Comparison of various Array Geometries with Respect to their Depth of Field for acoustic Mappings

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Introduction

The use of microphone arrays for the localization of sound sources with beamforming methods has found a broad range of applications in many industrial and research areas. With the basic method of classical delay-and-sum beamforming, the array will be successively focused on many different locations lying on a virtual measurement plane, as shown in Figure 1. For every individual focal point on this plane, the relative runtime delays between the microphone channels are compensated for. For the Acoustic Camera, this has always been done by completely calculating the correct euclidian distances between the actual focus point and every microphone within the array. Then, coherently adding up the shifted microphone signals and normalizing for the channel number results in an estimated time function for the current focus point for which the effective sound pressure level can be easily determined. Scanning the measurement plane point by point and colour-coding all the different resulting sound pressure values gives the well known planar acoustic beamforming mappings (acoustic photos).

In the sequel, we will point out the importance of a correct focal distance for planar mappings with structured objects as well as for 3D-mappings. Simulations for various 2D and 3D array geometries will be given. To demonstrate the observed effects in practice, a measurement example will be shown in addition to the simulations.

The Focus Problem

While planar mappings are sufficient in many cases, more advanced, modern beamforming systems actually map on 3-dimensional surfaces [1][2]. Therefore, simply using a plane for the calculations is no longer an adequate geometric model assumption.

This situation is demonstrated in Figure 2, where the placement of a small, transparent 3D-array inside a car leads to strong individual distance variations between different focal points on the 3D model's surface [3]. Here, simply mapping onto just a few planes instead of using the complete model would introduce severe geometrical errors and would hence give totally misleading beamforming results!

This also holds when planar arrays and a planar map are used but the device under test has a noticable geometrical structural depth. The effects of these incorrect calculation distances with respect to the actual distance to the object's surface depend on many factors such as the average measurement distance, signal frequency, array size and array pattern, as well as on the amount of the structural depth variation over the object's surface itself.

Because these relations are very complex due to the three-dimensional nature of the array patterns even in the simple case of planar arrays, an analytical treatment of the problem is not possible. Instead, we performed a simulation study for the comparison of different array geometries with respect to their depth of field [4]. The simulations include common planar array geometries and both of our 3D spherical arrays. Despite the restriction that the simulations assume perfect free-field conditions they give valuable insights into the focus problem and serve to clarify and better quantify those effects that have not received enough attention in the past.

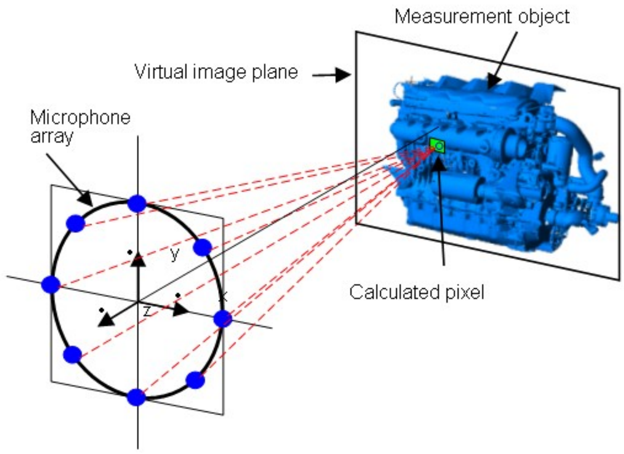

Figure 1: Classical 2D-beamforming focusing on individual points on a virtual measurement plane. This approach does not consider the effects of the actually 3-dimensional object surface structure.

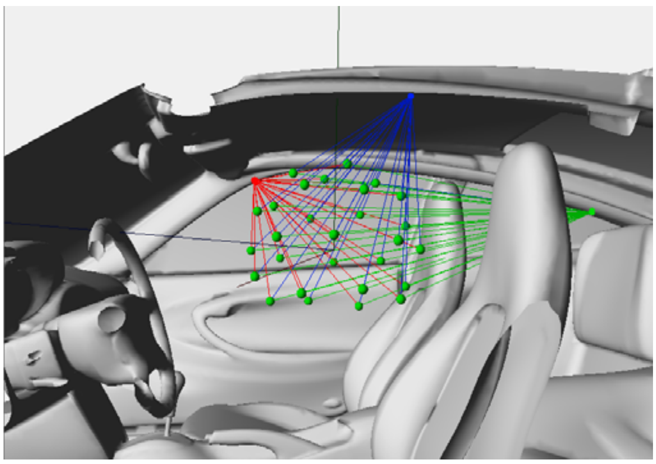

Figure 2: The typical measurement setup scenario in car interiors exhibits huge individual distance variations of the various focal points which demand a correct focus distance determination for successful 3D-beamforming.

