CONSIDERATION OF COMPLEX LOUDSPEAKER SETUPS, INCLUDING PHASE EFFECTS IN THE FRAME OF ENVIRONMENTAL NOISE PREDICTIONS ON THE BASIS OF THE ISO 9613-2 AND THE NORD2000.

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1 INTRODUCTION

In the past the main focus of loudspeaker producers and of electro acoustical planners was an efficient and high quality soundscape in the audience areas. The setup was optimised to guarantee the best sound quality for the licensers. With the increasing number of open air events and at the same time the growing numbers of participants, the noise levels in the surrounding increased together with the number of affected inhabitants complaining about such events. Therefore there is a need for tools to plan those event not only to assure the best quality for the spectators, but also to minimize the noise levels at the surroundings at the same time.

1.1 Loudspeaker setup

There are several acoustical indicators that are used to describe the sound quality at a concert. One of the main goals at an open air event is to have an equal sound pressure level distribution and an equal frequency response over the audience area. This means, the ideal loudspeaker setup would produce an equal sound pressure level at any position in the audience, with possibly a slight drop towards the back of the audience. That's quite difficult to achieve, since the sound pressure level decreases with the distance from the speaker. The common ways to create an even sound pressure level distribution across the audience and at the same minimize the disturbance to the surroundings are the following:

- using speakers with strong 3-dimensional directivities
- using multiple coherent sources
- time delays between single speakers to create a sort of a beam steering.

1.1.1 Coherency

The strongest effects due to the coherency of noise sources are observed if the signals are completely in phase or out of phase (180° phase shift). For these two cases the result for two identical overlaying point sources will produce a level increase of 6 dB, or the complete extinction. Most other noise types (no loudspeakers) that we normally encounter in the field of environmental acoustics, are considered as incoherent noise sources. Doubling the number these incoherent sources leads to an addition of 3 dB (diffuse addition) and not to a maximum addition of 6 dB, which is the maximum addition for two coherent loudspeakers. This means that two loudspeakers with coherent sound signals produce the same sound pressure level compared to a single cabinet with only half the electrical input, which means they are twice as efficient as a single cabinet. Leading to less cabinets and less amplifying power.

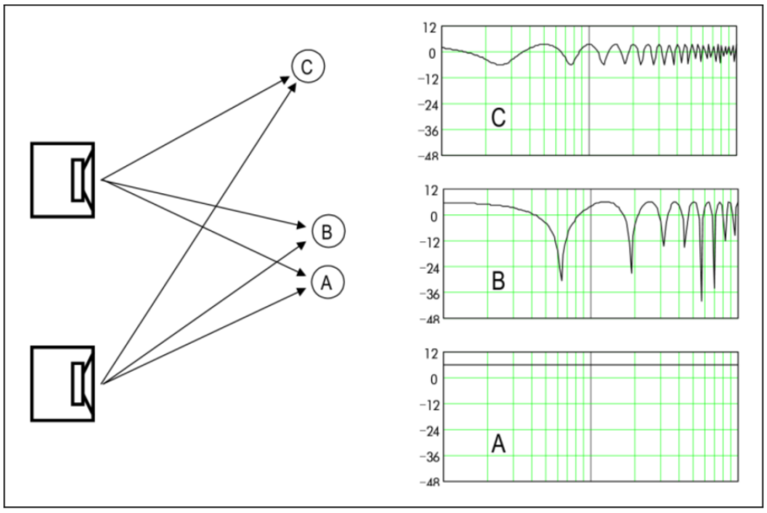

Figure1. Comb filter effect from two subwoofers with same signals for different receiver positions [1]

If the distance of a receiver point is different for two loudspeakers with identical signal, the so called comb filter effect will occur (Figure 1, receiver point B). The effect occurs since the phase shift is different for the different frequencies and is strongest if the level (amplitude) of the signal is similar (compare point B with point C). The comb filter effect will decrease if the array (multiple stacked speakers) becomes longer.

1.1.2 Loudspeaker position and directivity

The importance of positioning of loudspeakers is explained in Figure 2, showing a loudspeaker generating a sound pressure level in 1 m distance of 110 dB.

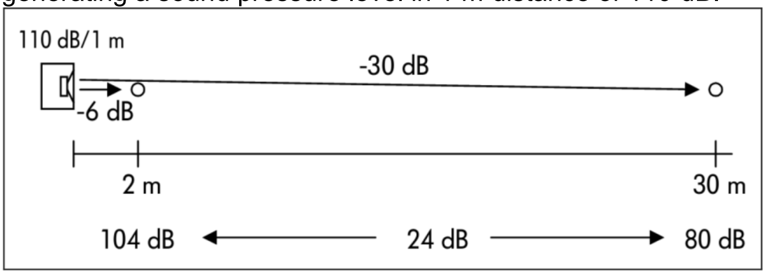

Figure2. Distance related level drop along the audience area [1]

If we assume the first spectators in a distance of 2 m from the loudspeaker and the last at 30 m the level difference between the two listener positions are unacceptable high with 24 dB. A solution to equalize the distances and at the same time the level is by elevating the loudspeaker above the audience.

