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Digital cinema: analysis of multi-channel systems to control sound levels

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ABSTRACT

Since 2014, Flemish Authorities have installed an auto-regulatory system for cinemas in order to control the sound pressure levels during screening of different digital source materials. In preparation of this regulation, an acoustic study was necessary to fully understand the existing sound pressure levels and how they are generated in different movie theatres. Therefore, the whole sound system was studied in extensive details to describe the subsequent steps in the motion-picture multi-channel sound reproduction chains. The analysis started at the levels [dBFS] of the DCP 5.1 multichannel digital source signals, passing through the signal processing and amplification, integrating the electro-acoustic and room responses at different listening positions. As a result, it became clear that in modern digital cinemas with proper room calibration, a good prediction of the resulting sound pressure levels can be achieved. This result provides therefore a mean of control of the resulting sound pressure levels even before actual playback. Different sources [film, trailer, commercial announcement], different sizes of venues and different audience positions were investigated. Results of the different analysis steps will be presented and discussed.

Keywords: Cinema, Signal, Loudness

1. INTRODUCTION

After having received several complaints about sound pressure levels being too loud in cinemas, with even a reported case of tinnitus, the Flemish Authorities decided to have an acoustic study of digital cinemas carried out. The aim of the study was to gain knowledge concerning the digital cinema industry and the sound pressure levels for the audience (public) at that time in order to prepare a new legislation for the hearing protection if it would seem necessary in the light of the obtained results.

The study was conducted in 2012, with final reporting in February 2013. Further work has been undertaken preparing a new regulation imposing a sound management system for the control of the sound levels in digital cinemas. This system is managed by the cinemas themselves, with obligation to keep logfiles that can be inspected by the authorities. Since the entry into force of this new regulation in January 2014, the number of complaints has decreased significantly.

The full report being available online since 2013, this paper will emphasize on the discussion of the performed analyses of the digital loudness and the resulting sound pressure levels in the cinemas.

For readability of the text, sound pressure levels [dB ref. 20 µPa] are referred to as sound levels.

2. SCOPE

2.1 Digital Cinema

The study concerns digital cinema with source material delivered as an DCP (Digital Cinema Package) of the 5.1 audio channel format. In order to have a good understanding how this works out in practice, 5 different cinemas were investigated. The selection of those venues targeted different sizes, with cinema 1 being the largest one with 684 seats and cinema 5 the smallest venue with 96 seats.

Throughout the study, following DCP 5.1 source materials were used: 2 movies, 5 cinematic trailers and 11 commercials. The first movie is “Ice Age 4 Continental Drift”, where the second movie is “The Expendables 2”. Movie 1 being intended for children, was played with the Flemish (Dutch) language. The second movie 2 was played with its original English soundtrack.

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2.2 Measurement of Sound Levels Playback

The aim of the authorities was to understand the sound levels that are produced during playback on different seating positions. Therefore, besides the more averaging measurement positions as used for room calibration, other positions were chosen in order to assess the risk for potential hearing damage caused by locally occurring louder sound levels then can be expected in the middle of the seating areas.

In 5 (to 6) positions detailed and synchronized sound measurements were carried out of $L_{Aeq,100ms}$, $L_{A,Slow}$, $L_{C,peak}$ and of $L_{eq,100ms}$ third octave band with central frequency between 12.5 Hz and 22 kHz.

In Figure 1 the fixed positions are shown for measurement during playback of all source material.

