WHY DOES CINEMA SOUND QUALITY MOSTLY FAIL TO REALISE ITS POTENTIAL? SOME INTERESTING RESULTS FROM THE SMPTE'S 2014 REPORT ON CINEMA SOUND SYSTEMS.

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1 INTRODUCTION

The SMPTE 'Theatre B-Chain Study Group' was formed in March, 2010 with the goal of studying the current standards and practices regarding cinema B-Chain electroacoustic response and calibration, and making recommendations for work that SMPTE should undertake in these areas. The "Theater Testing" subgroup embarked on a process of measuring and reporting the acoustical performance of sound systems in one reference theatre, two dubbing stages and three exhibition theatres.

A report (1) giving the measurement results, analysis and conclusions was completed in September 2014. The authors of this paper were part of the editorial team for this report, which has become an important milestone for the SMPTE's review of the B-Chain systems.

This report is comprehensive, with major sections covering items such as a glossary/definition of terms, specific goals for the testing work, descriptions of measurement process, and the methods used to analyse the temporal and frequency responses. Technical foundations underpinning the analysis and discussion about factors affecting the responses are also discussed. Numerous frequency and temporal responses are presented, which are accompanied by discussion and conclusions. In addition, recommendations for further work are given.

This work is probably the most comprehensive in-depth analysis of the cinema audio space that has ever been undertaken. A precis of the report is provided by Leembruggen in (2).

This paper examines some of the interesting results and trends in those measurements, which point to reasons why cinema sound is currently far from ideal.

2 GOALS OF THE B CHAIN STUDY

The current standards regarding theatre B-Chain electroacoustic response calibration were formulated in the 1970's, using the technology available at the time, and have since remained essentially unchanged. The overarching goal for the study was to gain an understanding of the state of the industry today, and to investigate alternative measurement methods.

The current standard documents SMPTE ST 202: 2010 (2), SMPTE RP 200:2012 (3) and ISO 2969 (4) specify single-channel measurements using a 1/3 octave real-time analyser with pink noise, based on responses measured deep in the theatre seating area.

Among the goals of the study were:

- To provide insight into the electroacoustic frequency response performance of the sound systems in the theatres and dubbing suites that have been measured.
- To understand the causes of differences in frequency responses and time-domain performances.

Significant questions to be answered were:

- Would the frequency responses of loudspeakers measured in close field and far fields show significant differences?

- Would the high frequency response be flatter in the close field, and exhibit more roll-off in the far field?
- Would the X-curve still manifest in the close field, or is this only a far field phenomenon?
- Would the use of temporal information provide new insights into the performance of the systems?

3 OVERVIEW OF MEASUREMENTS

3.1 Venues

The sound systems of four commercial cinemas and two dubbing stages were measured, which were anonymised as part of the testing agreement with the owners. The venues included a known and well regarded reference theatre (Cinema B), three commercial cinemas (Cinemas A, C and D), and Dubbing Stages E and F.

The following systems were measured:

- Centre screen speaker, including the “as found” and “bypassed” equalisation states where possible.
- Close-field of the centre loudspeaker
- Left and right screen channels.
- One set of surround arrays e.g. Left Surround in 5.1 configuration and Left Side Surround and Left Rear Surround in 7.1 configuration.
- Low Frequency Effects (LFE) loudspeakers including the “as found” and “bypassed” equalisation states.

In some venues a complete set of data was not measured due to time constraints.

In the commercial and reference theatres, the far-field microphones were generally located as per the layout specified in SMPTE ST 202:2010. The reference microphone location was 2/3 back from the screen on the longitudinal centreline as shown in Figure 1, reproduced from (1).

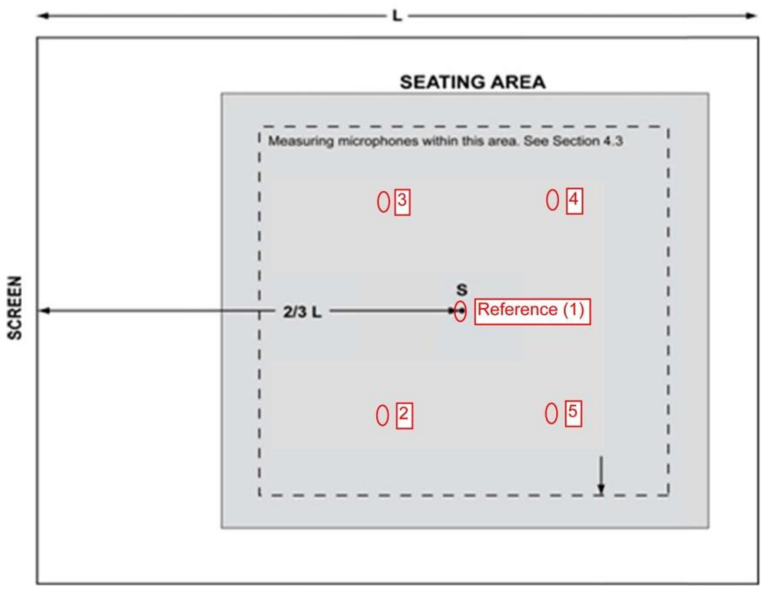


Figure 1. Microphone Placements - Cinemas

For the dubbing stages, the microphones were distributed in the area behind the mixing console and in front of the “producers” desk, with the reference microphone located at the main mix position.

The microphones were at approximately ear level at the seats. Figure 2 and Figure 3 are reproduced from (1) and show the plan and elevation views of the microphone locations in Dubbing Stage E. Note the presence of what is termed, “close field” microphones nearer the loudspeakers. In Dubbing Stage F, the layout was similar with the close-field microphones at 3 m from the loudspeakers.

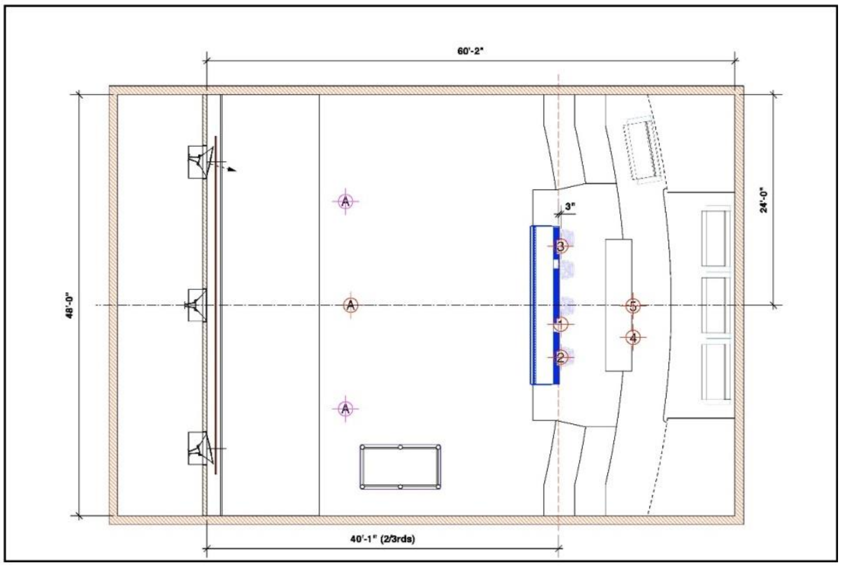


Figure 2. Plan view of microphone locations in Dubbing Stage E (reproduced from (1)).

