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EQUALIZING THE EFFECTS OF PERFORATED CINEMA SCREENS

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ABSTRACT

Perforated cinema screens are currently in widespread use in cinemas and dubbing stages due to their high light-reflectivity. However, in the acoustical domain, such screens form a low pass filter which attenuates the high frequency response of the cinema loudspeakers. Recent studies have shown that the X-curve, which has long been adopted by the SMPTE as a standard response curve, reflects this low pass filter action. It is therefore of significance to explore the ramifications of equalizing the effects of this low pass filter, in order to provide a flat frequency response for listeners. This paper measures the spectral content of an action-based segment of a sci-fi movie, and assesses the impacts on the headroom in the playback chain and the long-term power requirements of the loudspeaker drivers that equalization of this type would impose with the spectral content of these movies.

1. MOTIVATION FOR THE WORK

It is current practice to equalize a cinema sound system to the X curve specified by SMPTE standard ST202:2010 (1). Although the X curve has been used for at least two decades, there are now a range of opinions about its exact origin. Some audio practitioners consider that it was a preferred equalization based on subjective listening. Figure 1 shows a reproduction of the specified X curve.

The author recently calibrated two reference cinemas in Australia which are used to promote cultural awareness of moving image productions. In broad terms, the calibration consisted of level adjustments and setting the frequency response of the systems to match the X curve.

Before implementing the X curve, the systems were equalized to produce a flat average response over the listening area. The subjective result was essentially hi-fi when listening to music replayed from a CD source.

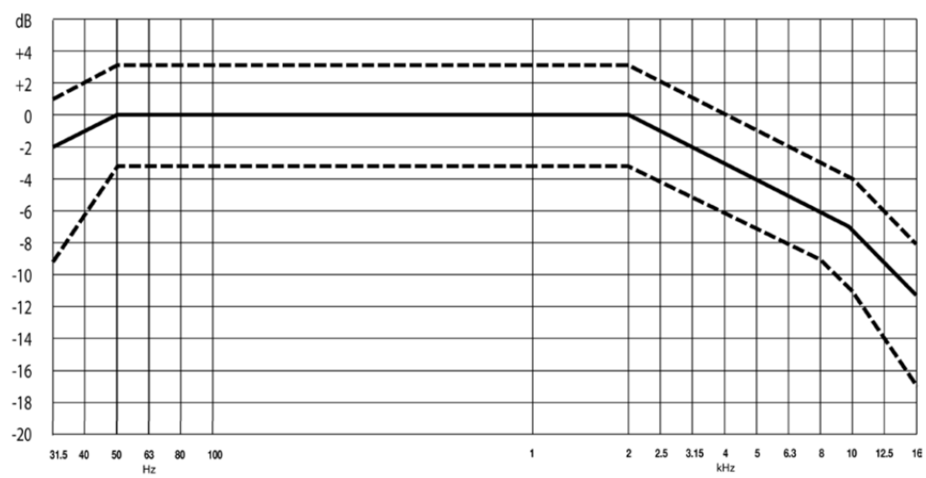
A set of parametric filters whose frequency response had been matched to the X curve was then applied to the signal chain so that the system's response complied with the specified response

It was then a simple exercise to listen to cinema sound tracks from Dolby Control Prints and DVDs with and without the X curve in the signal chain. .

My colleagues and I concluded that in every case, the system sounded better without the X curve. Voices sounded like voices, a piano sounded like a piano, and the speech clarity was much more comfortable.

There is also a growing body of learned opinion that the use of the X curve as a desired frequency response results in a substantial loss of fidelity, speech intelligibility and listener enjoyment.

If the goal of cinema sound reproduction is true hi-fi, then it is of interest to understand the implications of removing the X curve would have for power-handling capacity of cinema loudspeakers.



NOTE – Tolerances in this figure are based upon 1/3-octave measurements. If 1/1-octave measurements are used, reduce the tolerence by 1 dB.

Figure 5 – B-chain screen and surround characteristic for medium sized theater (see Annex A.5e and A.5f for modification factors and surround characteristic)

Figure 1 X curve given in SMPTE ST202:2010

2. OVERVIEW

Cinema screens generally consist of perforated vinyl and are available with a small range of hole sizes and percentage of open areas. As shown by Long et al in (2), a perforated screen forms an acoustical low pass filter in front of the loudspeaker; with the resulting loss of high frequency response (with normal incidence) being directly related to the percentage of open area, hole size and screen thickness.

The good agreement between predictions and measurements described in (2) confirms that these losses are entirely predictable for normally incident sound.

Figure 35 of (2) shows that when a loudspeaker with a flat on-axis response is located behind a "Mini-Perf" screen with a hole diameter of 0.5 mm and a perforation ratio of 1.7%, the resulting frequency response shows considerable similarity to the X curve.

