Audio Engineering Society

Convention e-Brief 670

Designing sound system in-band headroom based on expected difference between C- and A-weighted levels

Merlijn van Veen, Roger Schwenke, and Bob McCarthy

Meyer Sound Laboratories, 2832 San Pablo Ave, Berkeley, CA 94702, USA

Correspondence should be addressed to Merlijn van Veen (merlijnv@meyersound.com)

ABSTRACT

Sound pressure level (SPL) is the standard metric for regulations regarding environmental noise exposure. Because performances are often regulated by their A-weighted sound level, it is tempting to think that A-weighted level should be the primary design consideration for sound system headroom. Because A-weighting disregards significant low-frequency energy, it is possible to create a wide variety of spectra with the same A-weighted level, but each having a different spectral shape and C-weighted level. While regulators correlate excessive A-weighted levels with hearing damage, A-weighted levels are less well correlated with community annoyance. The Netherlands has recognized this and created a permitting system incorporating the difference between C- and A-weighted sound levels (C-A) as a measure of low-frequency content. This Brief gives supporting evidence for the correlation between C-A levels and different musical genres and offers complementary design guidance corresponding to sound system headroom with emphasis on in-band levels.

1 Introduction

Simulated program content test signals (Figure 1) agree that the RMS level of music and speech roll off with increasing frequency (noteworthy exception is pink noise whose energy is distributed equally by design). This was recently shown to be true independent of genre [1].
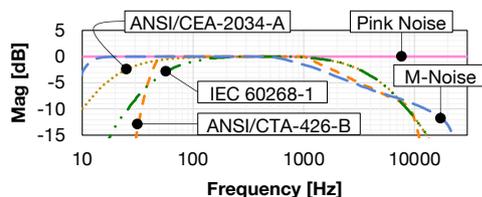

Figure 1. Line spectra — no banding — various Simulated Program Content normalized at 500 Hz.

In contrast, the Dutch Noise Abatement Society (NSG) has shown — this Brief presents additional supporting data — that the amount of low-frequency acoustical energy generated in (live-)sound reinforcement in exhibition and performance spaces is genre-dependent. Within this Brief the acoustic spectrum created by the audio engineer is considered the artist's intent.
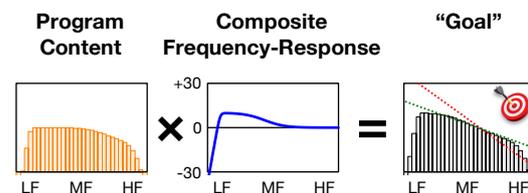

Figure 2. Spectral tilt - Conceptual.

The acoustic spectrum is the result of the mixing console (or equivalent device) output spectrum multiplied by the composite frequency response of the remaining signal path including — but not limited to — the sound reinforcement system (Figure 2).

A significant topic worthy of separate consideration is how the audio engineer achieves the desired low-frequency levels, whether by, e.g., a preferred sound system voicing or using auxiliary-fed subwoofers. This Brief instead focuses on providing sufficient headroom to achieve said levels.

It will be shown that the difference between C- and A-weighted content levels, strongly indicates the headroom needed for sufficient system performance as characterized by the relative headroom between the 50 Hz and 1 kHz third-octave bands.

2 Frequency Weighting Filters

As opposed to Z-weighting, C-weighting is a band-pass filter that admits most of the audible range (Figure 3).
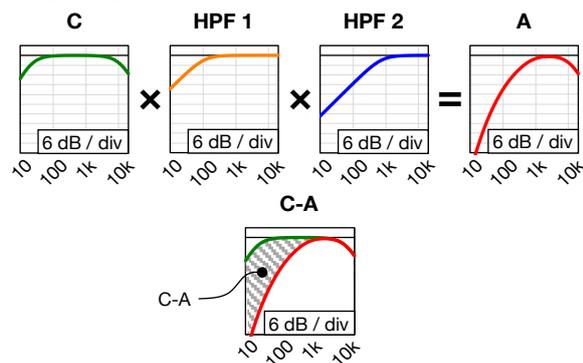

Figure 3. From C- to A- to C-A weighting.

A-weighting — sans normalization — is a high-passed version of C-weighting [2]. Therefore, the signal responsible for the difference between C- and A-weighted levels is essentially a low-passed signal.

3 C-A

C-weighting admits low-frequency energy otherwise rejected by A-weighing. Therefore, C-weighted levels tend to be higher than A-weighted levels for broadband program content.

The difference between C- and A-weighted sound levels, referred to as C-A (read: C minus A), is proportional to the spectral balance, or tilt, between low- and high-frequency energy.

Signal	C-A
SMPTE ST 2095-1 Pink Noise	1,8 dB
IEC 60268-1 Noise	2,3 dB
AES75-2022 M-Noise[1]	4,0 dB

Table 1. Example C-A values for various signals.

