XENSIV™ MEMS microphones in noise-cancelling headsets

Design challenges and best practices

About this document

Scope and purpose

This application note aims to educate readers on the challenges of designing noise-cancelling headsets, with a focus on the use of Infineon's XENSIV™ MEMS microphones.

Intended audience

This document is intended for design engineers, technicians, and developers of electronic systems, involved in designing noise-cancelling headsets or selecting silicon microphones for their product designs.

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1 Introduction to noise-cancelling headsets

Active Noise Cancellation (ANC) is a method by which undesired ambient noise is identified and removed in real time by generating an anti-noise signal to cancel the original noise. Modern noise-cancelling headsets adopt this technology for eliminating external noise sources, specifically at lower frequencies (<1 kHz), where passive noise isolation is insufficient. This can be particularly useful in industrial settings where workers are exposed to persistent factory noise or in cases where airline passengers need to filter out the ambient engine noise.

There are several topology options to consider when designing an ANC headset, such as feed-forward, feedback, and hybrid. The number and position of microphones in a headset determine its ANC topology configuration. A conceptual diagram illustrating the feed-forward topology is shown in Figure 1. This figure depicts a feed-forward topology, where an externally placed microphone picks up the noise signal from the environment, and the user wearing the headset hears the actual music from the headset speaker with a superimposed anti-noise signal that artificially removes external noise from the system. Regardless of the topology, there are two obvious challenges in implementing ANC in noise-cancelling headsets. The first challenge is to reliably capture the external environmental noise. To achieve this, microphones are used to detect the ambient noise sources surrounding the wearer and capture the signal in the audio band (20 Hz to 20 kHz). Several key microphone specifications are crucial for reliable noise capture, which is the main focus of this application note. The second challenge is to effectively cancel the captured noise from the original audio signal by generating an anti-noise signal that cancels the original noise. To overcome this challenge, adaptive algorithms need to be implemented efficiently, as the characteristics of the noise source, such as frequency, amplitude, and phase, can be time-varying. This application note will not address the algorithmic challenges of designing a noise-cancelling headset but instead focus on the challenges surrounding microphone selection and specifications.

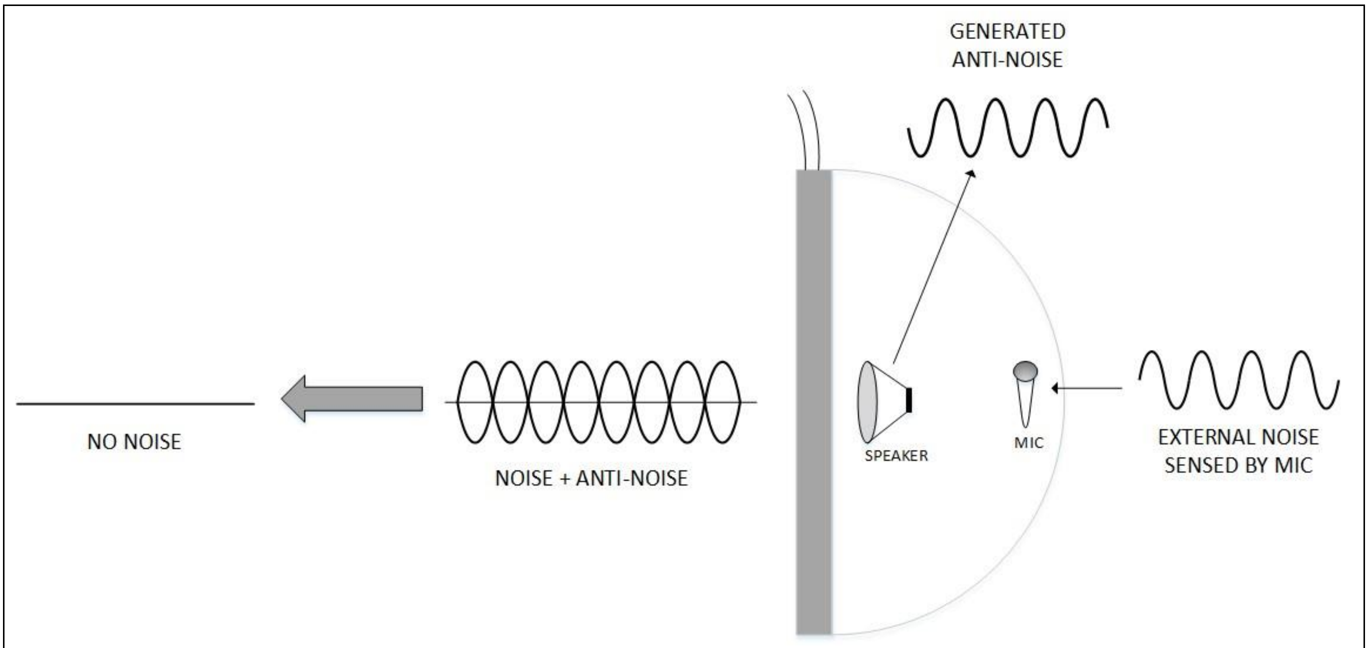

Figure 1 Noise cancelling headset – concept diagram

2 Key specifications for selecting a microphone

MEMS-based silicon microphones have largely replaced traditional Electret condenser microphones in most modern electronic devices due to their improved performance, tighter specifications, and compact size. Silicon microphones have several key specifications, including Signal-to-Noise Ratio (SNR), Acoustic Overload Point (AOP), Total Harmonic Distortion (THD), Cut-off Frequency, Sensitivity, Phase Response, Group Delay, and Current Consumption.

