CINEMA SOUND AND THE LOUDNESS ISSUE: ITS ORIGINS AND IMPLICATIONS

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1 INTRODUCTION

For over five decades after the introduction of 'talking movies', the soundtracks of films were recorded in various types of analogue forms, such as variable-area optical film, variable-density optical film and magnetically-coated film. From the 1920s to the early 1970s, the background noise (hiss) inherent in the recording processes limited the level to which the sound could be amplified before the noise became unpleasant and annoying. The cinemas, themselves, were often made from converted theatres, whose acoustics were designed more for reinforcing the voices of live actors, rather than for sound reproduction via loudspeakers. However, these limitations were usually taken into account by the film directors and sound mixers, who kept the soundtracks relatively simple. Actors also tended to deliver their dialogue with a semi-theatrical projection, and in most cases spoke clearly. Accompanying music and effects were usually interspersed with the dialogue, so each occurred in its own time.

Ever conscious of the need for the cinema audiences to follow the plots, soundtracks were almost universally mixed in theatres which were of reasonably similar size to the cinemas, and with similar amplifiers and loudspeakers. In this way, the mixers could hear during the post-production process a sound which was a reasonable representation of how the public would hear it in the less-than-optimal conditions of most cinemas. Various forms of standardised, high-frequency equalisation were also introduced, to aid in establishing a good balance between the capabilities of the loudspeaker systems, the noise from the recording media, and the intelligibility of the sounds. Nevertheless, other than for limited release formats in premier cinemas with expensive sound reproduction equipment, the general level of sound in the average cinemas was little more than 'adequate'.

Responding to this problem, in the early 1970s, Dolby Laboratories introduced their A-type noise-reduction to cinema soundtracks, along with Dolby Stereo. The latter was a '4-2-4' phase-matrixed system, allowing four channels of sound reproduction which could wrap around the audience, although without the accompanying noise-reduction system the noise level would have been unacceptable. In the 1980s Dolby improved the situation still further with the introduction of Dolby SR noise-reduction, but the system was still limited to the four, matrixed channels because there was no more room on a 35 mm film to add more tracks. The answer to delivering more channels in a compact form seemed to lie in the use of digital soundtracks.

2 THE ADVENT OF DIGITAL RECORDING

When digital audio recording was introduced into the music recording industry in the 1970s, there was a widespread reluctance to change from the well-established recording practices of the day. Despite there being some very different aspects between the optimisation of digital and analogue recording techniques, the equipment manufacturers did all they could to develop digital tape recorders in a way that they operationally resembled the professional analogue recorders. It seemed to be the only way to get the industry to accept digital recording, but it led to a lot of confusion because the reasons for many practices in analogue recording were not relevant to

digital. Optimising for analogue would not be optimal for digital, and vice versa, so there could be no direct substitution if the best results were required.

An important aspect of analogue recording was '*headroom*'. Electro-magnetic and electro-mechanico-acoustic devices (such as loudspeakers), as well as valve (tube) electronics to some degree, tend to have a reasonably linear range of operation before the input/output ratio begins to diverge from a straight line. Once at the top of this range, the input/output plot enters a 'knee', where distortion gradually increases, before hitting a hard overload-level. At this point, the output can increase no further, so any increase in the input level leads to gross distortion. The straight, 'linear' part of the line usually defined the normal operating range of the equipment, with the acceptable background noise setting the lower limit and the deviation from linear setting the upper limit. The 'maximum operating level' was usually indicated on signal-level meters, calibrated in a way which would clearly indicate to the recording engineers the optimum dynamic range for making the best recordings. The meters could take the form of VU (Volume Units) meters, or PPMs (Peak Programme Meters), although for the latter of which there were numerous standards (see Figure 1). Each of these metering devices required different interpretations by the recording engineers, because they each had their strengths and weaknesses. In addition, they also related differently to different instruments and genres of music.

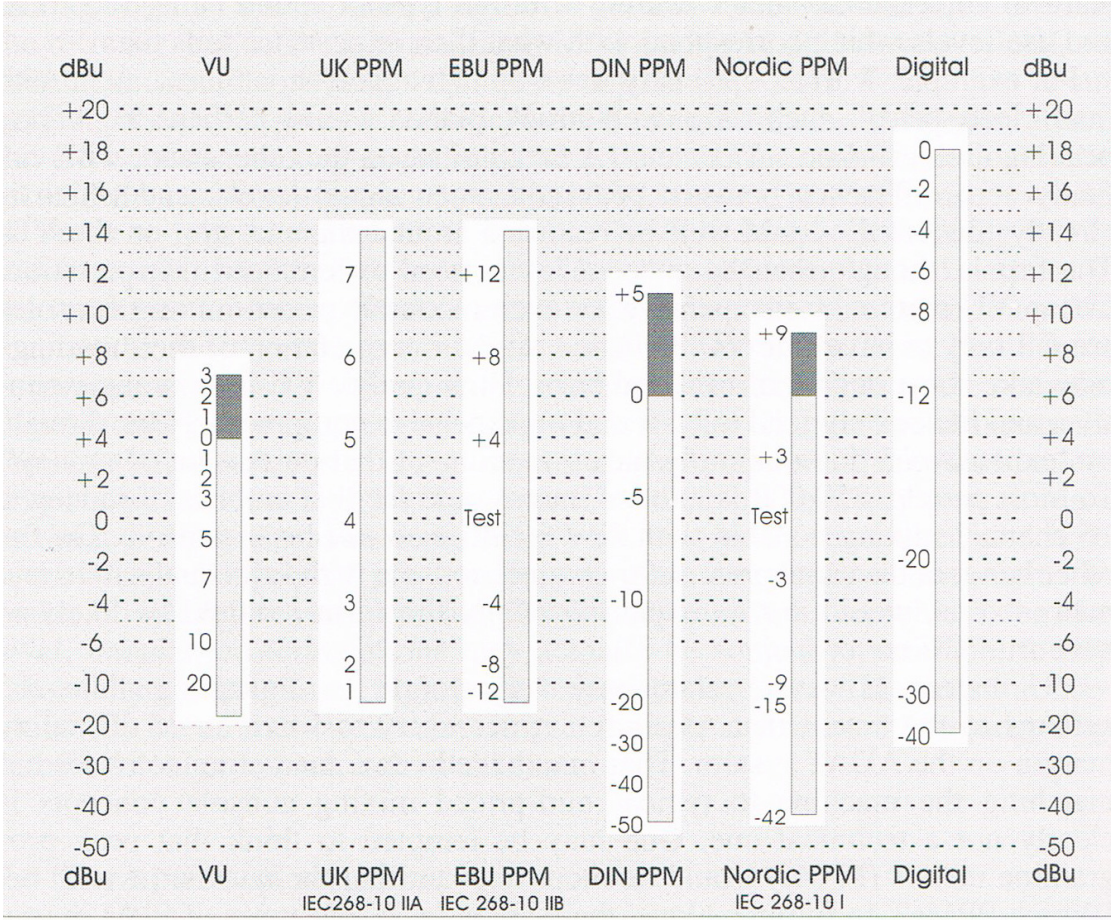

Figure 1 – Audio-level scale differences. Some commonly-used but widely varying meter scales. Note the non-linearity of the lower levels of the scales. The numbers shown on some of the scales indicate the general intervals, but not necessarily the precise intervals defined by the relevant Standards. The nominal digital level was set to a -18 dB FS reference, which was used widely in the 1990s. (After Peter M. Harrison)