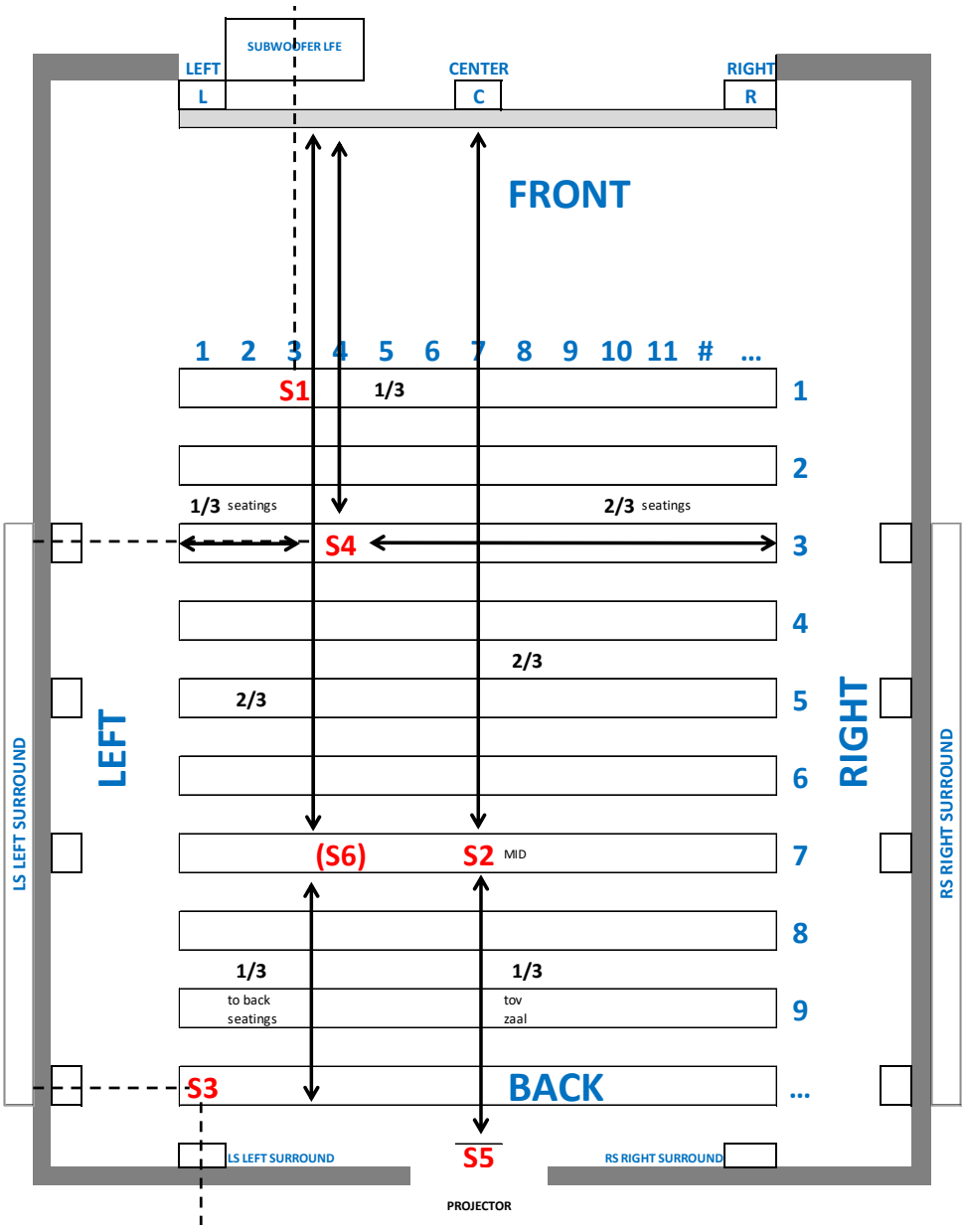


Figure 1 – Principle of distribution of sound level measurement positions over the seating area

Certain positions were specifically chosen being close to or "on axis" of a certain loudspeaker: S1 closest to the subwoofer, S4 on axis of a surround speaker, S3 at the back in the "focus" point of a lateral positioned surround speaker and of a surround speaker positioned behind that seat.

Each audio channel of the 5.1 source format has its corresponding loudspeaker(s) in the cinema: L: left, C: center, R: right, RS: right surround, LS: left surround, LFE: low frequency effect.

2.3 Measurements Transfer Function

In addition to the previous "fixed" measurement positions during playback of the different "clips" [movies, trailers, commercials], a second series of measurements has been carried out for a double purpose. First to verify the room calibration for each digital channel [L, C, R, RS, LS, LFE] separately over the whole audience zone. Secondly to establish the transfer function between each digital channel and the resulting sound pressure level at the seats distributed over the whole area.

To that purpose, a pink noise of well-known digital loudness [dBFS] was played for 30 seconds through each of the 6 channels consecutively. Per test sequence, six sound level meters distributed over the width of a seating row performed the same type of sound pressure measurements as in 2.2. Between 2 sequences, the 6 sound level meters were placed to the next row. For the two largest venues, C1 and C2, this was done for each second row. The first and last seating rows were always included.

Figure 2 illustrates the room calibration check in C3 for the digital Left Surround channel with Dolby Pink Noise played at Main Fader 7 (0 dB gain), and the resulting map of C-weighted noise level.