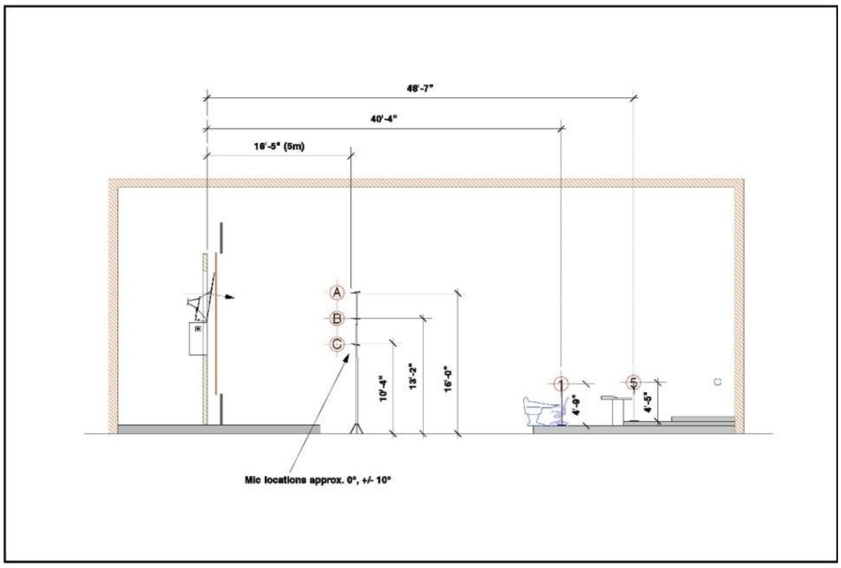


Figure 3. Elevation view of microphone locations in Dubbing Stage E (reproduced from (1)).

3.2 Processing of Acoustic Responses

A major platform of the report was the use of impulse response (IR) measurements. Currently, cinema measurements use single-channel analysers to produce steady-state, “time-blind” responses. These types of measurements cannot show the way a frequency response changes with time, nor can they show the temporal parameters that have a major bearing on perceived sound.

In each venue, recordings were made of pink noise signals that were i) fed to the system and ii) picked up by each microphone. A deconvolution process implemented in Matlab software off-line was used to compute each IR from recordings of each pair of input and output signals. From the impulse responses, the following temporal parameters were derived:

- Intensity vs time plot
- Schroeder decay plot
- reverberation times
- cumulative energy growth plot

By truncating the impulse responses with different length time windows, a range of frequency responses was computed for each position using the Fast Fourier Transform (FFT). The window lengths were:

- 10 ms, which roughly equates to the direct field plus ultra-early reflections
- 50 ms, which roughly equates to the direct field plus early reflections,
- 2 seconds, which equates to the steady state response in the cinemas
- Variable-length windows which slide from very short duration (direct field) at high frequencies to very long duration (steady state) at low frequencies. These windows are called Points Per Octave (PPO), as the sliding window results in a fixed frequency resolution (in octave terms) for each band of frequencies.

A Tukey window shape was used to truncate all IRs. The frequency responses were smoothed using a moving average filter, over a 1/12th octave or 1/3rd octave bandwidth, depending on how the response was to be used.

To facilitate easy assessment of the shape of the frequency responses, free of overall level change, most of the responses were normalised to the average level of the response at the reference position between 500 Hz and 2 kHz. With the LFE channel, the responses were normalised over the range of 40 Hz to 100 Hz.

An important benefit of the Matlab process was the ability to automatically process a very large set of recorded pink-noise files and impulse responses, eliminating the risk of errors in manually loading data, processing and saving of results. The Matlab processing was intended to replicate the calculations provided by commercial dual-channel analysers, with the code being written by the first author and colleagues in Australia.

The report provides extensive discussion about the different time windows and the method of truncating the IR using a half Tukey window. Attributes of the measured frequency responses are assigned to physical acoustic effects, and guidance on how to interpret the responses is given.

The report also notes three other benefits of the transfer-function method over real-time analysis: stability at low frequencies, rejection of background noise, and self-referencing to a specific point in the output signal chain which can eliminate errors due to unknown signals and equipment settings.

4 THE X CURVE

The X-curve (3,6) is a frequency response shape that provides the target for equalisation of current cinema sound systems. It is so called because of its eXperimental origins, being arrived at empirically. It was based on listening tests comparing loudspeakers with a flat response, positioned in the close field, with conventional cinema loudspeakers in the far field in the conventional cinema acoustics of the 1970s.

One of the possible reasons hypothesised in (6) for the use of the X-curve is that there are different rates of reverberant build-up at low and high frequencies. Figure 4 provides a conceptual explanation of this hypothesis. In the upper graph, the frequency responses are normalised to the direct field, while in the lower graph, they are normalised to the steady-state field.

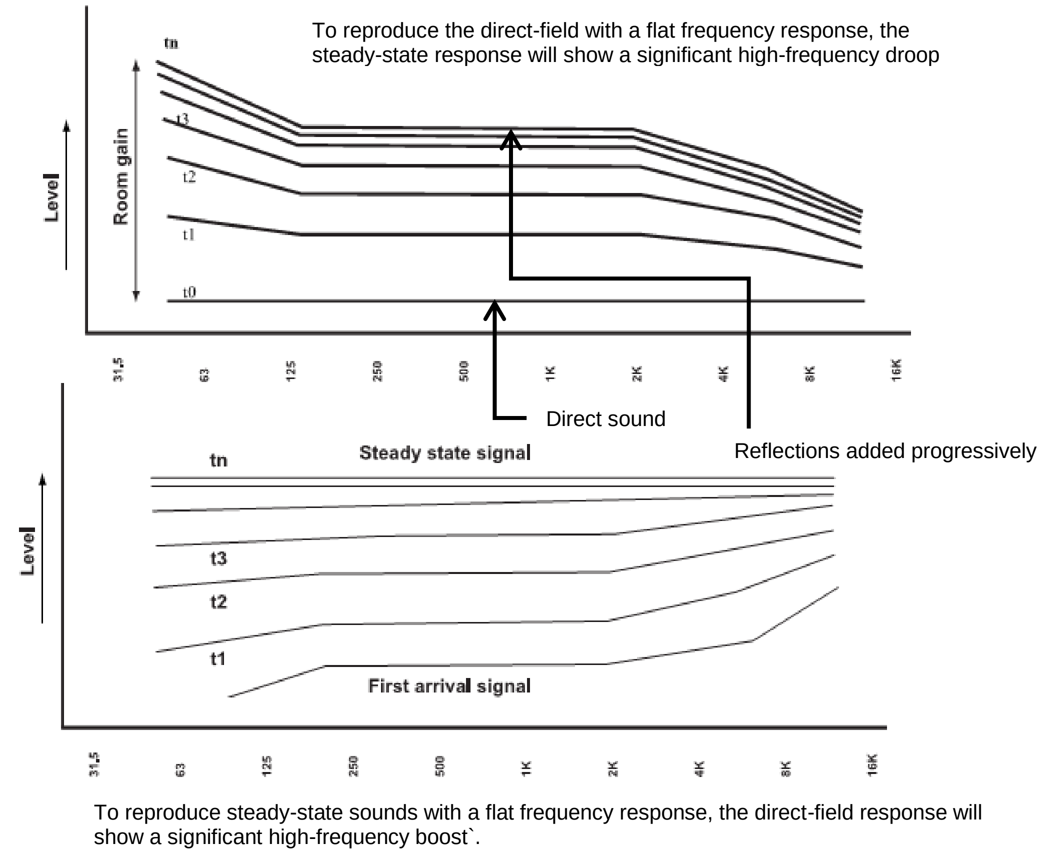


Figure 4. Conceptual representation of the X curve hypothesis from (6).

5 FREQUENCY RESPONSES RESULTS

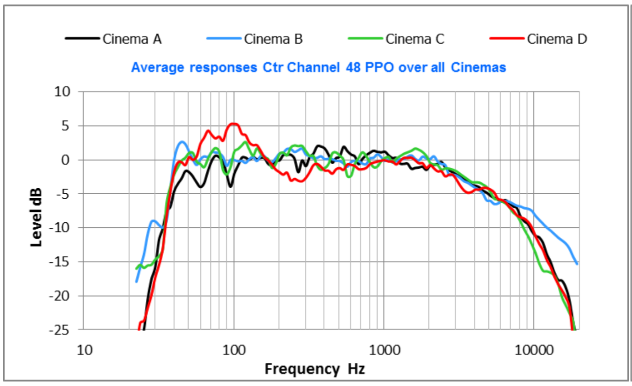
Although the report provides many frequency-response plots, only a few examples are reproduced here.