If the high frequency response of the loudspeaker is flat (presumably by design or equalization recommended by the manufacturer) and the room frequency response is equalized to the X curve, the resulting response will be a combination of screen loss due to low-pass filtering, air loss and any equalization applied in the cinema.

While there is current discussion about what the ideal high frequency response of the cinema playback chain should be, it is a useful exercise to consider what the additional power and headroom demands on the system would be if the high frequency response was equalized to be flat.

A mathematical model was used to explore the changes to the statistical temporal parameters that an equalizer with an inverse X-curve shape would impose on the system with a typical movie sound track. Changes to these statistical parameters will directly affect the amplifier power requirements.

It is most probable that the final mixdown of the movie would have been made in a dubbing stage that had been equalized to the X curve. As the sound track was intended for playback in public cinemas, the author assumes that the mastering engineer had optimized the sound of this movie for playback in a reference theatre.

3. FOUNDATIONS OF THE MODELLING

The modelling is based on a number of assumptions and foundations:

1. The model assumes that the loudspeaker system is operating comfortably with the calibration settings and equalisation specified by the SMPTE. The equalisation therefore imposes an increased stress on the loudspeaker from a starting point that is comfortably within the amplifier's and loudspeaker's power capacity.
    - The measured response of the system at the Reference Position noted in ST202 matches the nominal X curve, i.e. the solid plot in **Error! Reference source not found.**. A five minute sound track of an action movie, Transformers 4, was obtained in 5.1 format from the mastering house. The segment contained an action sequence, which had been selected for its strong high frequency content.
2. Figure 2 shows the specified location of the Reference Position in a cinema calibration. This measured response includes the following factors:
    - Loudspeaker and horn responses
    - Low pass filter action of the screen
    - Attenuation due to air absorption, which in a typical cinema is only significant at frequencies above 7 kHz.
    - A five minute sound track of an action movie, Transformers 4, was obtained in 5.1 format from the mastering house. The segment contained an action sequence, which had been selected for its strong high frequency content.

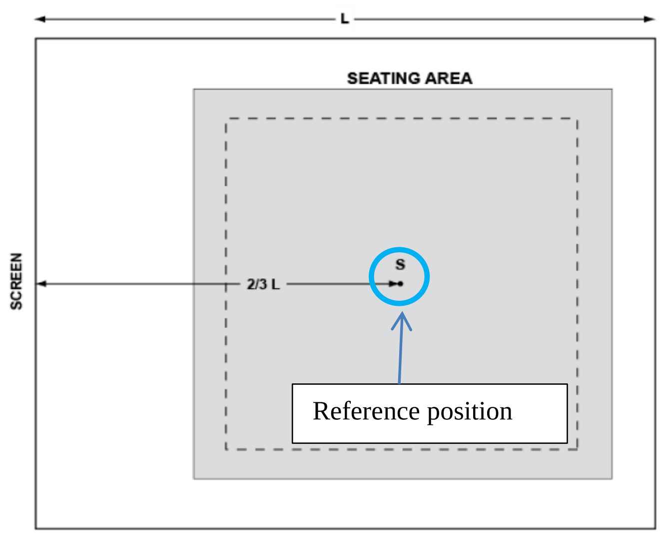


Figure 2 Physical layout of the reference position in a cinema.

3. The loudspeaker system is assumed to be operating comfortably with the calibration settings and equalization noted in 1 and 2 above.
4. The goal is to equalize the system to produce a flat frequency response; i.e. an inverse X curve is to be applied.
5. The loudspeaker is a two way type, using an 8th order Linkwitz Riley crossover with transition frequencies of 1200 Hz or 2500 Hz between the low and high frequency drivers.
6. The process ignores the distance dependence of loss due to air absorption and the desirability, or otherwise, of compensating for these losses.

    In a large room and assuming ideal loudspeaker directivity, flattening the response at the reference position would result in a slightly boosted response at positions near the screen. For example, if the reference position is 15 m from the screen, air absorption would introduce losses of 1.6 dB at 10 kHz and 3.5 dB at 15 kHz, while at 4 m from the screen, the losses are 0.4 dB at 10 kHz and 0.9 dB at 15 kHz.

In the context that the X curve is measured using stationary pink noise, the desirability of restoring a flat frequency response to the stationary sound field is a matter of current debate. Recent work undertaken by the B Chain Committee of the SMPTE (3) examined the relationship between direct field and steady state frequency responses.

Figures A6, B6, C6, D6 and E6 from the SMPTE B Chain Report (3) show that, for a typical cinema, the differences in the sound pressure level at frequencies above 1 kHz between the direct and steady state fields are typically less than 0.5 dB.

Illustrating this finding, Figure 3 reproduces Figure B6 from (3) and shows the direct field represented by the frequency responses with 10 ms and 48 points per octave windows while the steady state is represented by a 2 second window.

This small difference between direct and steady-state sound fields can be essentially ignored and therefore equalization of the steady-state X curve equates to a restoration of a flat direct-field frequency response.