Regulating authorities correlate A-weighted levels with hearing damage. However, A-weighted levels are less well correlated with community annoyance [3]. In recognition of this, The Netherlands created a permitting system incorporating C-A as a measure for low-frequency content.

4 Five Music Spectra

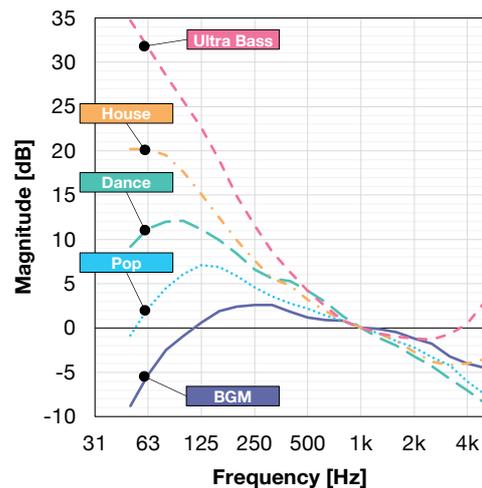The Dutch Noise Abatement Society standardized [4] five music spectra (Figure 4).

Figure 4. Five standardized — unweighted — music line spectra, normalized at 1 kHz.

These spectra were empirically determined using sound level meters in the hospitality industry, from cafés to concert halls. For each classification the NSG published the corresponding C-A value (Table 2 next page).

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[1] M-Noise is a trademark of Meyer Sound Laboratories, Incorporated

NSG Classification	C-A
Ultra Bass	20 dB
House	14 dB
Dance	10 dB
Pop	6 dB
Background Music (BGM)	3 dB

Table 2. Corresponding C-A values.

Notice that the C-A values rise with increasing low-frequency content. While the NSG-assigned names are derived from the measured music types, they now serve merely as labels for the associated spectral profile and corresponding C-A weighted level. Performances are held to the NSG classification they applied for regardless of the actual style of music performed.

5 Supporting Evidence

The authors applied the NSG classification scheme to two stages at a major multi-day festival using sound level meter log files to derive the C-A values. One was a main stage with a typical variety of contemporary music whereas the other was designated exclusively for "electronic and urban music".

Table 3 at the bottom of this page shows the C-A time history in 4-minute intervals for a subset of all main-stage acts across different music genres.

Figure 5 shows the five NSG classes' proportionality for all performances at both stages.

Main Stage
(21h13m)

16%   14%
32%   37%

Electronic & Urban Stage
(25h12m)

8%   5%
     30%
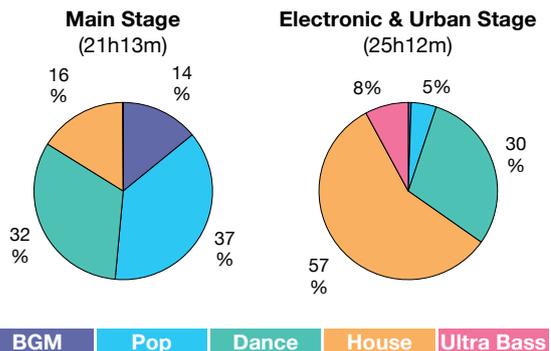57%

| BGM | Pop | Dance | House | Ultra Bass |

Figure 5. NSG classes' proportion for both stages.

The pie charts reflect the programming for each stage. The electronic & urban stage features significantly more bass-heavy content compared to the wider variety of music performed at main stage.
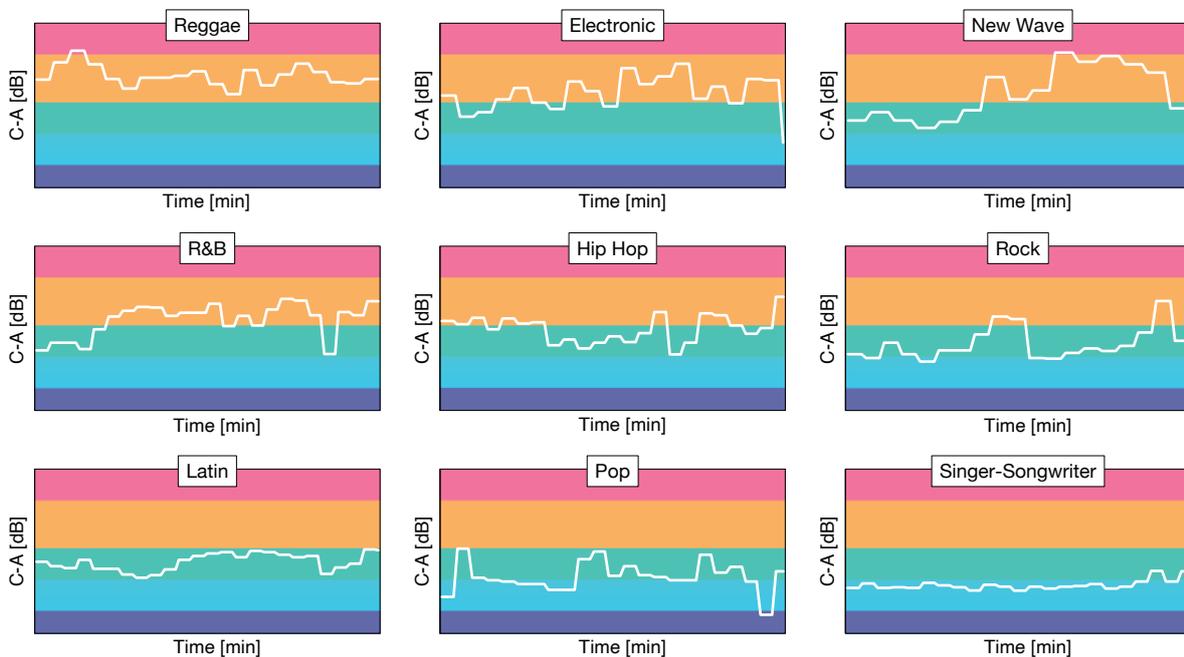
Table 3. C-A time history for a subset of all main-stage acts across different music genres.