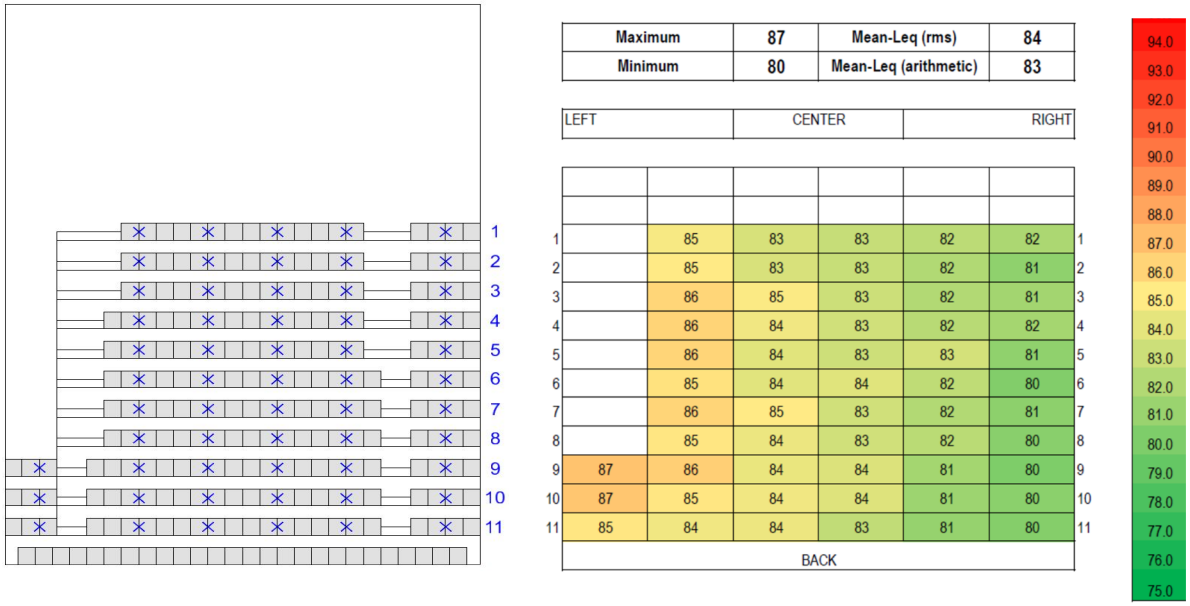


Figure 2 – Cinema 3: measurement positions and C-weighted noise level map for Dolby pink noise at LS

The transfer functions between each digital channel of the 5.1 system and the sound level at each measurement position were established spectrally with third octave band analysis.

2.4 Calibrated System Setup

In a digital cinema, many parameters of the total electroacoustic chain are well defined. At the source, the DCP 5.1 of a "clip" contains 6 channels of audio (e.g. 48 kHz, 24 bit) with a digital source loudness that will not change between cinemas. Secondly, for each digital cinema a room calibration has been executed. By sending a wide band audio pink noise signal of a well-known digital loudness through each channel separately, one can perform a calibration of the total gain (processor, equalizer, amplifier) to obtain an averaged C-weighted sound pressure level [dB ref. 20 µPa] on a set calibration positions in the venue: L 85, C 85, R 85, RS 82, LS 82 and LFE 85…88 (varies with room size).

The calibration process has also an equalization part to obtain a frequency response curve without any unacceptable tonal unbalance between different frequencies. Target curves for the frequency response are also pursued. Depending on the management of the (rooms of the) cinema(-complex), these curves (1) are met with more tolerance because also the subjective sound quality is considered.

An important element in the calibration process, and evenly important during play-back, is the "MF" Main Fader setting of the cinema-processor. Calibration is performed with the Main Fader at 0 dB gain. So, after the level calibration (including the equalization) the only gain parameter that can change before starting playback of an actual clip is that of a global (frequency-independent) volume control, better known as the Main Fader setting (or position) "MF".

When discussing sound level measurements, the MF-setting during playback is a key element.

3. MEASUREMENT RESULTS

During the study many sound level measurements and analyses were performed. In the scope of this paper some results will be only briefly mentioned. We refer to the report and its appendices (1), where all detail (time evolution, averages, …) can be found per source material, cinema, seat-position etc.