4. MODELLING METHODOLOGY

The modelling was undertaken using Matlab software. The following steps were used:

1. An equalization filter was designed to match the inverse of the X curve, and consists of three IIR parametric peaking filters. The responses of the filters and the inverse of the X curve are shown in Figure 4.
2. The digital audio file was divided into 30 seconds segments at 48 kHz sampling rate with 32 bit. The entire file of 5.5 minutes duration was also used.
3. Each raw broadband audio file was read into Matlab and filtered with the inverse X curve equalization.
4. Both the raw and equalized audio files were then low and high pass filtered with the crossover type stated above.

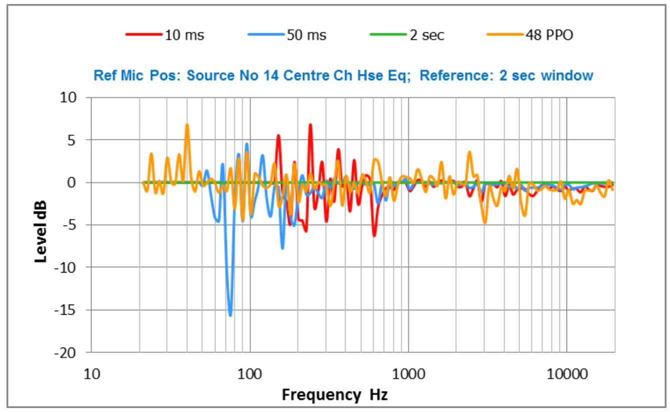


Figure 3 Responses shown in (4) with different windows at reference position of a Center Channel. NB 10 ms and 50 ms responses are truncated according to the time/frequency limit.

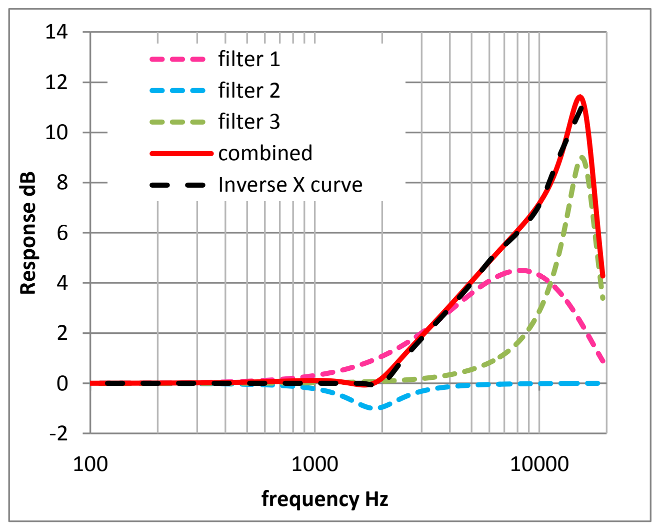


Figure 4 Responses of peaking IIR filters and inverse X curve.

5. The RMS, statistical exceedance levels and histogram were computed for the following signal types:
   - raw broadband content
   - equalized broadband content
   - unequalized low frequency content
   - unequalized high frequency content.
   - equalized high frequency content.

   All computations are relative to 0 dBFS.

6. The statistical exceedance levels are shown in the form of Ln, which is used by acousticians when referring to environmental noise levels. The Ln level is level that is exceeded for n percent of the measurement duration. In other words, for n percent of the time, the fluctuating sound pressure levels are higher than the Ln level. For example, the 90th percentile of the signal level becomes the L10 exceedance level.

   In terms of the effect of equalization on power handling and system headroom, the smaller exceedance levels will have most impact and, in this context, the use of exceedance levels assists consideration of the impacts by the use of small numbers.

7. When forming the histograms for each type, all samples less than -40 dBFS were discarded for clarity. The histograms were then found in half-dB steps ranging from -40 dBFS to +5 dBFS.

   The power spectral density of the five signal types was computed using the Welch method (4). For this computation, a Hanning window was used with a 16384 point FFT size and a window overlap of 1,024 samples. The responses were then smoothed over a sliding 1/12th octave bandwidth.

5. RESULTS

The temporal parameters were computed for each audio file for the following five different signal types or chains:

- original audio file - broadband (bb)
- original audio file with inverse x curve equalization (bb eq)
- low frequency chain (lf)
- high frequency chain (hf)
- high frequency chain with inverse X curve equalization (hf eq)

Figure 5 shows the RMS values with the 1200 Hz crossover of the five spectral types of eleven segments of the center channel along with the RMS level of the complete audio file. Figure 6 shows the same data for the 2500 Hz crossover.

Figure 7 compares the RMS values of the complete audio files of the Centre, Left and Right channels with the 1200 Hz crossover.

Figure 8 and Figure 9 show the exceedance levels of the broadband content with and without equalization. Figure 10 and Figure 11 show the exceedance levels of the high frequency chain with and without equalization. For clarity, only the range of 0% to 20% is shown.