Array Geometry Comparison

The following five arrays were simulated: First, as part of our own array set, the standard ring array with 48 channels and 70 cm diameter, a smaller transparent spherical array with 48 channels and 35 cm diameter and a bigger spherical array with 120 channels and 60 cm diameter. Second, as an example for common array geometries, a planar spiral-like array with 48 channels and 70 cm diameter, where the microphones are logarithmically distributed along the arms which are slightly curved parabolically. In addition, the same spiral array was simulated as a threedimensional structure, where the arms were folded inwards relative to the array plane for 30 degrees.

In the simulations, a single broadband point source (white noise) was placed directly in front (-z-direction) of the arrays except for the ring array, where the source position has been shifted by the amount of the ring radius (35 cm) in x-direction, because otherwise the ring array would not show any focus dependence at all. While the true focus has been kept fixed at the source distance of 1 m, the (intentionally false) focus actually used for the beamforming calculations varied from 20 cm up to 2 m in steps of 10 cm.

The sampling rate in all simulations was 48 kHz only. In a first step, the usual planar beamforming maps of the sound pressure distributions have been calculated for each array type and for each focus value. Therefore, all the acoustic maps for the true 1 m focus had to be recomputed using all the wrong focus distances in 10 cm steps.

The acoustic photos were computed for the broadband case (100 Hz to 20 kHz) as well as for the five frequency bands as shown in the Figures below. The different frequency bands were extracted using the white noise results and applying appropriate narrowband FFT bandpass filters for the computation of the spectral acoustic photos. In each individual acoustic map, simply the displayed maximum sound pressure value (peak value at the source position) was determined. No deconvolution or other postprocessing has been applied.

In a second step, the resulting sound pressure maxima for the false foci were then related to the absolute maximum which of course always occurs at the true focus distance (1 m). As a result, the relative difference to the true sound pressure maximum in dB (re 20 µPa) as a function of the calculation focus distance is shown in the curves below. Please note the different scalings of the y-axes for the various array types.

For the smaller of the two spherical arrays, an additional simulation series with a reduced true focus of 0,5 m was performed to investigate a more realistic near-field situation similar to that in Figure 2. Figure 3 and Figure 4 show the simulation results for the 48 channel sphere and a true focus of 0.5 m and 1 m, respectively. Figure 5 shows the result for the bigger 120 channel spherical array and 1 m true focus.

All the threedimensional arrays have a remarkably strong dependence on the calculation focus used. This effect is the stronger the shorter the true distance becomes (see Figure 3). Also, the focus dependency is more pronounced for the higher frequencies, but it still remains very important for broadband signals too, so it must be generally taken into consideration for all 3D arrays. This confirms the necessity to use CAD models for successful 3D beamforming.

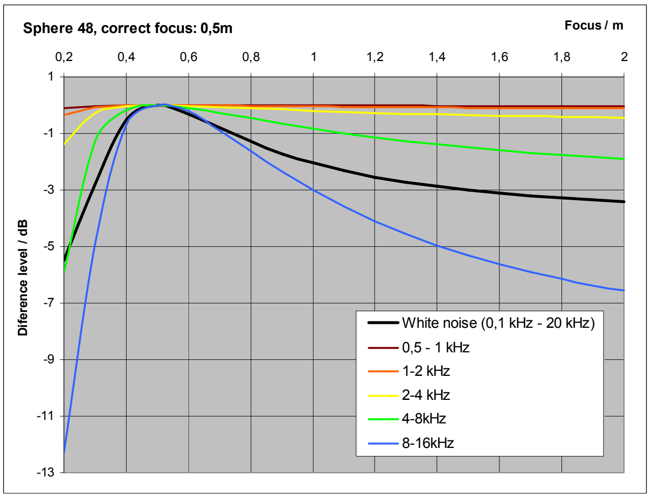

Figure 3: Sphere 48 at 0.5 m distance. Relative decrease in maximum sound pressure level as function of focus.