When using VU meters, some instruments could be allowed to visually go beyond the operating level without sonic degradation, such as electric guitars, but others could not, such as classical pianos. In fact, in the latter case, the meters would often under-read, so the engineers had to allow for this when interpreting the meter readings. With PPMs, if some instruments were *only* recorded without passing the operating levels they could be under-recorded and suffer from tape noise. No individual meter truly related to the capabilities of the recording media for all types of recorded sounds, so it was very much a part of the job of the recording engineers to know how to relate the meter readings to the instruments and the music. Furthermore, different brands of tape could respond very differently to overloads; as could the tape recorders and loudspeaker systems. The 'headroom' margin that needed to be allowed for, above the standard operating level, was therefore different in different situations, but it allowed some transients to be recorded without noticeable distortion at levels which would suffer gross distortion if sustained sound were recorded at the same levels. This is somewhat akin to the way that loudspeakers can be rated for continuous or peak input levels.

Understanding the headroom was an integral part of analogue recording, but as recording personnel became more familiar with using digital tape recorders, they began to realise that there was no concept of headroom in digital systems. The recording system was linear up to the abrupt onset of overload, known as 0 dB Full Scale (FS). What was more, the metering was absolute. That is to say, if an overload was not indicated, the recording would be fine, irrespective of what type of instrument or what type of music. Tape compression was also non-existent, so overdriving the tape for a characteristic sound was no longer possible because levels could not be manipulated for effect.

For some time, the analogue mixing consoles and the digital tape recorders were unhappy partners. Using the digital metering of the tape recorder to set the peak recording levels usually left the mixing console VU meters pinned to their end stops, thus rendering them useless. In fact, there was no way to make either VU meters or PPMs correlate accurately to digital signal levels, because the slightest overload of the digital system would introduce severe distortion. In addition, with the higher peaks that could come back off digital tape, even some mixing console tape-returns were being stressed when receiving signals 20 dB over their standard levels if the digital recorders were traditionally aligned. It took about 15 years for the industry to make the comprehensive change to digital recording without it being tied to a rather compromised compatibility with the analogue era.

3 DIGITAL SOUND IN THE CINEMA

In the world of cinema, the standards developed for analogue soundtracks were still totally dominant when the first digital soundtracks were introduced in the early 1990s. Whereas in the music world, digital was largely introduced as a step upwards in sound quality, in the cinema world it primarily offered more channels, more positioning flexibility and less noise than the older analogue formats (although Dolby SR sound was very quiet). Greater dynamic range was an added bonus! Nevertheless, as had originally occurred in the music studios, the new digital systems were required to fit into the old analogue theatres with a minimum of upheaval. At that time, it would have been commercially impossible to switch to digital sound tracks if they had required that all cinema theatres should change all their projectors and loudspeaker systems. The digital soundtracks were either squeezed into whatever physical space remained on a 35 mm film (such as between the sprocket holes for Dolby Digital), or a soundtrack on an external CD-ROM (such as with DTS) was locked to a synchronisation track (see Figure 2).

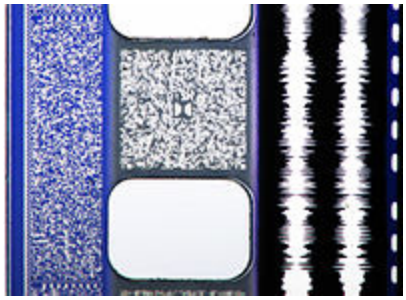

Figure 2 - Audio soundtrack physical distribution on a 35 mm film print (the image frames would be to the right of the diagram). The SDDS (Sony Dynamic Digital Sound) track is the blue area to the left of the sprocket holes (also on other edge). The Dolby Digital data is located in the grey area between the sprocket holes, and labelled with the Dolby "Double-D" logo in the middle. The analogue, optical soundtrack is the two white lines to the right of the sprocket holes, and the DTS time code is the dashed line to the far right. [Image taken from Wikipedia.]

For the first two decades of digital soundtracks, the industry was bound to 35 mm optical film because there was still not the digital storage or transmission capacity available for full-length feature films in 35 mm image definition. Fully-digital distribution and projection for cinemas did not become possible till around 2010. However, it is perhaps important, here, to add some further explanations as to why the digital levels remained under greater control until the 35mm optical prints ceased to be the dominant form of distribution.

One of the most important limiting factors on early Dolby Digital levels was the lack of long-term reliability of the digital soundtracks printed on 35mm positives. It was not uncommon for the digital-reader-heads installed in cinemas, worldwide, to 'lose' their capacity to read the digital soundtrack, due to either excessive print wear and/or reader misalignment. As the continuity of the show was of great importance for the audience, a simple mechanism was developed to allow a switching system to revert to the analogue, optical, Dolby SR soundtrack if, at any time, the digital track could not be read and/or sufficiently buffered. As this switching (or '*reversion*', as it was called by Dolby) should ideally not be noticed by the audience as an abrupt change, the levels on both the analogue and digital tracks had to be carefully matched. However, it should be noted that the reversion from digital to optical-analogue, although preserving the average levels, was not exactly imperceptible. The optical soundtrack was of a four-channel, matrix-derived nature, without LFE channel, whereas the digital soundtrack had five, discrete channels plus the LFE. The digital soundtrack was also not subjected to the hard limiting. Nevertheless, the aim was to make any necessary transition as smooth as possible.

In practice, these levels were significantly limited by the behaviour of the optical film recorders, as their light-valves could be damaged or destroyed if fed with high level signals (especially in the HF range) for more than 20-30ms. The manufacturers therefore put a hard clipper into the signal path, cutting everything a few decibels above the 100% modulation level. Physically, on 35mm film, there was space for almost 140% modulation on both tracks simultaneously, so the clipper was usually set at 130%. If the dialogue was mixed at higher levels than that which was considered normal, it would leave no additional 'headroom' for important, louder sounds, such as thunder, gunshots, punches, or crashes, so it was necessary to mix the dialogue in a way which would leave enough in reserve for the artistically-necessary, louder moments.