When designing a noise-cancelling headset, while all these specifications are important, the key parameters that influence microphone selection are SNR, AOP, Cut-off Frequency, Phase Response, Group Delay, and Current Consumption. Additionally, the tolerance, or part-to-part variation, of the cut-off frequency and phase response is also critical.

SNR

The microphone's intrinsic noise floor should be lower than the surrounding environmental noise level. A higher microphone SNR simplifies the implementation of the noise cancellation algorithm.

AOP

The microphone's AOP should be sufficiently high to capture loud noise signals from the surrounding environment without clipping or distortion. If the noise signal level exceeds the microphone's AOP specification, the captured signal will typically exhibit more than 10% distortion. To select a suitable microphone, it is essential to analyze the THD vs. SPL curve of multiple options and choose the one with very low distortion (< 1%) across a wide range of SPL levels.

Cut-off frequency

The microphone should have a low cut-off frequency specification (≤ 30 Hz). A higher cut-off frequency would render the ANC system ineffective in removing low-frequency noise signals. The cut-off frequency tolerance should be very narrow.

Phase response and group delay

Phase response refers to the variation of phase across the entire audio frequency band. Group delay is the frequency-dependent delay of the microphone, which is the derivative of the phase response. It represents the time delay experienced by different frequency components as they pass through the microphone from acoustic input to electrical output. Distortion in the noise signal measured by the microphone can prevent effective cancellation. Similarly, the phase response curve tolerance should be very narrow.

Current consumption

Current consumption is a critical specification to consider when selecting a microphone, particularly in always-on and battery-powered headset applications. A sleep/standby mode is needed to save power consumption over time and enable extended battery life for the system. The current consumption of a microphone is a function of the operating clock frequency, and certain datasheets clearly indicate performance trade-offs when the microphone is operated with a lower clock frequency to save power.

3 Performance limitations of existing designs

ANC headsets can be designed in various ways. As previously discussed, ANC headsets can be designed using different topologies, including feedback, feed-forward, and hybrid. Each of these topologies has its own advantages and limitations.

3.1 Feed-forward topology

The feed-forward ANC architecture is illustrated in Figure 2. In this topology, a single microphone is used per ear cup, positioned closer to the outside of the ear cup. The microphone's measurement serves as the reference noise signal for the ANC algorithm. The primary advantage of this configuration is that it allows for accurate measurement of the primary noise signal before it reaches the user's ear. The algorithm is then responsible for canceling out the noise signal, making it imperceptible to the user. However, the algorithm cannot verify the effectiveness of noise cancellation in real-time due to the absence of a feedback loop. This limitation is the primary drawback of the feed-forward topology. This configuration effectively attenuates mid-frequency noise signals (1 kHz to 2 kHz). The external placement of the microphone can lead to performance degradation due to wind noise. A microphone with a higher AOP and lower cut-off frequency is beneficial in this scenario. This topology is suitable for applications like Bluetooth headsets that require broad ANC bandwidth and can accept moderate noise cancellation performance.