The key-element during the acquisition of the sound pressure levels in a cinema is the MF-setting during playback. Whereas the "international industry standard" consists of playing movies at MF-setting 7 (which corresponds to a gain of 0 dB according the Dolby-curve), actual playback is at a lower setting. The main reason is that cinema managers receive complaints from the visitors about to high sound levels. This deviation from 0 dB gain however can vary from one cinema to another. Each cinema manager was asked for his playback MF-settings for the different type of source materials [publicity, trailer, main movie]. The sound level measurements were done with those MF-settings.

Table 1 – Main Fader Settings per cinema for different type of source material

Cinema / Processor	TRAILER		PUB		FILM 1 (children)		FILM 2 (action)	
C1 / QSC DCP300	-.-	**-15.0**	-.-	**-15.0**	-.-	**-10.0**	-.-	**-8.0**
C2 / DOLBY CP650	4.0	**-12.0**	4.0	**-12.0**	4.0	**-12.0**	4.5	**-8.3**
C3 / DATASAT AP20	3.5	**-17.5**	3.5	**-17.5**	5.0	**-10.0**	5.0	**-10.0**
C4 / DOLBY CP650	3.7	**-18.0**	3.7	**-18.0**	4.0	**-12.0**	3.9	**-14.0**
C5 / DATASAT AP20	3.5	**-17.5**			5.0	**-10.0**	4.5	**-12.5**
	MAIN FADER SETTING [-]				**GAIN [dB]**			

In Figure 3, the average $L_{Aeq,T}$ over measurement positions S1 to S6 is shown for the 5 cinemas.

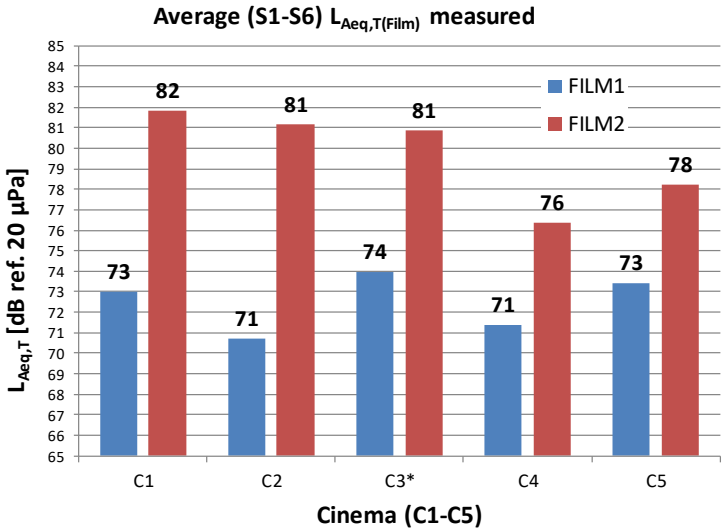


Figure 3 – Average (S1-S6) of $L_{Aeq,T,\ Film}$ for the 5 cinemas

C3: Measurement with Main Fader Gain -12.5 dB, Normal operation with Main Fader Gain - 10 dB*

The average over 5 cinemas of $L_{Aeq,T,Film1}$ is 73 dB, and for the second movie $L_{Aeq,T,Film2}$ 80 dB.

In the report (1) all results are presented and discussed in detail. *The report, the annexes, technical details and information can be found on: https://www.lne.be/geluidszorg-in-bioscopen.* Some global statistics however are interesting when looking at the resulting sound pressure levels in the cinemas for the assessment of the risk for potential hearing damage. The behavior of $L_{A,Slow,max}$ and $L_{C,peak}$ was very similar for both movies 1 and 2, considering all positions S1 to S6 over all 5 cinemas. The value of $L_{A,Slow,max}$ exceeds that of the $L_{Aeq,T,Film}$ with at least 11 dB, but never more than 16 dB. The value of $L_{C,peak}$ exceeds that of the $L_{Aeq,T,Film}$ with at least 30 dB, but never more than 38 dB. Global averaging yields $L_{A,Slow,max} = L_{Aeq,T,Film} + 13$ dB and $L_{C,peak} = L_{Aeq,T,Film} + 34$ dB. In the annexes (1) all the detailed analyses [C1-C5, S1-C6, Channels, …] are presented for the movies, the trailers and the commercials.