5.1 Screen Channels

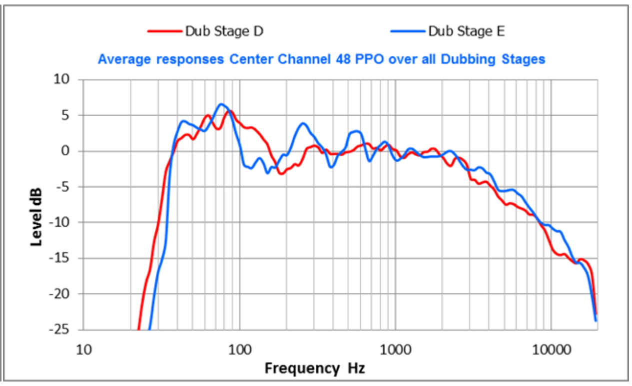
Figure 5, reproduced from (1), shows the average of responses over five positions of the centre channel for both cinemas and dubbing stages. Figure 6 compares the steady state responses of the centre channel at the reference position with and without equalisation, and with the X-curve overlaid.

It is apparent that, in all six theatres tested, a ‘Standard’ X-curve has been applied to the screen and surround-channels in the form of a target curve, irrespective of the screen types, room sizes or reverberation times of the different theatres. Comparison of the X-Curve with the averaged responses shows reasonably good alignment at high frequencies. This result is agnostic as to the relevance or non-relevance of the X-curve, as it simply shows the trend of the responses.

As Dubbing Stage F had a woven screen, it needed subtractive equalisation at high frequencies to meet the X-Curve, while Dubbing Stage E did not reach the X curve even with additive equalization. This result may be partly due to the responses of the high frequency drivers, but by far the biggest factor was the acoustic characteristics of the screen.

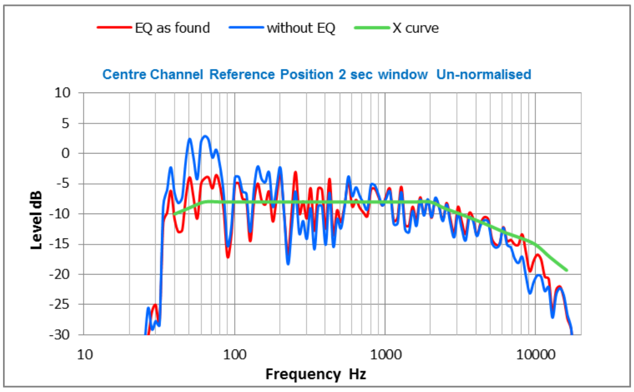


Cinemas

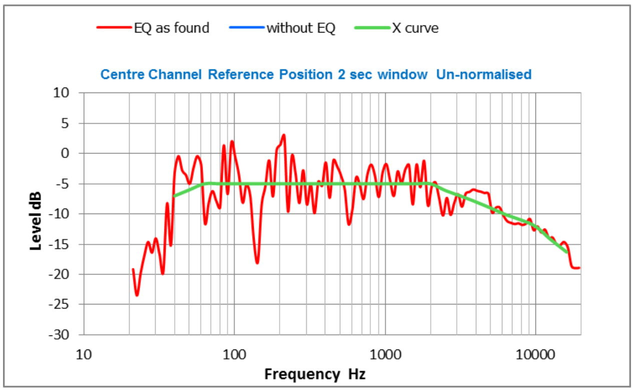


Dubbing Stages

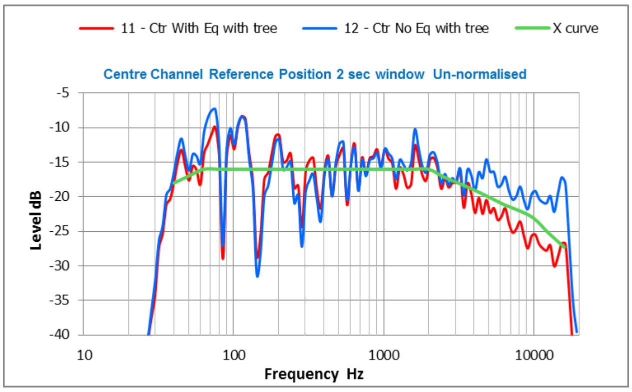
Figure 5. Average of responses over five positions of Centre Channel smoothed over 1/3rd octave bandwidth with 48 PPO window. Responses were normalised before averaging. - from (1)



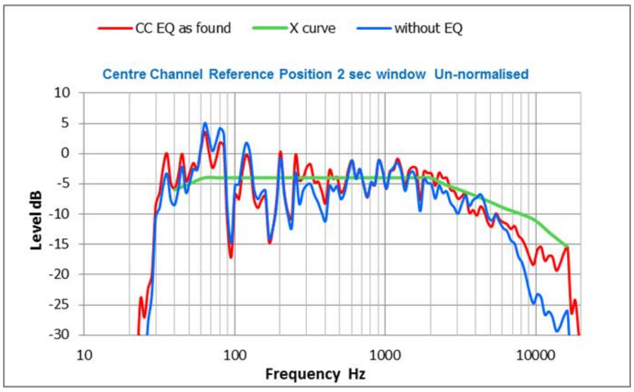
Cinema A



Cinema B



Dubbing Stage E



Dubbing Stage F

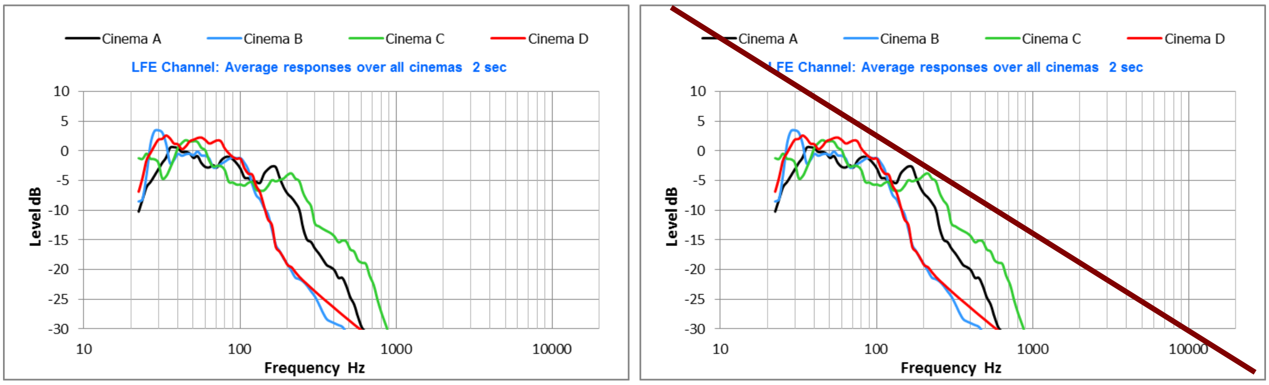
Figure 6. Steady state responses of centre channel of each venue at reference position with and without equalisation (where applicable) with the X-curve overlaid.

It can also be seen that the LF responses of the screen channels exhibit different frequencies at which the roll-offs begin, and also exhibit different slopes.

as this graph is the same as the on on the left, replace graph with graphic named "Revised Graph for Dubbing Stages in Figure 7"

5.2 LFE Channel

Figure 7. The average of responses over five positions of LFE channel, smoothed over 1/3rd octave bandwidth with 48 PPO window.



Cinemas | Dubbing Stages

Figure 7 Average of responses over five positions of LFE channel smoothed over 1/3rd octave bandwidth with 48 PPO window. Responses were normalised before averaging. - from (1) *add full stop* *delete full stop*

It is clear that there are wide variations in the LFE responses, with significant differences apparent in the low-frequency response-extensions between venues, ranging from 25 Hz to 50 Hz. The average response of each venue is also not particularly flat. Given the closeness of the equal-loudness curves below 60 Hz, substantial differences in the perceived low-frequency responses would be expected with these systems.

The ST202:2010 Standard states that for the LFE channel, 'After adjustment, the response between 25 Hz and 120 Hz shall be flat to within + 3 dB', when measured with pink noise in 1/3 octave bands. At least up to the 100 Hz band, the responses shown in Figure 7 could just about meet this specification, but the responses of the green and red traces (Cinemas C and D respectively) could not possibly be expected to sound the same, which questions the concept of the Standard, itself. What is more, the means of measuring the low-frequency responses in the theatres also need re-assessment, as the way that it is currently carried out, using very arbitrary microphone positions, is known to lead to great variability in the measured results; and hence any applied equalisation.

