

Infineon microphone in noise-cancelling headsets

About this document

Scope and purpose

This application note is intended to illuminate the reader on the challenges of designing a noise-cancellation headset, specifically related to the use of silicon microphones in the design.

Intended audience

This document is addressed to anyone who is either involved in designing noise-cancelling headsets, or involved in selecting silicon microphones for their product design.

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1 Introduction to noise-cancelling headsets

Active Noise Cancellation (ANC) is a method by which undesired audio source is identified as noise and removed in real time by generating an ‘antinoise’ 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 cancellation technology doesn’t provide desired results. This can be very useful in applications where workers need to be protected against persistent factory noise or in cases where airline travelers need to filter out the 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 concept diagram 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 superimposed anti-noise signal to artificially remove external noise from the system. Irrespective of the topology, there are two obvious challenges in implementing ANC in Noise-cancelling headsets. The first challenge is that the external environmental noise needs to be captured reliably. To accomplish this, microphones are used and they listen to the noise sources that exist around the person wearing the headset and capture the signal in the audio band (20Hz-20 kHz). There are several microphone specifications that are vital to establish this reliably, which is the main focus of this application note. The second challenge is implementing the cancellation of this captured noise from the original sound signal by super-imposing it with an anti-noise signal. 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.

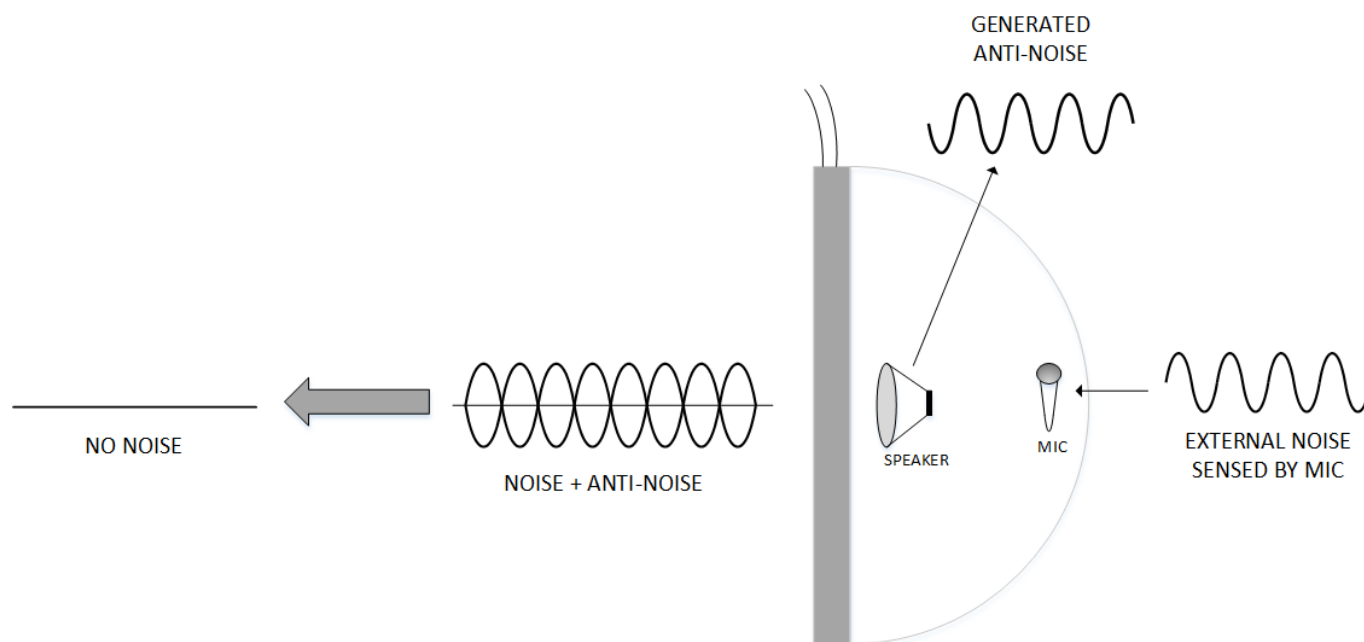


Figure 1. Noise cancelling headset- concept diagram

2 Key specifications for selecting a microphone

MEMS based silicon microphones have replaced the traditional Electret condenser type microphones in most modern electronic equipment as they offer better performance and tighter spec tolerances in a smaller package. Silicon microphones have several important specifications such as Signal-to-Noise-Ratio (SNR), Acoustic Overload Point (AOP), Total Harmonic Distortion (THD), Cut-off Frequency, Sensitivity, Phase response, Group delay and Current consumption. For the design of a noise-cancelling headset, though all these specifications play a role, the key parameters that influence the selection of a microphone are SNR, AOP, Cut-off frequency, Phase response, Group delay and Current consumption. The tolerance, or in other words, the part-to-part variation of the cut-off frequency and phase response is also very crucial.