The largest differences in each percentile with and without equalization taken over all the file segments and the complete file were computed and are shown in Figure 12 for the 1200 Hz crossover and Figure 13 for the 2500 Hz crossover.

Histograms of the high frequency center channel chains with the complete audio file are shown in Figure 14 with and without equalization for the 1200 Hz crossover.

The long term power spectra of the three screen channels are shown in Figure 15.

6. DISCUSSION

The center channel has the highest RMS levels of the three screen channels.

Table 1 shows the differences between the L1 and L0 values of the high frequency chain with and without equalization; they are unexpectedly high for both cases. The results suggest that if dynamic range issues were important, a substantial decrease in dynamic range could be achieved by reducing the level of comparatively few samples.

Parameter	Crossover point	
	1200 Hz	**2500 Hz**
L1 without eq dB re FS	-13.0	-18.6
L1 with eq dB re FS	-13.4	-17.4
L0 without eq dB re FS	-2.3	-4.0
L0 with eq dB re FS	+1*	0.05*

Table Exceedance levels of high frequency chain *re dBFS of unequalized signal (NB L0 is the peak level)

Table 1 discusses the change in RMS and exceedance levels with equalization for the two crossover points.

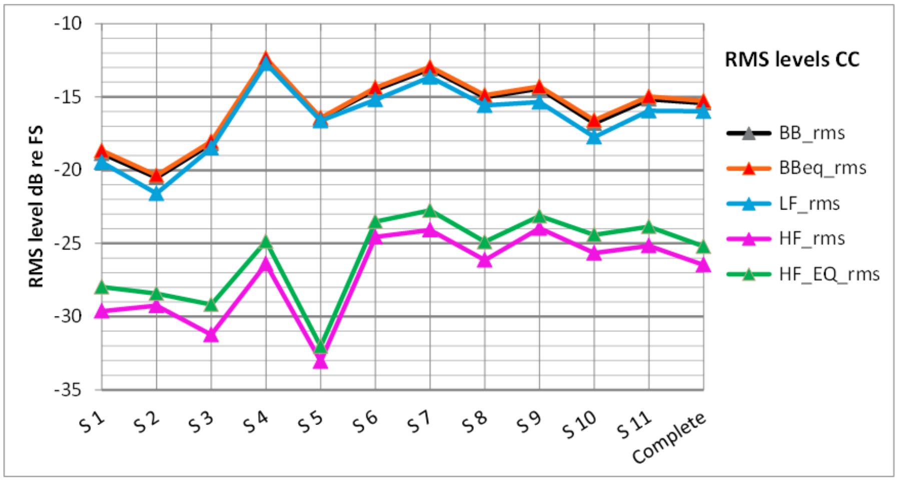


Figure 5 Computed RMS values for five signal chains of the Centre Channel with 1200 Hz crossover.

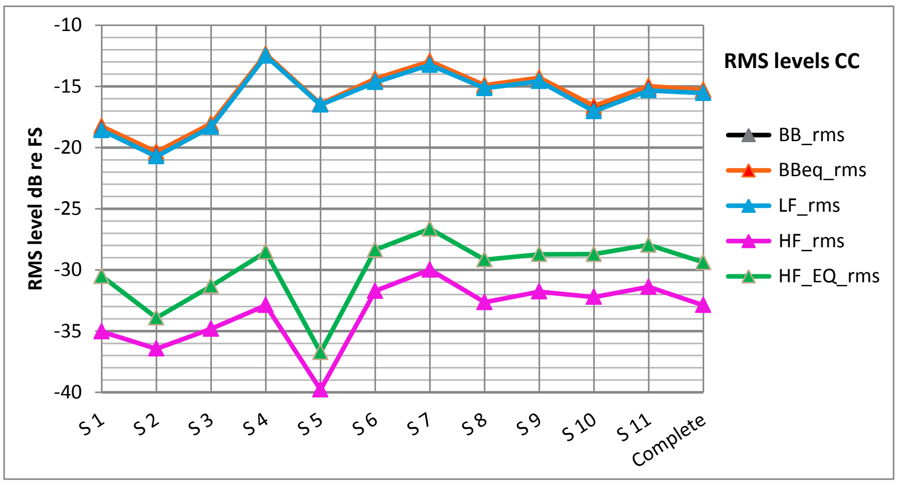


Figure 6 Computed RMS values for five signal chains of the Centre Channel with 2500 Hz crossover.