The responses of the upper band edge of the LFE channels are also highly variable, with turnover points ranging from 90 Hz to 225 Hz, and with variable roll-off slopes. Clarification is needed from the industry as to whether LFE filtering should be done during film mixing or in the loudspeaker system itself. If band-limiting is not done in mix-down stage, signals above the nominal LFE cut-off point of 125 Hz will produce undesirable audible effects in venues with higher LFE bandwidths.

5.3 Frequency Responses with Different Length Windows

Figure 8, from (1), shows the frequency responses of the six venues with 10 ms, 50 ms and 48 PPO Tukey windows, relative to the responses with a 2 second window.

In all venues, from approximately 800 Hz up, the responses of the 10 ms, 50 ms, 48 PPO and 2 second windows are remarkably similar, indicating that the direct field strongly dominates the measurements and that reverberant build-up contributes only a small amount of sound to the total energy at these frequencies. These results are completely contrary to the hypothesis that the X-curve is a measurement effect resulting from the difference between the direct field and steady-state measurements in a typical cinema environment.

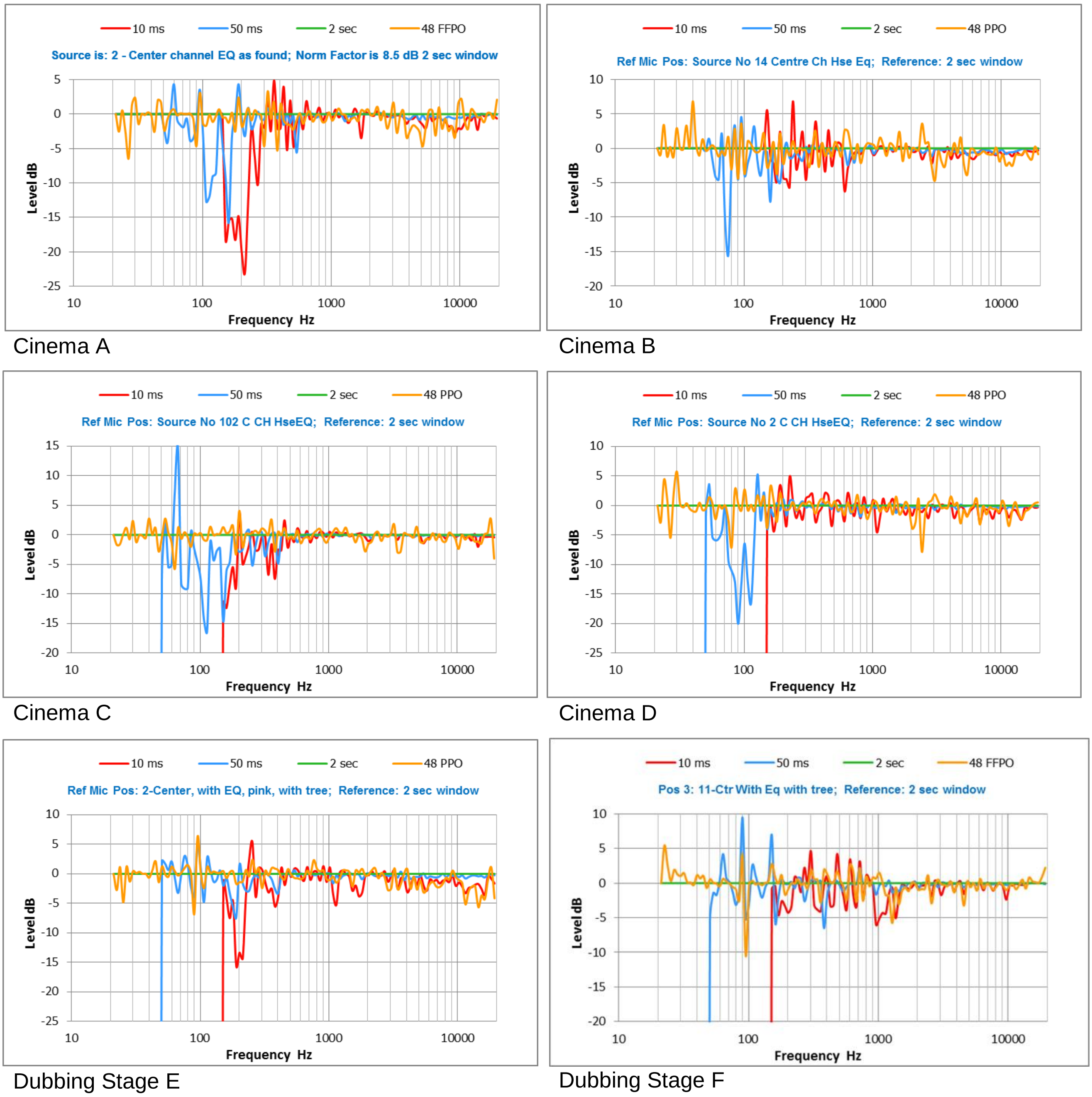


Figure 8. Frequency responses of the six venues with 10 ms, 50 ms, 48 PPO windows relative to responses with 2 second window - reproduced from (1).

These results are in line with studies undertaken in 2011 by the authors (7,8). Figure 9 from (8) shows the average responses of eighteen cinemas and dubbing stages normalized to the steady state response.

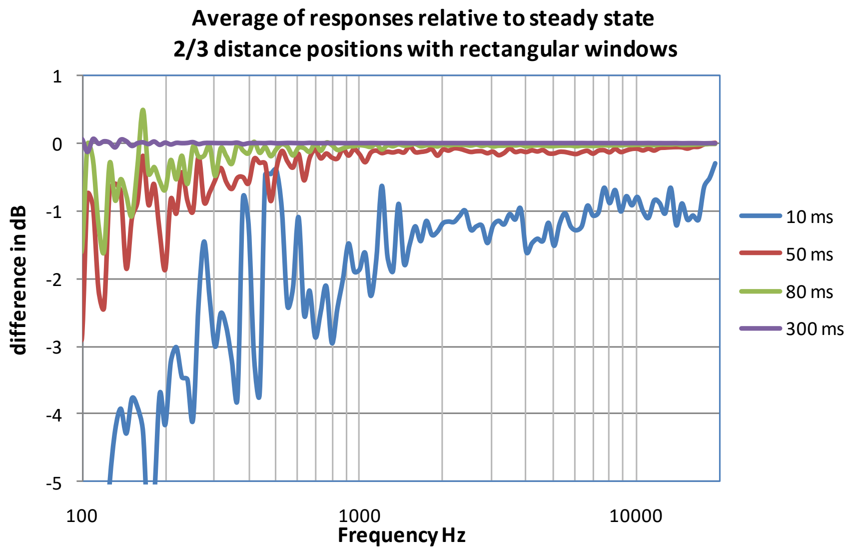


Figure 9. Average difference between short-time responses and steady-state responses taken over eighteen cinemas and dubbing stages – from (8).

5.4 Far field vs close field

Microphones placed in the close field of the loudspeaker can provide useful overall frequency response information, but the results must be interpreted carefully as they can be strongly affected by transducer directivity and phase interactions between drivers at frequencies near crossover points.

Figure 10, from (1), compares the average responses over the listening areas with close-field responses for the Centre Channel of two cinemas and two dubbing stages. In Cinema B, the response at the reference position is also shown. Aside from Dubbing Stage F, the responses of the close-field microphones are generally not particularly flat. Examination of these close-field responses does not indicate the extent to which directivity and interactions between drivers have affected the responses.

The close field measurements in two venues show evidence that low frequencies may have been partly equalised-out of the direct sound to compensate for the reverberant build up in the room. This practice inevitably changes the tonal balance of the direct sound, which is known to be an important reference for the ear. If different equalisations applied in different theatres lead to significantly different direct responses, it cannot really be expected that the overall sounds will be perceived to be the same if they do not even begin with the same responses. What a room may restore to the overall spectral balance cannot compensate for the time-domain imbalances to which the ear is also sensitive.

