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A Comparison of Directional Beamforming Capabilities: High-Order Ambisonic Microphone vs. Shotgun Microphones

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ABSTRACT

This article presents the practical implications of the directional beamforming capability of a higher-order ambisonic microphone compared with popular shotgun microphones. Five different microphones were used in the study: Sennheiser MKH 416, Rode NTG2, Panasonic AG-MC200, Zoom SGH-6, and Zylia ZM-1 (ambisonic microphone). The results highlight the versatility of higher-order ambisonics for non-immersive use, which allows for beamforming in any direction even in post-production, as opposed to typical shotgun recordings. Measurements indicate that shotgun microphones show directional characteristics with apparent frequency-dependent directivity. The Zylia microphone has 5 beamforming modes, among which the S1 and S2 modes exhibit directional characteristics similar to shotgun microphones.

1 Introduction

This study compares the directional beamforming capabilities of traditional shotgun microphones with high-order ambisonic microphones within structured experimental setups. It provides direct comparative insights into their beamforming efficacies, grounded in a detailed examination of frequency-dependent directivity. Leveraging advanced measurement methodologies, this research extends the theoretical framework for the application of ambisonic and shotgun microphones in professional audio capture, offering robust evidence to guide future technological advancements and application-specific decisions.

2 Literature review

Numerous studies show that shotgun microphones are the best when it comes to directional sound collection [3, 4, 5]. Shotgun microphones are highly directional, which means that they can pick up sound from a specific direction while filtering out background noise. This study, titled "A Comparison of Directional Beamforming Capabilities: High Order Ambisonic Microphone vs. Shotgun Microphones," extends the current understanding of this idea by comparing traditional shotgun microphones with high-order ambisonic microphones in structured experimental setups [12]. Unlike previous studies that separately analyzed the capabilities of these two microphone types, this research provides direct comparative insights into their beamforming efficacies, illustrated through empirical analysis [1]. The innovation lies in the detailed comparison of frequency-dependent directivity and the correlation between frequency and directivity in these microphones, areas that have not been thoroughly explored in a comparative format.

By using advanced measurement methodologies, this study enhances the theoretical framework for using ambisonic and shotgun microphones in professional audio capture, offering substantial evidence to guide future technological developments and application-specific choices [2].

2.1 Directional microphones

Directional microphones are designed to capture sound from a specific direction while minimizing sounds from other directions. This characteristic is often described through polar patterns, which graphically represent the microphone's sensitivity at different angles around the microphone.

One of the most common types of directional microphones is the cardioid microphone, which offers a heart-shaped pattern that captures sound primarily from the front and sides, with limited pickup from the rear. The super-cardioid and hyper-cardioid microphones extend this concept with even tighter front pickup areas, offering better isolation and higher resistance to feedback from the sides and rear [8].

Shotgun microphones are another category of directional microphones often used in film and television production. Their main characteristic is the presence of a main lobe that is noticeably thinner than any other microphone. These microphones use an interference tube in front of the diaphragm to enhance directionality along the axis, making them highly effective at picking up sounds from a distance while rejecting off-axis sound [9].

2.2 Beamforming techniques

Beamforming is a signal processing technique used in microphone arrays to direct the sensitivity of the array towards a desired sound source while nullifying interference from other directions. This technique enhances the capture of sound from a specific location or direction, which is particularly useful in noisy environments.

The basic principle of beamforming involves combining elements in a microphone array so that signals at particular angles experience constructive interference while others experience destructive interference. This process can be dynamically adjusted to focus on different sound sources over time, a technique known as adaptive beamforming [6].

In practical applications, conference systems often use beamforming to enhance voice clarity by focusing on the speaker while diminishing background noise. It is also employed in smartphone technology to improve call quality and in smart speakers to enhance voice command recognition [7].

Advances in digital signal processing have significantly expanded the capabilities of beamforming techniques, allowing more complex and adaptable configurations. Modern beamforming systems can use algorithms that adapt in real-time to changing acoustic environments, optimizing pickup patterns dynamically for the best performance [10].

