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COMPARISON OF SPATIAL MICROPHONE PROBES IN ROOM ACOUSTIC MEASUREMENTS

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Abstract

Spatial room acoustic measurements have become common practice in room and concert hall acoustics. The authors have been using different spatial microphone-probes in room acoustic measurements for several years. These microphone-probes typically consist of 4 to 8 microphone capsules either omni-directional or cardioid directivity pattern. Slight differences have been noticed in auralisation use as well as when plotting spatiotemporal visualisations based on the measured room impulse responses. This paper presents a study where the performance of three different microphone probes is compared by measuring room impulse responses in controlled test environment. The analysis of the spatial response is done using spatial decomposition method (SDM)[1]. The aim of the study is to find and build an optimal microphone probe for room acoustic measurements for acoustic consulting use. Based on the analysis of spatiotemporal visualisations, an array with 7 microphone capsules (six capsules used for directional analysis) was found to give more accurate reflection tracking compared to 4 capsule arrays. 4 capsule arrays, however, could be sufficiently accurate for visualizing the overall reflection pattern or a certain space to assess the amount of lateral energy against frontal energy and showing the “shape” of the early reflections for instance. The strong reflections from relatively small surfaces, however, could be difficult to pinpoint accurately with 4 capsule arrays. 6-7 capsule array could be accurate enough to pinpoint individual specular reflections for consulting use. Further work is required to confirm these conclusions in real spaces.

Keywords: *room acoustics, spatial sound, spatial room acoustic measurements*

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1. Introduction

Spatial room acoustic measurements have moved beyond a single omnidirectional impulse response. Directional information is now captured with multi-capsule microphones to support realistic auralization and spatiotemporal visualizations of soundfields. Both are valuable for acoustic design and consulting work. Multichannel measurement techniques for this purpose date back at least to the four-point microphone method presented by Yamasaki and Itow in 1989, which measured the direction and strength of individual reflections using closely spaced omnidirectional capsules [1]. Today's spatial microphone probes, typically arrays of at least four omnidirectional or cardioid capsules follow the same basic idea.

The authors have used several such probes for room acoustic measurements over the years. Slight but consistent differences have been noticed between probes, both in auralization and in the spatiotemporal visualizations. The measurements have been mostly composed with the spatial decomposition method (SDM) [2]. SDM has been widely adopted for assessing room acoustics in concert halls [3], stages [4], rock clubs and nightclubs [5], studio control rooms [6], domestic listening rooms [7], car audio systems [8], and movie theaters [9-10]. SDM estimates a direction of arrival (DOA) for every sample of a measured room impulse response. The corresponding energy is then reassigned to that direction. This yields both an auralizable spatial room impulse response and a spatiotemporal visualization of direct sound, reflections, and reverberation.

SDM has known limitations but remains a practical choice for room-acoustic fieldwork. Method’s temporal resolution is bounded by the physical size of the microphone array [11]. Its original sound-field model also assumes one direction of arrival per sample, an assumption that breaks down in the anisotropic, multi-source conditions typical of late reverberation. Various methods have been proposed to mitigate these limitations [12-14]. In additions, very transient signals can also pick up roughness and spectral whitening artifacts [15], although compensation strategies exist [8]. Even so, the broadband analysis stage of SDM is a robust way to identify reflections directly from a measured impulse responses.

SDM operates directly in the time domain and needs no further signal-processing infrastructure to produce a directional estimate for each sample. This simplicity, together with straightforward hardware requirements, is why SDM has become a handy, fast, and robust method for room acoustic measurements in the field.