4. DIGITAL LOUDNESS AND SOUND LEVELS

4.1 Digital Loudness

The movie source material is delivered as a DCP 5.1 containing 6 channel digital audio. This DCP remains unaltered between cinemas. So, analyzing the source can yield useful information when analyzing the rest of the reproduction chain up to the resulting sound pressure levels in the cinemas.

Different schemes for the calculation of the loudness and other metrics of 5.1 channel clips exist. The methods are based on the energy summation of the different channels, they can use different frequency-weightings and the results are expressed in [dBFS] (dB ref. Full digital Scale).

The analyses were digitally performed on the DCP of each clip to calculate the $L_{eq,Tclip}$ [dBFS] to obtain the multi-channel global M-weighted (3), A-weighted and the K-weighted (5) values. The latter can also be found as LUFS, Loudness Units ref. Full Scale according (6) for as long as the non-gated integration method is performed (which is the case in the study and this paper).

The A- and M-weighted values are obtained by summing all channels, but with a gain correction of -3 dB for left and right surround channels to reflect the room calibration for those 2 channels. The results for the K-weighted values are obtained with the non-gated integration method according ITU-R BS.1770 and corresponds to the LUFS-value. For LUFS, the LFE-channel is not taken into account and a correction of + ~1.5 dB is applied on the surround channels before summing and a global correction of -0.691 dB on the over all channels summed value. All W(K)-loudness values correspond to LUFS.

The figure 4 shows the different frequency weightings.

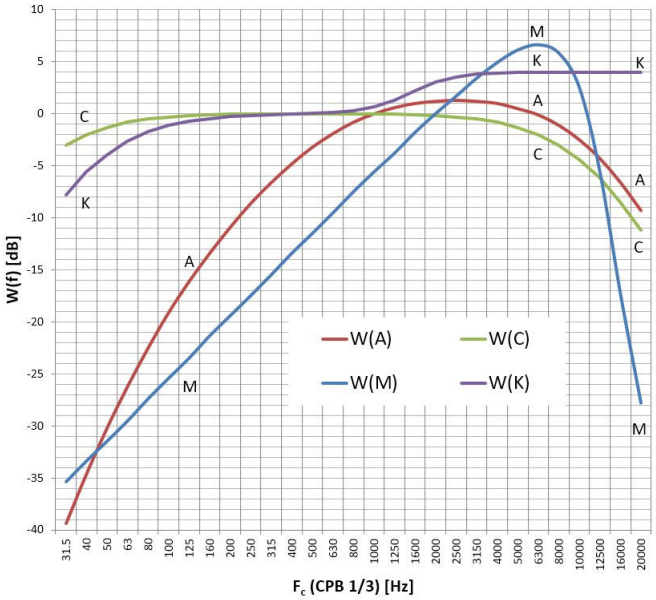


Figure 4 – Frequency weightings – applicable in the digital and/or the acoustic domain

In Table 2 the results of the digital loudness calculation on various clips are shown.

Table 2 – Digital Loudness Analysis performed on the DCP 5.1

		W(A)	W(M)	W(K)
TRAILER	1	-21	-23	-17
	2	-21	-23	-16
	3	-22	-24	-19
	4	-22	-23	-16
	5S	-20	-23	-15
	5L	-21	-23	-16
MOVIE	1	-27	-29	-23
	2	-20	-21	-15
		$L_{eq,T}$ [dBFS]		

		W(A)	W(M)	W(K)
PUB	1	-21	-24	-15
	2	-23	-23	-19
	3	-22	-23	-17
	4	-24	-22	-20
	5	-24	-22	-20
	6	-25	-23	-20
	7S	-21	-23	-14
	8	-21	-24	-16
	9	-21	-25	-17
	10	-21	-23	-18
	11	-18	-18	-15
		$L_{eq,T}$ [dBFS]		

Remark: a non-gated integration in the loudness methods, corresponds to the same operation as for the calculation of the "equivalent value" $L_{eq,T}$ in acoustics.

During the study there was also an opportunity to perform in a production studio a Leq(M) analysis on the electric signals with a "hardware" Dolby Loudness meter Type 737 on 2 trailers and 4 commercials. The 5 clips produced for 85 Leq(M) dB, yielded in the digital domain W(M) -23 [dBFS]. One clip at 90 Leq(M) dB on the loudness meter, yielded W(M) -18 [dBFS] in the digital domain.