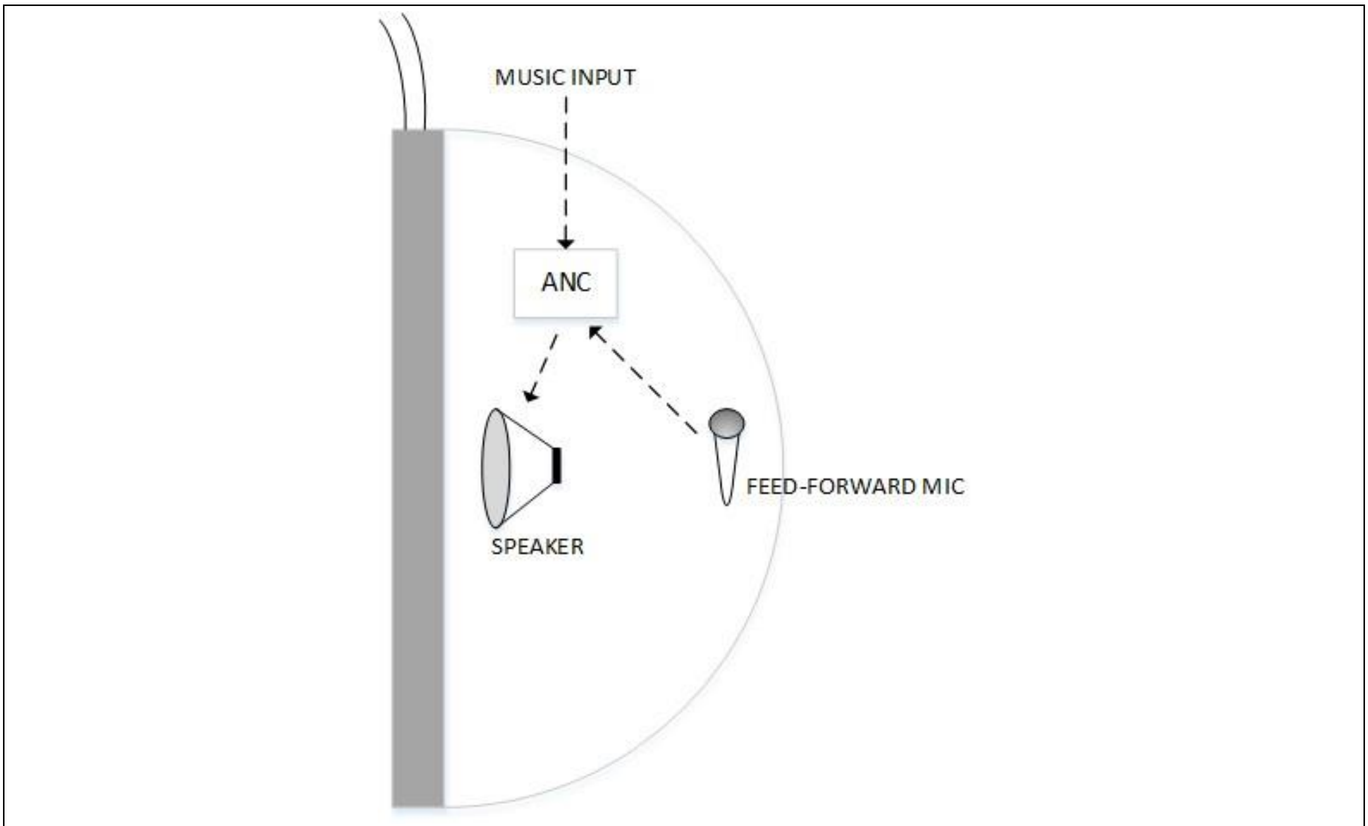

Figure 2 Feed-forward ANC architecture

3.2 Feedback topology

The feedback ANC architecture is illustrated in Figure 3. This topology also uses a single microphone, positioned closer to the user's ear. The primary benefit of this topology is that the microphone captures the same signal that reaches the user's ear, and a feedback loop is implemented to iteratively remove noise from the system. While this configuration performs well at low frequencies, it is less effective at attenuating frequencies between 1 kHz and 2 kHz compared to the feed-forward configuration. This configuration is effective in removing the residual, predictable narrowband components of the primary noise signal. Despite its limitations, this topology is widely used in ANC headsets due to its effectiveness in removing low-frequency noise. This limitation arises from the phase shift introduced in the secondary path, which spans from the output of the ANC block to its input. As a result, this topology is less effective at canceling out higher frequency components. A microphone used in this configuration should have a flat group delay across frequencies, with minimal variation across multiple microphones.

