ENHANCED SOUND LEVEL MONITORING AT LIVE EVENTS BY MEASURING AUDIO PROGRAM LOUDNESS

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1 INTRODUCTION

Front-of-House (FOH) sound engineers are often expected to remain within a specified sound level limit. This limit is usually expressed as an A weighted and time-averaged sound level: an equivalent continuous sound level, $L_{p,\text{Aeq},T}$. Typically, a limit is set according to off-site noise pollution regulations and is determined by reproducing suitable program material at the desired sound level at FOH and comparing its propagation levels at noise-sensitive locations: a 'propagation test'. Low-frequency levels at noise-sensitive locations can be considered when setting the 'A' weighted limit, as such spectral content is often a significant factor in noise-related annoyance [1].

The World Health Organization's (WHO) Global Standard for Safe Listening Venues & Events, from 2022, recommends a 100 dB $L_{p,\text{Aeq},15min}$ at a representative location in the audience, typically the centre of the audience area. The UK's current Code of Practice on Environmental Noise Control at Concerts, from 1995, also recommends a 15-minute averaging of 'A' weighted sound levels.

The $L_{p,\text{Aeq},T}$ one-figure metric is simple and straightforward to implement; however, limitations in terms of a live meter limit for sound engineers at the FOH mix position can be problematic, specifically regarding responsiveness of data to allow for real-time adjustments to levels. This paper, therefore, details research into alternative metrics and tools which can work alongside official $L_{p,\text{Aeq},T}$ limits in order to provide sound engineers with timely information on current sound levels, allowing them to respond to potential issues quickly without diverting significant attention away from the primary role of mixing the performance. Specifically, the use of an ITU BS.1770 / EBU R 128 audio program loudness meter as a tool to benefit this situation will be explored.

2 BACKGROUND

The responsibility for ensuring any imposed FOH limit is adhered to may vary by situation and territory. In the first instance, sound level information needs to be relayed to the FOH engineer during the event. The official one-figure $L_{p,\text{Aeq},T}$ limit is usually monitored by engineers whilst performing their primary task of balancing the mix to ensure audience satisfaction. This is typically done using sound level monitoring software with easy-to-read user interfaces (Figure 1). 'C' weighted sound levels are often monitored alongside the official 'A' weighted limit as a measure of low frequency energy. In some situations this will be specified as a secondary $L_{p,\text{Ceq},T}$ limit, or an octave band measure.

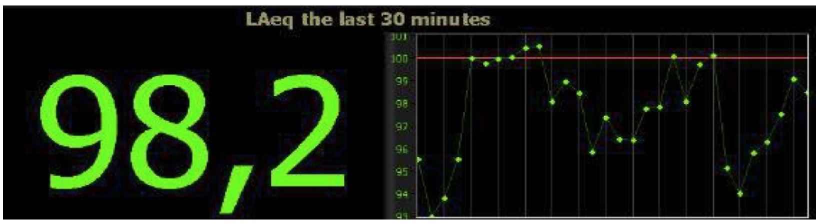

Figure 1 A screenshot from the '10EaZy' sound level monitoring software from (SGAudio Aps)

In general, the $L_{p,\text{Aeq},T}$ target limit is not translated into an electrical audio signal level limit. The typical built-in metering available on digital and analogue mixing consoles uses a signal's broadband average (RMS, VU), its peak (PPM, QPPM), or a combination. These simple calculations performed on program or speech cannot be relied upon to adequately predict the 'A' weighted SPL in our situation: spectral variances are not differentiated by these metering methods. In other words, a calibration of signal flow from the mixing console(s) to a sound system's output using only these metrics does not accurately predict compliance with an 'A' weighted SPL limit.

In a typical situation, a FOH sound mixer's initial judgement of the relationship between their mixing console's output level and an unfamiliar sound system is primarily subjective and reactive. A reliance must be made upon the Sound Level Meter's (SLM) reading of $L_{p,\mathrm{Aeq},T}$ at any given moment. However, an accurate prediction of the time-averaged level at any instant can only be made with predictive knowledge of the sound output that will occur after the time interval T has passed.