In general, the responses above 1 kHz at close-field positions show substantial similarity with both the reference position and average responses, with slightly less high-frequency energy in the audience responses, consistent with the losses from air-absorption (typically around 1 dB per 5 metres at 10 kHz). Accordingly, the close-field microphones basically show an X-curve characteristic with a little more high frequency level, again confirming that the X curve is not due to differences between direct and steady state sound fields.

These frequency response results are in complete agreement with responses measured in 2010 by Newell et al, and first presented to the Reproduced Sound conference in Cardiff, the same year. (9). Figure 11, taken from that paper, compares the steady state responses at 2 m and at the reference two-thirds distance in twenty Dolby-certified cinemas and dubbing stages.

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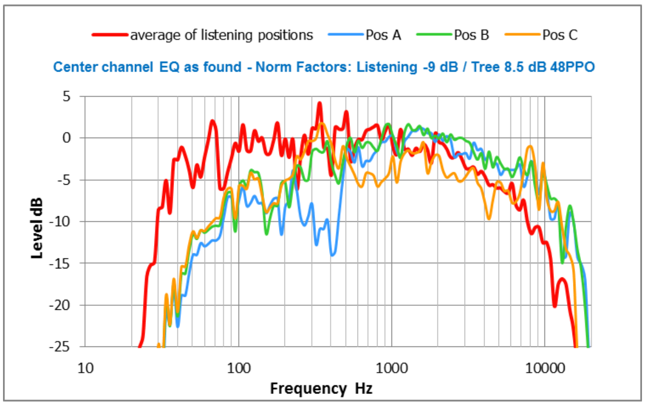
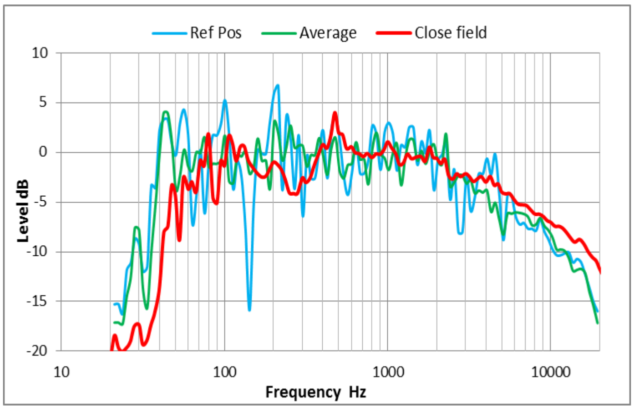
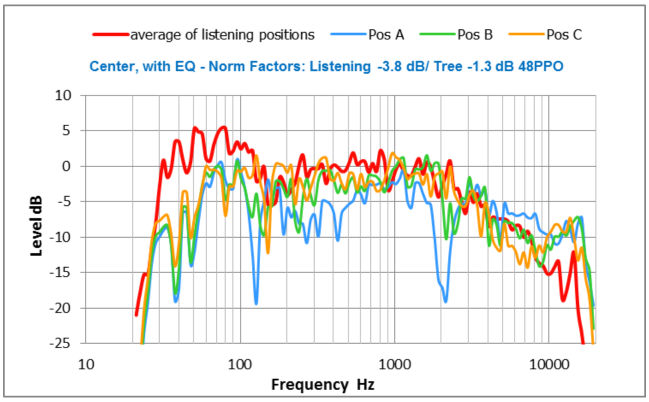


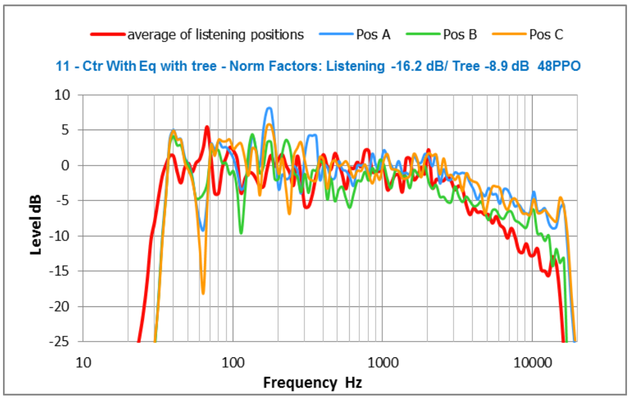
Cinema A Comparison of average listening area response with close-field responses



Cinema B Average of six positions measured in the close field

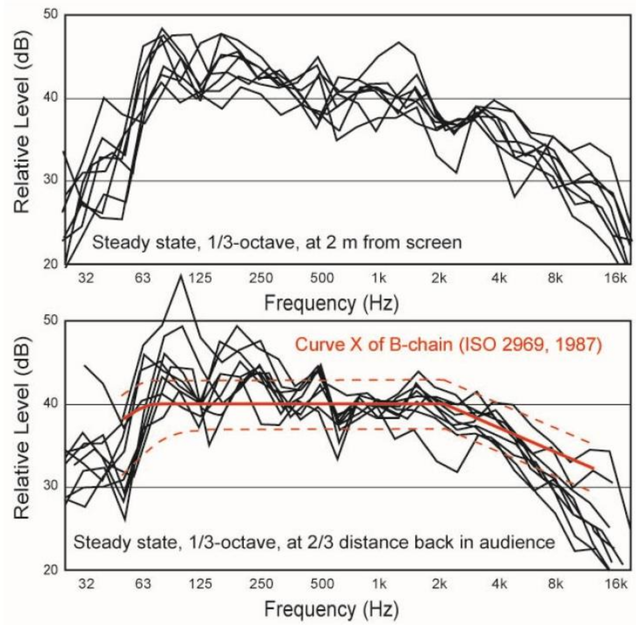


Dubbing Stage E

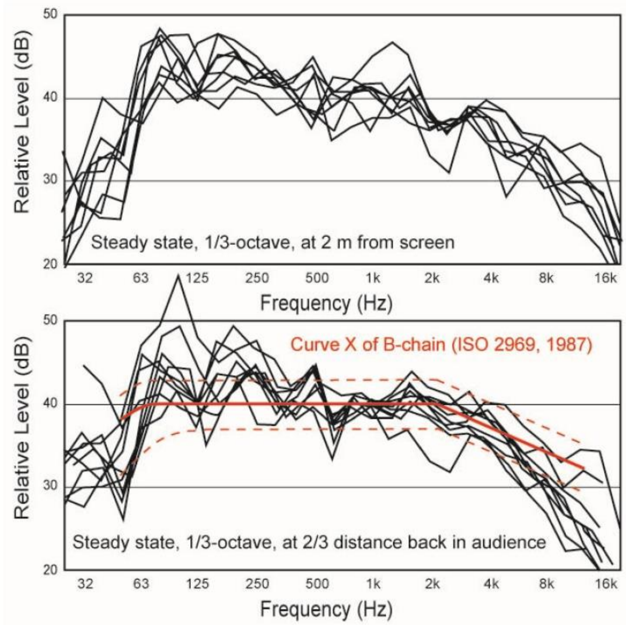


Dubbing Stage F

Figure 10. Comparison of average listening area response with close-field responses for Centre Channel and 48 PPO window. Venues A, E and F: Close-field responses are normalised to average level of Pos B. Venue B: average of close field responses with 2 second window, also with reference-position response.



Cinemas



Dubbing Stages

Figure 11. Comparison of steady-state responses at 2 m and at the reference two-thirds distance for twenty Dolby-certified cinemas and dubbing stages.

5.5 Effect of Cinema Screens

In (10), Long et al show that the acoustic transmission properties of a perforated cinema-screen are directly related to the thickness of the screen, percentage of open area and hole diameter. With woven screens, flow resistivity is the primary parameter. The woven screen has the definite advantage in transmission loss, which is the reason for the good high-frequency response in Venue F.

Figure 12 shows the changes in the anechoic frequency response a loudspeaker with an ostensibly flat frequency response when two types of perforated screen (“theater perf” and “cinema perf”) and a woven screen were located 300 mm in front of the loudspeaker baffle. The responses with the perforated screens show a strong similarity to the X-curve shape, which is overlaid on the lower of the two graphs.