The reference level was set such that -20 dB FS for digital corresponded to 50% modulation for analogue. One-hundred percent modulation would therefore be -14 dB FS, and on exceptionally good-quality analogue recorders only, the peak level could perhaps reach an equivalent of -8 dB FS (digital level) before being chopped off by the built-in safety clipper. As previously mentioned, for compatibility, these levels had to be respected on both the analogue and digital tracks to ensure the step-free switching, but there was still a difference between analogue and digital in terms of the 8

dB of 'extra' headroom, between the -8 dB FS clipping level of the analogue system and 0 dB FS in the digital domain. In general, the 'undistorted' digital headroom, which could only be reserved for transients in the analogue domain (for several dBs *below* the clipping level), led to the digital soundtracks sounding more 'transparent', 'open' and dynamic. However, once the distribution of films switched to fully-digital, and the level limitations applying to the analogue tracks were removed from the process, not only the analogue headroom margin but also the extra 8 dBs were quickly filled with programme. Perhaps this, more than anything else, is why the master faders in cinemas can now frequently be seen at Dolby 4.5, effectively reducing the output by the 8 dB that digital distribution has unlocked.

The reason for setting the digital reference level around -20 dB FS, whereby the analogue hard limited at 8 dB less than the digital maximum of 0 dB FS, probably dates back to the customary 20 dB of headroom, above the nominal 0 VU reference level for analogue tape, that was provided in the professional analogue electronic devices. Even with the compression due to the tape itself, the peak levels for transient signals *coming back from* the tape could still exceed 10 dB over reference level. In addition, rapid peaks of around 16 dB over the calibrated 0 VU metering (and which would *not be seen* on the VU meters) could actually be *sent* to the tape recorders. It was therefore important that the electronics of the mixing consoles and tape recorders should not clip before reaching this level, so at least 20 dB of headroom was usually provided above the standard operating level. It followed that, for reasons of direct interchangeability of analogue and digital tape recorders, a digital reference level with the same 20 dB of headroom provided a good match because the digital recorders then clipped at about the same level that the *electronics* of many mixing consoles and analogue tape recorders would clip.

When the first digital tape recorders began to enter the professional music-recording studios, in the late 1970s, many of the mixing consoles were still equipped with VU meters, and the studio staff treated the digital machines just like the analogue machines (which needed a good 16 dB of headroom when working with VU meters). In fact, in the early 1980s, CDs typically peaked around -12 dB FS. Had this not been the case, and as the CD players usually had no volume controls, their outputs would have overloaded the inputs to the pre-amplifiers of many of the domestic hi-fi systems that did not have professional headroom margins.

Almost all of the early digital-audio equipment was effectively forced to fit into the then-current, standard, *analogue* practices because the digital devices would not have been readily accepted in a world which was still very sceptical of its possibilities. Few people, at that time, could even *envisage* an all-digital recording studio. Digital was often seen as an alien invader into the analogue world of 1970's audio.

In hindsight, it could be said that if the early digital formats for cinema sound had chosen -12 dB FS as the reference level (as with CDs) or even -16 dB FS (matching the very best analogue recorders, it would have limited the extent of the loudness wars, but the -20 dB level was basically a result of the hardware that was originally chosen. It follows from this that, as the 0 dB FS was not expected to be reached on any recording, neither did anybody initially foresee that the loudspeakers would have to deal with maximum levels of 105 dBC at the reference positions. Consequently, as many of the loudspeaker systems still installed in cinemas are built to analogue era specifications, they were never intended to handle the levels which are currently delivered to them from modern, digital soundtracks if calibrated at standard level.

3.1 Dynamic consequences

Just as with analogue music recording, analogue film soundtracks employed the concept of headroom, which allowed a margin above the nominal, maximum recording level for the passage of short duration peaks. Although the average sound levels of digital soundtracks were not originally intended to be much different from those of the then-current analogue mixes, the new, Low-Frequency Effect (LFE) channel, with its own loudspeaker system, was added to the digital formats to reinforce the low frequencies of sounds such as explosions. [The LFE channel is the '.1' channel

of so-called '5.1', with its bandwidth restricted to low frequencies.] Nevertheless, the dynamic range of the digital recordings, running parallel to that of the analogue recordings on the same film prints, was not subject to the progressively-increasing distortion as the 'reference' level was surpassed. Loudspeakers permitting, things *could* be recorded on the digital tracks much louder than before. For the first time, rock bands in the soundtracks could play almost at concert levels, and battle scenes could be almost war-like. Many directors gradually began to exploit this historical 'headroom' margin for longer-duration sounds, and the recorded levels crept upwards.

The first phase of the so-called 'Loudness Wars' in cinema was initially marked only by an increase in soundtrack *dynamics*. For quite some time, the dialogue was still being mixed at the older, conservative levels, but the action scenes soon became louder than before. The next phase was when producers, directors and engineers realised that *all the levels* could be pushed higher in the digital domain, and analogue compatibility began to be increasingly ignored. It was at this time when it began to become necessary for many cinemas to lower their playback levels, not only to avoid equipment overload and/or damage, but also because some members of the audiences began to complain about the soundtracks being too loud. By this time, the average levels were no longer being consistently referred back to the 85 dBC for 50% modulation rule. Analogue had disappeared much faster than expected, and many of the unregulated level-changes took the industry by surprise.

In less than a space of five years, dubbing theatres went from requiring a 35 mm projector for their certification by Dolby, (along with all of the attendant level-mastering processes), to being totally digital, and sending out almost all the soundtracks in DCP format. The less-constrained productions began to overtake the analogue-compatible alignment levels at a considerable speed. As a result of these higher levels, many studios were effectively forced to lower their monitoring levels by 3 to 6 dB, simply because it was impossible for the mixing personnel to work at the higher levels, full time, without either suffering from fatigue or risking hearing damage. In fact, there had been a tendency for mixing personnel to work with ear protection during repeated passes through the louder passages, ever since the early days of digital soundtracks.

Even during the 1990s, 'Digital Sound' had become almost synonymous with 'digital impact', which led many directors to seek even more impact. Some dubbing theatres up-rated their loudspeaker systems to take this into account, as did a few cinemas, but it was in no way obligatory for them to do so. As a result, the higher levels, when played in cinemas that were barely capable of handling anything beyond the usual analogue levels it often led to unpleasant distortion in the louder passages. This distortion led to the annoyance of many clients, who claimed that the sound was 'too loud'. In response, cinema operators frequently reduced the playback level from the 'standard' Dolby 7 down to 6,... 5,... or even 4.5, which is close to 8 dB lower. [The Dolby numbers refer to the position of the level-calibration knob on the Dolby cinema processors, which have effectively been an industry standard reference for decades. At Dolby 7, each channel is calibrated to a sound pressure level of 85 dBC (although all the surrounds may be treated as one channel) at a standard reference position, usually about two-thirds of the way from the screen to the back wall. Digital soundtracks have a margin of about 20 dB above this calibration level, which corresponds to an SPL of 105 dBC.)