SNR:

The intrinsic noise floor of the microphone needs to be lower than the signal level of the surrounding environmental noise in order to capture noise signals reliably. Thus, in quieter environments, microphones with high SNR are desired for this application. If the microphone SNR is higher, then the implementation of the noise cancellation algorithm becomes easier.

AOP:

The microphone's AOP needs to be high enough to capture signals from all loud noise sources in the surrounding environment without clipping and/or distortion. If the noise signal level exceeds the AOP spec of the microphone, then the captured signal will have more than 10% distortion typically. This makes it difficult to remove the noise completely in the headset. It is necessary to analyze the THD vs. SPL (sound pressure level) curve of multiple microphones and pick the one that has very low distortion (< 1%) up to large SPL levels.

Cut-off frequency:

The microphone will need to have a low cut-off frequency spec (30Hz or lower) so that low frequency noise signals can also be captured reliably. If the cut-off frequency is higher, the ANC system would be ineffective in removing very low frequency noise signals. The tolerance of the cut-off frequency needs to be very tight. If there is a wide variation of cut-off frequencies between multiple microphones, then the ANC algorithm implementation becomes challenging, and the low frequency noise cancellation performance of the headset would be inconsistent.

Phase response & group delay:

Phase response is the variation of phase over the entire audio frequency band. The phase response curve of a microphone provides insight into how the phase relationship between the different frequency components of the input signal will be handled by the microphone.

Group delay is the frequency dependent delay of the microphone, and the derivative of the phase response. It describes the time delay incurred by tones of different frequencies as they pass through the microphone from acoustic input to electrical output. It is necessary to keep group delay to a minimum and constant across frequencies, to prevent distortion in the output signal due to phase misalignment.

If the noise signal being measured by the microphone is distorted, then effective cancellation cannot take place. Similar to the cut-off frequency, the tolerance of the Phase response curve should also be very small. This enables the ANC algorithm to effectively remove noise from the system.

Current consumption:

Current consumption is a very critical spec to consider while selecting a microphone, especially for always-on and battery operated headset applications. A sleep/standby mode is needed to save power consumption over time and it enables an 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

All ANC headsets are not designed in the same way. As mentioned earlier, several topologies exist for designing ANC headsets such as 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 shown in Figure 2. In this topology, only one microphone is used per ear cup and it is placed closer to the outside of the ear cup. The measurement of this microphone forms the reference noise signal for the ANC algorithm implementation. Being able to get a good measurement of the primary noise signal, before it even gets to the user's ear, is the main benefit of this configuration. It is then up to the algorithmic implementation to cancel out this noise signal such that the person wearing the headset doesn't even realize its existence. However, there is no way for the algorithm to ensure the noise-cancellation actually worked in real-time, due to the lack of a feedback loop in the system. This is the main disadvantage of the feed-forward topology. This configuration ensures that the mid-frequency noise signals (between 1-2 kHz) are well attenuated. As the microphone is placed externally, there can be an impact on performance due to wind noise. A microphone with higher AOP and lower cut-off frequency will be useful in this scenario. This type of topology works well for applications such as Bluetooth headsets that require wide ANC bandwidth but are willing to tolerate moderate noise cancelling performance.

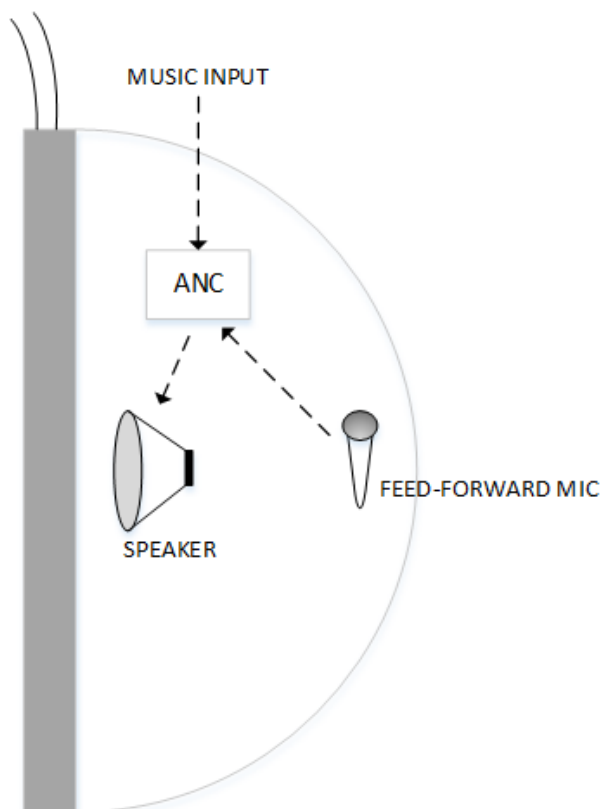


Figure 2. Feed-forward ANC architecture

3.2. Feedback topology

The feedback ANC architecture is shown in Figure 3. This topology also utilizes only one microphone but it is placed closer to the ear of the user. The main advantage of this topology is that the microphone hears the exact same signal which is going into the user's ear, and there is a feedback loop in place for iteratively removing