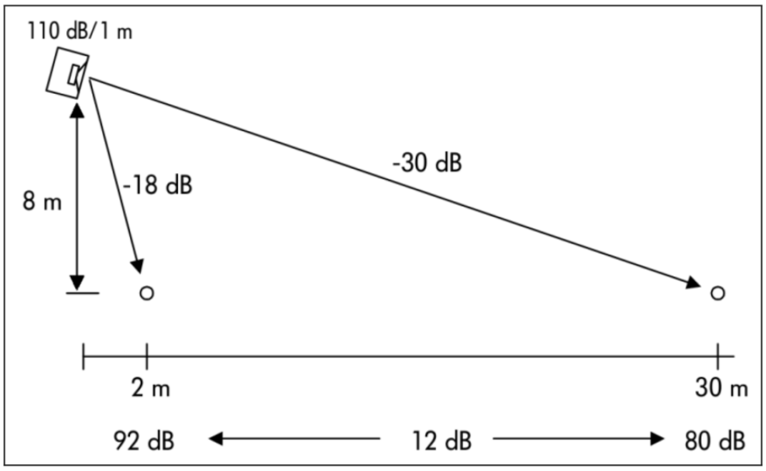

Figure3. Improved coverage with a “flown” speaker system [1]

By elevating the loudspeaker 8 m above the audience the level difference between the first and the last row of the spectators reduces to a reasonable value of just 12 dB (shown in Figure 3).

Another circumstance can be used to produce a more constant noise exposure over the area of the audience and this is the use of the vertical directivity of a loudspeaker system.

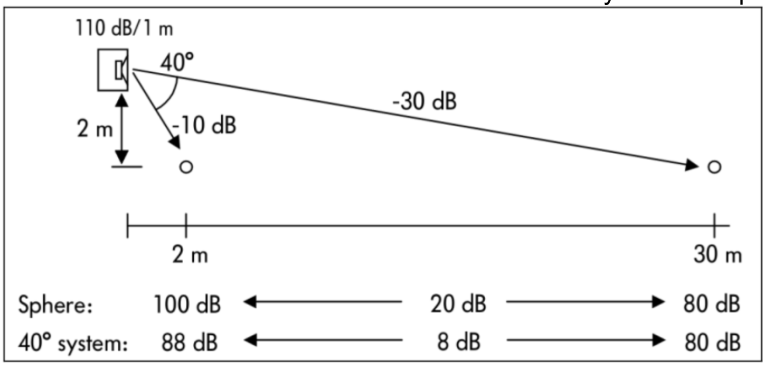

Figure4. Improved coverage with a vertical directivity design [1]

1.2 Environmental noise prediction

The approval procedures of open air events are handled more and more stringent by public bodies since more and more complains are encountered. Especially in highly condensed countries like Germany such events can only take place if the organizers can prove that the produced noise levels in the surrounding will be below the allowed limit values. Unfortunately the people doing the acoustical stage layout are normally not the same who are in charge to do the environmental noise predictions. This leads very often to a difficult interface and sometimes misleading communication between the two parties. The main problems can be summarized as follows:

- Bad communication - not all relevant information is available and is transferred between the planners.
- Not all acoustical parameters used during the layout of the loudspeaker setup can be used in environmental noise prediction models (for example delays).
- Environmental noise prediction can use noise sources with frequency dependent 3-dimensional directivities, which are independent on the distance to the source.
- Any effects based on wave interference cannot be treated by typical environmental noise prediction software and are therefore ignored.

This means most of the relevant source descriptors could be handled by noise modeling software. The main exception are wave interference effects, causing different "directivity patterns" for different distances.

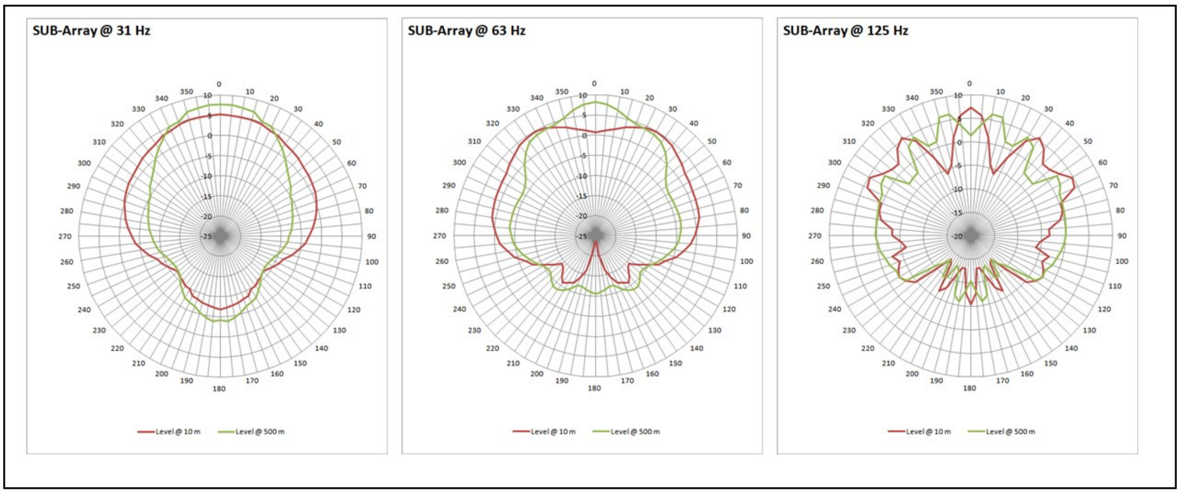

Figure 5: "Directivity pattern" of a SUB-array over the distance for different frequencies

These phenomena are not considered in the common noise propagation standards like the ISO 9613 [2] or the Nord2000 [3].