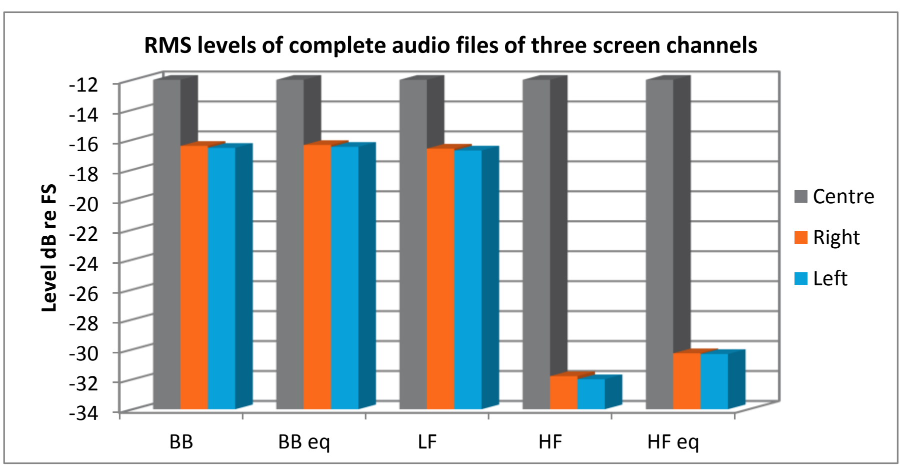


Figure 7 Computed RMS values for five signal chains of the three screen channels with 1200 Hz crossover.

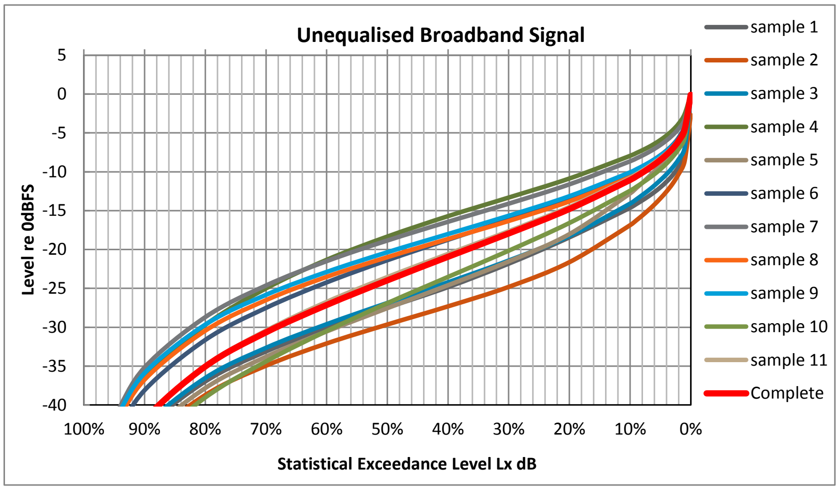


Figure 8 Exceedances values 0% to 100% for unequalized broadband centre channel signal. (1200 Hz crossover)

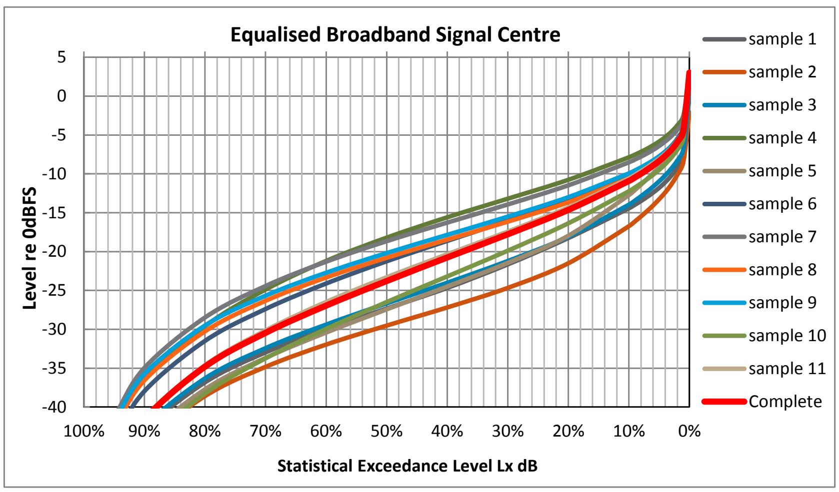


Figure 9 Exceedance values 0% to 100% for equalized broadband center channel signal ((1200 Hz crossover)

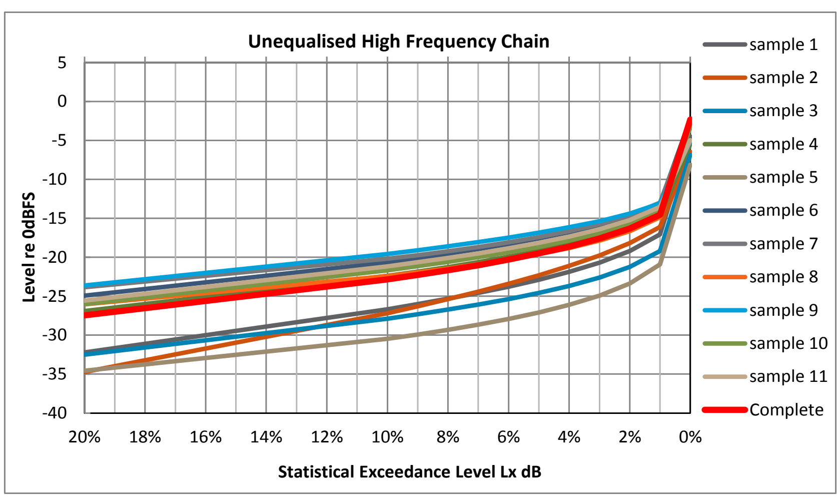


Figure 10 Exceedance values 0% to 20% for unequalized high frequency center channel signal. (1200 Hz crossover)