4.2 Main Fader

As discussed above, digital cinemas have a calibrated playback chain. After calibration, the only factor that will influence - under normal operation conditions not causing any clipping of the amplifiers and in absence of any compressing or limiting - the sound level in the cinema is determined by the gain set through the Main Fader of the cinema processor (i.e. Linear Time Invariant System).

During the study and discussion with the whole sector (studios, postproduction, cinemas, …) the Main Fader setting is the common variable in the loudness discussions. According the Dolby Curve, Main Fader position "7" corresponds to a main gain of 0 dB, at which room calibration is performed. Playback is in general not done at this level, but at a lower setting. As this is a key element for all parties concerned, the gain-curves of the cinema processors were tested and compared. The QSC-processor (C1) has no Main Fader "position" but indicates directly the applied main fader gain in dB.

Figure 5 shows the real gain curves as a function of the Main Fader position on the different processors. All curves pass through 0 dB at MF 7, a zoom is made on fader settings from 3.0 to 5.5.

Main Fader Setting	CINEMA PROCESSOR		
[3.0 - 5.5]	DATASAT AP20	DOLBY CP650	Dolby Curve
5.5	-7.5	-5.0	-5.0
5.4	-8.0	-5.3	-5.3
5.3	-8.5	-5.6	-5.7
5.2	-9.0	-6.0	-6.0
5.1	-9.5	-6.3	-6.3
5.0	-10.0	-6.6	-6.7
4.9	-10.5	-6.9	-7.0
4.8	-11.0	-7.3	-7.3
4.7	-11.5	-7.6	-7.7
4.6	-12.0	-8.0	-8.0
4.5	-12.5	-8.3	-8.3
4.4	-13.0	-9.0	-8.7
4.3	-13.5	-9.8	-9.0
4.2	-14.0	-10.5	-9.3
4.1	-14.5	-11.3	-9.7
4.0	-15.0	-12.0	-10.0
3.9	-15.5	-14.0	-12.0
3.8	-16.0	-16.0	-14.0
3.7	-16.5	-18.0	-16.0
3.6	-17.0	-20.0	-18.0
3.5	-17.5	-22.0	-20.0
3.4	-18.8	-24.0	-22.0
3.3	-20.1	-26.0	-24.0
3.2	-21.4	-28.0	-26.0
3.1	-22.7	-30.0	-28.0
3.0	-24.0	-32.0	-30.0
[-]	GAIN [dB]		

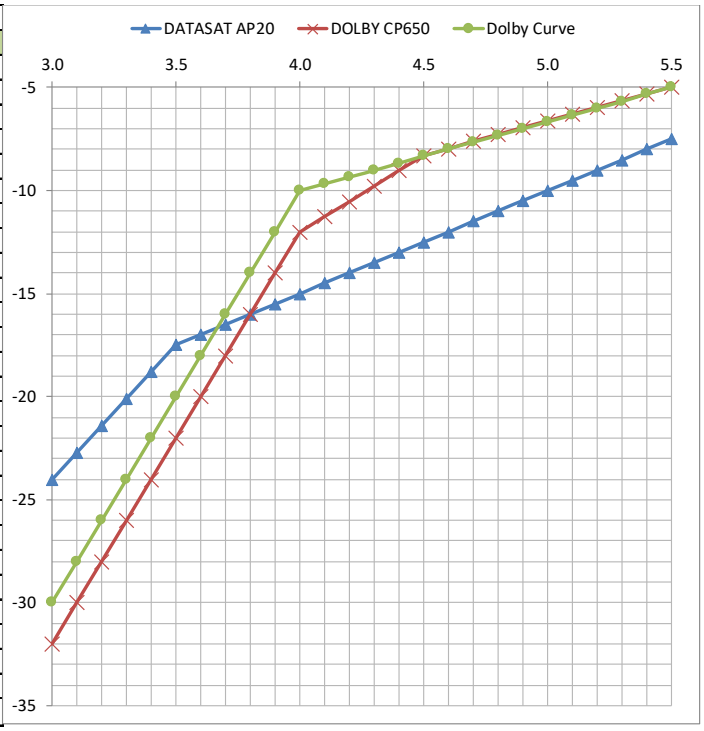


Figure 5 – Gain as a function of Main Fader Setting on the processors versus theoretical curve

One can see that the actual gain in dB corresponding to the same Main Fader setting on different cinema-processors can vary significantly. So before discussing the sound levels in a cinema for a certain (new) movie, one should verify that everyone talks about the same (main fader) gain in dB.