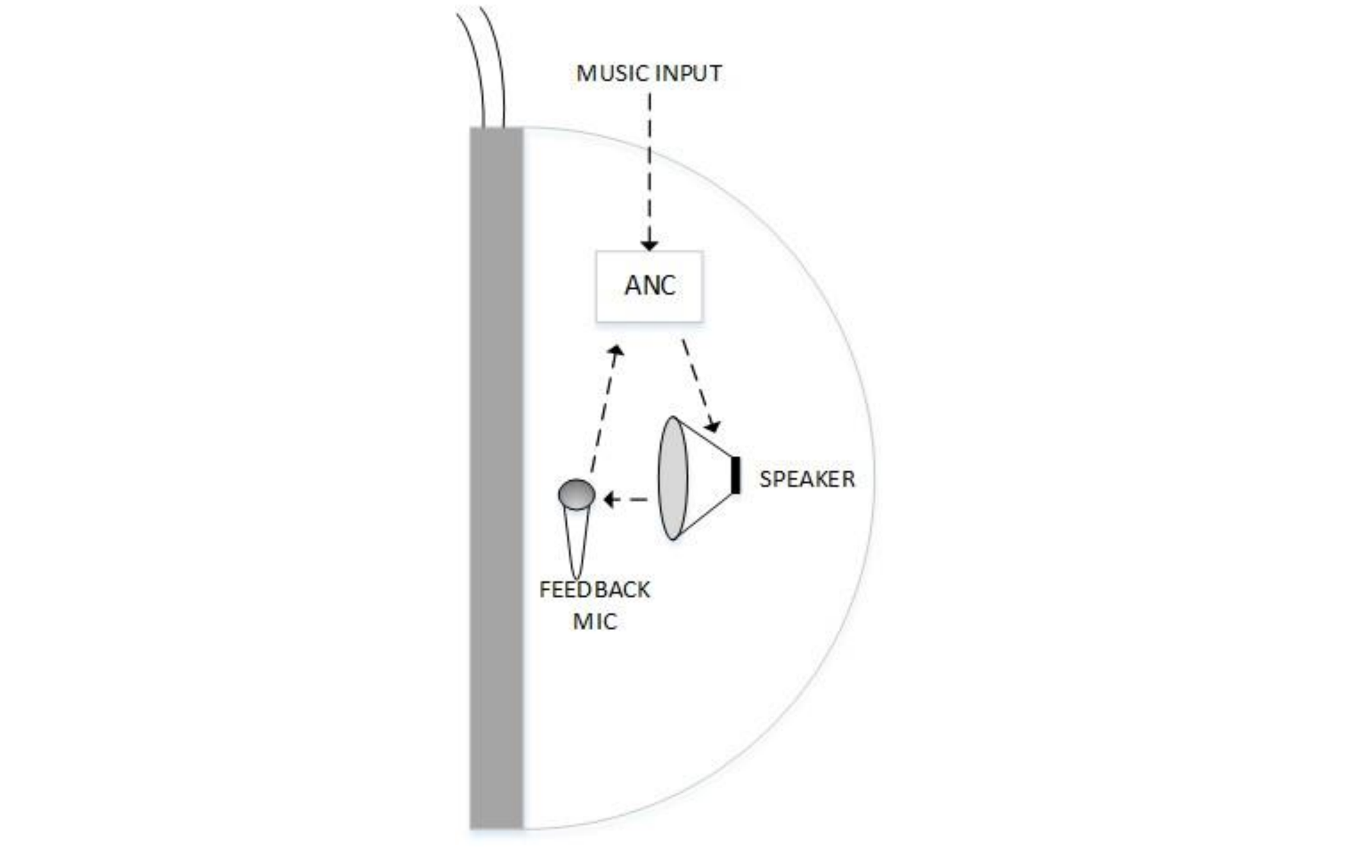

Figure 3 Feedback ANC architecture

3.3 Hybrid topology

The hybrid ANC architecture is illustrated in Figure 4. This configuration combines the feed-forward and feedback topologies discussed earlier. The goal is to leverage the benefits of both topologies, but this comes at the cost of increased complexity, cost, and size. This topology requires two microphones, one for the feed-forward signal path and one for the feedback signal path. The outward-facing reference microphone captures the primary signal, which serves as the reference signal for the feed-forward ANC filter. The error microphone detects the signal entering the user's ear, which serves as the reference signal for the feedback ANC filter. The error microphone output is also used to determine the coefficients for both the feed-forward and feedback ANC filters. When properly designed, this configuration can effectively combine the benefits of both feed-forward and feedback topologies.

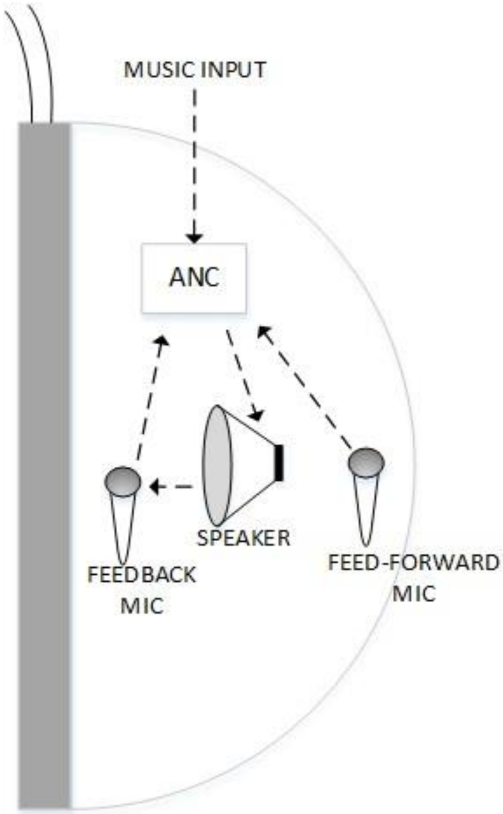

Figure 4 Hybrid ANC architecture

Figure 5 illustrates a simplified block diagram of the hybrid ANC topology. This diagram illustrates how the two signal paths are combined. $G(w)$ and $M(w)$ represent gain and phase compensation filters, where Dff and Dfb represent the delays introduced by the speaker and microphones in the system.

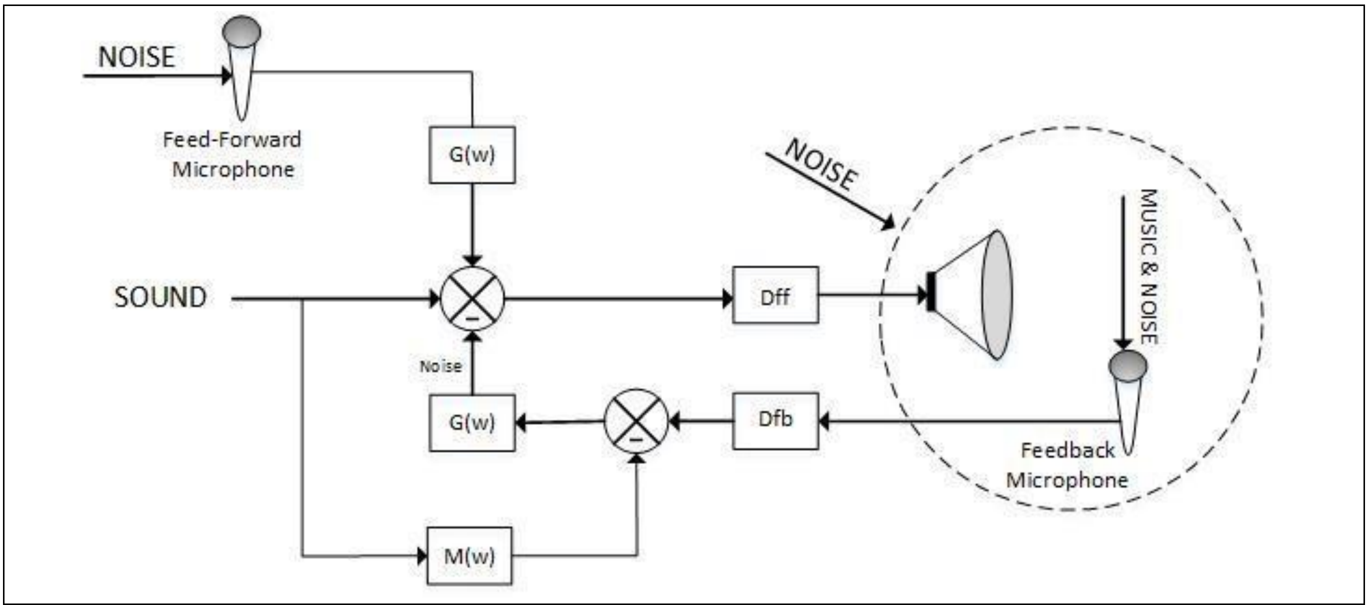

Figure 5 **Hybrid ANC topology: block diagram**

The hybrid ANC headset design offers the best ANC performance and widest noise cancellation bandwidth among the three topologies. However, its adoption is limited due to the increased cost and complexity of the design. This architecture is preferred in high-performance ANC headset designs where cost is not a primary consideration. Even in this configuration, ANC performance above 2 kHz is not satisfactory. As a result, headset designers often combine passive noise cancellation techniques with ANC to improve high-frequency noise cancellation performance.