The changes in the responses of Figure 12, introduced by the screens, are not surprising from a theoretical perspective. Figure 13, from (10), compares the measured and predicted frequency response of the sound transmission loss of two types of perforated screens and a woven screen. The predicted responses were calculated using the transfer matrix method, while the measured results were produced in a plane wave tube. These transmission loss results show significant similarity to the effects of the screens in Figure 12. Additional investigations into the effects of cinema screens are described by Newell et al in (11).

The result of these considerations is that the X-curve shows strong similarity in shape to the theoretical sound transmission loss of a perforated panel, and is therefore highly likely to have historically resulted from the screen losses, rather than from any effects of room acoustics. Accordingly, these losses can be equalised (12).

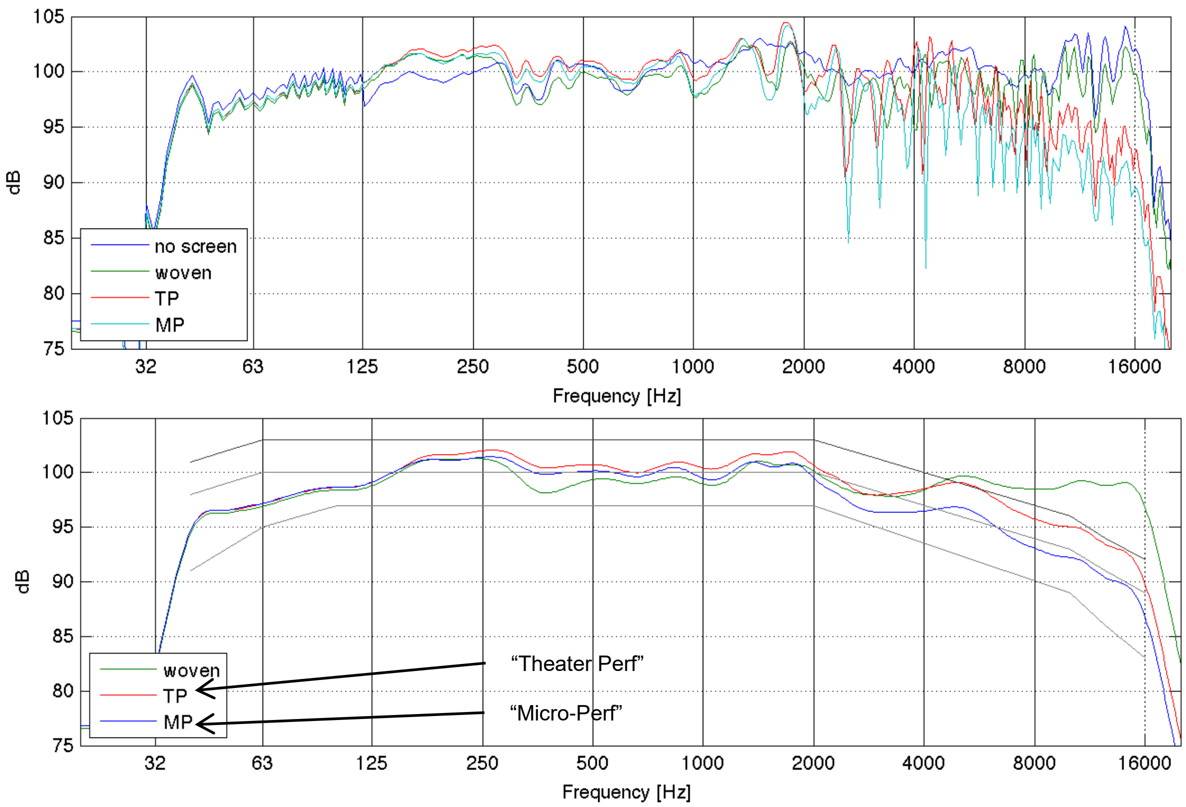


Figure 12. Effect of locating three types of cinema screens 300 mm in front of a loudspeaker with an ostensibly flat frequency response. Upper graph: unsmoothed; lower graph: smoothed.

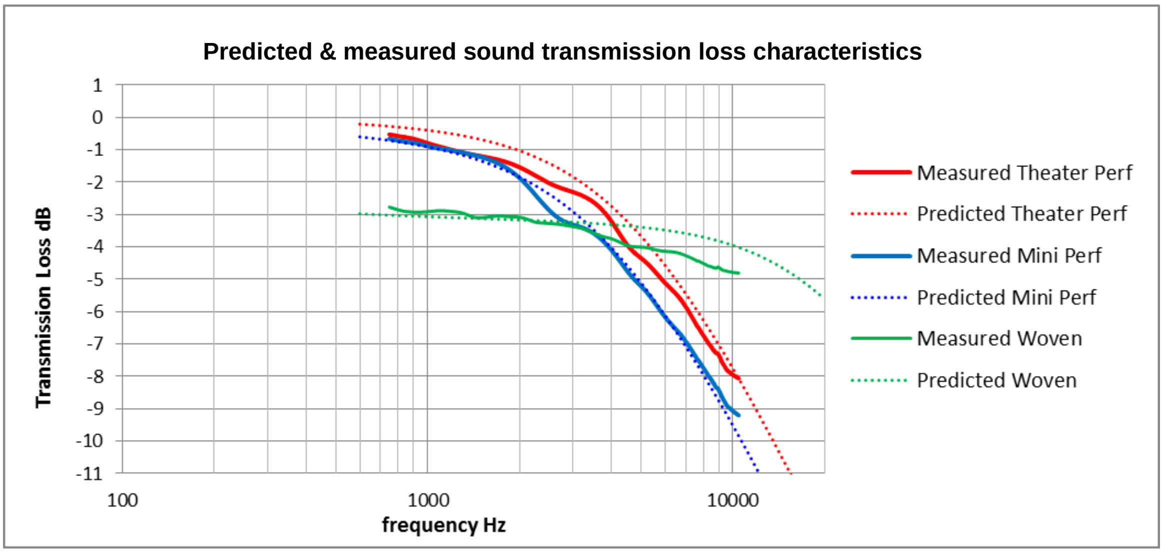


Figure 13. Measured and predicted tranmission losses of perforated and woven cinema screens. Measured results have been smoothed over a sliding 1/3rd octave bandwidth.

6 TEMPORAL RESPONSES

6.1 Schroeder Decay and Reverberation Times

The Schroeder decay plots of the six rooms all show respectably straight decay lines indicating that there are no gross problems with coupled spaces or exceptionally strong reflections.

As these are acoustically dry spaces, source directionality has a major effect on the temporal structure of the IR, with early arriving sound being heavily absorbed. As such the reverberant decay between -5 dB and -15 dB can be highly non-linear. The reverberation times (RTs) were therefore computed from the Schroeder decay curve over the range of -15 dB to -40 dB, where possible.

Reverberation-time measurements showed that all the cinemas ranged between 0.35 secs and 0.7 secs in the mid-band frequencies. With the dubbing stages, the RTs ranged from 0.25 to 0.5 secs. Figure 14, reproduced from (1), shows the RTs of each venue in octave bands. Overall, there is a significant range in the RTs. The well-regarded reference-cinema, Venue B, has an RT of 0.35 s which is virtually flat between 125 Hz to 8 kHz.

There was concern in our editorial committee that the spaces were not sufficiently diffuse to allow the use of the term “reverberation time” to describe the decay time of sound in each room. However, ultimately, we agreed that the term ‘reverberation time’ is colloquially understood, and so would continue to be used. It could be approximated by a measurement of the decay-time during the late part of the IR.

The modern, ‘state of the art’, Californian dubbing theatre with the 0.25 second decay time is typical of many modern dubbing theatres, especially those for mixing 7.1 channels and above. Many cinema and dubbing theatres are still designed to have a decay time in accordance with established minimum reverberation times for given room volumes, but this concept also now appears to be a throwback to older concepts of employing room reverberation to average the steady-state spectral responses. Modern measurement techniques now show this concept to be counter-productive, and leading to confusion in the spatial definition in the responses of multi-channel cinema formats.