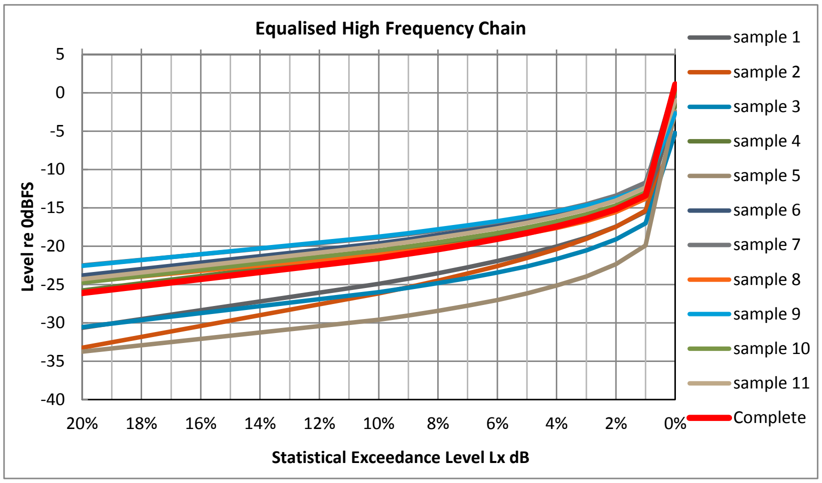


Figure 11 Exceedance values 0% to 20% for equalized high frequency center channel signal. (1200 Hz crossover)

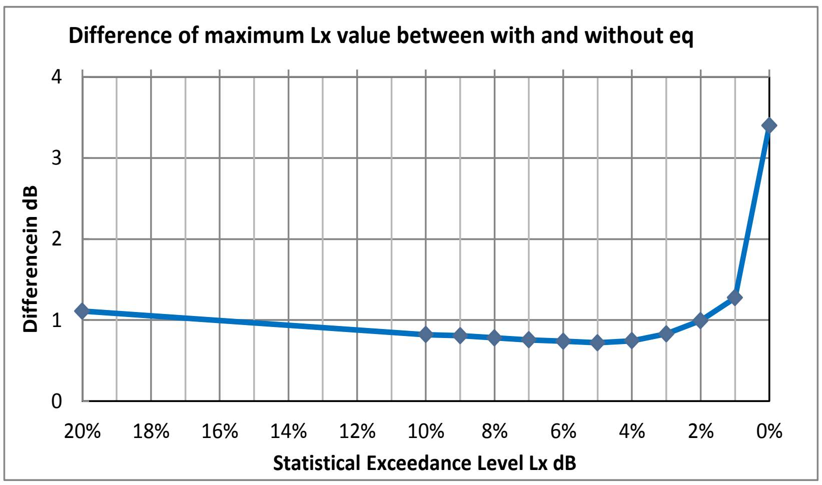


Figure 12 Difference of exceedance values for equalized and unequalized high frequency center channel chains with 1200 Hz crossover.

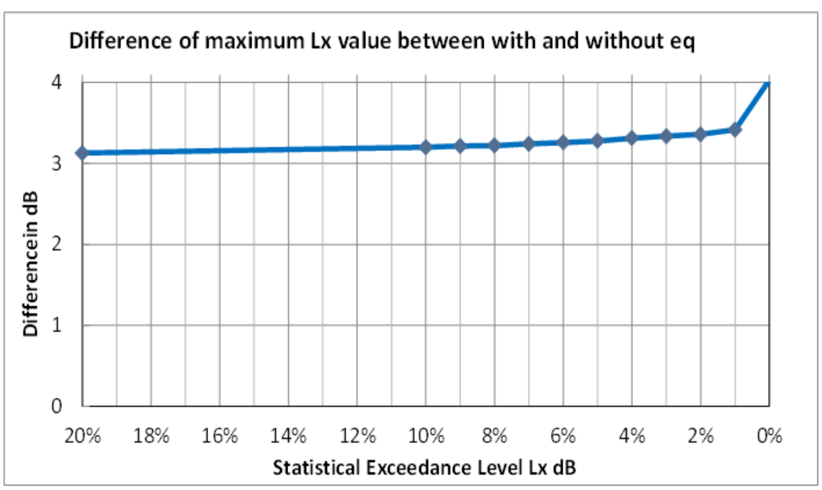


Figure 13 Difference of exceedance values for equalized and unequalized high frequency center channel chains with 2500 Hz crossover.