2 GOALS OF THE COLLABORATION

With ArrayCalc from d&b audiotechnik GmbH there is a powerfull tool available to design the loudspeaker setup and to calculate the sound distribution in the listening area. The software is not designed for long distance calculation and is not usable for noise predictions in the surrounding, since for the spreading only the distance is taken into account. Screening effects and/or reflections are not treated. On the other hand the software considers in detail the loudspeaker setup and interference effects happening between the different speakers.
SoundPLAN® from Braunstein + Berndt GmbH is one of the leading software products in the field of environmental noise prediction for over 25 years. All common noise prediction standards worldwide (around 40 different standards) are implemented in the software. These are for example the ISO 9613, part 2 [2] which is worldwide the most frequently used standard for industrial related noise mapping projects and also the Nord2000 [3], which is considered one of the most advanced standards available in the field. Unfortunately none of these standards describes how to handle phase effects caused by the setup of the source, for example, a loudspeaker array.
With the collaboration between d&b audiotechnik GmbH and Braunstein + Berndt GmbH we tried to close this gap in the available mapping tools. The goal is to predict the noise levels in the surrounding of a stage using SoundPLAN®, while taking into account all specific loudspeaker setups already defined in ArrayCalc, including complex directivities and delays. For the calculation of the sound propagation, the ISO 9613, part 2 [2] and the Nord2000 [3] were adopted to be able to consider coherency effects.

2.1 Data exchange

Loudspeaker setups designed and optimized in ArrayCalc are saved as *.dbac files. They contain all relevant information on which loudspeakers and how many are used, the mounting, the three dimensional orientation, the relative level difference and the time delay of each speaker.

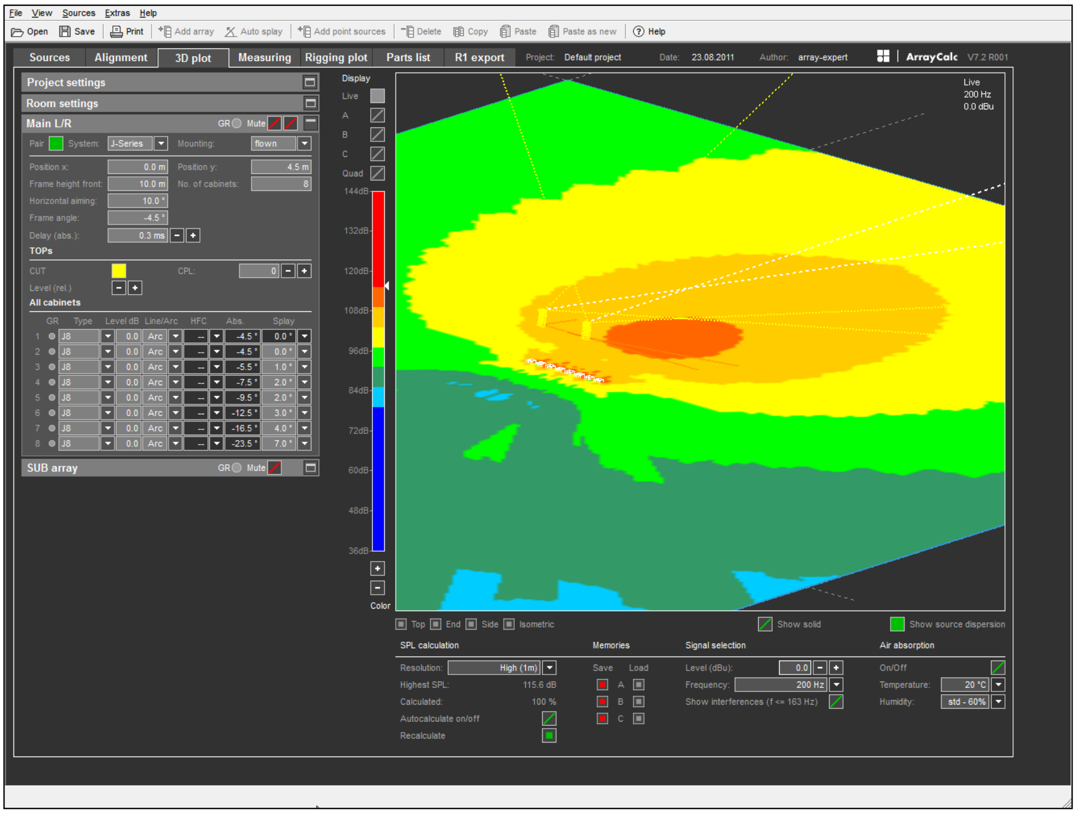

Figure 6: Typical stage setup defined in ArrayCalc

These setup-files from ArrayCalc can be loaded and combined with a typical environmental noise model in SoundPLAN®. Additionally, the direction in the global coordinate system, the frequency spectra of the radiated sound and the time histogram (activity of the source over the day) are defined for every source.