The accuracy of the DOA estimate depends strongly on the microphone probe used to capture the impulse response, which in turn affects the reliability of both the auralization and the visualization. The estimation method itself also differs by probe type. Open-air arrays typically use time-difference-of-arrival (TDOA) estimation, based on cross correlation between capsule pairs. B-format arrays instead use pseudo intensity vectors (PIV), computed directly from the coincident pressure and velocity signals [4,12]. Amengual Garí et al. [4] systematically compared open-array geometries and analysis window lengths for SDM. At a 48 kHz sampling rate, an open array of 100 mm diameter and an analysis window of 36 samples gave the lowest DOA estimation error among the configurations tested. The same study shows that coincident B-format arrays perform even better in ideal simulation, since all capsules effectively occupy the same point in space. In practice this advantage is hard to realize, because the capsules of a real B-format probe are not physically coincident. Imperfections in the A-to-B conversion and in the achieved capsule directivity patterns introduce errors in the analysis. The theoretical benefit of a coincident array therefore does not necessarily transfer to measured signals [4,11].

This creates a practical dilemma for acoustic consultants. Among the configurations tested so far in the literature, the best-performing is a 100 mm, seven-capsule open-air probe [4]. In practice, it requires up to seven microphone preamplifiers and need more physical space than compact alternatives, increasing the effort needed for transport and on-site setup. Compact alternatives exist: a smaller four-capsule open-air probe, or a B-format "ambisonic" microphone. Both are more practical for everyday consulting use. However, their smaller aperture and near-coincident capsule arrangement raise a question: how much spatial accuracy is sacrificed for that convenience?

This study compares the performance of three spatial microphone probes, including a reference 100 mm open-air probe, a smaller four-capsule open-air probe, and a B-format microphone. Room impulse responses were measured in a controlled test environment. The resulting spatial responses are analyzed with SDM. The spatiotemporal visualizations from the two smaller probes are then compared against the larger reference probe. The research question is: how well does a compact A-format microphone or a smaller four-capsule open-air probe capture the sound field relative to the established 100 mm open-air reference? And is either compact alternative accurate enough for practical use in room acoustic measurements in acoustic consulting?

2. Microphones tested

The microphones tested in this experiment were "Akukon Probe MF1" which consist of four omnidirectional microphone capsules in an open-air arrangement with ~ 38 mm radius (Figure 1) and "Aalto FRL Array", which consist of 7 omnidirectional microphone capsules in a spherical open-air arrangement with 100 mm radius (Figure 2.). Aalto FRL Array was built based on Facebook research FRL Array [16].

Both microphone probes used DPA 4060 Omni miniature lavalier microphone capsules. The gain of the capsules was checked against each other in both microphone probes.

The third microphone was the Röde NT-SF1, a four-capsule ambisonic microphone with cardioid capsules arranged in a tetrahedral configuration (Figure 3). Unlike the two open-air probes, its capsules are positioned closely together to approximate a single coincident point in space.

Figure 1: Akukon Probe MF1

Figure 2: Aalto FRL Array

Figure 3: Röde NT-SF1

3. Testroom

Testroom was an empty office space where controlled reflection surfaces and absorption surfaces were introduced. The space was about 16 m x 19 m x 3 m of size. The details of the testroom are illustrated in Figure 4 and Figure 5.

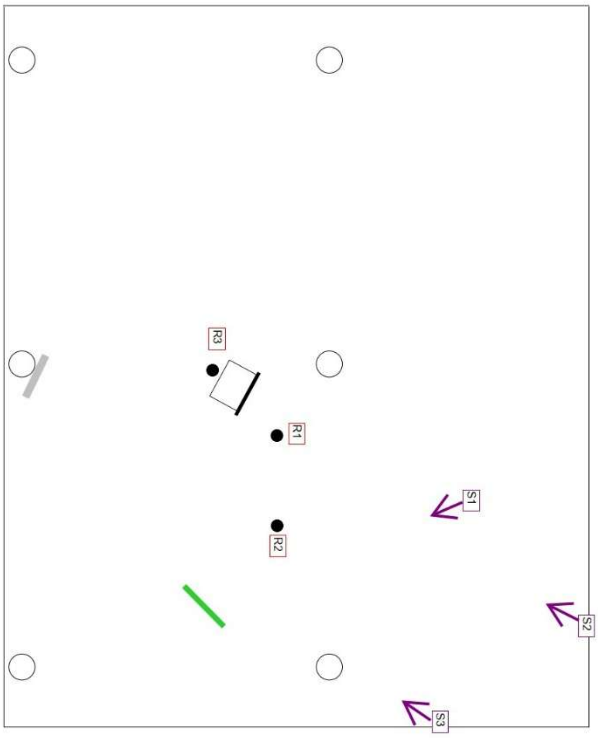

Figure 4: Plan of a testroom, where purple boxes S1, S2, S3 denote the loudspeaker positions, R1, R2, R3 are the microphone receiver positions, Green line is a reflective surface, black line is absorptive surface. Grey line is reflective surface.