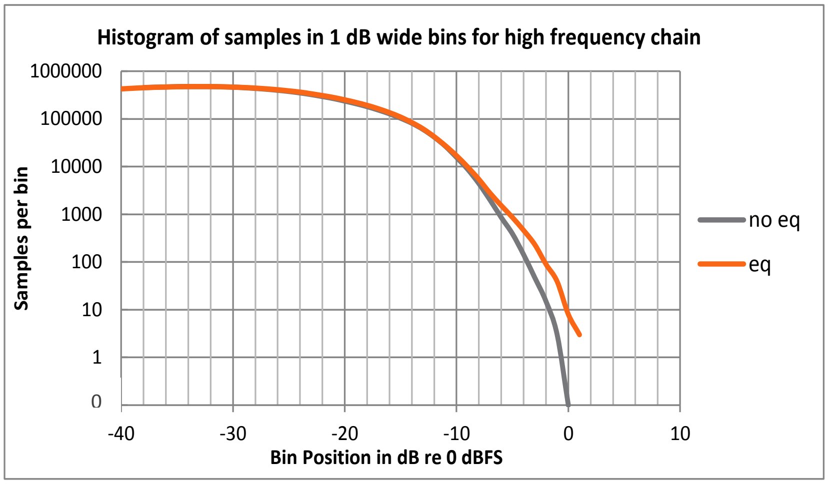
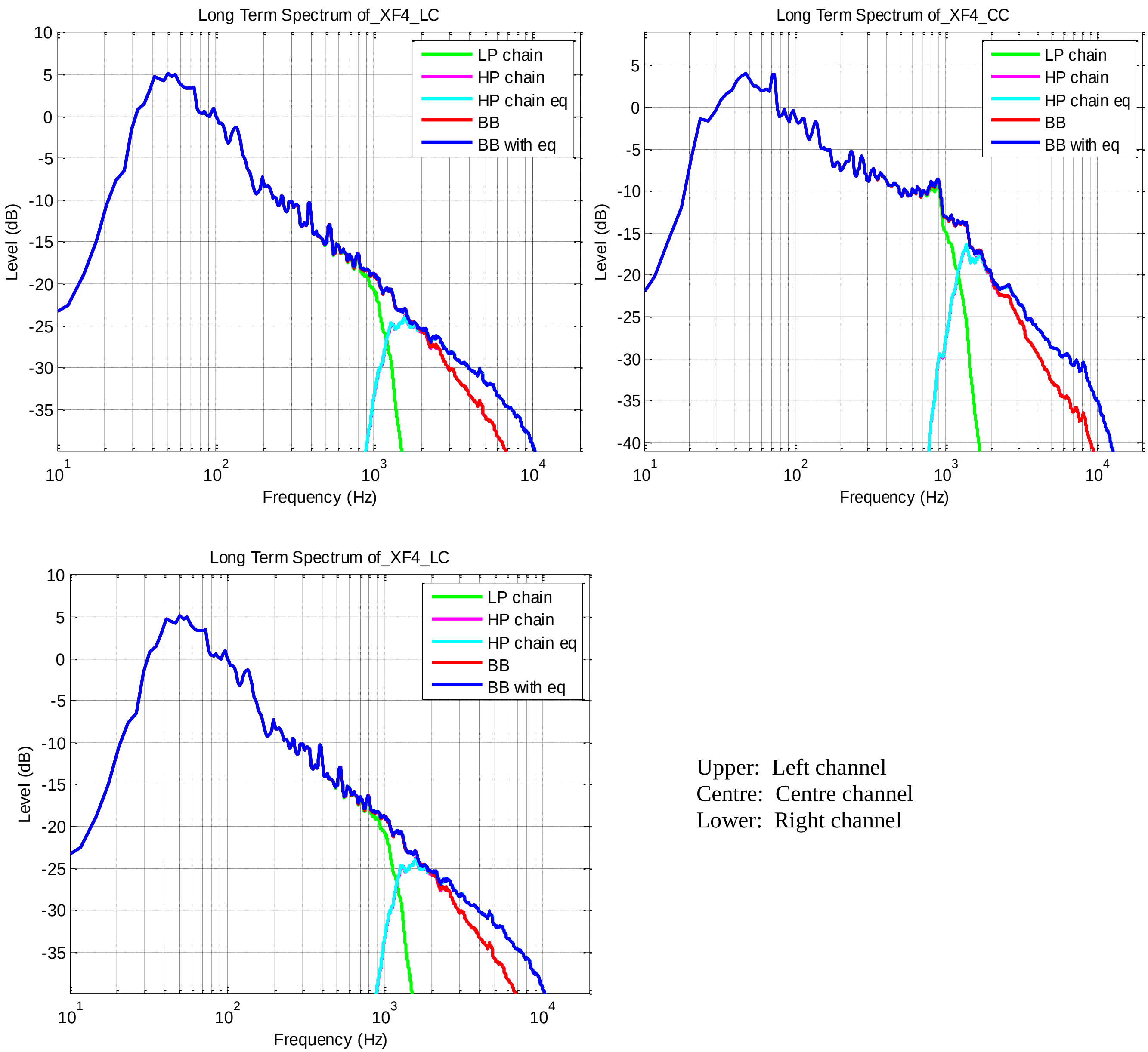