As a further illustration of this point, the highly respected, ‘Hollywood’ reference theatre also exhibits the lowest RT of the cinemas tested. This is yet another indication that the X-curve is being applied simply as a standardised target curve, and not because of the reasons stated in ‘standard’ literature, related to room reverberation build up.

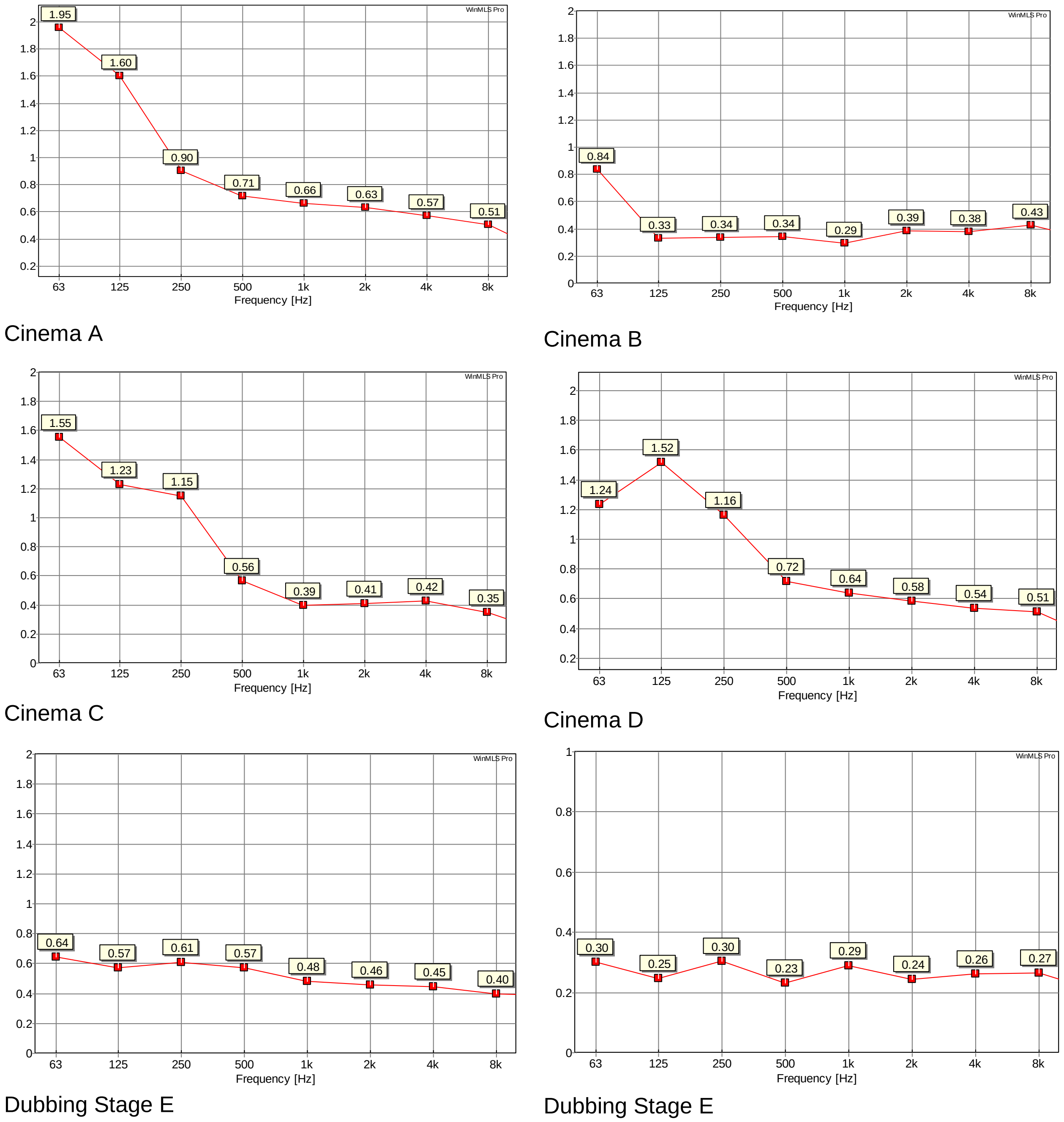


Figure 14. Measured reverberation times of the six venues - reproduced from (1).

6.2 Cumulative Energy Responses

As acousticians, we are accustomed to thinking about the reverberant tail, and we regularly look at decibel-based IR and Schroeder decay plots, but in spaces with low RTs, the question arises as to what happens while the total sound field is “charging up”. Could the ‘build-up’ time be more perceptually important than the decay tail?

The clarity ratio metric represents an attempt to understand the relationship between the early and late time periods of the IR, and is often used as a measure of a system’s ability to deliver speech intelligibility. The Cx ratio is calculated by Equation 1, where x is the dividing time between the early and late periods.

$$Cx = 10 * log_{10}\left\{\int_0^x \frac{p^2(t)dt}{\int_x^{inf} p^2(t)dt}\right\} \qquad \text{Eq. 1}$$

In the rooms under study in the 'Theater Testing' report, the C50 ratios were all very high (10 dB to 15 dB) at all frequencies. Comparison of these values would yield few insights, as analysis would suggest they are high enough to not be problematic. In contrast, the C7 ratio is too short for frequencies below 300 Hz, as insufficient cycles are included. For example at 250 Hz, the C7 ratio represents only 1.75 cycles, which is insufficient time for a useful number of cycles to arrive.

The authors considered using a C20 ratio, with a dividing time period of 20 ms, but this met with concerns in the editorial group of being non-standard. In addition, intervals of this length still only represent one cycle at 50 Hz, and 2 cycles at 100 Hz.

Using a different approach, we determined that cumulative energy (CE) plots would be a useful way of comparing the progressive aggregation of sound arrivals among venues. Equation 2 shows the way that cumulative energy is calculated over t.

$$CE(t) = 10 * log_{10}\left\{\int_0^t p^2(t)dt / \int_0^{inf} p^2(t)dt\right\} \qquad \text{Eq. 2}$$

As CE plots are normalised to the steady-state level of the sound field, they allow the development of the early sound field to be quantified relative to the total sound field. An important feature is their ability to reveal the way in which the levels of direct field and strong early reflections influence the development of the total steady-state sound field.

If reverberation times are low, and the sound field is sufficiently diffuse such that there are no strong arrivals, the CE plots rise quickly and smoothly to within 1 dB to 2 dB of their final steady state value. The arrival of strong reflections has the effect of slowing the aggregation of energy, often introducing roughness or plateaus into the plot.

Inspection of the CE plots also eliminates the need to consider whether or not the reverberation time in a non-diffuse space can be used as a way of understanding the temporal response of sound.

Figure 15 shows cumulative energy plots for the six rooms; reproduced from (1).

The cumulative energy plots were able to reveal important differences between rooms, particularly at low frequencies.

a) In Venues A, C and E, the growth in cumulative energies of the centre channels at 125 Hz and 250 Hz show significant prolongation, resulting from the arrival of strong, early reflections. This prolongation is over and above the naturally occurring build-up of energy that is associated with reverberation.

b) Of surprise is that the rate of growth of the 63 Hz band in Cinema A is approximately twice that at 125 Hz, particularly given that the RT at 63 Hz is 20% higher than at 125 Hz.

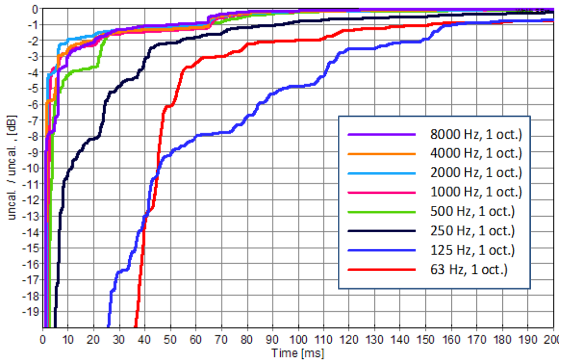
   Another surprise is Cinema D, in which the RT at 125 Hz is 20% higher than at 63 Hz, yet the cumulative energy at 80 ms is 7 dB higher than at 63 Hz.

   It appears that phase cancellations resulting from reflections are sufficiently high, and of early arrival, to substantially change the frequency response of the system at low frequencies.