3. Directivity measurements

3.1 Study procedure

All measurements were conducted in an anechoic chamber to ensure an uncompromised acoustic environment. The measurement system consisted of a loudspeaker REVEAL 601p, amplifier type 2716-C-001, the turntable type 5960 with controller type 5997, managed via the Brüel & Kjær PULSE electroacoustic measurement system type 7540 using PULSE Lab Shop version 17, and the microphone under test. The directivity measurement setup is shown in Fig.1.

Fig. 1. Directivity measurement setup

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Each microphone was mounted on a tripod placed on the rotating table, which completed a 360-degree rotation about its axis in 5-degree increments. The performance of analog microphones (Sennheiser MKH 416, Rode NTG2, and Panasonic AG-MC200) was assessed at one meter between the sound source and the tested microphone. Similarly, the performance of digital microphones (Zoom SGH-6 capsule attached to a Zoom H6 recorder and Zylia ZM-1 array) was measured. For digital microphones, it was necessary to convert the digital signal back to the analog domain. This conversion was eased by an Apogee One USB interface, which also enabled real-time signal processing of the ZM-1 signal. This setup allowed the signal from a USB-connected microphone to be directly sent to an analog output of the audio interface and later to the PULSE system.

3.2 Data analysis

The analysis was performed using Matlab to process data from text files containing measurements of microphone directivity at multiple frequencies. A Matlab script extracted data points from these files to calculate the directivity index for each microphone, quantifying its ability to focus on sound from specific directions. Polar plots were generated for each microphone across various frequency bands, visually representing the directional sensitivity and beamforming capabilities.

4. Results

4.1 Polar pattern plots

Eight polar pattern charts were created for the following microphones and their settings. Figures 2 through 9 illustrate the directional characteristics of various microphones utilized in the study, encompassing the Sennheiser MKH 416, Rode NTG2, Panasonic AG-MC200, Zoom SGH-6 capsule attached to a Zoom H6 recorder, and different configurations of the Zylia ZM-1 microphone, including omnidirectional, cardioid, and S1 and S2 modes. Each chart was divided into two main frequency categories: low frequencies (125 Hz, 250 Hz, 500 Hz, 1 kHz) and high frequencies (2 kHz, 4 kHz, 8 kHz, 16 kHz). Polar patterns for low frequencies are represented by solid lines on the left side of the chart (from 0 to 180 degrees), while the patterns for high frequencies are represented by dashed lines on the right side (also from 0 to 180 degrees). Each chart also includes a decibel scale compared to zero, marked in 5 dB steps (0, -5, -10, -15, -20 dB).