Figure 14 Histograms of signal levels in the high frequency chain with and without equalisation. Note the ordinate scale is logarithmic axis to allow comparisons at bin-position values close to 0 dBFS. (1200 Hz)

Parameter	Crossover point	
	1200 Hz	**2500 Hz**
RMS level of high frequency chain relative to broadband level without equalization	-11.1 dB	-17.5 dB
Increase in RMS level of broadband signal with equalization	0.2 dB	0.1 dB
Increase in RMS level of high frequency signal with equalization	1.3 dB	3.5 dB
Exceedance levels of broadband signal affected by equalization	Top 1%	Top 1%
Increase in exceedance levels of high frequency signal with equalization	approx. 1 dB	approx. 3.2 dB
Increase in peak level (L0) of high frequency signal with equalization	3.4 dB	4.0 dB
Number of samples in top 1% bin (between L1 and L0) (Figure 14)	3	
Number of samples in top 3 exceedance bins (between L3 & L0) (Figure 14)	140	127
Crest factor of unequalized/equalized high frequency signal	25/27 dB	29/30 dB
Increase in crest factor	2 dB	1 dB

Table 1 Calculated parameters with crossover points of 1200 Hz and 2500 Hz.



Upper: Left channel
Centre: Centre channel
Lower: Right channel

Figure 15 Power Spectral Density of the five signal chains of the three screen channels. 1200 Hz crossover system shown.

6.1. Spectra

The long term power spectra of the three screen channels shown in Figure 15 show surprisingly small energy at high frequencies compared to low frequencies. Of the three channels, the center channel contains the greatest amount of high frequency energy.

6.2. Power Requirements

The results produced for this sound track segment with a crossover frequency of 1200 Hz show that there will be a 1.3 dB increase in the long-term power dissipation requirements for the high frequency driver. This equates to a 35% increase. With the crossover frequency of 2500 Hz, the increase is 3.5 dB, equating to a 124% increase.

However, these increases must be considered in relation to the current powers being dissipated by the driver. These powers are estimated as follows in the 1200 Hz crossover case:

- A typical 35 mm throat compression driver is likely to have a power rating of 75 watts AES.
- Based on the 6 dB crest factor of the AES rating, the driver can accommodate 300 watts instantaneous peak power.
- The average power rating of an amplifier delivering this peak power would be 150 watts. (3 dB above the average power rating)
- A power amplifier with 200 watts average power is therefore likely to be used with the driver. The peak power capacity of this amplifier is therefore 400 watts.
- Taking a conservative approach, let's assume that the driver sensitivity is too low for the situation and the amplifier is being driven into 3 dB of clipping.
- With the crest factor of the no-equalization case at 1200 Hz, this degree of clipping equates to an RMS level of 22 dB (-25+ 3) below the peak amplifier power, or 2.5 watts average power.
- With equalization, the thermal power dissipation would increase by 35% to 3.5 watts.

For the 2500 Hz crossover, similar reasoning predicts an average power of 0.9 watts without equalization and 2.0 watts with equalization.

In relation to the driver rating of 75 watts, the increases in thermal power are negligible.

Accommodating the increased crest factor would necessitate a greater peak power capacity from the amplifier, but with the plethora of power outputs available in contemporary amplifiers, this capacity is readily accommodated. Alternatively, the top 0.5% of levels in the high frequency chain could be reduced by judicious hard limiting.

7. CONCLUSION

An investigation has been undertaken to determine the impact on power capacity and dynamic range of a cinema sound system when equalization is applied to the system to flatten the system's frequency response at the reference listening position. This equalization effectively removes the X curve from the response which a calibrated system should have at the reference position.

The investigation computed the temporal statistical and RMS parameters for an action-based segment of the movie Transformers 4, which was in cinema release format. These parameters were computed for both the broadband signal and the signal fed to the high frequency driver of a typical two way high frequency cinema loudspeaker with crossover points of 1200 Hz and 2500 Hz.

The increases in thermal power dissipation and crest factor resulting from the equalization were computed from these parameters.

The results show that equalization increases the RMS level applied to the high frequency driver by 1.5 dB and 3 dB for crossover points of 1200 Hz and 2500 Hz respectively. The crest factors increase by 2 dB and 1 dB respectively.

Although the RMS increase with equalization appears to impose a considerable percentage increase in thermal power dissipation, the increases in power must be considered in relation to the crest factors of the program content and the actual power being dissipated. Estimates of a typical driver and amplifier combination indicate that the power increases are negligible.

8. REFERENCES

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