The "box-and-whisker" plots in Figure 6 show the total in-band level distribution per octave relative to 1 kHz for all performances at both stages, where the boxes and whiskers represent 50% and 95% of all observations respectively. The horizontal line that divides each box denotes the median value, whereas the cross (X) denotes the average value.
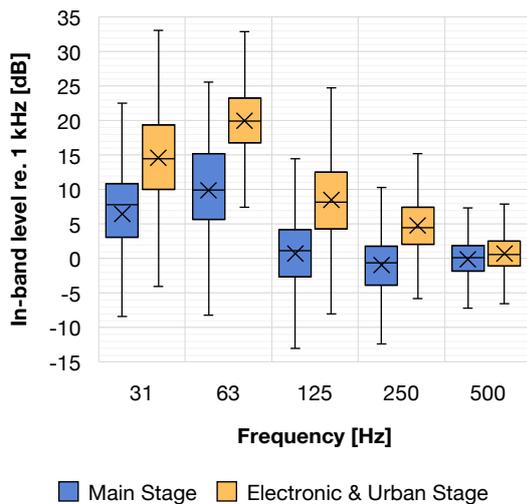

Figure 6. In-band level distribution per octave band relative to 1 kHz.

The onset of increasing levels with decreasing frequency occurs roughly at 500 Hz. It is notable that the in-band levels are significantly higher for the electronic & urban stage than the main stage.

6 In-band Headroom Allocation

Because A-weighting disregards significant low-frequency energy, it is possible to create a wide variety of spectra, all having the same A-weighted level, but each having different spectral shapes and C-weighted levels.

Therefore, headroom should be evaluated with some resolution in frequency — fractional-octave bands — rather than a single broadband metric.

Table 4 on the next page shows 16 unweighted band spectra whose broadband A-weighted sound levels are normalized to 0 dBA.

Notice the low-shelf characteristic featuring three variables:
- start of ramp (corner frequency),
- LF headroom, and
- plateau width.

Each row represents a NSG Classification and each column signifies a different ramp starting frequency. The authors would like to stress that Figure 4 on page 2 and Table 4 on the next page show single-ended spectra (i.e., not the loudspeaker frequency response).
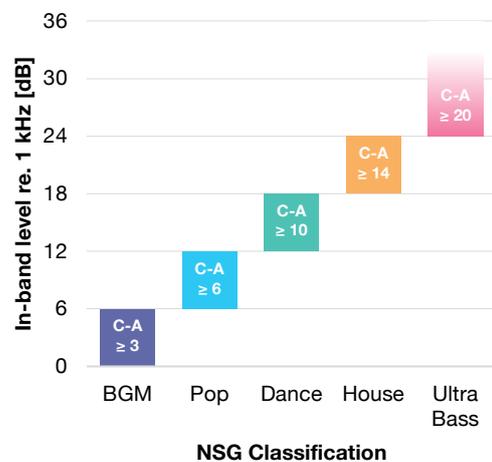

Figure 7. Recommended in-band headroom levels at 50 Hz relative to 1 kHz.