The problem with reducing the level in this way was that the dialogue at the lower levels could frequently become too quiet to be understood when reproduced below the level at which it was mixed, so the plots of the films were sometimes lost. Cinemas, of course, unlike theatres and music concerts, do not have sound operators in the rooms to raise or lower the individual levels in accordance with the needs, so soundtrack calibration levels need to be set in a 'one-level-fits-all' manner. There can often be a fine line between too high and too low if the music and effects clash with mumbled dialogue (as '*cool*' fashion sometimes dictates). Nevertheless, despite the complications, if reducing the playback levels led to the overall number of complaints being reduced, this was often the chosen option because it was an important matter for the cinema operators. Complaining customers are not good for business. Unfortunately, after the levels had been turned down for the louder films, they were often not returned to the normal levels for the

subsequent films, which was partly due to the cinema managers taking a cautious approach so as not to risk inviting complaints.

Realising that this situation was becoming relatively widespread, some film directors began asking the re-recording mixers to raise the average recorded levels of their soundtracks. As a result of this, the distortion suffered in the normally-calibrated cinemas with only marginally-rated loudspeaker systems became even more widespread, because the gradually increasing levels began to affect a greater number of cinemas. So; as more cinemas turned down the playback levels, more level often began to be added at the mixing stage, and a circular loudness war resulted. A survey done within an SMPTE Technology Committee in 2013 indicated that, even in the USA, more cinemas were typically using 'Dolby 5' as a standard level than the recommended level of 7; the difference being about 6 dB.

This situation could not have occurred in the days of analogue, because the analogue recording media themselves would have begun to show signs of inherent distortion, audible on *whatever* size of loudspeaker systems. Up until that point, the problem had been self-limiting, because the directors would have heard the distortion in the mixes; even if the playback level was turned down. The analogue headroom allowed the odd peaks to pass, such as gunshots, but extended battle scenes could never have been mixed at the ear-shattering levels that became possible with digital soundtracks unless a whole new standard for level calibration had been introduced; which would have been very unlikely.

Despite the fact that Dolby provided professional mastering services (which were obligatory for any films which required the use of the patented Dolby Digital technology), and tried as best they could to hold the levels down, the elevation of soundtrack levels nonetheless became evident very early in the digital era. The film *Jurassic Park* shocked many people with its dynamic range when it was released in 1993. Early versions of the film also proved difficult to listen to on domestic televisions, at least without the continual adjustment of the playback volume controls. The tendency was for the sound to overload the loudspeakers in the louder parts, but if turned down it would render some of the quieter dialogue unintelligible. While it is true that cinema mixes are not generally made with television audiences in mind, the switch to multichannel digital mixing, with its wider dynamic range, made the incompatibility more noticeable. It was the same, wider dynamic-range that was also taxing many cinema systems.

4 DIGITAL CINEMA AND LEVEL INCOMPATIBILITY

For forty years, the general specifications and standards for cinema sound systems had largely remained unchanged since the mid 1970s; other than for some small extensions of bandwidth.[1, 2] Frequent attempts had been made by different organisations to try to stem the trend of increasing levels, so that existing systems would remain compatible with digital mixes, but many directors saw the increased dynamic range that was offered by the digital systems to be within their legitimate scope of artistic freedom. After about 2012, when linear-PCM digital-cinema was introduced, the whole process of soundtrack mixing became open to anyone who could afford the equipment to put a studio together, because no licences or patents applied to the linear process. No approval was required from any, outside, commercial organisation. Getting 6 or 8 digital soundtracks on to 35 mm film had required patented audio coding to compress the audio data sufficiently to fit into the available, physical space, but with fully digital projection and no data compression, no such limitations existed. As a result, much of the tight control of the mastering process became a thing of the past. Mainstream, commercial mixing was no longer the privilege of those who could afford expensive projectors and proprietary processors. The tiger of unregulated mixing was let loose!

In recent years, a growing number of dubbing theatres producing cinema soundtracks have not respected the industry-standard calibration levels and have lowered their monitoring levels to mix 'louder'(perhaps more notably in Europe). This has been partly in response to it becoming more common for cinemas to lower their calibrated levels between around 3 and 8 dB below standard

levels However, this type of practice leads to tail-chasing. If a soundtrack is mixed to sound loud in a dubbing theatre calibrated at a lower-than-normal level, it will probably be excessively loud if played back in cinemas calibrated at the standard level (which for a nominal signal at -20 dB results in an acoustic level of 85 dBC at the calibration position). On the other hand, a soundtrack mixed to sound 'normal' in a dubbing theatre calibrated to Dolby fader 7 may suffer from significantly reduced dialogue intelligibility in cinemas which are calibrated to a level of Dolby 5. Granted, soundtracks mixed loud at Dolby 7 may *only* be able to play back at 5 in many cinemas for reasons of system overloads (as well as complaints from the patrons), but without uniform calibration in the mixing environments, it leads to guesswork and the likelihood of unintended level problems in the cinemas due to wrong guesses being made.

Some directors insist on mixing at 5 because they know that many cinemas will be set at 5, and they still want their soundtracks to play back loud, but they fail to appreciate that many cinemas are set at 5 because they simply *cannot* play at a higher level. A soundtrack which still sounds 'too loud' at 5 may result in the playback level then being reduced to 4, which is an absurd situation.

There is little doubt that digital cinema was introduced without a satisfactory review of the capability of the installed loudspeaker systems to deal with the newer soundtracks, which have unquestionably been mixed at higher levels than would have been the case 25 years earlier. This is despite the fact that 25-year-old equipment is still to be found in regular use in very many cinemas. It is now becoming apparent that this situation cannot be allowed to continue if the industry is not to suffer from legislation which may be brought into force in many countries, states and cities, in response to complaints from the public and the press about the perceived excessive loudness of many films.

Despite the undesirable lack of uniformity of calibration, it seems that, for cinema operators, there is less likelihood of complaints about loss of intelligibility at lower playback levels than about the excessive loudness if the standard levels are maintained. Furthermore, they do not want the risk of fines for breaching local regulations. Playback level therefore becomes a business issue, rather than an artistic one, but insufficient work has been done in the search for answers as to what it is that actually provokes the complaints about the loudness. Had there been no complaints, it is more likely that there would have been no pressure for legislation.