It is proposed that the EBU R 128 live loudness meter [2] be used alongside standard $L_{p,\mathrm{Aeq},T}$ sound level monitoring to provide sound engineers live metering of sound levels, and how they relate to perceived loudness. It is clear that it would be beneficial for the sound engineer to know at any time how the electrical signal relates to loudness; this having a direct relationship upon the retrospective $L_{p,\mathrm{Aeq},T}$. Note: A 'live meter' is a meter that can be used in a live environment, measuring an audio signal as it happens.

2.1 The measurement of audio program loudness in the broadcast industry

In early 2000's the Advanced Television Systems Committee (ATSC) and the European Broadcasting Union (EBU) issued recommended practices for the loudness of television station output (A/85:2013 and R 128, respectively). This was, in part, a response to US legislation some years earlier mandating loudness regulation to reduce differences in loudness levels between content and commercials[3].

The International Telecommunication Union's 'Recommendation ITU-R BS.1770-5: Algorithms to measure audio programme loudness and true-peak audio level' [4] describes the human loudness model used by both the ATSC and EBU. The algorithms are designed for live broadcast with a low computational cost. Whilst alternative loudness models with more complexity and accuracy exist, they are more computationally expensive (e.g. ISO 532-1:2017, ISO 532-3:2023, ECMA-418-2:2020). A live meter using these alternate models may not be feasible at the time of writing.

2.2 ITU BS.1770 algorithm: 'K' weighted filtering

The ITU BS.1770 algorithm has four stages: the first is 'K' frequency weighting (Figure 2), with other stages used for level calculations and summing. Figure 3 illustrates the average power per one-third octave of a red or Brownian noise signal with various filtering applied. Brownian noise has a spectrum that approximates real musical material.[5]

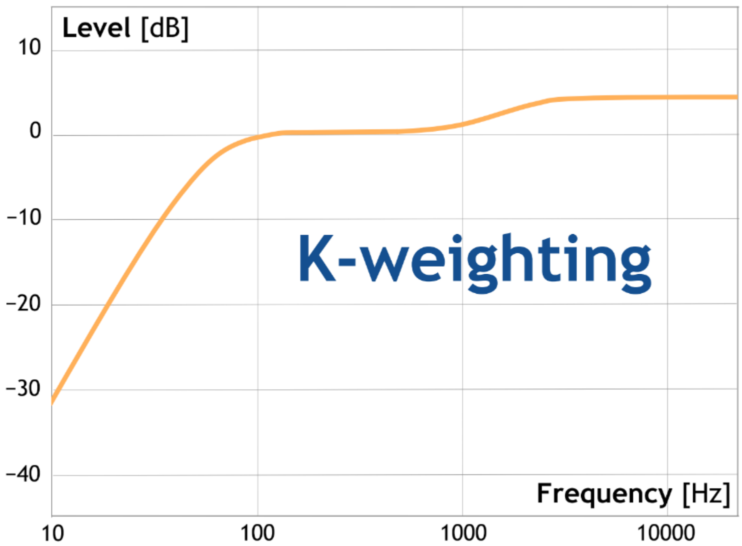

Figure 2 'K'-weighting filter curve for loudness measurement [2]