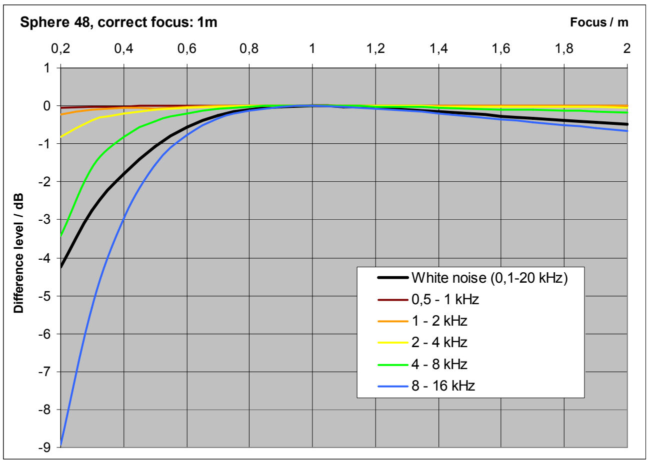

Figure 4: Sphere 48 at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

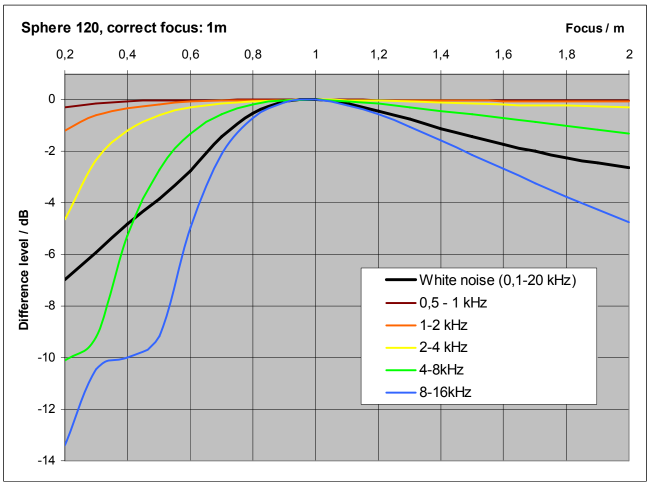

Figure 5: Sphere 120 at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

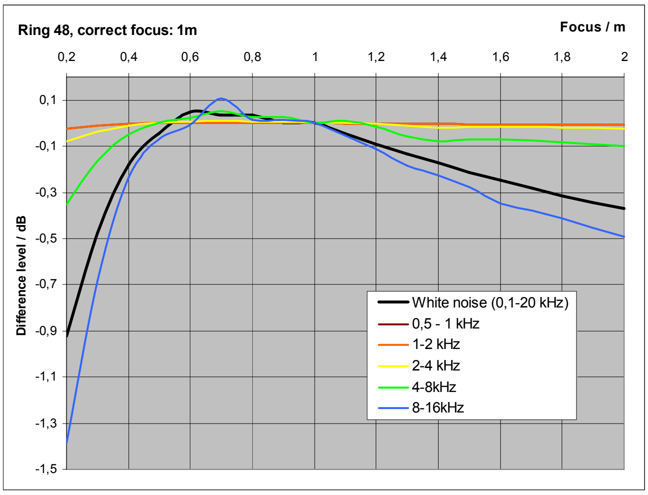

Figure 6: Ring 48 at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

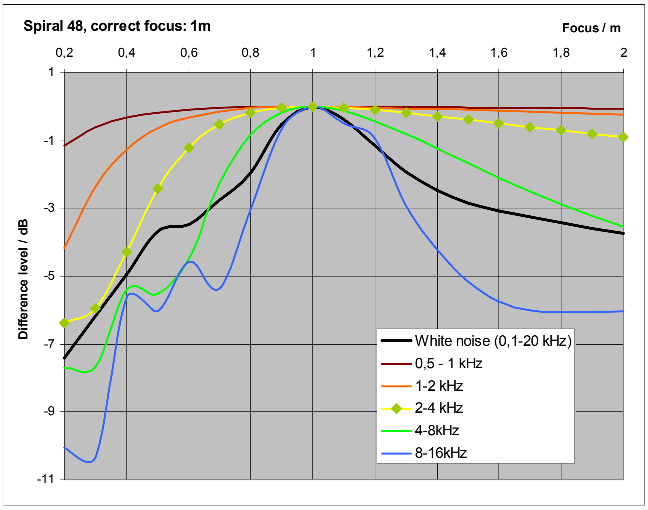

Figure 7: Spiral 48 (planar) at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