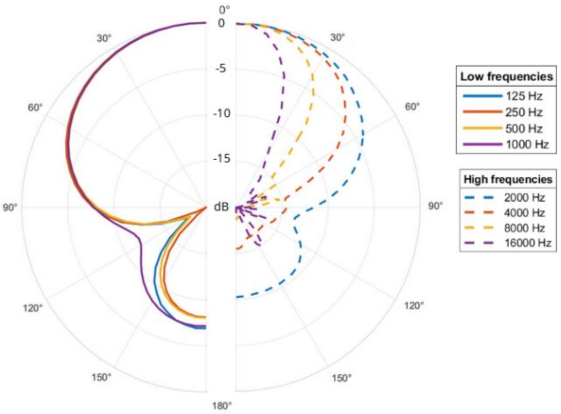

Fig. 2. Directional characteristic of the Sennheiser MKH 416 microphone

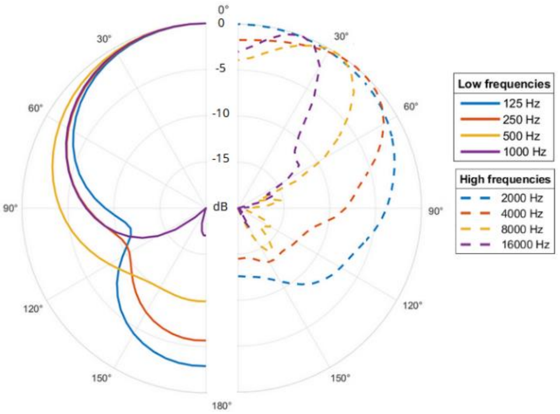

Fig. 3. Directional characteristic of the Rode NTG2 microphone

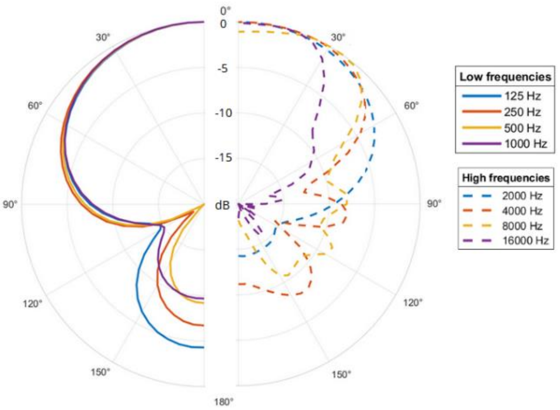

Fig. 4. Directional characteristic of the Panasonic AG-MC200 microphone

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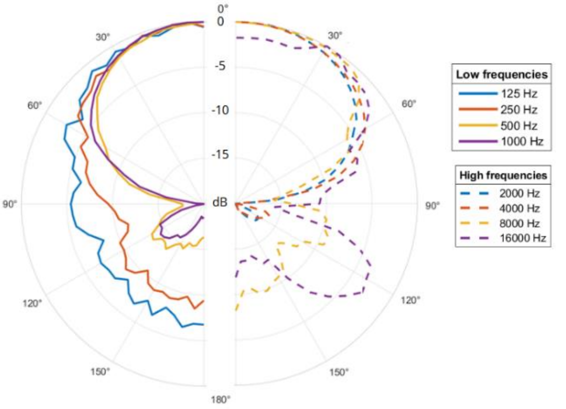

Fig. 5. Directional characteristic of the Zoom SGH-6 capsule attached to a Zoom H6 recorder

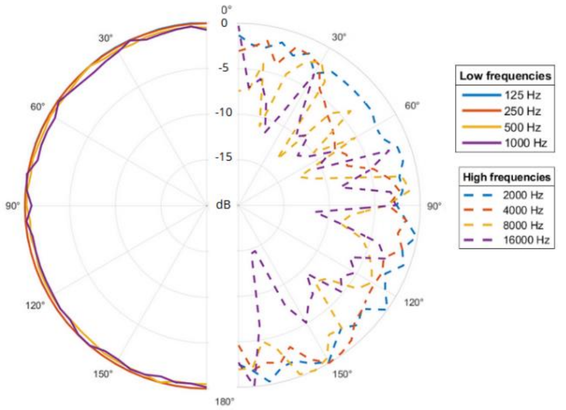

Fig. 6. Directional characteristic of the Zylia ZM-1 microphone (omnidirectional mode)

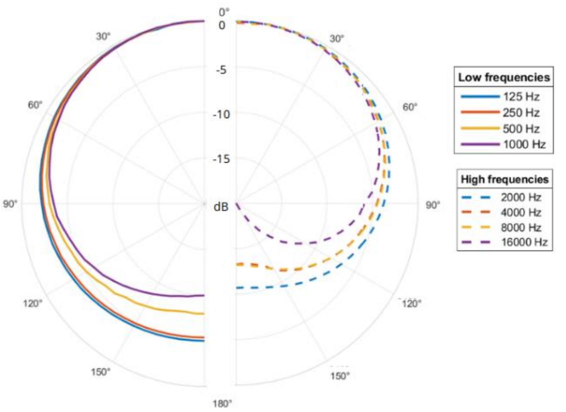

Fig. 7. Directional characteristic of the Zylia ZM-1 microphone (cardioid mode)

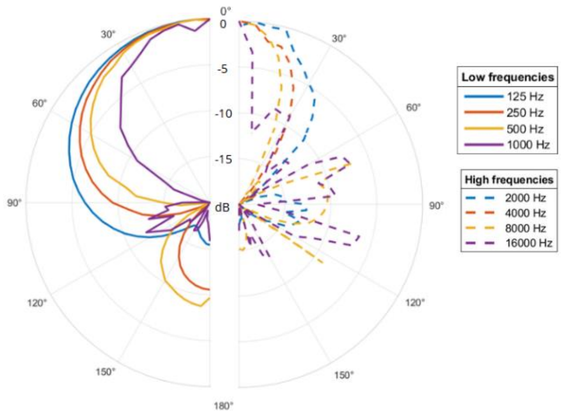

Fig. 8. Directional characteristic of the Zylia ZM-1 microphone (S1 mode)