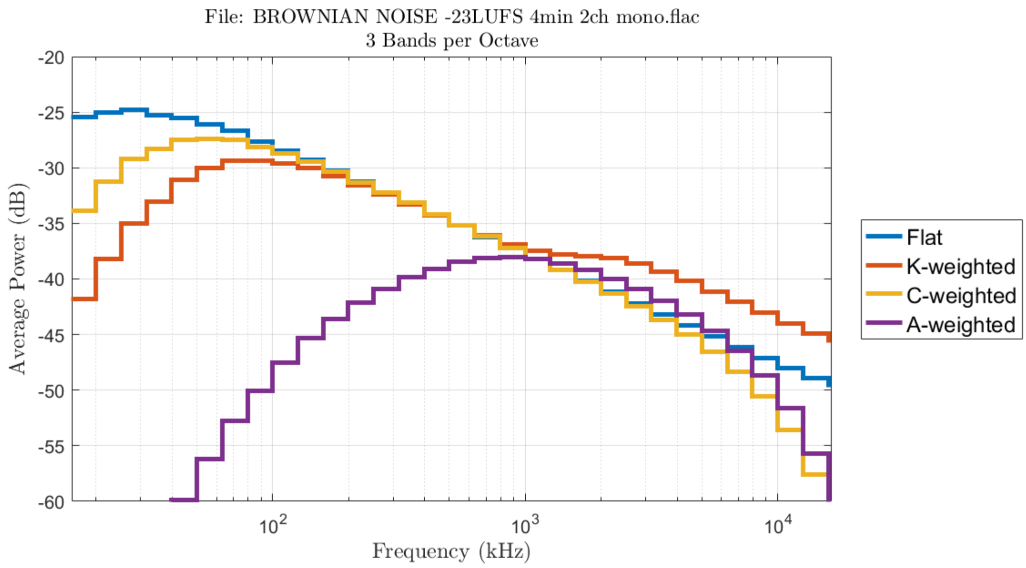

Figure 3 Brownian noise 1/3 octave band spectral analysis with various weighting filters applied (created with MATLAB's 'poctave' function and 'AUDACITY' audio editing software)

2.3 ITU BS.1770 algorithm: Level calculations and summing

The EBU R 128 extension of the ITU BS.1770 measurement method includes a recommended **'Target Level'** for loudness normalization which is useful for our purpose (discussed here and in later sections).

> An 'EBU Mode' loudness meter as defined in EBU Tech Doc 3341 offers 3 distinct time scales:
>
> > Momentary Loudness (abbreviated "M") — time window: 400 ms
> > Short-term Loudness (abbreviated "S") — time window: 3 s
> > Integrated Loudness (abbreviated "I") — from 'start' to 'stop'
>
> The M and S time windows are intended to be used for the immediate levelling and mixing of audio signals. If he/she wants to, a mixer has to know at any time how loud the actual signal is, and that is the main purpose of the Momentary and Short-term measurement. [2]

As a comparison, the ISO 532-3 Moore-Glasberg-Schlittenlacher model uses short-term loudness for "individual brief segments of sound…typically lasting up to 500 ms", and long-term loudness lasting up to 5 seconds.

EBU R 128 loudness measures are expressed in Loudness Units (LU), with 1 LU ≡ 1 dB. A target level to allow comparison between program content and to ensure consistency for listeners is defined as −23 LUFS: a level 23 dB below 0 dB Loudness Units Full Scale (LUFS). Additionally, a digital true peak meter is used to indicate overloads that can occur between samples.

EBU R 128 states that "any graphical or user-interface details of a loudness meter complying with 'EBU Mode' have intentionally not been specified".

3 METHODOLOGY

This study compares graphical representations of 'A' weighted sound levels and EBU R 128 audio programme loudness metrics at a small sampling of outdoor concerts held in the UK. An RME Babyface Pro, Windows 11 Pro laptop, and 'AUDACITY' audio editing software were used to capture the signal from a calibrated omnidirectional measurement microphone at the FOH mix position, alongside a line-level mono sum of the sound system feed. The measurement microphone's on-axis response was author verified as Class 2 (or better) by acoustic comparison against a Class 1 reference.

MATLAB was used for post-processing of audio data and creating figures. Custom scripts used 'splMeter', 'loudnessMeter', and 'audioLevelMeter' from the MATLAB 'Audio Toolbox'. A Galaxy Audio 'CMC200 SPL Meter Calibrator' (Class 2) was used for on- and off-site microphone calibrations. The MATLAB level readings were verified against the following software: 'EASERA Pro', AFMG 'Systune', 'ARTA', 'Room Eq Wizard', and 'SMAART 8'. The MATLAB programme loudness readings were verified against: RME 'DigiCheck NG' (a companion software for the RME Babyface Pro); 'AUDACITY' audio editing software; and Cockos 'REAPER' digital audio workstation software.

Note that the unmodified $L_{p,\text{Aeq},T}$ readings generated by MATLAB's 'splMeter' indicate consecutive time-averaged results. This differs from the recommended cumulative rolling-average (or 'moving-average'), as used in the graphs presented below.

4 RESULTS + DISCUSSION

The results in Figures 4–6 are taken from a small sampling of recent outdoors live events in the UK. All shows featured a festival-style stage, and large format line-array loudspeaker systems with delay towers. Each figure shows 'A' weighted sound level measures in the upper plot, and EBU R 128 audio programme loudness in the lower. All graphs show $L_{p,\text{Aeq},15min}$ (900 seconds), with a time interval of 10 s for other measures.