Headset designs can also be categorized based on their placement around the human ear, including in-ear, on-ear, and over-ear headsets. For over-ear and on-ear headset designs, combining passive and active noise cancellation techniques can provide excellent ANC performance across the entire audio bandwidth. For in-ear headset designs, where physical space is limited, implementing traditional passive noise cancellation techniques to remove high-frequency noise is challenging. As a result, microphones used in in-ear ANC headsets must also contribute to canceling high-frequency noise signals. Microphones with lower group delay and a relatively flat phase response across frequencies can improve high-frequency performance. The phase response tolerance is also crucial. A tight distribution of this specification enables effective optimization of ANC algorithms, resulting in improved and consistent high-frequency noise cancellation performance.

4 Solution provided by Infineon microphone

Infineon's XENSIV™ MEMS digital microphone, IM69D130, boasts an exceptional combination of best-in-class SNR (69 dB) and an extremely high AOP (130 dBSPL). This microphone is an excellent choice for noise-cancelling headset applications, as its specifications and tolerances meet all the criteria discussed in previous sections of this document.

4.1 Magnitude and phase response

As previously discussed, the tolerances of cut-off frequency and phase response are crucial in selecting a microphone for noise-cancelling headset designs. Figure 6, Figure 7, Figure 8, and Figure 9 illustrate the mean and standard deviation of the magnitude and phase response of the IM69D130 microphone. The 6-sigma limits are also included for reference. The measurements were taken at a temperature of 25°C.