2.2 Enhanced ISO 9613-2 and Nord2000

In order to use all the information coming from ArrayCalc the existing calculation procedures of the ISO 9613-2 [2] and the Nord2000 [3] where enhanced and are now able to consider coherency effects. The data from ArrayCalc is transferred, translated and rotated from the local coordinate system to world coordinates. The array will be represented by a number of loudspeakers with defined delay and relative geometrical position. Each loudspeaker is represented by a number of point sources. 3 point sources were used for each subwoofer system, in this case J-SUB, and either one point source with a 3D complex directivity with 5°resolution for each fullrange system, if the CDPS model is used, or 17 points forming a wavefront, each with a complex horizontal directivity, if Huygens principle is used [4].

For each point source the sound pressure level according to the chosen standard will be calculated as real number:

$$Lp_i = Lw + DI + Adiv + Aair + ... \quad (1)$$

$$p_i = 10^{(Lp_i/20)} \quad (2)$$

DI is the (horizontal) directivity of the point source.

Normally the pressures would be summed energetically:

$$Lp,tot = 10 \cdot \log \sum (10^{(Lp_i/10)}) \tag{3}$$

$$Ptot^2 = 10^{(Lp,tot/10)} = \sum p_i^2 \tag{4}$$

To consider the relative phase between the sources it will not be summed energetically but using complex summation. The contributions of each source will now be complex numbers:

$$p_i = 10^{(Lp_i/20)} \cdot e^{(j \cdot (k \cdot r + \varphi 0))} \tag{5}$$

$$Ptot = \sum p_i \tag{6}$$

$$Lp,tot = 20 \cdot \log(|Ptot|) = 20 \cdot \log((Ptot \cdot Ptot^*)^{0,5}) = 10 \cdot \log(Ptot \cdot Ptot^*) \tag{7}$$

Whereas:
k = 2*pi/λ
r = (curved) propagation path between source and receiver
φ0 = phase shift due to loudspeaker controlling (delay) and directivity
The speed of sound depends on meteorology (temperature) and therefore also the frequency.

This complex summation is performed for each of the main arrays and for the bass array. The levels of these three contributions are summed optionally complex for frequencies ≤ 160 Hz (assuming mono signals), while the level contributions of each array are always summed energetically for higher frequencies.

3 VALIDATION

The loudspeaker data and the calculation procedure used in ArrayCalc is very well validated over the past years against hundreds of real setups and can be assumed to work very well for the spectator areas. For this reason we used the results produced by ArrayCalc in the first step to validate the implementation in SoundPLAN®. This was done for four different speaker setups. In both software we calculated noise maps with a grid distance of around 1.5 m.

3.1 One subwoofer

In this case one subwoofer of the J-series of d&b audiotechnik GmbH was used. Below in figure 7 the calculated result for a frequency of 50 and 125 Hz is shown. The calculated noise levels from SoundPLAN® are shown as colored areas and the results of ArrayCalc are represented by the black ISO-lines of equal levels. As expected the two results fit very well to each other and nearly no deviation is observed.

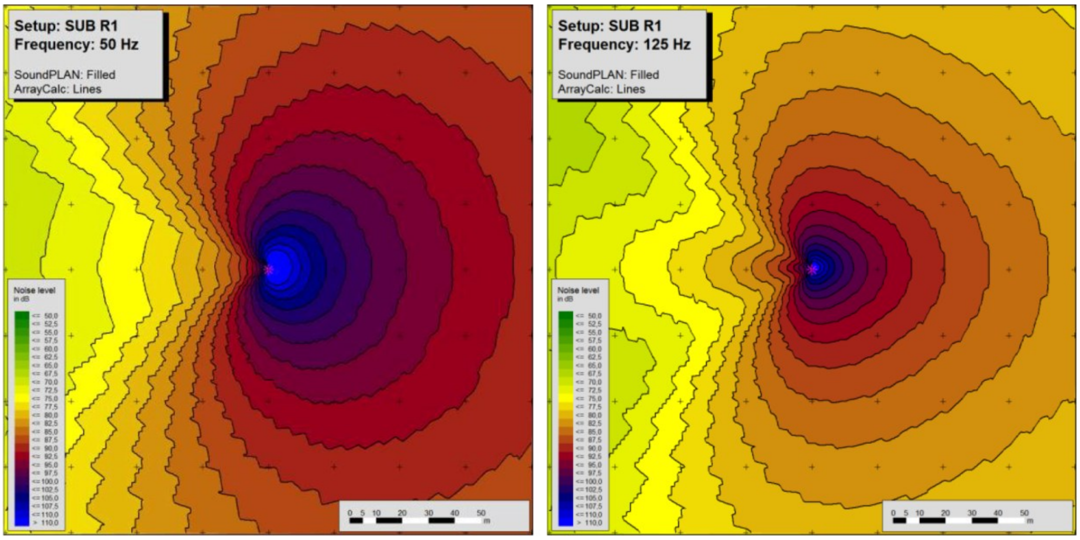

Figure 7: Noise levels for one single subwoofer of the J-series

3.2 Array of subwoofers

For this test case an array of 6 subwoofers of the J-series of d&b audiotechnik GmbH was considered. There was a distance of 2 m between the single speakers and the delay between the two center subs and position 2 and 3 to the left and the right was 1.1 and 4.5 ms.