5 WHAT IS 'TOO LOUD'?

Loudness and sound-pressure level (SPL) are not always related in any clearly defined way, although to the general public the terms can often be interchangeable, such that 'louder' means 'more decibels'. The reality, however, is very different. There was the classic case in the 1960s, when Ampex introduced a new model of tape recorder with significantly quieter noise figures, yet recording engineers almost universally considered the new machines to be noisier. A quieter, 'B' model of the new machine soon followed. So, when audiences complain about soundtracks being too loud, is it the absolute sound pressure level that they are referring to, or could it be the distortion from the overdriven loudspeaker systems which are reproducing digital soundtracks after having only been specified for the previous, analogue requirements? In some individual cities, regions, states and even countries, pressure from activists has resulted in legislation to limit the SPLs of cinema playback, but is this really addressing the correct problem? Legislation would be acceptable if it was solely intended to safeguard ears, but if *distortion* is the culprit, the simple annoyance which results should be of no concern to health authorities. It would be a travesty if legislation, which is often to all intents and purpose irreversible, were to be introduced based simply on the 'noise at work' regulations which, whilst easily available to the politicians, are *totally* inappropriate for the artistic presentation of an entertainment event. Indeed, it would be a tragedy if legal controls were unnecessarily imposed for erroneous reasons, yet this does appear to be happening.

So far, no reliable evidence has been presented by any competent authority which indicates that visiting the cinema, as a recreational event, can in any way damage the hearing of a normal human

being. It can also be shown that the noise exposure levels, even during loud, 'action' films, is considerably less than can occur at entertainment events such as football matches and motor-racing events of similar duration, yet there is no call to restrict public noise-exposure at such gatherings. The question must therefore be asked; 'Why cinema?' Why is cinema coming under such close scrutiny? The answer may well be that it has largely been ignoring the realities 'on the ground', and the industry has done virtually nothing to address the complaints at any 'institutional' level.

Recent examination of the situation has revealed that, in properly specified, maintained and calibrated cinemas, the occurrence of complaints about the volume level is relatively low. The root of the problem seems to lie in the fact that little has been done in the past 25 years to bring the analogue-era loudspeaker systems into the digital age. Distortion is now rife, and many complaints about soundtracks being too loud would often seem to be, in reality, more about them being too *distorted*. A vicious circle now seems to have developed whereby inadequate systems are leading to lower sound levels, less excitement and falling attendances, which is being countered by mixing soundtracks louder and leading to more cinemas lowering their calibration levels. The continued complaints are leading to potential and real legislation to control the sound levels by law, yet the sound levels, *per se*, may often really not the problem. This ill-defined situation discourages the cinema owners from investing in the better equipment that could largely solve the majority of the problems, but by *not* investing they run the risk of exacerbating the situation, which needs urgent attention if the cinema industry is to remain healthy.

Confusion and uncertainty are leading to *ad hoc* solutions which may be very specific to circumstances, whereas what the industry actually needs are clear explanations and guidelines which can restore common practices and give the confidence to all concerned which will allow them to make investments which they can be assured will not be in vain. There is little doubt that uncertainty and business interests have been involved in the lack of response to the loudness issue. It is also true that a degree of artistic intransigence has existed in the creation of the soundtracks, but what has been conspicuous by its absence is a comprehensive approach to the problem.

6 THE OBSTACLES TO PROGRESS

It is true to say that cinema owners were never adequately advised about the probable requirements for the screening of digital soundtracks. As mentioned in Section 3.1, the headroom margin to allow for the electro-magnetic limitations of analogue recording became available for more than just the occasional peak in digital recording, but this was not something that was either promoted or warned against the use of. The door was simply left open, and some people wandered through it; into the unknown. Quite incredibly, the majority of standards for cinema calibration have never defined any performance requirements at maximum recorded level. What is more, no adequate counterpart of the old, analogue test films have been made generally available for modern, all-digital cinema. Consequently, cinemas had few opportunities to check that their loudspeaker systems were capable of dealing with the growing demands of digital sound. If they rattled and produced flatulent sounds, it was sometimes taken as a cue to reduce the overall level, but inappropriate equalisation during calibration could also provoke these effects, so it was unclear if the calibration level, *per se*, was to blame.

There was no clear indication to the cinema owners to suggest to them that they might need to invest in a new loudspeaker system if they wished to take full advantage of the dynamic range of the digital sound. Few owners would commit to spending £50,000 on a new loudspeaker system if there was nothing to clearly state that the existing one was inadequate. Lack of guidance was therefore an obstacle to improvement, but the failure to make improvements often led to either reduced playback levels or unpleasant distortion; not to mention component failure. As has already been discussed, reduced level could lead to reduced intelligibility of quiet dialogue, but increased distortion could lead to increased complaints about being too loud. Neither was a good solution, but

cinema owners and operators were left in a limbo of ignorance due to a lack of credible guidance. And neither were subjective nor objective distortion assessments at maximum SPL ever a part of cinema calibration standards.

In recent years, commercial cinema theatres have suffered from falling attendances due to economic downturns and the availability of films for home viewing. Profit margins have been cut, so investment in new equipment has not been an easy decision to make in uncertain circumstances. Technically and artistically, it may be easy to visualise the increased satisfaction of the audiences which could result from better specified, better installed and better calibrated loudspeaker systems, but it has not been easy for the cinema owners to see how any such investments could be recouped from increased takings at the box-office, and the *production* side of the industry (the film studios) have done little to encourage the cinemas to make changes.

The investments of, and the competitions between, the major film studios have become multi-faceted. The film-production side of the industry has been reluctant to interfere in the exhibition side. Even when the majority of films used the patented and licenced soundtrack formats, the owners of the patents could only advise the cinemas about recommended playback conditions. It was neither legally possible nor commercially acceptable to *impose* any electroacoustic standards, so market forces were relied upon to encourage the cinema owners to ensure adequate sound quality, with the implication that the better-sounding cinemas would attract the bigger audiences. However, as the number of competing cinemas in any single town dwindled, such market forces reduced in intensity. Survival became a more important concern, and worn-out equipment became less likely to be replaced. However poor it may be, the *only* cinema in town is still *the best* cinema in town. The financial concerns of the cinema owners are therefore a definite obstacle to the improvement of cinema loudspeaker systems on a widespread basis.