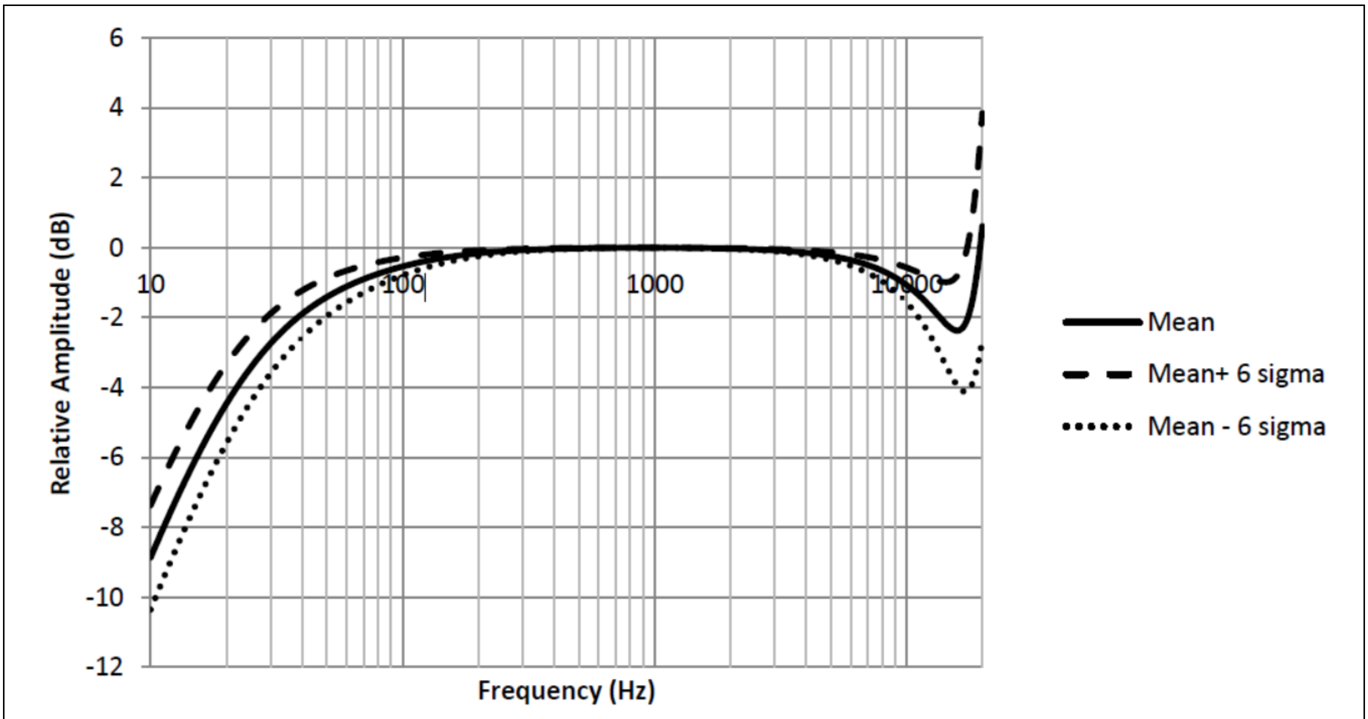

Figure 6 Magnitude response with tolerances

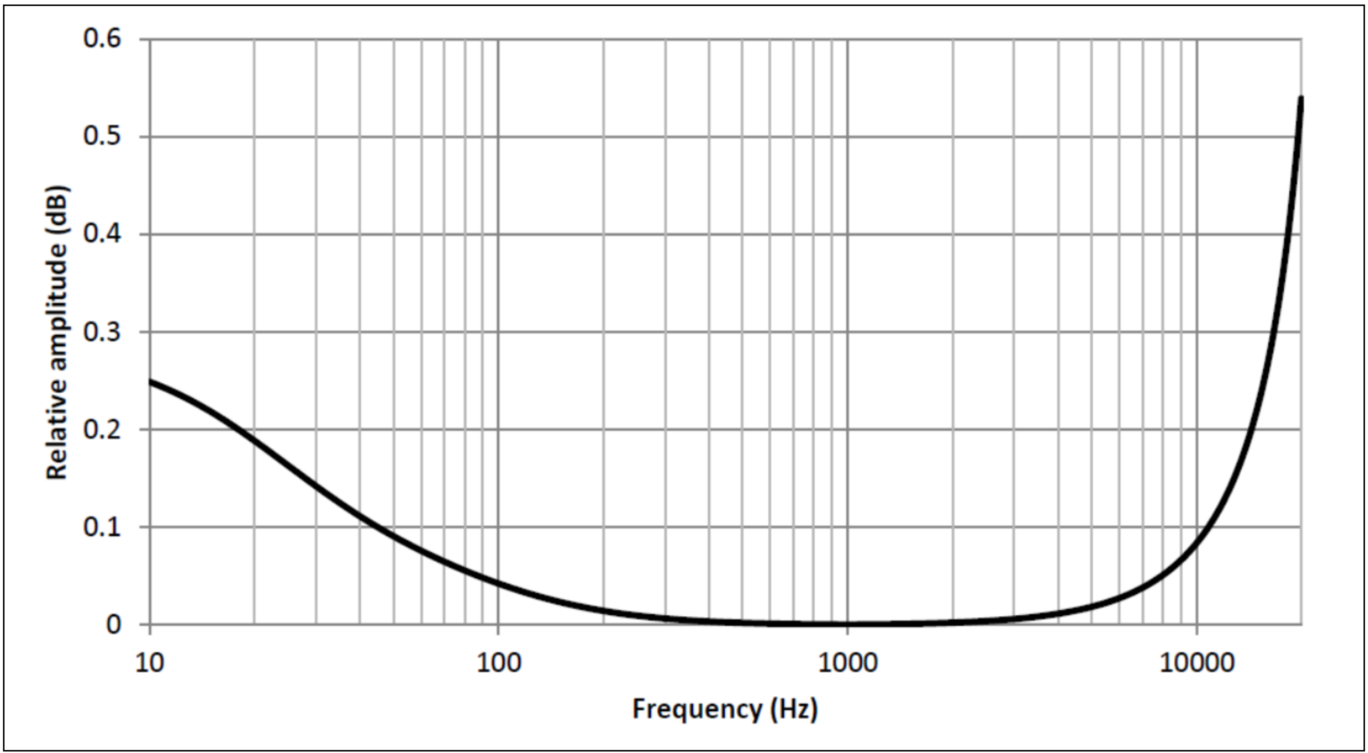

Figure 7 **Standard deviation – Magnitude response**

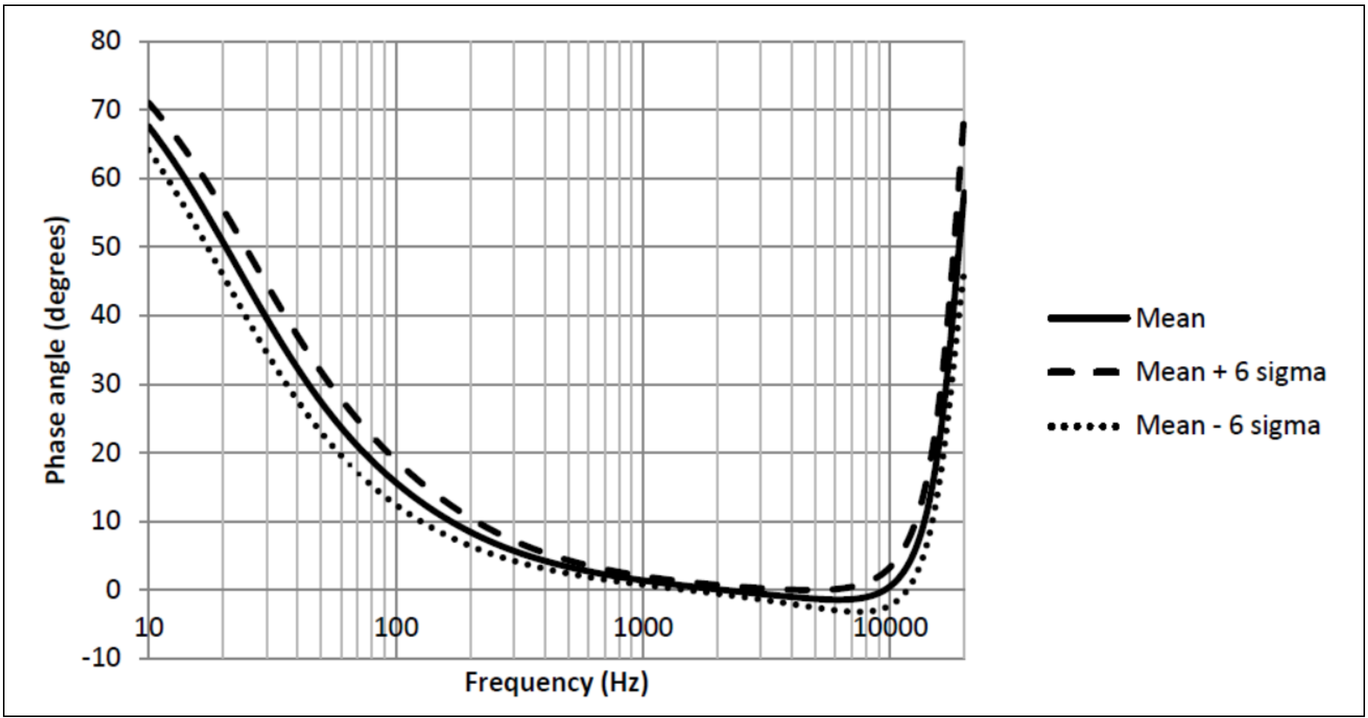

Figure 8 **Phase response with tolerances**

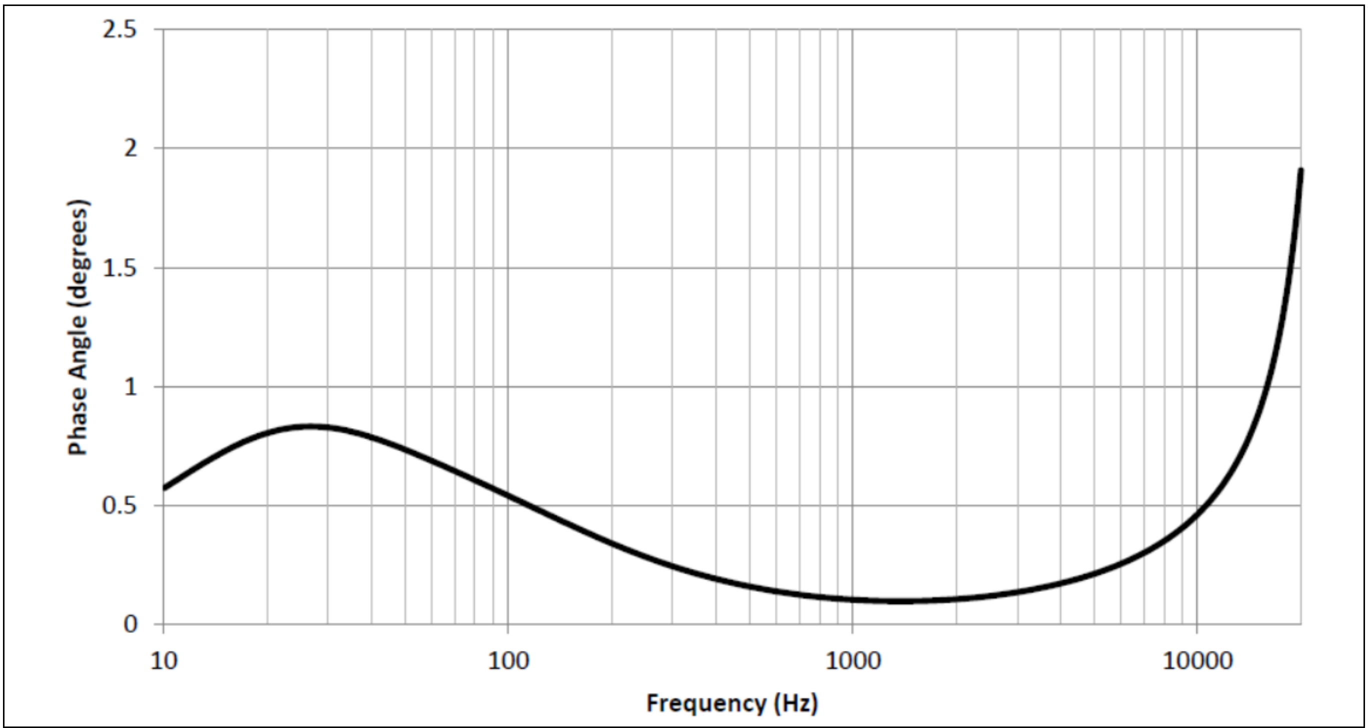

Figure 9 **Standard deviation – Phase response**

As evident from these plots, the magnitude and phase response tolerances of the IM69D130 are very narrow. This ensures that the part-to-part variations in corner frequency and phase response are minimized. As a result, the ANC algorithm implementation is more accurate and reliable.

4.2 Group delay

The group delay of the IM69D130 was measured in the lab, and Figure 10 shows the typical group delay observed across the frequency band. The data shows that the group delay at 1 kHz is less than 10 µs. This low group delay enables more effective ANC algorithm implementation.