The in-band level difference from 1 kHz and up pales in comparison to differences observed for low frequencies (for a given ramp start, LF headroom, and plateau width). Consequently, the band spectra shown in Table 4 can be largely accomplished by designing systems with in-band headroom level at 50 Hz relative to 1 kHz — i.e., the quantity of subwoofers — as shown in Figure 7. Keeping in mind that, in practice, effects like boundary loading and room reverberation tend to cause an SPL increase over a greater bandwidth for subwoofers than mid-high speakers, above and beyond their data-sheet or free-field predicted values. Even for flown subwoofers, listener's ears are effectively boundary loaded for a significant portion of the typical subwoofer bandwidth.
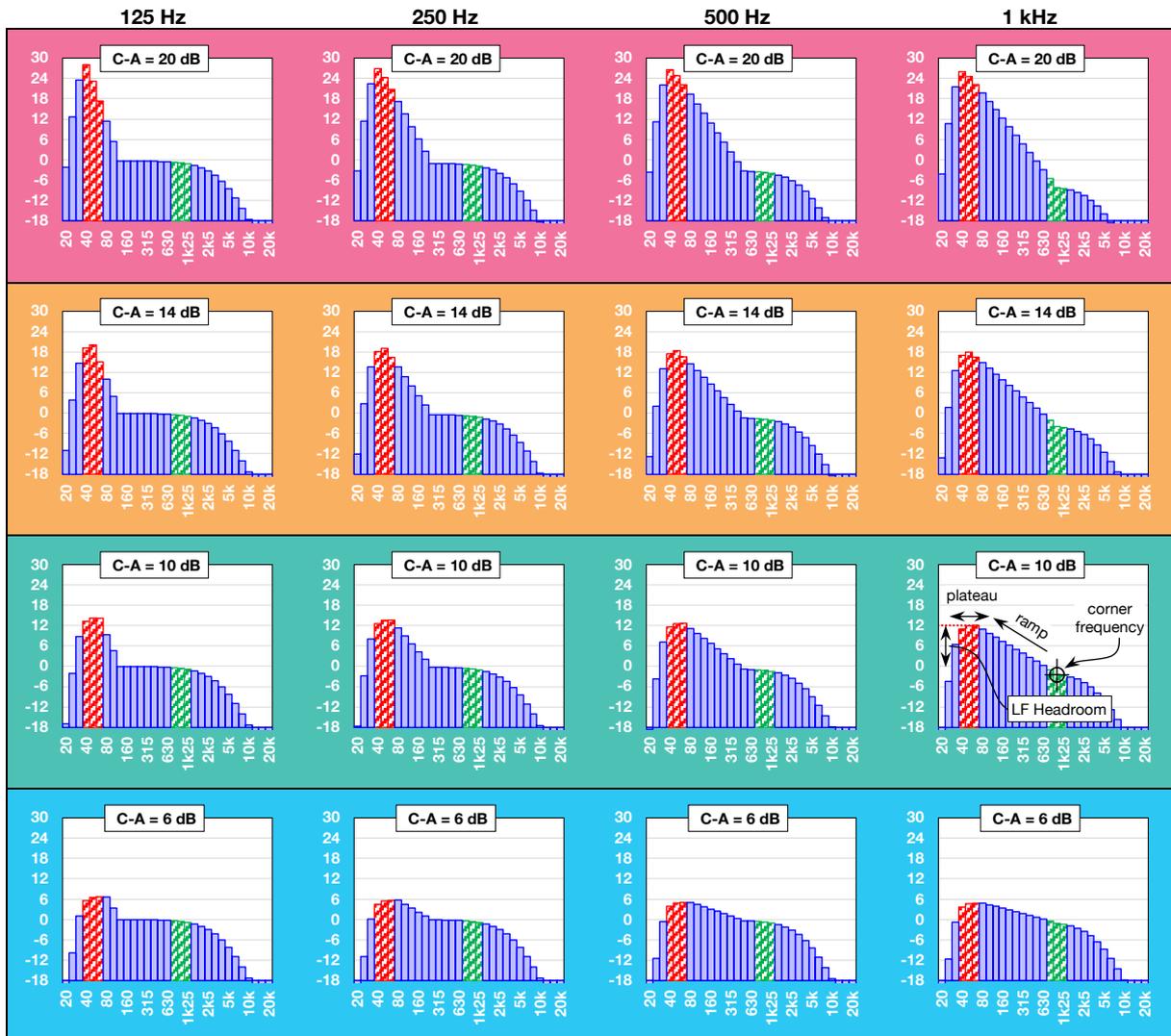
Table 4. Sixteen unweighted third-octave band spectra normalized to 0 dBA.

References

[1] R. Schwenke, "A New Signal for Measuring Loudspeaker Maximum Linear SPL" *SMPTE Motion Imaging Journal* vol. 129, issue 5, pp. 25—29 (2020)

[2] IEC 61672-1 Electroacoustics - Sound level meters - Part 1: Specifications

[3] AESTD1007.1.20-05 "Understanding and managing sound exposure and noise pollution at outdoor events"

[4] Nederlandse Stichting Geluidshinder (NSG), "Richtlijn muziekspectra in horecabedrijven", richtlijn + aanvulling (mei 2021).pdf, https://nsg.nl/nl/muziekspectra_horeca