Standard-Compliant Sound Immission Forecasts for Open-Air Music Events

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Motivation

A worldwide increase in noise complaints in connection with open-air music events can be observed. As a result, immission control authorities are increasingly requiring noise studies to be conducted as part of the approval process for open-air concerts. Corresponding calculations are usually carried out using software products that provide the standardized calculation methods for industrial noise in a quality-assured form. Within these methods (e.g. ISO 9613-2 [1] or CNOSSOS-EU [2]), sound sources are always considered incoherent, which justifies the underlying sound propagation conditions. In contrast, sound reinforcement systems consist of a large number of coherent sources with highly frequency dependent directivity characteristics. The data sets in brand-agnostic electro-acoustic simulation software and manufacturers' modelling environments are typically based on high-resolution measurements of complex-valued, far-field radiation patterns for the individual sources (CDPS model [3]). The radiation of the overall system depends on the superposition of the sources, which is optimized for a specific sound reinforcement situation and audience area. As it is not yet possible to transfer these overall sound situations into the calculation methods of noise immission control, improvised solutions are often used causing a high degree of scatter in the results of the consultants involved. Another major challenge is that electro-acoustic planning and noise assessments are generally carried out by different processors and software tools.

Ideally, a solution approach would take these facts into account and build on existing software solutions. It would define a well-defined transition point between the parties involved. Since the noise calculation methods themselves are determined by country-specific regulations on noise protection, the research of this paper concentrates on a substitute sound source model which, on the one hand, reflects the complex directivity of modern sound reinforcement systems and, on the other hand, leads to sufficiently accurate and reproducible results within the normative calculation methods.

Proposed approach

The solution approach proposed here is based on the assumption that for most sound reinforcement systems, groups of sources can be identified that are mutually incoherent but consist of internally coherent elements. Each group can be transformed into a so-called *Aggregate Point Source* (APS) by computing its far-field directivity pattern for use as a noise source in immission modelling software. This approach is justified as typical distances for noise impact analysis are significantly larger than the near-field distances at which the above parts of the sound system are naturally used. In consequence, this concept offers compatibility with existing standards and regulations that define how noise propagation assessments have to be conducted.

A previous article [4] has detailed the theoretical basis of this concept and demonstrated its practical applicability using a number of large-scale outdoor concerts for which good agreement between measurement and simulation was found (Fig. 1). However, due to the lack of information about the sound system setups at low frequencies the validation happened only in the frequency range of about 200 Hz to 4 kHz. In this article, these data are complemented by results from another setup for both the mid- and high-frequency range as well as for the low-frequency range.

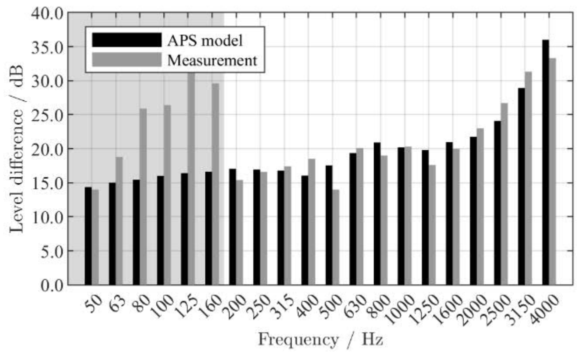

Figure 1: Measured level difference vs predicted level difference at a measurement location relative to a reference location at a large-scale outdoor concert. The mean deviation is about 1.7 dB. The greyed-out area indicates frequency bands missing in the modelling data.

Validation

The experimental setup consisted of a simulated outdoor stage with a total width of about 12 m. A flown line array was placed on each side and a horizontal subwoofer array was arranged on the ground (Figs. 2a and 2b). Different combinations of these parts of the sound system were used for the test. While playing pink noise, SPL recordings were taken with several sound level meters simultaneously at distances of 80 m, 120 m, and 200 m. These measurements were conducted for ten different directions at an angular resolution of 36° around the stage.

With respect to the environment, the surrounding landscape consisted mainly of grassland hills with some tree lines and shrubs. Weather conditions were stable with light winds and temperatures around 15°C.

Figure 2a: Experimental setup with two flown line arrays and a subwoofer array on the ground.

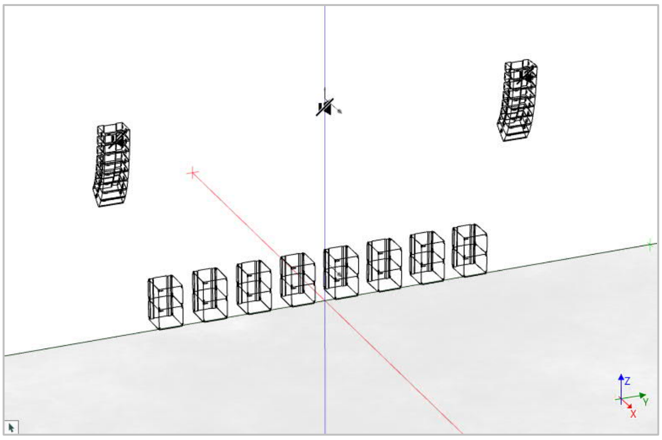

Figure 2b: Model of experimental setup.