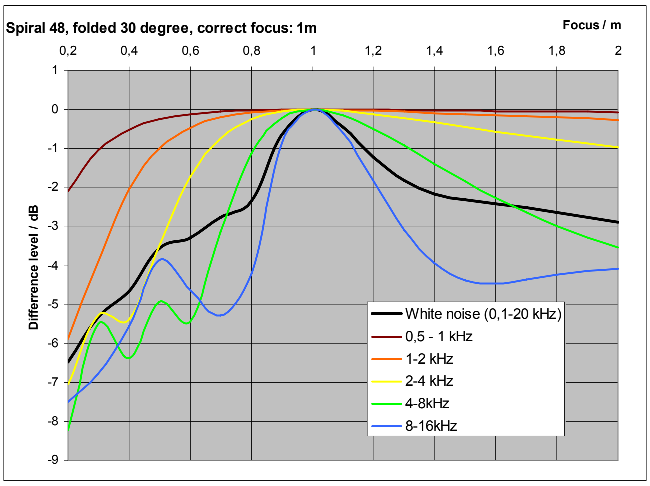

Figure 8: Spiral 48, folded 30° at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

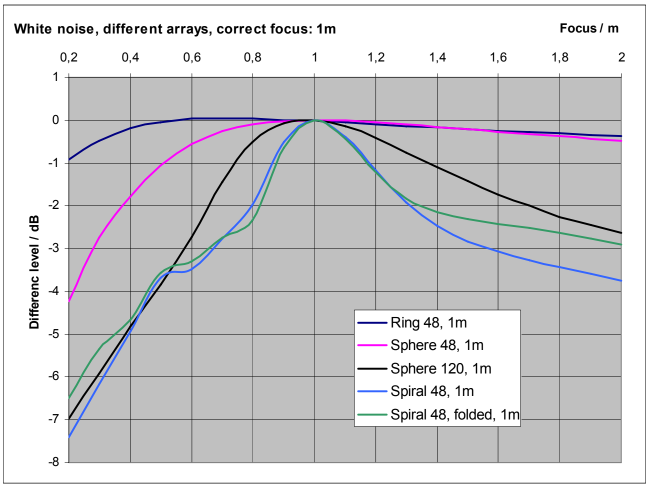

Figure 9: Array comparision (100 Hz to 20 kHz) at 1 m distance. Relative decrease in maximum sound pressure level as function of focus.

The result for the 48 channel ring array is shown in Figure 6. Only for very short calculation focus and for the higher frequencies, the ring has a noticable focus dependency, whereas for all the other frequencies the ring array is extremely robust with respect to focus variations. The physically unsound, small +0.1 dB overshoot at 0.7 m calculation focus may be due to rounding effects in the computation of the beamforming maps. Note also the much smaller scaling of the y-axis in comparison to the other diagrams.

Contrary to the ring, the two spiral arrays again exhibit a remarkable focus dependence, see Figure 7 and Figure 8, which is even comparable to the 3D-arrays in its order of magnitude. The behaviour in the 8 kHz to 16 kHz band is more variable as it is for the other array types.

In order to get a better impression of the overall behaviour of the various arrays in relation to each other, Figure 9 gives an array comparison for the broadband case, using a common y-axis-scaling for all level difference values. While the level derivations for the ring stay below -1dB, the other array types are much less robust. Especially the spiral-shaped arrays show relatively narrow peaks around the true focus. For all arrays, again, the level decrease for too short a focus is stronger than with a calculation focus that is too large.

Measurement Example

As a check we intended to verify the practical relevance of the simulation results by means of some simple loudspeaker tests. Because the simulations always assumed perfect free-field conditions, these measurements were performed in an anechoic chamber. The speakers used were two active Hifi monitor boxes (Tannoy) that were level-matched as good as possible using a Norsonic SA 110 sound level meter with a Nor 1220 type capsule. The small 48 channel (35 cm diameter) sphere array was used to investigate especially the effects for the shorter distances. The left box was placed only 0.3 m in front of the array, and the right box was placed at a distance of 0.5 m. The results are shown in Figure 10 and Figure 11.