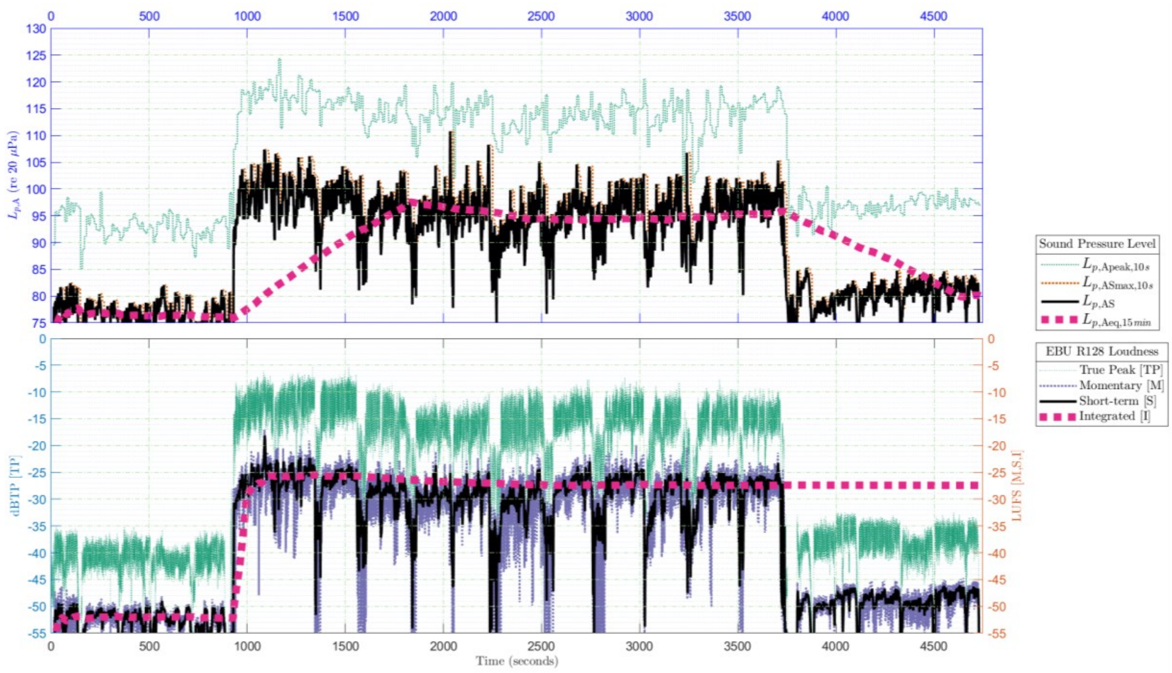

Figure 4 – Show 'G', Act 2 with background music (BGM) interludes. A 2–3 dB downward correction is evident at 1700 s (15 min). This demonstrates how an $L_{p,\text{Aeq},15min}$ limit breach may not be indicated until period T is accumulated. In most cases such a noticeable downward correction is not preferred. The EBU R 128 levels reveals this activity whilst it happens.