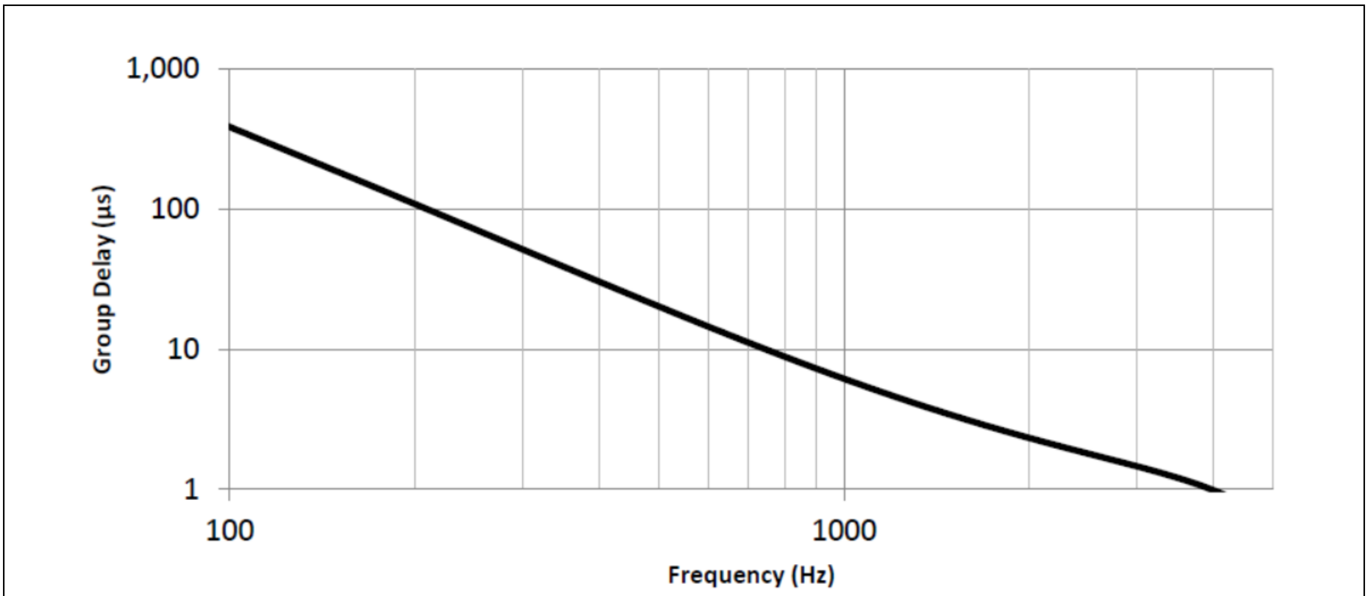

Figure 10 **Group delay vs. frequency**

4.3 Total harmonic distortion

Another important microphone specification is the Acoustic Overload Point (AOP). Figure 11 illustrates the THD vs. SPL plot for the IM69D130, along with two competing products. The IM69D130 reaches the 10% THD limit at 130 dBSPL, which is its specified AOP. Notably, the IM69D130 maintains distortion levels below 1% THD up to approximately 128 dBSPL. This enables reliable capture of loud noise signals with minimal distortion, resulting in more effective ANC algorithm implementation. The competing microphones shown in Figure 11 have slightly better AOP specifications than the IM69D130. However, as evident from Figure 11, the IM69D130 exhibits significantly lower THD up to approximately 128 dBSPL compared to the other two microphones.

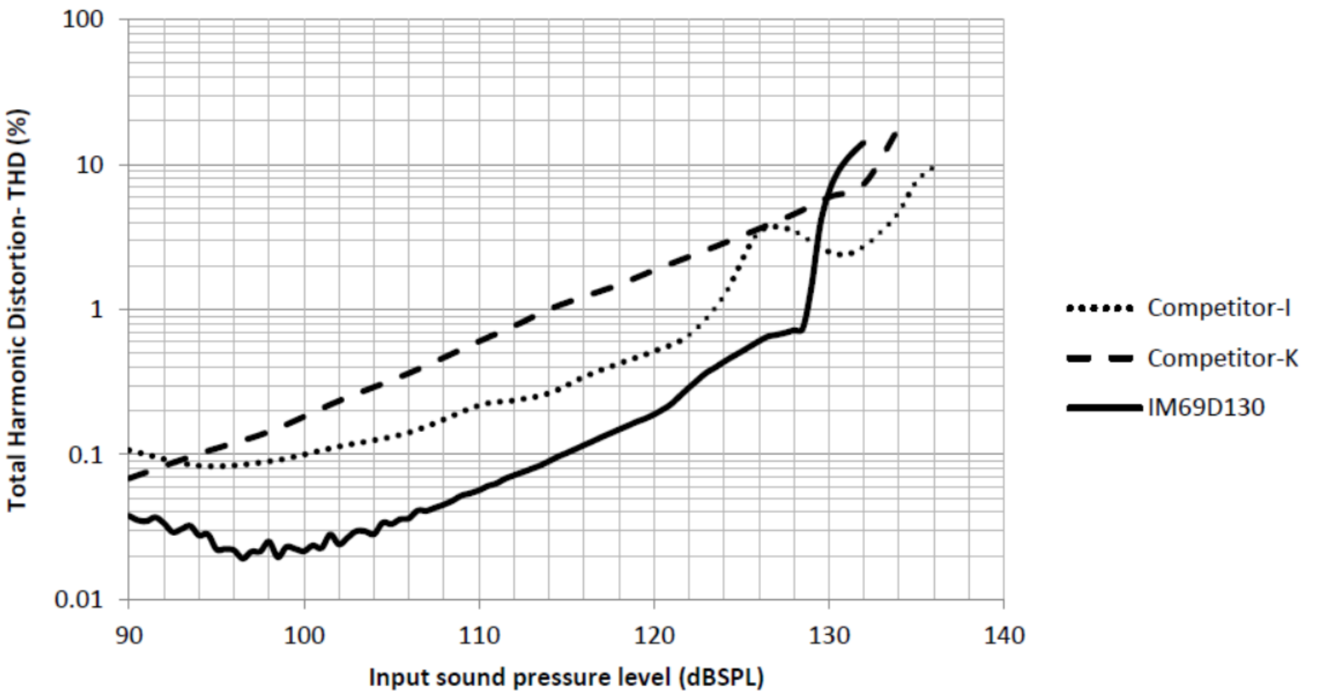

Figure 11 THD vs. SPL

For additional specifications and details on the IM69D130 microphone, please refer to the datasheet [1]. The results presented in this section, combined with the datasheet specifications of the IM69D130, provide a strong case for how the IM69D130 can help address the challenges discussed in Section 3 of this document.

References

[1] Infineon Technologies AG: *IM69D130 digital MEMS microphone datasheet;* Available online

Revision history

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