This is of the utmost importance for present and future discussions about how to handle loudness in cinema, from production stages to the final viewing and listening in the cinemas.

4.3 Measured Sound Levels versus Digital Loudness

In this part, the relationship between the digital loudness and the measured sound pressure $L_{Aeq,Tclip}$ will be discussed. For this operation, all sound level pressure results measured with a MF setting under 7 are "amplified back" to a (main) gain of 0 dB. So, the actual gain in dB of the processor is used and not that what the theoretical Dolby Curve indicates for the specific fader position whilst playback.

In Table 3 the measured sound level $L_{Aeq,T}$ [dB ref. 20 µPa] averaged over all positions S1-S6, for each cinema separately and for the average C1-C5 are presented for playback at gain 0 dB ("MF 7").

Table 3 – Measured sound levels $L_{Aeq,T}$ [dB ref. 20 µPa] for Main Fader Gain 0 [dB] (“MF 7”)

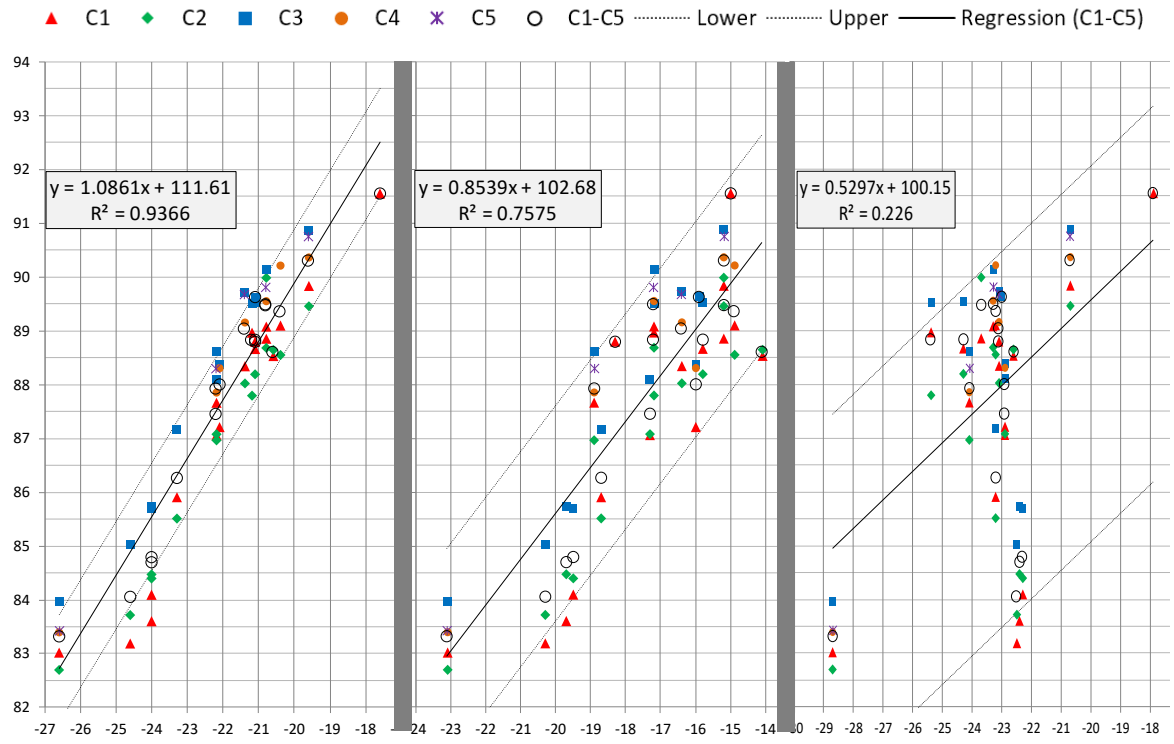
		C1	C2	C3	C4	C5	C1-C5
TRAILER	1	89	89	90	90	90	89
	2	88	88	90	89	90	89
	3	88	87	89	88	88	88
	4	87		88	88		88
	5S	89	89		90		89
	5L			90			90
FILM	1	83	83	84	83	83	83
	2	90	89	91	90	91	90

PUB	C1	C2	C3	C4	C5	C1-C5
1	89	90				89
2	86	86	87			86
3	87	87	88			87
4	84	84	86			85
5	84	84	86			85
6	83	84	85			84
7S	89	89				89
8	89	88	90			89
9	89	88	90			89
10	89					89
11	92					92

The relationships between the different digital loudness metrics $L_{eq,Tclip}$ [dBFS] as discussed in 4.1, and the measured sound pressure level $L_{Aeq,Tclip}$ [dB ref. 20 µPa] at Main Gain 0 dB were investigated.