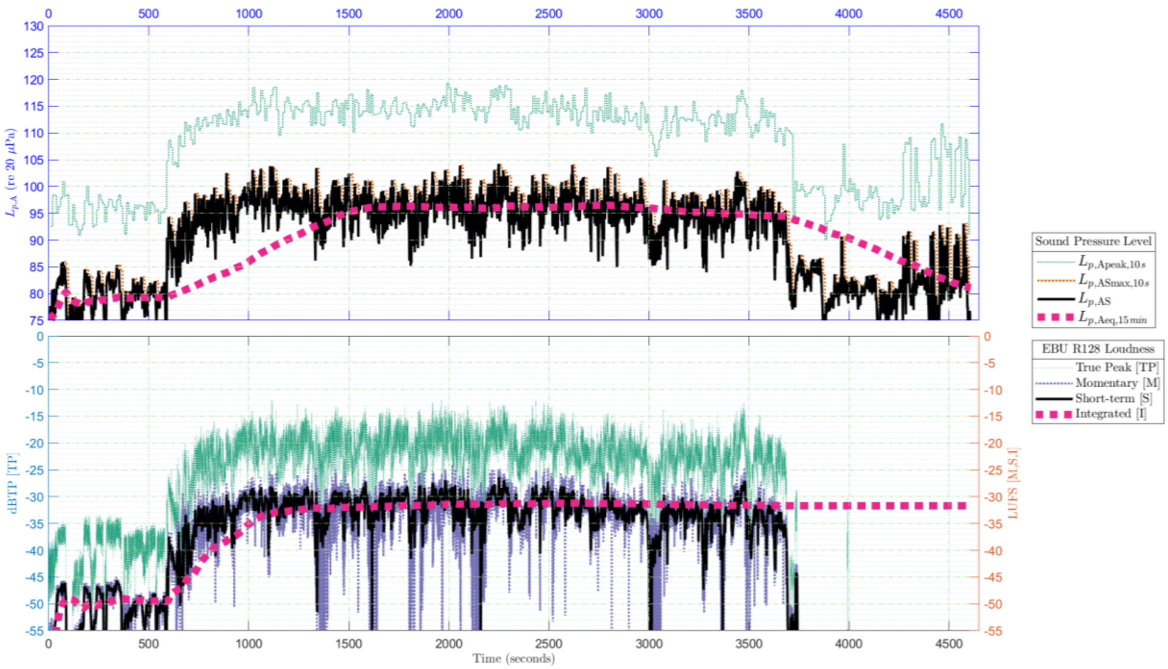

Figure 5 – Show 'G', Act 4 with BGM interludes. Rapped vocal over a DJ, long intro build. A reduced dynamic range is evident. There is a clear correlation between the live EBU R 128 measures and SPL.

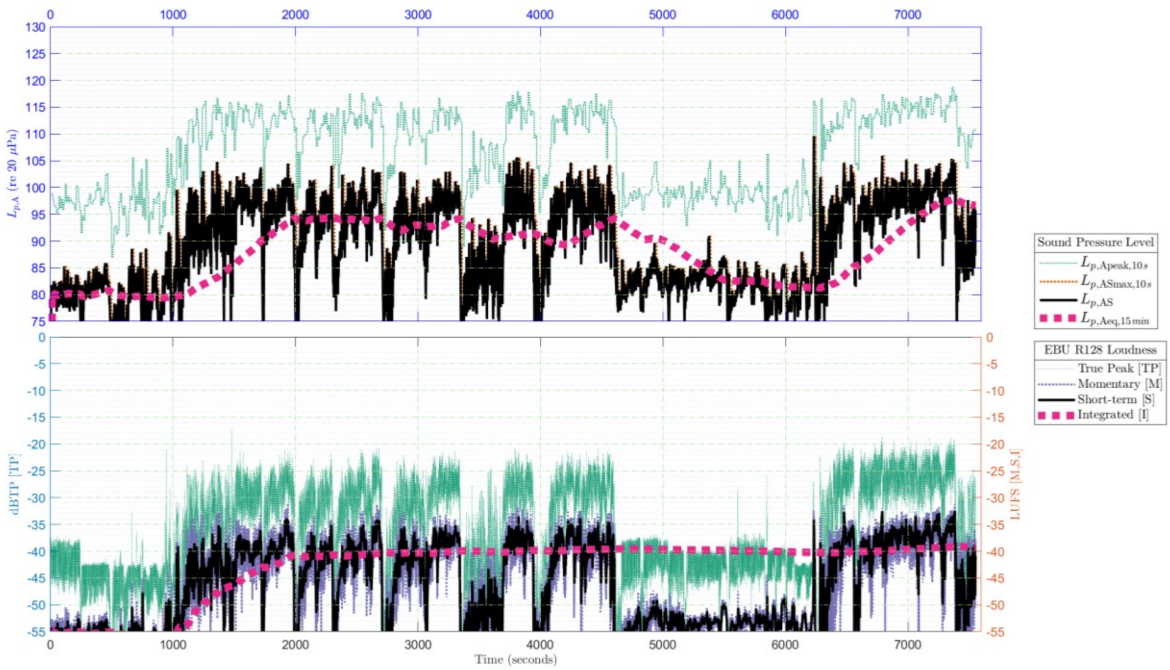

Figure 6 – Show 'E', Acts 6 and 7 with BGM interludes. Note the variance in $L_{p,\text{Aeq},15min}$ in comparison with **'Integrated Loudness'** and other R 128 measures. The input level drop between acts is interpreted by EBU R 128 as a pause, hence **'Integrated Loudness'** is not updated during this time. **'Integrated Loudness'** is a gated measure which can be reset at the start of a program section, during, or used continuously.

