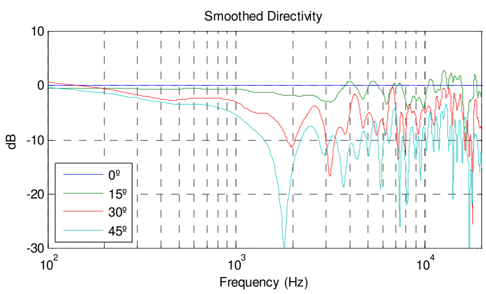
45 cm spacing



60 cm spacing



Angled 10 degrees



Angled 25 degrees

Figure 15 Directivity for Screen C

5 DISCUSSION OF RESULTS

Despite what is often heard in the cinema industry, there is no evidence from these measurements that there is any great tendency for the screens to change the polar responses of the loudspeakers. What little direct evidence there is of directivity changes seems to be dependent on not only the screen type, but also the angle of incidence of the screen and the distance from the loudspeaker. What is more, if any of the directivity changes are also due to the secondary reflexions from the front of the loudspeakers and the wall behind it, they would also be specific to mounting conditions or loudspeaker baffle size and treatment.

Depending on the acoustic reflectivity of a screen, its close proximity to the loudspeaker could have a loading effect on the driver diaphragms. We are not sure to what degree such effects may have been affecting the irregularity of the responses shown here, but they could be connected with the improved regularity of the responses at distances of 30 cm and beyond, because the loading effects reduce with distance. Clearly, as a screen is moved further away from a loudspeaker, the wave expansion would tend to return less energy to the loudspeaker diaphragms (as would also be progressively the case for any subsequent reflexions).

It can be seen from the attenuation and directivity plots (Figures 7 to 9 and 13 to 15) that the attenuation due to any of the screens, angles and distances is quite low below 800 Hz, and that there is little sign of any comb filtering. As previously mentioned, whatever irregularity can be seen may be due to be the result of either directivity or diaphragm-loading effects.

The power cepstra show very clearly how the reflexion patterns return from the loudspeaker baffle both later and reduced in energy as the screens are drawn away from the loudspeaker. However, the important question that still needs to be answered is what the trade-offs are in terms of audibility between the reducing level and the temporal separation of the reflexions. This question also relates to the way that the erratic response-patterns on the attenuation plots at the shorter distances are perceived relative to the more orderly patterns at the longer distances.

During the first analysis of the results, a Pressure Transmission Factor calculation was made for the 0º measurements, which indicated that the best distance for getting the overall energy through the screen was around 30 cm, but it should be noted that this may only apply to the precise conditions of mounting that were used in these tests. Some studies will shortly be undertaken to look into these questions.

The mini-perforated screen does not appear to meet the HF attenuation specification mentioned at the beginning of Section 3, although the performance of this particular screen does not seem to be unusual in this respect. In fact, it was an excellent example of its type.

The smoothed directivity plots shown in Figures 13 to 15 indicate that whilst there is a little change in the directivity, perhaps due to the various mounting conditions, it does appear that greater irregularity within narrow frequency bands is evident when the screen is mounted at the closer distances of 15 cm or less.

6 CONCLUSIONS

What is very clear from these tests is that there are multiple factors affecting the way in which a cinema screen interacts with a loudspeaker. When many things are changing at once, each component of any aspect of the response can mask the effects other changes. It has proved to be very difficult to tell from visual inspection of the plots, either in isolation or in groups, precisely which mounting angles or distances could definitively be stated to be most desirable from a sound-quality point of view.

It is evident that the woven screens out-perform the mini-perforated screen acoustically, but as explained in Section 2 there are situations where the latter have overriding advantages from an optical point of view or where great size is required.

Before any reliable recommendations can be made about precisely how best a screen should be mounted for optimal sound transmission, even from this limited series of tests, auralisations would be required, based on the convolution of the measured impulse responses with a representative selection of cinema soundtracks. Actual listening tests in realistic environments would be very difficult to realize in practice. Long time-intervals between tests would perhaps be unavoidable, and room acoustics would add a further complication. However, such tests may ultimately prove to be necessary.