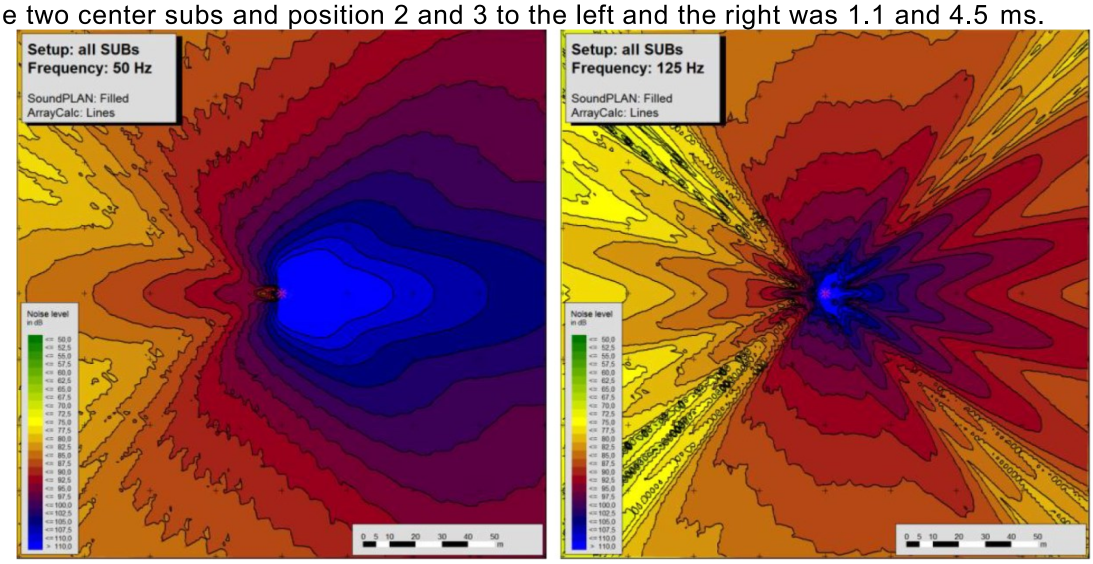

Figure 1: Noise levels for an array of 6 subwoofers of the J-series

Again there are nearly no differences between the results of the two calculation software.

3.3 One main array

Such a main array consists of 8 speakers of the type J8 positioned above each other. The array is located 4.5 m to the left of the center of the stage in a height of 10 m. Between the single speakers the angle of inclination changes from -4.5° for the top speaker down to -23.5° for the lowest speaker.

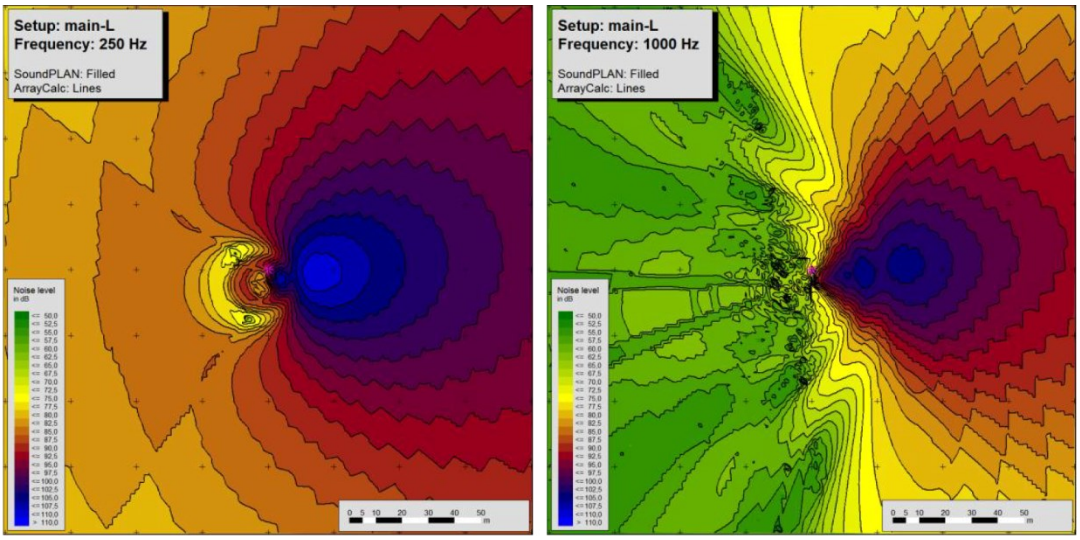

Figure 9: Noise levels for one main array of the J-series

3.4 Complete stage

For this setup we have a combination of the subwoofer array and the two main arrays (left and right side of the sub array). The setup of the single speakers is the same as described in the previous paragraphs.