So; despite the advent of the many, more-demanding, digital soundtracks, a very large number of cinemas continue to use loudspeaker systems which were developed from the analogue-era requirements. One solution to the problem would have been for film directors to use self-restraint and make soundtracks which still respected the old norms of peak loudness and average levels, but it was often seen as the directors' prerogative to take full advantage of the technical freedoms that digital recording offered to the creative process. In fairness, however, the financial success or failure of a film can depend very much on the reaction of the press to the first public screenings. As the 'Premiers' usually take place in premium cinemas, with good loudspeaker systems, few producers would be happy with their chosen directors if the impact of a film was considered to be weaker than a competing film from a rival studio. As a consequence, there is pressure on directors to have a soundtrack mixed for maximum impact at the premier, rather than for maximum compatibility with the equipment of average cinema theatres. This pressure is unlikely to go away, because the initial reaction of the press will follow through into sales of DVDs, Blu-rays or Internet streaming. Rattling loudspeakers in many cinemas is not of prime concern to the production team. Once again, profitability concerns are an obstacle in terms of seeking greater cooperation from the film producers, and asking them to give more consideration to the problems of screenings in average, commercial theatres.

It is worth emphasising the fact that producers, distributors and exhibitors are completely different entities, and they tend to each protect their own financial interests. If, tomorrow, a distributor decides to release films through the Internet only, there is nothing that an exhibitor can do about it. Likewise, if an exhibitor decides to stop showing films, and to begin screening live football matches in their theatres, there is nothing that producers and distributors can do about it. At this moment, these three entities coexist in a very unstable relationship. So; although it would be desirable for close cooperation to exist, more concern from the producers about the plight of the cinemas is not really to be expected because they operate in different markets. It could even be said that, in many cases, each is looking for an opportunity to get rid of the other two, in order to control more of the potential earnings. Such is the commercial reality.

So, to sum up some of the main realities that we currently seem to be dealing with:-

1) Many cinemas do not have equipment that can properly reproduce 'blockbuster' soundtracks at Dolby (fader) 7.

2) Many cinemas could not reproduce a flat response to 10 kHz.

3) Of the cinemas mentioned in 2, above, some *could* reproduce a flat response if calibrated at Dolby 5 or thereabouts.

4) Despite the inconsistencies and shortcomings, many cinema owners and operators do not want to invest money in new loudspeaker systems.

5) There is a good possibility that many of the complaints about excessive loudness are, in fact, complaints about excessive distortion.

6) Potential driver-failure and distortion are likely to be as much responsible for cinema operators lowering the playback levels as complaints from the public.

The lack of confidence in the long-term viability of cinemas is a disincentive for theatre owners to make significant investments in better loudspeaker systems. Direct delivery of films to people's homes is a significant threat to cinema attendances. Despite the fact that improved loudspeaker systems could allow big improvements to the quality of soundtrack enjoyment, the degree to which it would boost a cinema's profits is an unknowable risk factor, and businesses tend to be conservative in unstable financial circumstances. Nevertheless, from the point of view of the film producers, the competitive pressures on the film production companies places a great emphasis on the sound of a film *at its premier*, rather than its compatibility with average cinemas.

In general, the film production stages create the mixes in rooms calibrated at Dolby level 7 (where, in each screen channel, about -20 dB FS results in an SPL of 85 dBC at the reference position), and they put great effort into installing and maintaining loudspeaker systems which can perform optimally at that level. Some cinemas also do this, but not all of them have loudspeakers which can handle this level of calibration. However, content providers still try to insist that the cinemas should be set up exactly the same as the dubbing theatres, or the artistic control over the whole experience will be lost.

The content-creation side of the industry will probably not currently endorse any lower playback levels if they are simply due to the fact that many cinemas fail to meet what has been a long-established standard. Neither will they take into account the facts that many cinemas avoid proper maintenance regimes, and may use improperly chosen and poorly installed systems. Nevertheless, this is the reality of cinemas today, but in those circumstances they cannot expect the highest playback quality. In the final analysis, if the cinemas turn down the playback levels, then that is their choice, but catering to the lowest common denominator is not what the content-creators wish to consider, so we have something of an impasse, here. It should be pointed out, though, that as was mentioned at the end of Section 3, it is arguable that the established standards (to which the levels are still set) never truly anticipated that SPLs of 105 dBC per channel would be a practical necessity.

7 THE SOLUTIONS

The question therefore arises as to how the industry can tackle the question of so many cinemas still playing modern, digital soundtracks on systems which were only designed around performance standards for the analogue era? Given all of the above-mentioned obstacles in the way of getting better cooperation between the various interests within the film industry (at least in terms of mixing levels and calibrated SPLs), it would appear that the most practicable answer lies in improved sonic

quality, and not in precise loudness level. Better equipment, better installation and better calibration practices (preferably combined; but even in isolation), can make significant differences to the perceived quality, intelligibility and impact of a soundtrack, even at lower SPLs.

In the March 2016 edition of the AES Journal, there were some interesting papers on loudness. The final paper concluded that for the overall assessment of *pleasantness*, the fidelity was far more significant than the level. It suggested that people can tolerate a considerable range of levels as long as the 'naturalness' and 'fidelity' are good.[3] This finding agrees quite well with what many people in the cinema industry have been suggesting for a long time, which is that much of the level 'problem' in cinemas could well be related to many of the loudspeaker systems distorting prematurely. The consequent lack of fidelity has a very negative effect on pleasantness, and unpleasant sound is perceived by many people to be too loud.

Without always being able to lucidly explain the reasons for their discomfort, cinema-goers may complain about the loudness because they cannot express their discomfort in any other way. However, this situation is provoking all sorts of political nonsense, where authorities feel that they must react to the public [i.e. voters'] complaints, and must be seen to be doing something about them. In a growing number of places, the powers that be are trying to introduce legislation to limit the SPLs in the cinemas. However, this may only be treating a symptom, and not dealing with the root of the problem. As a more effective solution, lower perceived distortion and a smoother spectral response, can not only make great improvements to the intelligibility of dialogue and overall pleasantness, but can also reduce the tendency for soundtracks to sound excessively loud, *even at higher SPLs*. SPL and loudness are most definitely *not* the same thing.

There is therefore an urgent need to reassess the general specifications for cinema loudspeaker systems, and the most important factors to address would seem to be:-

1) Use loudspeaker systems which can adequately deal with modern, digital soundtracks and deliver average levels of 90 dBC, with repeated, 'long' peak levels of 105 dBC, to the calibration-reference location. These SPLs should be achievable without significant thermal compression or the perception of any unpleasant distortion. Although it is notoriously difficult to specify precise figures for harmonic distortion which relate to unpleasantness thresholds, guidelines need to be published which will allow the assessment of adequate sound quality at required SPLs.

2) Use loudspeakers with adequate directivity, which can cover the large majority of the audience within reasonable, pre-specified limits. The specification should be venue-coverage related, not simply loudspeaker-directivity related.