The ‘best distances’ between the screen and the loudspeaker may depend on the screen type and the loudspeaker mounting arrangements (flush-mounted in an absorbent-covered wall; free-standing; backs to a solid wall in an untreated cavity; backs to a wall in an absorbent-filled cavity; etc.). Even the size of the loudspeaker cabinet in all but the flush-mounted situations will have a bearing on the quantity of reflexions and the areas of the screens over which they will spread.

It should be noted that not much experimentation seems to have been done into the thresholds of detection of comb-filtering when it comes from the same direction as (and indeed is a part of) the source. Although some work on this subject has been published by Toole [8], comb-filtering is usually associated with reflexions from different directions.

Whether reflexion patterns returning from the loudspeaker baffle are more detrimental to the dialogue intelligibility at higher levels and short delays, or later arriving and reduced in energy as the screens are drawn away from the loudspeaker, is not easy to determine from any classic literature in cases where the responses are so complex. The answer would perhaps also depend on the absolute sound level in relation to any perceptual threshold. In cases where the threshold was not exceeded, no concern would need to be given to the subject, even though with a different type of screen material the matter may require considerable attention. This question also relates to the way that the erratic spectral response patterns at the shorter distances are perceived relative to the more orderly patterns at the longer distances. Would the afore-mentioned pressure transmission factor be relevant if global acoustic transparency were to be overridden by other facets of the acoustic performance? The answer is still not known.

It seems to be quite probable that many currently accepted ‘rules’ may have been specific to the conditions of their testing circumstances, and should never have been generalized. Nevertheless, they have found their way into standards and recommendations on a routine basis. For example, given the variability in the attenuation versus frequency characteristics, global ‘screen-loss compensation’ would not seem to be viable in anything except particular groups of circumstances, yet such compensation does exist on much cinema equipment.

The degree of reflexion from the woven screens came as something of a surprise, as much had been made in commercial and industry publications about their ‘reflexion-free’ nature. Whilst it is clear that the quantity of energy reflected by them is considerably less than that from the perforated screens, they are certainly not ‘reflexion-free’. Consideration should still therefore be given to treating with absorbent material the front surfaces of any loudspeaker cabinets mounted behind them. This treatment would also be beneficial in reducing the cabinet edge diffraction in non flush-mounted situations.

According to a survey carried out by Brawn Consulting for Stewart Filmscreen in 2006 [6], several sources recommended that the distance at which a perforated screen should be placed from the loudspeaker should never be less than 30 cm. It is interesting to note, however, that this recommendation is in conflict with the recommendations of some leading and respected industry organisations who suggest that the screens should be mounted less than 10 cm from the loudspeaker baffles.

Throughout the work reported in this paper it has been shown that comb filtering appears at all the measured distances and for all three screens (which broadly cover the available attenuation range), from 2 cm to 60 cm, and even with the loudspeaker baffles at 10º and 25º to the screen. It has also been explained that as the distance grows larger it will lead to later reflexion arrivals as the reflected wave has to cover a longer path. The reduction in the reflexion level is largely due to wave expansion, which will be affected by the loudspeaker mounting conditions.

Overall, it seems that the interaction of the different screens at different distances, different angles of incidence and different methods of loudspeaker mounting is very complex. Only by repeating tests such as those carried out for this paper for each common set of mounting conditions could it be expected to find any common factors which might lead to more clear generalisations about the loudspeaker/screen interactions and best recommended mounting practices. Without this information it is not possible to be sure whether many of the current recommended practices are valid for all circumstances, or not.

The major findings of the work reported in this paper can be summed up as:-

1) It is difficult to give clear indications of the general effect of any changes of directivity due to the nature of the screens alone, but they do not appear to be as great as has often been suggested.

2) Comb filtering is evident in all the measurements for each of the three types of screen and at all the measured distances and angles of sound incidence.

3) Auralisation tests would be needed before making any concrete recommendations about the time/amplitude characteristics of the reflexions and their effect on perceived colouration with different loudspeaker-to-screen distances.

4) It would seem to be wise for the cinema industry to revise, and make more consistent, some of the recommended practices relating to the mounting of the screens with respect to the loudspeakers. Present recommendations tend to be rather variable and short of clear explanations of their validity.

7 ACKNOWLEDGEMENTS

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