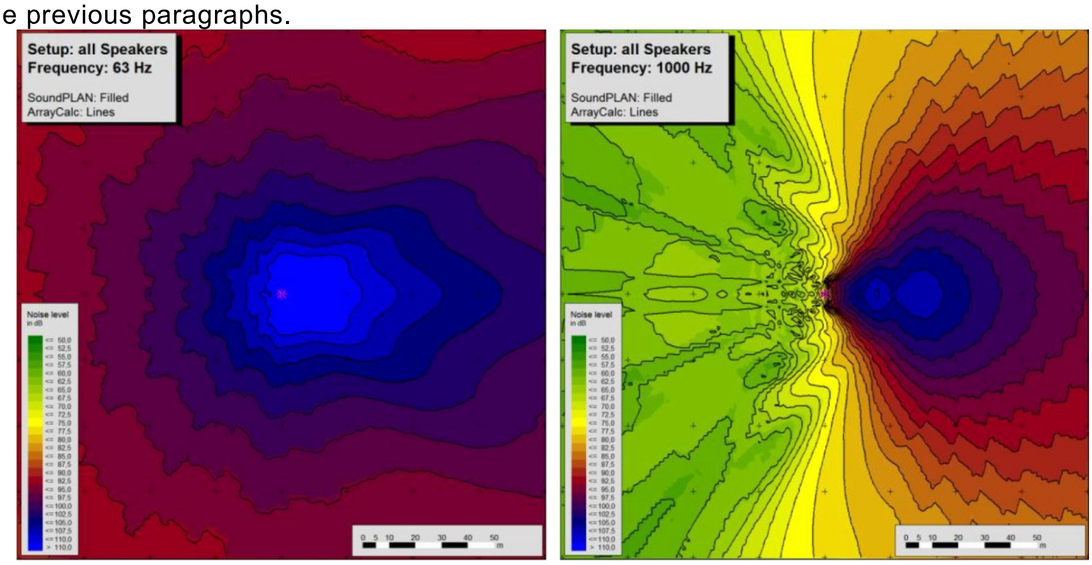

Figure 10: Noise levels for a complete stage with speakers of the J-series

4 IMPACT ON NOISE PREDICTION

With the more detailed information about the loudspeakers, directly based on the loudspeaker manufacturer and the precise stage layout, the source modeling is more reliable and less prone to errors. In addition we achieve with the consideration of the phase effects more reliable predictions in the surrounding of the stage. To show this effect we compared two models of such a stage setup:

- The first one (conventional approach) is based on simple assumptions, each loudspeaker is described with a single point source and no interference effects are considered for the calculation of the spreading.

- The second calculation (advanced approach) includes a complex definition of the stage (import from ArrayCalc) and the consideration of phase effects.

The below picture 11 shows that for 50 Hz the noise level in the surrounding decreases, apart from a small angle behind the stage, with the second, the complex prediction method, if we have the same noise level in the spectator area (35 m in front of the stage). This means that with such a complex setup and prediction method it will be easier to fulfill the noise limits in the surrounding, since the simple, standard approach is overestimating the expected noise levels in large areas.

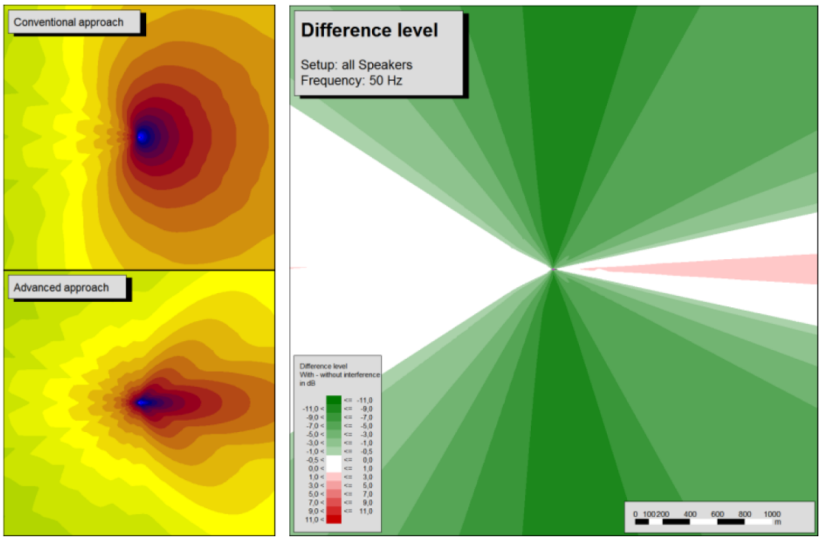

Figure 11: Noise levels in the surrounding for a complete stage at 50 Hz calculated with the standard and the advanced approach

For another typical frequency of 1.000 Hz we get the results shown in Figure 12. In this case the simple approach is overestimating the noise levels mainly in front and behind the stage. Only in an angle opening of around 30° perpendicular to the stage the noise levels are increasing with the advanced prediction compared to the simple standard approach, which could lead to an exceeding of the noise limits if we would rely on the simple, but commonly used method.