3) Install the loudspeaker systems in a way which actually permits them to cover the target areas. Unfortunately, there are a great number of loudspeakers which are mounted in cinemas with scant regard to the ideal coverage of the audience. The mis-orientation can be due to various reasons, including the inexperience or lack of authority of the installers, and the adherence to misleading recommendations relating to the positioning of the horns with respect to the screens.[4]

4) Calibrate the loudspeaker systems in a way which ensures the temporal and spectral integrity of the direct sound from each loudspeaker system *after passing through the screen*, because if the sound is not of high fidelity at its source, it cannot be expected to achieve its maximum fidelity elsewhere.

5) Aim for a calibrated frequency-response which can convey to the audience a credible sound. This may mean allowing for a flatter HF response than is currently used in cinemas, so the loudspeaker specifications should allow for this.

6) Re-assess the whole LF generation issue. By using some bass management, redirecting the content below 50 Hz (for example) from the screen loudspeakers to the LFE

loudspeakers, a considerable amount of stress could be removed from the screen channels. This could facilitate the use of smaller loudspeakers with improved directivity characteristics.

Regarding point 5, above, as Toole has pointed out, in home-theatre, (as well as with hi-fi music systems) it has long been noted that as systems acquire deeper, smoother bass, the overall playback volume, as selected by the users, tends to go down. Bass is considered to be about 30% of a typical person's overall assessment of sound quality, but within the margins of the X-curve, there is a very wide tolerance at low frequencies, as shown in Figure 3. The response can be within +2 and -6 dB at 40 Hz, and still be within specification, but if the bass is deficient in a dubbing theatre it may be boosted by the mixer.[5] As the cinema measurements published by the SMPTE[6], Newell *et al*[7] and Holman[8] all indicate, in practice, people calibrating cinemas do often deviate from the X-curve target response by boosting the bass – simply because it sounds better! High-end home-theatres technicians routinely boost the bass during calibration[5], and recent work by Gedemer has also shown that blind, subjective evaluations favour programme spectra with more bass and only a gentle high frequency (HF) roll off, at the most.[9]

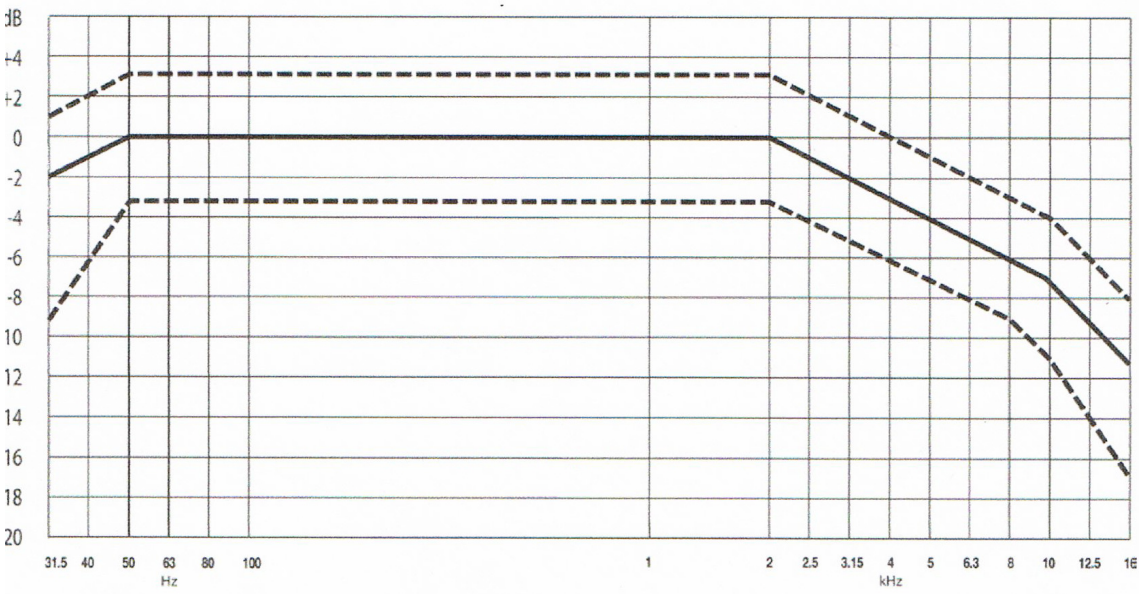

Figure 3 – The X-curve, as of 2010, defined in ST202:2010[2]. Note the LF extension to the 31.5 Hz band, and the wide margins of tolerance below 50 Hz

Despite this desire for a rich LF content, some theatre systems are calibrated with reduced LF, simply because they cannot deliver the optimal level without overload, especially down to the 31.5 Hz-band as defined in the 2010 version of ST202[2] (and shown in Figure 3). When operating at higher SPLs, even with the LF remaining within the allowable margins, they do not deliver a satisfactory result because insufficient LF can also result in a perception of unpleasant loudness, even at moderate SPLs. Somewhat counter-intuitively, increasing the LF can reduce the unpleasantness, even though the overall SPL actually rises. Once again, inadequate system capability can give rise to complaints about loudness which are contrary to the actual SPLs. If a slight bass rise were to be applied, the woofers would need to work harder, but, if the subjective effect of the extra bass was that of increased overall loudness, the overall levels could probably be reduced whilst maintaining the same sensation of overall loudness. Nevertheless, the technique is rarely applied because the standard methods of level calibration concentrate on the mid-band levels, even though these concepts were developed in an era when peak SPLs were generally lower, and have not been updated since the advent of Digital Cinema.

Currently, at the mid and high frequencies, the X-curve calls for a response that is largely flat until 2 kHz, above which there is a roll-off at high frequencies, as shown in Figure 3. In the authors' opinions, the knee in the response is not conducive to a subjectively natural sound. It can be a source of significant colouration, and it is being suggested in many circles that a gentler roll-off may be better in terms of both intelligibility and fidelity. Despite this, many people in the industry have expressed doubts that this could be achieved without over-stressing the high-frequency components of the loudspeaker systems, especially given the HF attenuation of the perforated screens through which many of them must radiate. However, given the spectral energy distribution of typical programme material, the overall burden on the compression driver might not be much different than now[10], but whenever systems are already operating close to breaking-point, no increase is likely to be tolerable without increased stress. Once again, the possibility of progress is being limited by the prevalence of inadequate loudspeaker systems.

In some ways, it may seem somewhat perverse that a means of ameliorating the loudness problem would be to use loudspeakers of *greater* output capability, but higher sound quality can not only allow higher SPLs without the perception of excessive loudness, it can also yield greater impact and intelligibility, even at reduced SPLs.