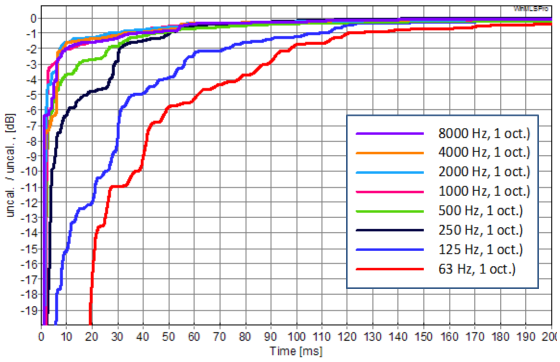
c) At 30 ms, the cumulative energy at 30 ms is generally only 2 dB below the steady state level at frequencies 500 Hz and above. However, the Cinemas A, B and C all reveal jumps in growth between 20 to 30 ms, corresponding to strong reflections.

d) Cinema A also shows the effect of a strong reflection at 65 ms, while Cinema C has a strong reflection at 22 ms.

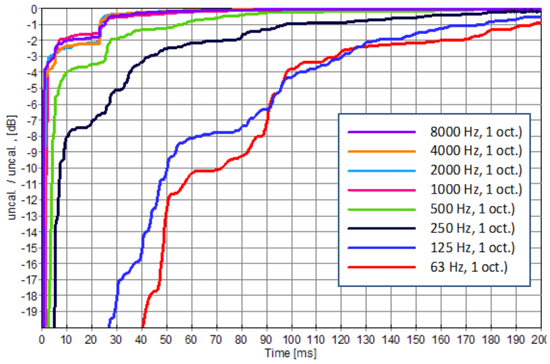
   These prolongations are bound to have a negative impact on imaging and subjective intimacy with the sound.



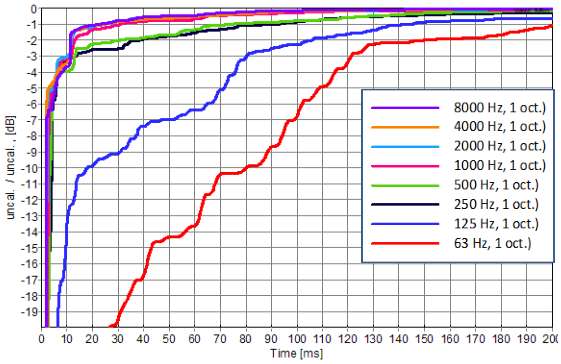
Cinema A



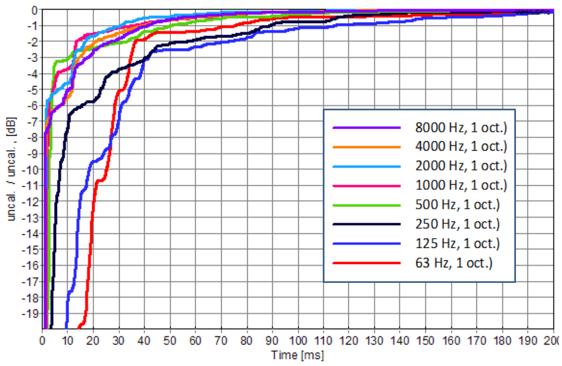
Cinema B



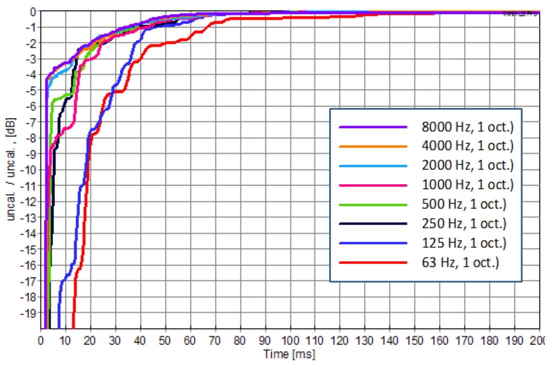
Cinema C



Cinema D



Dubbing Stage E



Dubbing Stage F

Figure 15. Measured cumulative-energy plots of the six venues - reproduced from (1).

7 CONCLUSION

The SMPTE B-Chain report is deemed a milestone in the consideration of cinema sound. Data in the report is sufficiently comprehensive and sophisticated to allow further study by interested parties for some years to come.

This paper has focussed on some of more analytic aspects of that report; aspects that relate to close-field and temporal responses, the changes that occur in the frequency responses over time and the effect of cinema screens on frequency response.

The results provided by these more analytical aspects support results from earlier studies by the authors. Analysis shows that the hypothesis underpinning the X-curve's rationale is incorrect, and that the X curve is quite similar to the frequency response of the sound transmission loss of a perforated screen. The X-curve appears to be something which the cinema industry has developed, over time, to address the limitations of the loudspeakers, screens and measuring-equipment of the 1970s, and has now found itself working to a frequency-response standard which does not relate to any other part of the audio industry, neither professional nor consumer. (13)

Cumulative energy responses have been used to gain an insight into the temporal response of the cinemas and dubbing stages. It appears to be a useful tool to understand the way that sound develops in a space, without the limitations inherent in the definitions of reverberation time and clarity ratios.

8 REFERENCES

1 "B-Chain Frequency and Temporal Response Analysis of Theatres and Dubbing Stages" https://www.smpte.org/standards/reports (October 2014)

2 Leembruggen, G., 'Précis of the TC-25CSS Theater Testing Report', SMPTE Motion Imaging Journal, Vol. 124, Nº5, pp 43 to 47, (July/August 2015)

3 SMPTE ST 202:2010, "For Motion-Pictures—Dubbing Stages (Mixing Rooms), Screening Rooms and Indoor Theaters: B-Chain Electroacoustic Response," https://www.smpte.org/standards.

4 SMPTE RP 200:2012, "Relative and Absolute Sound Pressure Levels for Motion-Picture Multichannel Sound Systems—Applicable for Analog Photographic Film Audio, Digital Photographic Film Audio and D-Cinema," https://www.smpte.org/standards.

5 ISO 2969, "Cinematography—B-Chain Electro-acoustic Response of Motion-Picture Control Rooms and Indoor Theatres: Specifications and Measurements," International Organization for Standardization, Geneva (2015)

6 Allen, I., The X-Curve" SMPTE Motion Imaging Journal (July/August 2006)

7 Leembruggen, G., Newell, P., Newell, J., Gilfillan, D., Holland, K, McCarty, B., 'Is the X Curve Damaging Our Enjoyment of Cinema?', SMPTE Convention, Sydney (2011)

8 Newell, P, Leembruggen, G., Holland, K., Newell, J., Torres-Guijarro, S. Gilfillan, D., Santos-Dominguez, D. Castro, S., 'Does 1/3 Octave Equalisation Improve the Sound in a Typical Cinema?', Proceedings of the Institute of Acoustics, Vol. 33, Pt 6, Brighton, UK (Nov. 2011)

9 Newell, P., Holland, K., Torres-Guijarro, S., Castro, S., Valdigem, E., 'Cinema Sound: A New Look at Old Concepts', Proceedings of the Institute of Acoustics, Reproduced Sound Conference, Vols. 32, Part 5, Cardiff, UK (Nov. 2010)

10 Long, B., Schwenke, R., Soper, P., Leembruggen, G., "Further Investigations Into the Interactions Between Cinema Loudspeakers and Screens", SMPTE Motion Imag Journal, vol. 121 no. 8 46-62 (November-December 2012)

11 Newell, P., Guijarro-Garcia, J., Holland, K., 'An Investigation into the Acoustic Effect of Cinema Screens on Loudspeaker Performance', Reproduced Sound 2013, Proceedings of the Institute of Acoustics, Vol. 35. Pt. 2, Manchester, UK (November 2013)**2011**

12 Leembruggen, G., 'Equalizing the Effects of Perforated Cinema Screens', AES 57th International Conference, Hollywood, CA, USA, (March 6–8 2015)

13 Newell, Philip, 'Cinema Calibration and the X-curve – facts and myths', Journal of the Audio Engineering Society, Vol. 62, Nº 11, pp 808/9 (November 2014)