Figure 5: Photograph of a testroom looking from the source position S2 towards the reflective and absorptive surfaces.

4. Measurement results

All impulse responses were analyzed at a sampling rate of 48 kHz using functions elaborated from the original SDM Toolbox [2]. For the two open-air probes (Akukon Probe MF1 and Aalto FRL Array), the direction of arrival was estimated using time-difference-of-arrival (TDOA) with an analysis window of 32 samples. For the Röde NT-SF1, the four captured capsule signals were first matrixed to B-format using the standard first-order encoding equations. Then the direction of arrival was estimated using the pseudo-intensity vector (PIV) method with the same window length, together with an additional low-pass filter at 4 kHz. This was applied to stabilize the resulting direction estimates, as the raw PIV estimates have been found to be prone to considerable angular scatter [11]. The omnidirectional pressure channel of each probe was normalized to unit peak amplitude to allow level-independent comparison between probes.

4.1 Akukon Probe MF1 vs. Aalto FRL Array

Following presents selected spatiotemporal plots to illustrate the main differences in reflection tracking between the microphones. All plots include all three loudspeaker sources, unless otherwise stated.

4.1.1 Lateral plane

Figure 6 shows a spatiotemporal plot in lateral plane for Aalto FRL Array with Akukon Probe MF1 ‘envelope’ plot added in semi-transparent orange. Aalto FRL Array seems to give clear direct sound directions that match the locations of the loudspeakers very accurately. Instead, Akukon Probe MF1 seems to plot the direct sound into shifted directions, which is expected to be mainly due to the difficulty in locating the probe to 100 % correct direction, the probe being relatively small in physical size.

Figure 7 shows the same comparison, but Akukon Probe MF1 ‘envelope’ plot has been rotated to better match the loudspeaker locations. Regardless of that, it seems that Akukon Probe MF1 direct sound does not quite match with the loudspeaker positions. At least not as well as Aalto FRL Array.

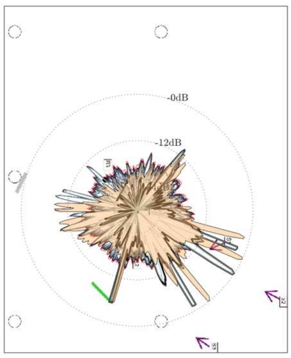

Figure 6: Aalto FRL Array lateral plane, with Akukon Probe MF1 semi-transparent overlay in orange.

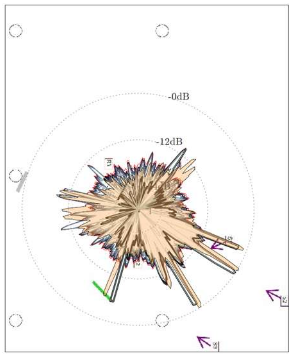

Figure 7: Aalto FRL Array lateral plane, with Akukon Probe MF1 semi-transparent overlay in orange. Akukon Probe MF1 plot has been rotated to better match with direct sound directions.

It is also interesting to note that the reflection from the green reflective surface and the reflection from upper right corner of the room seem to be consistent between Aalto FRL Array and Akukon Probe MF1 when MF1 is not rotated to match with direct sound. This is interesting observation which authors can't find a meaningful reason. This same phenomenon can be seen when looking at S3 loudspeaker separately (Figure 8, Figure 9).