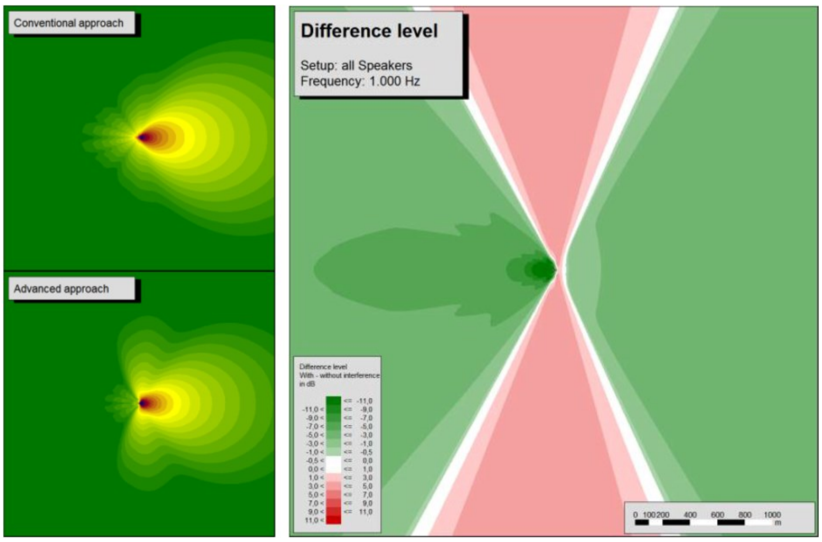

Figure 12: Noise levels in the surrounding for a complete stage at 1.000 Hz calculated with the standard and the advanced approach

5. LIVE MEASUREMENTS

In this section some preliminary results of the live measurements are shown.

The measurements were performed at Wacken Open Air, a large festival in Germany. During the festival measurements were taken at various points around the stage, located from 500m to 1500m away from the stage. We have compared the calculations made in ArrayCalc with those made in SoundPLAN® and with the measurements.

Figures 13-15 shows the SPL distributions calculated in ArrayCalc and SoundPLAN® within an area of 2x2km around the stage.

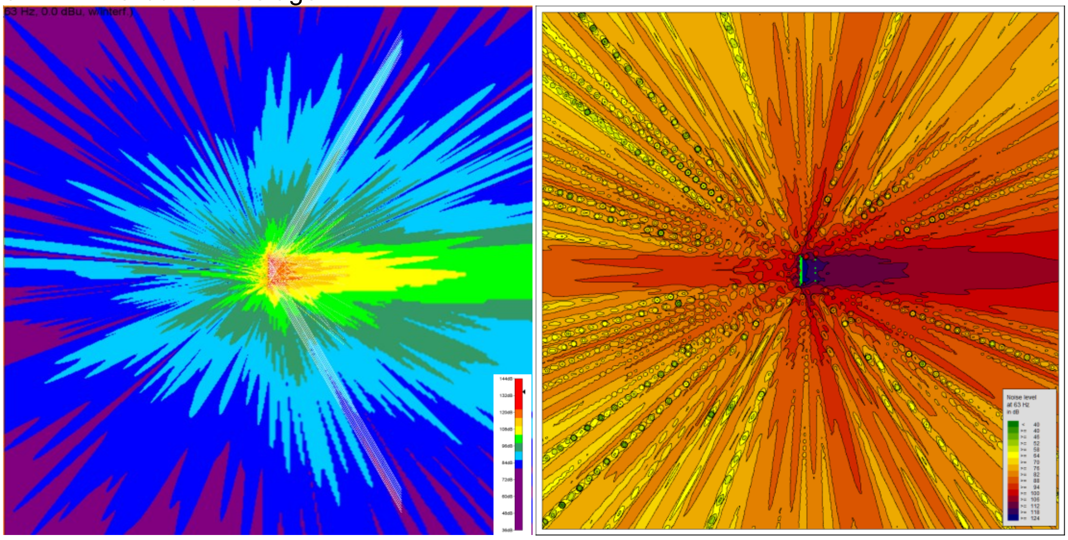

Figure 13. Sound pressure level distribution calculated in ArrayCalc (left) and SoundPLAN® (right) at 63 Hz