Expected correlations existed in all analysed data, without exception. The start of each performance reveals the advantage of the live EBU R 128 measurement of the signal sent to the sound system against the time required for the retrospective moving-average $L_{p,\mathrm{Aeq},15min}$ to indicate the eventual outcome. Additional advantages will now be discussed.

4.1 Advantages of using site-calibrated audio program loudness measures for live events

It is acknowledged that $L_{p,\mathrm{Aeq},T}$ is widely used to monitor sound levels and annoyance of environmental noises, and provides consistency between measurements. However, the limited information provided by $L_{p,\mathrm{Aeq},T}$ presents a number of obstacles to FOH engineers, including aspects of hearing health:

- $L_{p,\mathrm{Aeq},15min}$ is the ruling indication of sound level at the FOH mix position: a sound level estimate of minutes past, not the present.[5] This acoustic measure includes complicating effects from preceding content and crowd noise.
- $L_{p,\mathrm{Aeq},T}$ averaging across the specified time window, T, does not indicate the effects of duration of sounds on loudness (impulse or impact sounds).[6]
- ‘A’ weighting suppresses most low-frequency spectral content, giving it a reduced influence on the reported loudness. The one-figure $L_{p,\mathrm{Aeq},T}$ offered to FOH engineers does not adequately account for the increasing and varied levels of extended low-frequency content common to modern music production.[7]
- ‘A’ weighting and time-averaging in minutes under-represents ‘bass beat’ loudness levels which are the dominant cause of annoyance and disturbance for local involuntary hearers.[1] This is of relevance for two reasons: at low frequencies loudness growth is more rapid than at higher frequencies [8]; and impulse noise exposures produce greater than expected damage to the human auditory system.[9] — “Research has shown that the frequency weighting A, alone, is not sufficient to assess sounds characterized by tonality, impulsiveness or strong low-frequency content.” [10]
- Shorter time intervals (e.g. $L_{p,\mathrm{Aeq},5min}$) may lead FOH engineers to make unnecessary changes by being more sensitive to dynamic fluctuation in program content and crowd noise.[11]
- $L_{p,\mathrm{Aeq}}$ is a measurement of sound level, not perceived loudness. Program content comparisons may register a similar ‘A’ weighted sound level, but substantial spectral differences that contribute to loudness perception (especially low frequency) may be minimized and unrepresented. Therefore, ‘A’ weighted measures should not be relied upon for loudness comparisons; for example, where a gradual increase in loudness is required over the duration of an event.[5]
- An ‘A’ weighted sound level limit does not prevent one program item from sounding louder than another; this is a likely contributing factor where a steady increase in levels occurs throughout the duration of an event - ‘level creep’.[5] FOH mix engineers may feel obliged to use compression and limiting techniques to increase loudness without breaching the SPL limit.
- An $L_{p,\mathrm{Aeq},T}$ limit does not distinguish content with an intentionally reduced dynamic range. This was used in the broadcast and recording industries to increase loudness by comparison, and tackled by ITU BS.1770 / EBU R 128 (see section 2.1, and references discussing the music industries ‘loudness wars’ [12 13]).
- Over-compression of vocals may have a negative impact on intelligibility, contrary to the notion that compression increases loudness and ‘louder is better’. A reduced dynamic range between a vocal and musical accompaniment will influence masking levels which may not be equally apparent in all audience areas due to variances in sound system coverage. Vocal compression alters the normal contrasts between speech amplitude variations, a non-linear distortion, and is therefore capable of reducing intelligibility as well as enhancing it.
- Sound level regulations do not distinguish between musical and non-musical content. A method of quantifying the sound system’s contribution to the measured sound level would be of benefit to FOH operatives[11].

The proposed utilization of EBU R 128 audio program loudness metering is capable of adequately addressing the issues mentioned (see section 5 Conclusion).