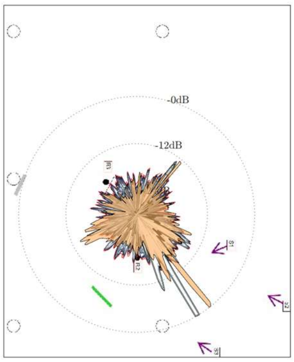

Figure 8: Aalto FRL Array lateral plane, with Akukon Probe MF1 semi-transparent overlay in orange. Only loudspeaker S3 plotted.

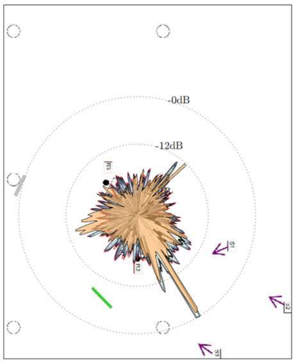

Figure 9: Aalto FRL Array lateral plane, with Akukon Probe MF1 semi-transparent rotated overlay in orange. Only loudspeaker S3 plotted.

Figure 10 shows a lateral plot from receiver position R3, which was located behind the absorptive 50 mm polyester fibre 'wall'. No line of sight to any of the sources was visible. Akukon Probe MF1 'curtain' plot in orange was rotated slightly so that the direct sound matches with the loudspeaker locations.

It seems that both arrays give equal accuracy in finding the loudspeaker directions (through the absorption panel), and the rear wall reflections were also similar between the different arrays.

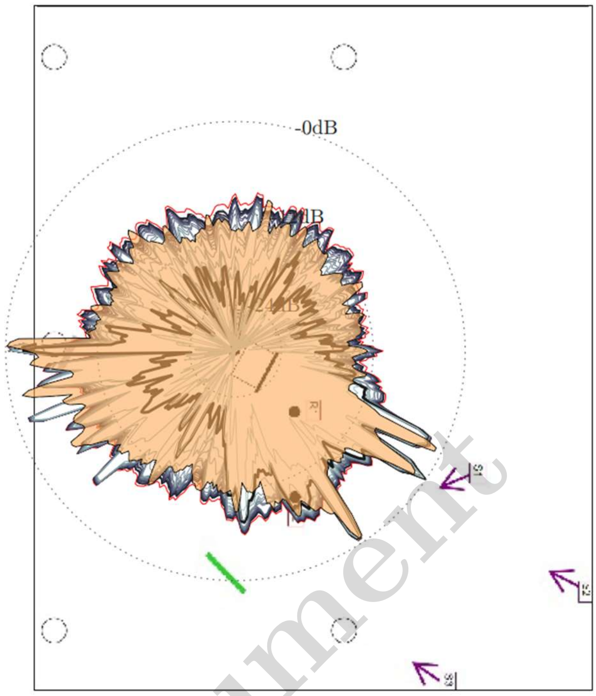

Figure 10: Aalto FRL Array lateral plane, with Akukon Probe MF1 semi-transparent rotated overlay in orange.

The authors can't explain the reason why Akukon Probe MF1 and Aalto FRL Array seem to perform similarly when the sources are further away and behind the absorption panel, and Akukon Probe MF1 seems to be less accurate compared to Aalto FRL Array when the sources were closer to the receiver and a clear line of sight is present.

4.1.2 Median plane

When looking at median plane, Akukon Probe MF1 seems to give similar reflections, but the directions are not as accurate as with Aalto FRL Array. This can be seen in Figure 11 below.

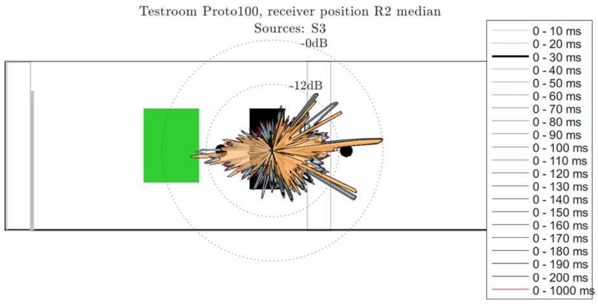

Figure 11: Aalto FRL Array median plane, with Akukon Probe MF1 semi-transparent overlay in orange. Only sound source S3 plotted.