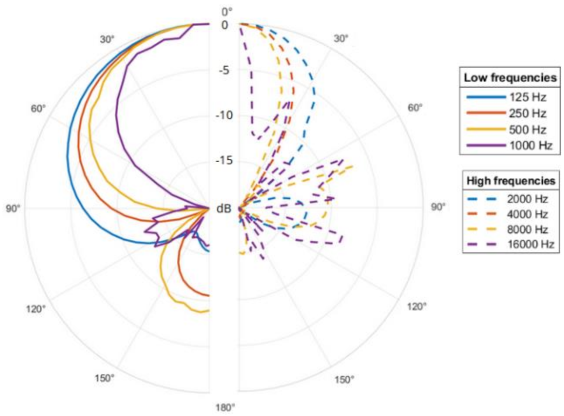

Fig. 9. Directional characteristic of the Zylia ZM-1 microphone (S2 mode)

4.2 Directivity comparison

The Zylia S1 and S2 microphones, despite their ambisonic capabilities, exhibit directional characteristics similar to those of shotgun microphones. The comparative analysis of directivity among the microphones evaluated reveals specific patterns related to their operational modes. The Zylia microphones, both in S1 and S2 modes, demonstrated directional characteristics similar to shotgun microphones, which was a key observation in the context of their ambisonic capabilities.

The Zoom SGH-6 displayed sharp directivity at lower frequencies (125 Hz and 250 Hz). However, at 16 kHz, a strong side lobe was observed, indicating a shift in how the microphone captures sound at higher frequencies, which may influence its application depending on the specific audio requirements.

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The Sennheiser MKH 416 consistently showed a super-cardioid pattern below 1 kHz with deep nulls at approximately 120°. Above 2 kHz, the polar pattern becomes narrower, although this narrowing is not consistent across all measurements. This characteristic may be beneficial in scenarios requiring precise sound isolation from specific directions.

The Panasonic AG-MC200 shotgun microphone is characterized by its hyper-cardioid polar pattern at lower frequencies, with side lobes becoming more pronounced at higher frequencies. This pattern allows for enhanced front directionality with a narrow-angle of sensitivity [11].

The Rode NTG2 demonstrates a super-cardioid polar pattern at lower frequencies, which allows for focused sound capture from the front while reducing sound input from the sides. This pattern shifts as frequency increases, with the widest directivity seen at 2 kHz.

4.3 Frequency and directivity correlation

In the analysis, two modes of the Zylia microphone, S1 and S2, were compared. These modes are designed to simulate shotgun-like directional characteristics. The objective was to examine the differences in these modes for the same microphone. The percentage relative error was used as an indicator of similarity between S1 and S2. The formula describing this error is as follows:

$$\delta = \frac{|x1 - x2|}{|x2|} \cdot 100\ \% \qquad (1)$$

where $x1$ represents a single measurement of relative attenuation for mode S1, and $x2$ stands for a single measurement of relative attenuation for mode S2. The absolute value is used to eliminate negative values and focus on numerical values.

The analysis of the charts (Figures 10 and 11) shows that the average percentage relative error varies depending on the microphone rotation angle. The most significant errors recorded for mode S2 compared to S1 were 2.58% at 110 degrees and 3.28% at 235 degrees. Additionally, the relative error between modes varies by frequency: 1.91% at 1 kHz and 2.72% at 16 kHz.

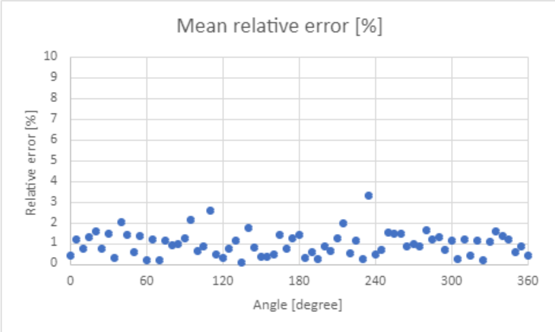

Figure 10. The average relative error depending on the rotation angle of the Zylia microphone