4.2 Strategic use of EBU R 128 audio program loudness metering for live events

The solution is a coupling of the sound system's acoustic output ($L_{p,\text{Aeq},T}$) to predictable electric input signal levels which are *loudness* normalized using a live EBU R 128 meter to the recommended 'Target Level' of –23 LUFS. Initial guidelines for consideration:

- Appropriate test signals at the EBU R 128 'Target Level' of –23 LUFS should be used to perform on-site propagation tests. The propagation test is used during set-up to determine an appropriate acoustic gain for the loudness normalized signal, to conform with a desired L_p at any on- or off-site receiver. It is possible for the propagation to be investigated during the event, if necessary, but is not recommended for optimum results. Guidelines for a suitable offset of measured L_p at a receiver in relation to setting a suitable FOH limit should be investigated.
- An investigation should be made into the appropriate choice of propagation test stimuli. This will include the choice of a stimuli's spectral balance, dynamics, signal duration and intervals, and repetition rates. A combination of the following should be investigated: targeted band-passed pink noise signals [2] ; broadband Brownian noise [5] ; and cosine bursts shaped with a Gaussian window at strategic bass and sub-bass frequencies. Correct adjustments from propagation tests, coupled with the predictability and consistency of loudness normalized signal levels, can prevent sound level limit breaches from occurring. Mid-show alterations of a carefully crafted spectral balance to address off-site issues should be avoided.
- A master EBU R 128 meter should be used at the sound system input, and displayed alongside the $L_{p,\text{Aeq},T}$ (the ballistics and graphics of the RME DigiCheck 'EBU R 128 Meter' is recommended).
- EBU R 128 meters should be used at the 'pre-EQ' output of each FOH console.
- The EBU R 128 metering point should not include sound system equalization. The spectral balance of audio monitoring in the broadcast and recording industries show strong variances between installations; a result of reproduction recommendations and customized voicings. [8] Spectral balance recommendations for live event sound systems are less formalized. The effect of a heavily skewed loudspeaker spectral balance upon EBU R 128 metering should be investigated.
- Ensure FOH operatives and production management are informed about the use of EBU R 128 in advance of the event to allow them time to prepare, discuss, and familiarize. This may include the use of EBU R 128 in pre-production and rehearsals, make a 'loudness plan' outlining any desired contrasts between different sections of the show, and to normalize pre-recorded program material off-line (backing tracks, video files, etc.). FOH mix engineers who routinely use the EBU R 128 'Target Limit' in their workflow automatically comply with SPL limits with a site-calibrated system after minimal adjustment, if any.

4.2.1 Extended investigations

- The 'Loudness Range' (LRA) feature defined in EBU R 128 may be applicable to the live event situation, if target recommendations can be determined.
- ITU BS.1770 / EBU R 128 are typically used over a wide dynamic range; however, live event sound systems can operate at more than twice the loudness. Specific guidance that may be necessary for the use and applicability of EBU R 128 at these higher sound levels should be investigated, with particular attention paid to effects at low frequency. A modification or pre-emphasis of the 'K' filter's high-pass filter (the revised low-frequency B-curve, RLB) may be appropriate. [4]
- The LFE sub channel is not currently included in ITU BS.1770 / EBU R 128. A parallel EBU R 128 meter for the event sound system's sub-bass loudspeaker feed may be appropriate. Experimentation could made into using a 'stretched' LU range when compared with the companion meter; in consideration of the reduced level difference for loudness doubling at low frequencies. [8]

5 CONCLUSION

It is clear that it would be beneficial for sound engineers to know at any time how the actual electrical signal coming from the desk is impacting the perceived loudness of an event; this having a direct relationship upon the retrospective $L_{p,\mathrm{Aeq},T}$. The coupling of the acoustic output measure, $L_{p,\mathrm{Aeq},T}$, to normalized electrical input signals is a logical step forward. The use of EBU R 128 audio program loudness metering and protocol is recommended for this purpose. EBU R 128 loudness normalization is applicable to the whole signal chain; therefore, calibration of the acoustic gain of a sound system becomes a straightforward process.[2] The EBU R 128's multiple time-constant broadband mean square metering gives a mix engineer the necessary information to remain within range of the electrical signal 'Target Level' of -23 LUFS, in turn ensuring 'A' weighted SPL compliance.

The paradigm shift in the area of live events from the existing practice of *peak normalization* to *loudness normalization*[12] would provide a consistent, predictable, and transferable loudness balance and contrast for all audio segments at a live event. The FOH mix engineer could be assured, *in advance,* of sound level limit compliance by referring to an industry standard metering tool designed for the task. A net result, in general, would be a downward correction in sound exposure for all concerned, whilst maintaining or improving the audience experience.

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