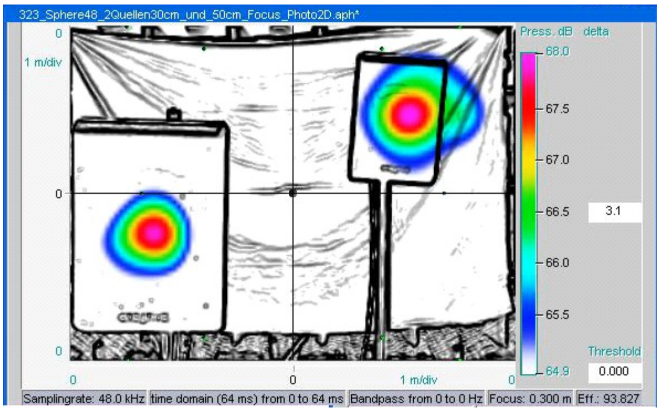

Figure 10: Sphere 48, true source distances are 0.3 m and 0.5 m. The focus used in the beamforming calculation was 0.3 m. Both sources are still visible at 3.1 dB image contrast.

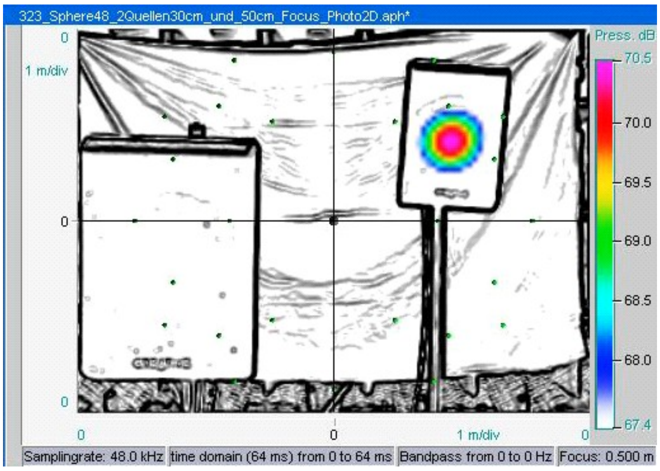

Figure 11: Sphere 48, true source distances are 0.3 m and 0.5 m. The focus used in the beamforming calculation was 0.5 m. In this case, at 3.1 dB image contrast the nearer source virtually vanishes.

Each speaker was excited with an independent white noise signal. In Figure 10, both speaker boxes will be displayed in the acoustic map as the calculation focus of 0.3 m is the true distance for the left box, and the decrease in level for the box at the greater distance is not too strong. On the other hand, in Figure 11, for the 0.5 m calculation focus, the nearer source will now be dropped at about 3 dB image contrast. This result is in good accordance with the data from Figure 3 that suggest that for the Sphere 48 channel array especially the short distances are sensitive with respect to focus errors.

Summary

A simulation study to investigate the sensitivity of various array geometries with respect to errors in the focal distance used for beamforming calculations was presented.

While the simulations assume some simplifications as perfect free-field conditions and no occurence of frequency-dependent amplitude attenuation, they could nevertheless clearly demonstrate that the beamforming focus is a very important issue for 3D-mappings as well as for the usual planar mappings.

All array types show a remarkably strong dependency on the focus which is more pronounced for higher frequencies. Only the simple ring geometry is quite robust against focus errors, which is to be expected due to its nearly perfect radial symmetry.

For the acoustically transparent spherical arrays, the focus dependency is much more relevant than for the ring, and it gets even stronger for shorter measurement distances. The results for the sphere arrays confirm the fact that for a successful 3D-beamforming it is necessary to have complete knowledge of the correct object geometry, i.e. to use CAD-models of the tested device, especially in case of interior measurements in cars or in smaller rooms.

The spirally shaped arrays with both planar and folded geometry exhibit a focus sensitivity comparable to that of the spherical arrays, but with a sharper peak in the vicinity of the correct focus value. Therefore, even for planar mappings it is very important to use the correct beamforming focus here.

If this sensitivity of the spirals is an advantage or a disadvantage depends on the intended application. It can be advantageous in the special case of fixed array installations, e.g. in aeroacoustic wind tunnels with mainly planar objects and an always perfectly known distance. In this case, a better suppression of the out-of-focus sources is a desired property. However, in the everyday mobile field and troubleshooting applications of our Acoustic Camera, were the aim is to find all the relevant sources at first instance, this focus sensitivity may even be a severe handycap. Therefore, in case of depth structured objects we still prefer the ring geometry for planar mappings.

In the future, we will perform more simulations with other array geometries and array sizes and also with varying source positions, and we will also try to better verify the simulation results with more systematic practical measurements. Up to now, our practical measurement experience strongly supports the often underestimated importance of the focus distance in acoustic beamforming.

References

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