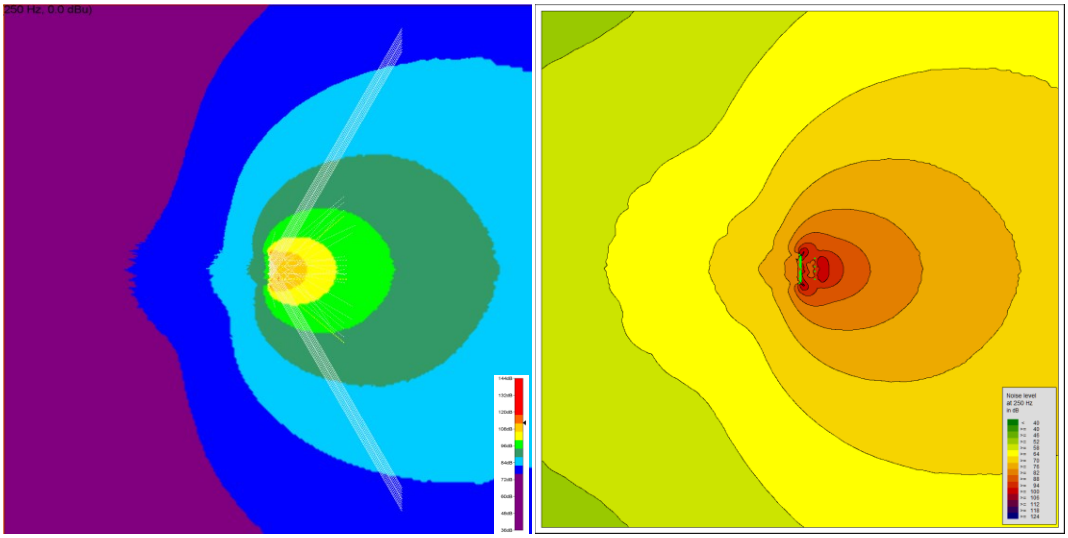

Figure 14. Sound pressure level distribution calculated in ArrayCalc (left) and SoundPLAN® (right) at 250 Hz.

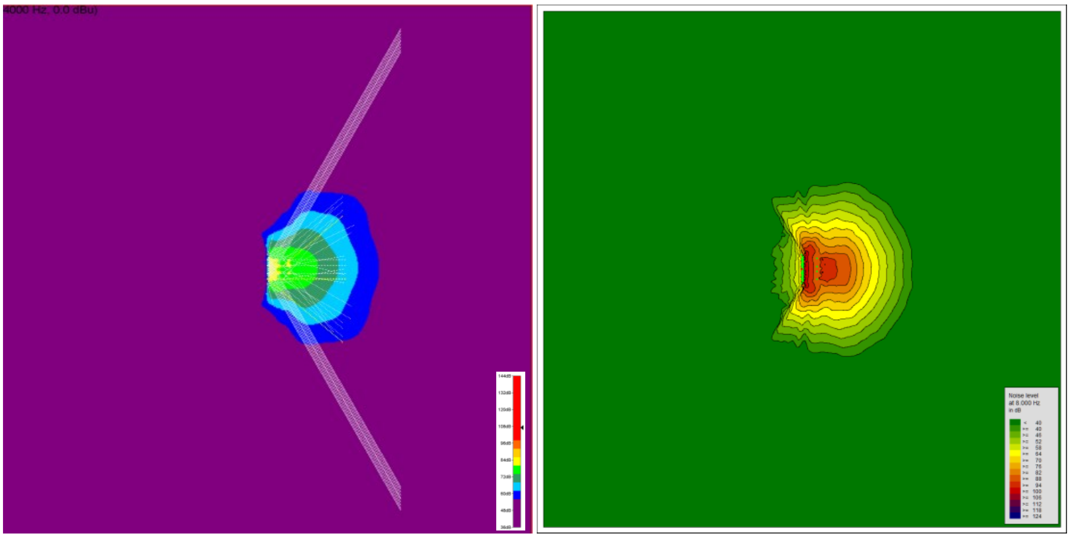

Figure 15. Sound pressure level distribution calculated in ArrayCalc (left) and SoundPLAN® (right) at 4000 Hz.

The measured values of Lp (A-weighted) and corresponding values, calculated in SoundPLAN®, along with the values at the front of house and the distances to it, are shown in the Table1.

Position N	**Distance to FOH (m)**	**Lp (dBA) measured**	**Lp (dBA) calculated**	**Lp (dBA) FOH**
P1	1296	64,7	63,7	106,3
P2	1462	54,5	61,7	105,9
P3	1397	60,1	59,4	105,6
P4	885	65,7	68,4	107
P5	817	62,1	70,3	104,9
P6	456	60,7	71,1	80,8

Table 1. measured and calculated values of Lp (dbA) at Wacken Open Air.

6. OUTLOOK

After the first validation of the complex summation model, the method has to be tested at various open air events. Various setups have to be considered, including complex festivals with several stages. The influence of the program material spectrum has to be taken into account, too.

5. CONCLUSIONS

With the implementation of the direct use of loudspeaker setups and the consideration of phase effects, the gap between loudspeaker producer / stage planners and environmental acousticians has become smaller. It is possible now to predict precise noise levels in the surrounding of open air events without any friction losses between the two planners. The results are beyond the former possibilities of typical noise mapping software and allow a much better evaluation of the expected noise in the surrounding. This will lead to an easier evaluation of a stage setup not only fulfilling the planers requests in the audience areas but also in the surrounding, making it easier to compare the different setups. This will help to choose the more efficient sound system taking the phase effects into accounts, avoiding at the same time prediction errors, which might cause the exceeding of the limit values in the surrounding.

5 REFERENCES

1. Basic Electro Acoustics and Sound Reinforcement (04 / 1998), d&b audiotechnik GmbH.
2. ISO 9613-2, Attenuation of sound during propagation outdoors - part 2: General method of calculation (1996).
3. Nord2000, A General Nordic Sound Propagation Model and Applications (Group Nordic Noise, 31 December 2001).
4. Stefan Feistel, “Modeling the radiation of modern sound reinforcement systems in high resolution”, 2014