4.2 Akukon Probe MF1 vs. Röde NT-SF1

Following presents a comparison between Akukon Probe MF1 and Röde NT-SF1 ambisonics microphone. This measurement was conducted in a separate session from those presented above, so a direct comparison with the Aalto FRL Array is unfortunately not possible.

Figure 12 shows the lateral spatiotemporal plot of Röde NT-SF1 with Akukon Probe MF1 'curtain' plot overaly in semi-transparent light orange. The Akukon Prove MF1 plot is rotated slightly to better correspond the loudspeaker directions. Neither of the arrays point the loudspeaker directions exactly correct, but Akukon Probe MF1 seems to give more sharp plots for direct sound. Röde NT-SF1 almost shows like there was two separate sources for S1 and S2.

Both arrays show the reflection from the green reflective surface and rear wall reasonably accurately.

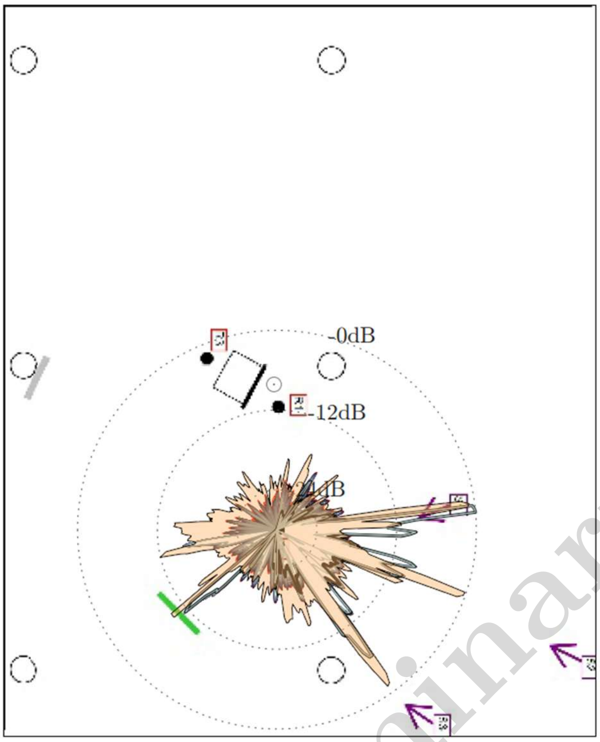

Figure 12: Spatiotemporal plot in lateral plane of Röde NT-SF1, with Akukon Probe MF1 semi-transparent overlay in orange. The Akukon Probe MF1 plot is rotated slightly to match better with direct sound. All sources S1-S3 plotted.

5. Discussion

Several conclusions can be drawn from the above figures. First, the 100 mm Aalto FRL Array with seven capsules provides direct- and reflected-sound directions that closely match the actual loudspeaker positions and the reflection surfaces in the lateral and medial plane. Second, the 38 mm Akukon Probe MF1 with four capsules has direct-sound directions that are shifted from the true loudspeaker positions even after manual rotation. This suggests either a systematic bias or an inherent limitation in DOA accuracy due to the probe's smaller size, consistent with prior findings that larger open-air arrays achieve lower DOA error [4]. Finally, the B-format Röde pattern shows more angular scatter than the open-air TDOA plots, even the direct sound spreads rather than forming tight, distinct spikes. This is consistent with the known limitation that raw PIV estimates are prone to angular scatter [11]. The low-pass filter stabilizes but does not eliminate this scatter.

A natural question follows: how important are these differences in an acoustician's day-to-day fieldwork? The answer likely depends on the case. In most situations the differences are probably not critical, but some detailed design decisions may still call for the larger probe with more microphones. All tested probes are likely to be accurate enough for visualizing the overall reflection pattern or a certain space to for example assess the amount of lateral energy against frontal energy and to show the "shape" of the early reflections for instance. The strong reflections from relatively small surfaces, however, could be difficult to pinpoint accurately with 4 capsule arrays. 6-7 capsule array could be accurate enough for consulting use. Further work is required to confirm these conclusions in real spaces. Auralization quality is not addressed in this study and would also need to be evaluated separately.

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