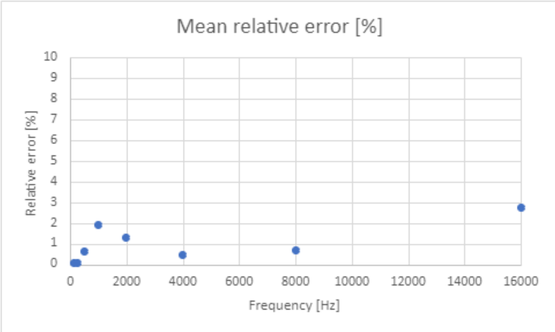

Figure 11. The average relative error depending on the frequency of the Zylia microphone

Additionally, modes S2 and S1 were compared using the Manhattan norm to assess the differences in relative attenuation values. The Manhattan norm is defined by the formula:

$$d(x1,\ x2) = \sum_{k=1}^{n} (|x_{1k} - x_{2k}\ |) \qquad (2)$$

where $x1$ and $x2$ represent the values of relative attenuation for modes S1 and S2, respectively. The sum is calculated separately for each frequency and for angular values. The results are displayed on two charts. The lower the values on the vertical axis, the more it indicates the similarity of both characteristics in modes S1 and S2.

The Manhattan norm graph (Figures 12 and 13) demonstrates the consistency of directivity across different angular positions for Zylia S1 and S2 microphones. This norm further supports the data by showing how the microphone's directivity is not only dependent on frequency but also varies with the angle of incidence, illustrating the complex interaction between frequency and directivity.

The analysis of the charts shows that the values of the norm differ depending on the angle of rotation of the

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microphone and the frequency at which they occur. Errors exceeding 3 dB relative occurred for mode S2 compared to S1 at angles of 110 degrees and 235 degrees. Meanwhile, the value of the Manhattan norm calculated with respect to frequency reached up to 8 dB relative to frequencies of 1 kHz and 16 kHz. Analyzing the polar charts for the Zylia microphone in modes S1 and S2, it is evident that the value of this norm was influenced by the smoothing and sharpening of the side lobes and the main lobe.

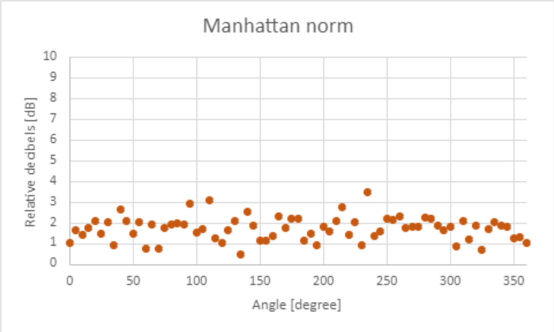

Figure 12. The value of the Manhattan norm depending on the rotation angle calculated for the Zylia microphone

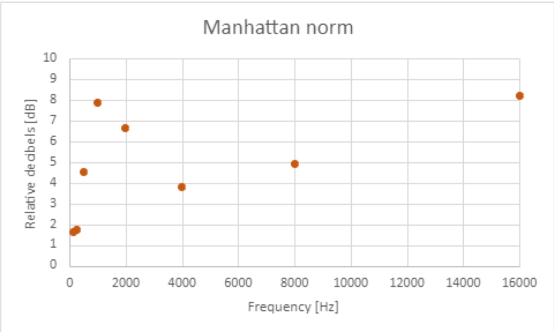

Figure 13. The value of the Manhattan norm depending on the frequency calculated for the Zylia microphone

5 Conclusion

In conclusion, the study underlines the distinctive advantages of higher-order ambisonic microphones over traditional shotgun microphones, particularly in their versatility and adaptability in audio recording environments. Ambisonic microphones' primary benefit lies in their ability to capture sound from all directions, which allows for extensive manipulation and directional adjustments during post-production. This capability is termed flexible beamforming. Unlike shotgun microphones, which are highly directional and thus limit recording to a fixed area directly in front of them, ambisonic microphones record a complete spherical sound field around them. This comprehensive capture makes it possible to isolate audio from any direction in post-production or even to create a virtual microphone pattern that can be dynamically adjusted to focus on different sound sources as needed.

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