8 CONCLUSIONS

It currently appears that the cinema industry is facing several problems:-

1) Poor quality reproduction, where the theatres do not meet the requirements of many modern soundtracks. This can be due to inadequate equipment, incorrect setup or inappropriate alignment.

2) There is now a wide range of programme material, much of which does not respect traditional loudness recommendations; although it must be said that many previous guidelines have become somewhat 'lost' since analogue soundtracks disappeared.

3) It also needs to be more widely recognised that many people in the audiences are sensitive to excessive loudness.

Eric Benjamin noted in a paper on preferred listening levels (albeit for domestic cinemas), *'The large range of preferred listening levels is in contrast to the narrowness of the acceptance windows for various categories of annoyance. Only [a +3/-4] dB level change is required for a listener to describe the sound as noticeably louder or quieter. And [+6/-9] dB elicits a reaction of too loud or too quiet. One implication of this is that if two listeners are selected from opposite ends of the distribution of preferred listening levels, then one or both of them will be quite dissatisfied no matter what listening level is chosen. Thus it may not be possible to select a single listening level that satisfies all of the listeners in a group.*'[11]

However, we can propose some practices that would make our listening experience more uniform and more room-to-room compatible, such as adopting a new alignment procedure for the B-chains which abandon the 'room response' concept, although they may require considerably more technical knowledge to implement. Also, it would seem prudent to accept the fact that the –20 dB FS = 85 dBC is very prone to abuse. Perhaps a new reference level could be set, such as -14 dB FS = 85 dBC, which would reduce the unrealistic abuse of the dynamics of film mixes that has become an everyday practice all over the world. The big question is how to implement these changes.

Of course, if film directors could be convinced that more constraint was frequently needed if audiences were not to be made inappropriately uncomfortable, changes in the standards would not be necessary, but doing so in the short term would seem to impossible in an artistic industry which has ruled itself for almost 90 years.

The fact that cinemas currently operate at different calibration levels is a commercial reality, despite ostensibly all being required to calibrate to the uniform level set out in RP200[1], and it will probably remain so until all cinemas can afford to use systems which can emulate the levels and quality of the sound in the 'big movie' dubbing theatres. The significant problem that accompanies this state of affairs is that there is no consistency in the motivation for reducing the levels. Some theatres persist in using underrated loudspeaker systems, so reduce the levels to avoid damage and harsh sounds, whilst other theatres, especially the smaller ones, follow the basic level-calibration standards without considering the subjective repercussions, such that higher SPLs in smaller rooms can be disturbing to many people. In both of these circumstances, the upward creep in peak recorded levels which has accompanied Digital Cinema can give rise to many complaints about excessive loudness from the public unless the playback levels are reduced. We therefore badly need a consistent set of guidelines which can help the cinema operators to reproduce soundtracks at widely-tolerable levels yet which also maintain the artistic intention and satisfactory intelligibility.

One of the authors recently attended a pre-release screening of a major American production, in which there is a scene in which the music repeatedly reached 0 dB FS on every channel (in 7.1) including the LFE channel. The scene lasts for about five minutes, and all the professional staff in the room agreed that they were being undesirably disturbed by the 'unpleasant' levels of sound coming from all sides. In general, the dialogue levels throughout the film were normal, so turning down the playback level could risk losing the intelligibility. Clearly, it is seen as the prerogative of directors to shock their audiences, as has always been the case in the arts, but it seems somewhat absurd if the degree of shock will lead, in perhaps most cases, to an inevitable dilution of the impact of the overall programme. Cinema patrons do not have the possibility to turn the volume down on loud sections only, so, in circumstances such as the one being discussed here, the cinema manager will almost certainly turn the whole projection down to avoid complaints. Whilst this is not what the director wished, it is perhaps as predictable a result as making a children's television programme with excessive bad language. It simply will not get shown to any typical audience in an unaltered manner.

Whilst there is no scientific evidence that the peak levels in a correctly calibrated cinema will give rise to any hearing damage if restricted to selected scenes, the press have enjoyed making the case to the contrary, and some local and state bodies have been calling for legal limits to be imposed. It is perhaps worth re-stating the fact that once legislation is introduced it can be all but impossible to withdraw, because it will be difficult to summon the same degree of vociferous campaigning for the *removal* of the restrictions as that which was calling for their introduction. What is more, if ill-conceived limits are imposed by the politicians at too low levels, they might significantly damage the ability of cinemas to provide an experience that will attract people out of their homes, especially now that good home-cinema systems are affordable and films can be seen on demand. Legislation may leave no way back for the restoration of cinema to its true capability to entertain, which is sad, because relatively inexpensive technology is easily available which can make digital soundtracks not only wonderful to listen to, but also truly stunning. [In fact, the word 'entertain' could be a crucial one, here, because the problems tend to begin when many of the people in the audiences no longer find the higher levels entertaining. A sudden shock can be exciting, but 'too much' can soon become disturbing in a way that is not entertaining at all.]

Some people in the cinema industry still say that the concept of using different calibration-level standards for different circumstances will never be accepted by the directors or producers, because the artistic control over the performances will be lost. However, only a relative few feature films demand blockbuster sound effects at high sound levels, so part of the future calibration process could be to identify those cinemas capable of reproducing the full dynamic range without stress, and rate them accordingly (like hotels can be rated with stars for the services offered). Not only the content providers (production companies) but also the cinema-goers could favour such cinemas for certain films requiring maximum dynamic range if they chose to do so. The cinemas that fell short of the full standards would have the choice of either turning down the volume, taking a risk and playing at the standard level, or avoiding certain films, but this situation could also provide the motivation to upgrade for the cinemas with less than adequate equipment (if or when they could

afford to do so). Most importantly, such a system could significantly reduce the number of complaints about the sound being too loud, and hence the consequent calls for legal controls. Patrons could also get to know the cinemas which tended to most suit their own tastes for most screenings.

It is also worth noting another point made in Benjamin's paper[11], that '*an increase in level causes the sound to get louder more than an equal decrease in level causes the sound to get quieter. By inference, if it is desired to set the levels within a system in order to get loudness that is satisfying to the largest number of listeners, it is more important to avoid getting the level too high than it is to avoid getting the level too low'*. This corresponds well with the fact that there seem to be more complaints about cinema soundtracks being too loud than being too quiet. Perhaps the production side of the cinema industry should give more consideration to this point.

In conclusion, as measured SPLs and perceived loudness do not always correlate well, it would seem wise to deal realistically with the loudness issue and try to avoid any legally-imposed SPL limits. What is certain is that the whole subject of cinema loudness levels is in urgent need of a significant and wide-ranging reassessment.

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