Combination of flown systems

The measurement series included SPL recordings of only the right line array as well as of the level of the left and the right line array combined. For two incoherent sound sources, due to the summation of their sound power, one would expect the sound pressure level to increase by 3 dB when both systems are active compared to only one. This was well confirmed within the accuracy of the measurement setup. Fig. 3 shows the broadband A-weighted level over a 42 s time section of the recording.

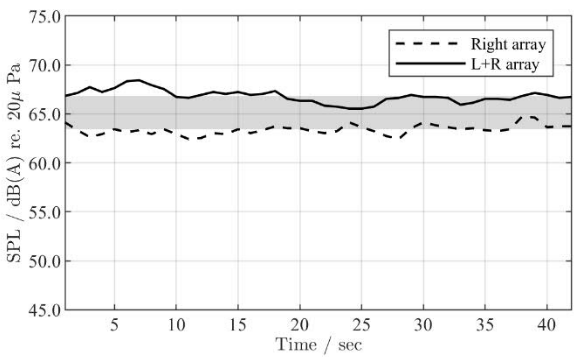

Figure 3: Recorded broadband sound pressure level over time for a single line array and for two line arrays at an exemplary measurement location. The expected 3 dB offset is indicated in grey.

Modelling of subwoofer array

For the low frequencies, roughly ranging from 25 Hz to 200 Hz, measurement results for the subwoofer array were compared with modelling results. At 100 Hz, the nominal transition to the far-field [4] is at about 15 m distance, at 200 Hz it is at 30 m for an array length of $L = 10$ m:

$$R_{\mathrm{Far}} = \frac{L^2}{2\lambda} \qquad [\mathrm{m}] \qquad (1)$$

where λ is the wavelength.

Fig. 4 shows the spatial SPL map for the sub array at the 1/3[rd] octave band of 100 Hz as simulated in EASE 5 [5]. Here each element of the array was modelled individually including directivity and filters applied. It can be seen that around the first radius (marked N) the directional pattern is not entirely stable over distance, indicating that the far-field distance has been reached only approximately. In contrast, the pattern outside of the second radius (marked M, L) seems independent of the distance from the array.

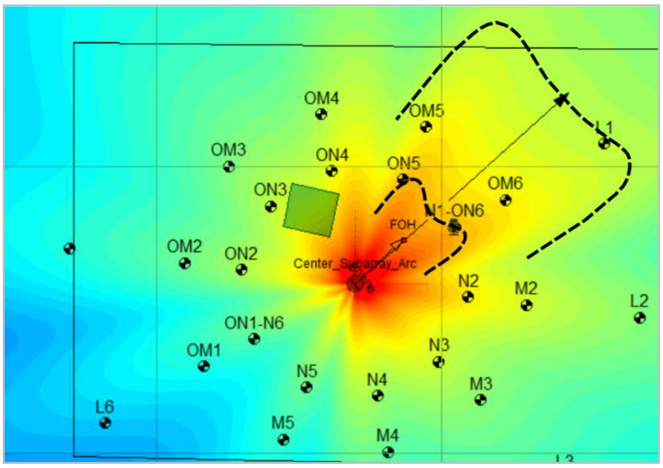

Figure 4: Free-field SPL calculation with a CDPS model in EASE 5 at 100 Hz in 1 dB isoline steps. The subwoofer array is represented by individual elements. Note that the directional pattern becomes fully stable only beyond the 1[st] radius (locations marked N).

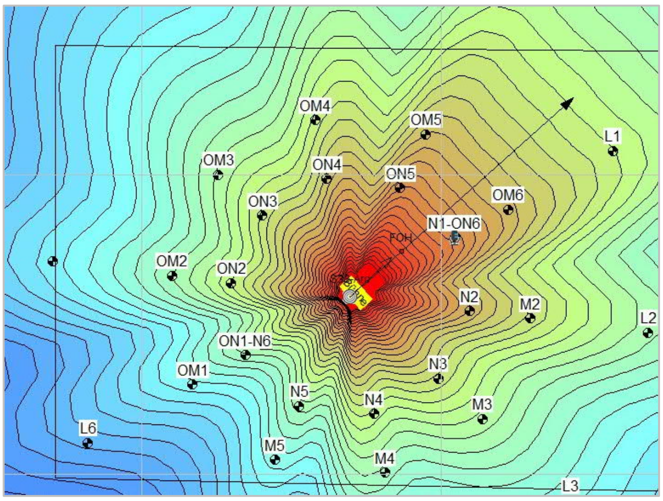

Figure 5: Free-field SPL calculation of a single APS in IMMI at 100 Hz in 1 dB isoline steps.