Even though there seems to be some sort of reluctance (in standards, in the community) to use the A-weighting in the digital domain, it was included nevertheless because the aim of this study was to specifically assess the risk of hearing damage. To that purpose, many limits for exposure during diverse leisure activities are determined for the A-weighted sound pressure values [dB ref. 20 µPa].

Moreover, having a fully calibrated digital chain at disposal together with in an amplitude and (rather good) in frequency calibrated rooms, this should be an interesting relation to investigate.



(a) A-weighted (b) K-weighted [LUFS] (c): M-weighted

Y-axis: Sound level $L_{Aeq,T}$ [dB ref. 20 µPa], X-axis: $L_{eq,T}$ Digital Loudness 5.1 CH [dBFS]

Figure 6 – Measured sound levels with main fader at 0 dB gain as a function of digital loudness

When analyzing the relationships, the best correlation +/- 1 dB is obtained with the A-weighted digital loudness of the source material. The K-weighted digital loudness (= non-gated LUFS) performs not so good as the A-weighting but accepting the bigger spread +/- 2 dB it remains still a good indicator. The M-weighted digital loudness has the biggest spread (+2.5 / -4.5 dB) and does not seem appropriate at all in predicting the sound pressure level $L_{Aeq,Tclip}$ [dB ref. 20 µPa] in the cinemas.

4.4 Controlling the Sound Levels

With the established relationships of Figure 6, two ways of controlling the sound levels are feasible. Suppose one wants to limit the sound pressure level to $L_{Aeq,T,ActionMovie}$ 80 [dB ref. 20 µPa].

For movie 2, with loudness values A-weighted -20 [dBFS] and -15 [LUFS], both predictions give an expected (averaged) $L_{Aeq,T}$ 90 [dB ref. 20 µPa]. Setting the main fader gain at -10 dB will do the job.

A second method could consist of a playback at 0 dB main fader gain, corresponding to "MF 7". To limit the (averaged) sound levels, the digital source loudness should be controlled. Inverting the relationships, the loudness limits (for any movie) are found: A-weighted -29 [dBFS] and -27 [LUFS].

5. CONCLUSIONS AND FINAL REMARKS

As one of the outcomes of the study, the relation between the digital loudness of the source material DCP 5.1 and the resulting A-weighted sound pressure levels in 5 cinemas was investigated. With the results of an extensive measurement campaign during playback, the analysis of the whole digital chain together with the verification of the room calibration and the check of the real gain in dB as function of the main fader position, predicting the sound levels is possible once the digital loudness is known.

Although the number of sampled movies is small, together with all the other clips the correlation between the A-weighted digital loudness and the resulting +/- 1 dB A-weighted sound pressure levels is very good. The LUFS (non-gated) performs a bit less precise with a +/- 2 dB spread.

The goal is not to discard existing tools and expertise in the management of the (digital) loudness of movies, trailers and commercials. However, besides the LUFS loudness one could easily calculate an A-weighted loudness (with – 3 dB correction for surround channels) in order to have very useful meta-data for cinema managers all over the world that are confronted by regulations imposing limits to the sound levels and/or that just want to avoid customers complaining about too loud sound levels.

During the discussion of the results, no digital loudness target is proposed. The creative process as such should not suffer (too much) from any sound pressure level control when using all available tools.

More research is necessary to include more movies and cinemas in the datasets. Also, the dynamics should be further considered. Other loudness metrics exists also: short-term (3 s), momentary (400 ms) loudness and TPL: true peak level analysis. Further investigations of the relations between the first two and $L_{Aeq,1sec,max}$ sound levels, and between TPL and $L_{C,peak}$ sound levels are recommendable.

For the same reason as above, no limit for the LRA loudness range (dynamic) is proposed. Keeping in mind that many cinema visitors do not like very high sound levels at all (besides potential hearing damage) and the fact that (other) legal initiatives may be imposed, the industry can only benefit of further data-collection and the development of new tools with an open mind. This will enable the whole sector to make their own proposals for the necessary sound level management in cinemas.

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