Fig. 5 shows the same setup in the IMMI software [6] where the array of subwoofers was approximated by a single point source. Accordingly, the directional pattern is constant as a function of the distance. It matches the mapping produced with EASE 5 further away from the array. Including the actual environmental conditions yields the IMMI plot shown in Fig. 6. The changes in the map indicate the strong influence of the terrain profile, reflective and obstructive boundaries as well as other effects not considered in free-field calculations.

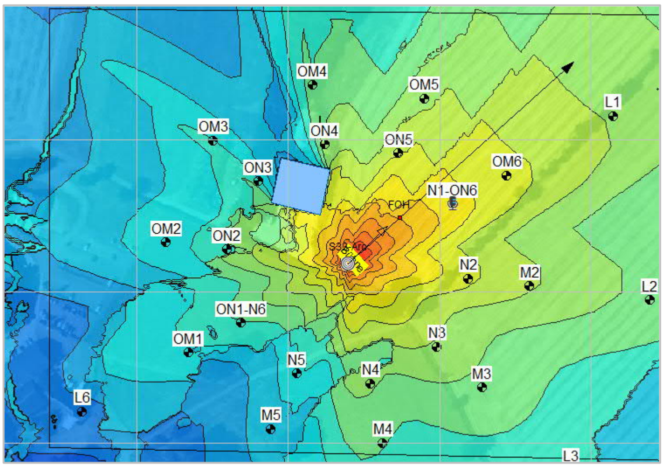

Figure 6: Environmental SPL calculation of a single APS in IMMI at 100 Hz in 3 dB isoline steps.

Subwoofer array as a point source

The point source characteristics of the subwoofer array as well as the transition from near-field to far-field could be verified in the measurement. As an example, the level reduction over the distance from radius R_{M} = 120 m to R_{L} = 200 m is displayed in Fig. 7. The theoretically expected loss of ΔL = -4.4 dB for a point source is well matched by the measured reduction averaged over all directions within the given uncertainty.

$$\Delta L = 20 \log R_{\mathrm{M}} - 20 \log R_{\mathrm{L}} \qquad [\mathrm{dB}] \qquad (2)$$

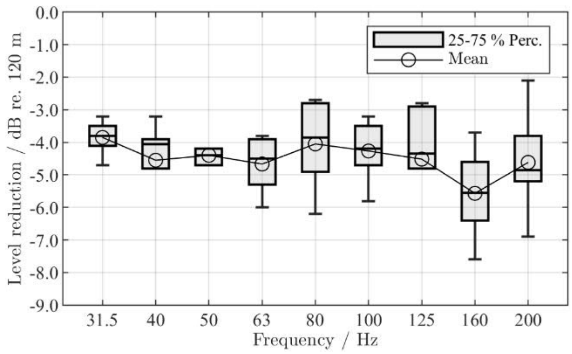

Figure 7: Measured level reduction over the distance from 120 m to 200 m, averaged over all 10 angular directions. The theoretically expected value is -4.4 dB.

Open questions and outlook

The results presented in this and the preceding paper [4] show that with the Aggregate Point Source (APS) approach an accurate substitute sound source model has been proposed, which can represent the radiation behaviour of large sound reinforcement systems and aligns with the calculation methods used in noise immission control. It assumes that the APS in the model are incoherent from each other and that the distances to the PA systems fulfil the far-field criterion. Three frequency ranges can be distinguished, of which the following two have already been analysed: the low-frequency range, where only the subwoofers emit relevant energy, and the mid/high-frequency range, where only the line arrays emit relevant energy. For these frequency ranges, the far-field conditions are generally given at distances that are relevant in practice.

There is a need for further research in the crossover frequency range, where all loudspeaker systems radiate relevant energy and thus influence the radiation behaviour. However, the error for the relevant result parameter of the A-weighted sum level can be classified as negligible: for typical excitation spectra (e.g. rock/pop), prediction errors in the 1/3rd octave bands from 80 Hz to 160 Hz of ± 10 dB cause deviations in the overall A-weighted sum level of significantly less than 1 dB. With regard to the assessment of low-frequency noise immissions (e.g. on the basis of DIN 45680 [7]), this frequency range will again be given special attention in a subsequent study. For future research, the question should be addressed as to what extent the coherence of the sources in typical outdoor situations can be described as a function of the source spacing, the distance of the receiver from the source, the frequency and the assessment time.

Irrespective of these still pending investigations, the consortium of this paper considers the proposed APS approach to be a practice-relevant method that adequately meets the accuracy requirements of noise immission control, already. The working group aims to draw up a recommendation for action that describes the entire process from electro-acoustic planning and the use of the source model, including frequency-dependent power adjustment, to the determination of the rating levels.

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