noise from the system. Although the low-frequency performance of this configuration is good, frequencies between 1-2 kHz do not get attenuated as effectively as the feed-forward configuration. This configuration works well to remove the residual predictable narrowband components of the primary noise signal. This is one of the most commonly used topologies when implementing ANC in headsets despite its inability to remove mid-to-high frequency noise signals effectively. This limitation is due to the phase shift introduced in the secondary path (signal path starting from the output of the ANC block all the way back to its input). This leads to the higher frequency components not being effectively cancelled out by this topology. A microphone picked to be used in this configuration will need to have a flat group delay over frequency and the variation across multiple microphones should be as low as possible.

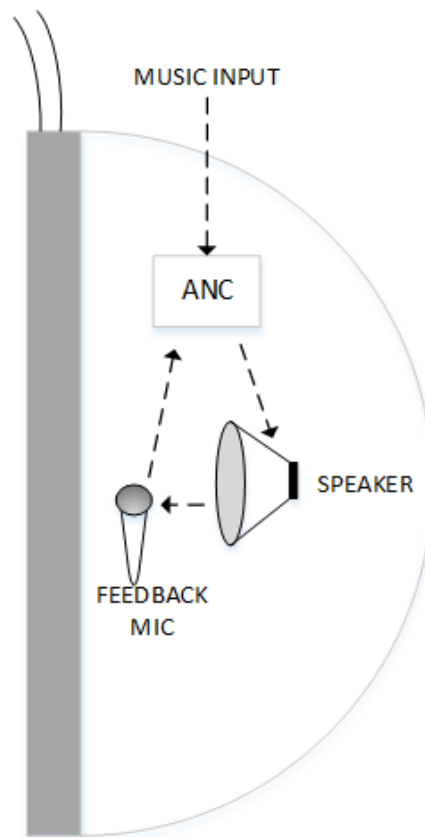


Figure 3. Feedback ANC architecture

3.3. Hybrid topology

The hybrid ANC architecture is shown in Figure 4. This configuration is a combination of both the feed-forward and the feedback topologies discussed earlier. The motivation is to combine the benefits of both the topologies, but it comes with an increase in complexity, cost and size. As this topology has both feed-forward and feedback signal paths, it requires the use of 2 microphones. The outward facing reference microphone senses the primary signal, which acts as the reference signal for the feed-forward ANC filter. The error microphone senses the signal entering the users' ear, which acts as the reference signal for the feedback ANC filter. The error microphone output also helps in determining the coefficients for both the feed-forward and feedback ANC filters. If designed correctly, this configuration can leverage the potential of both feed-forward and feedback topologies.

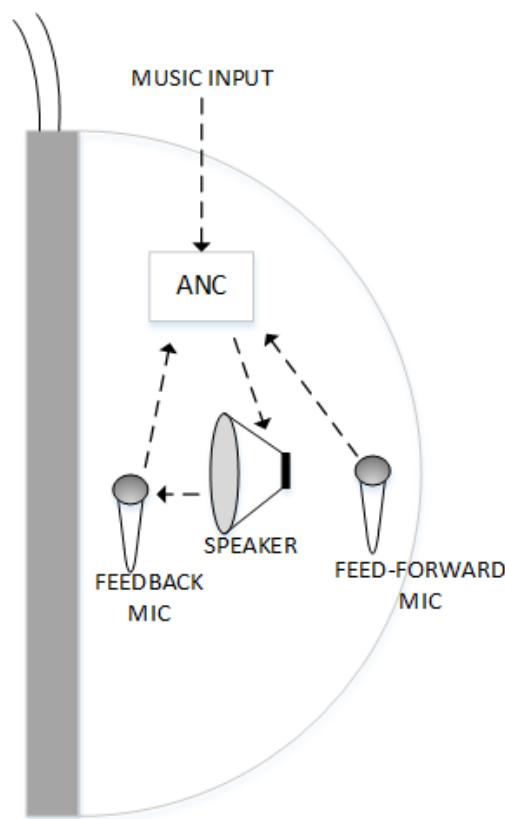


Figure 4. Hybrid ANC architecture

Figure 5 shows a simplified block diagram of the hybrid ANC topology. This diagram shows how the two signal paths merge with each other. $G(w)$ and $M(w)$ are gain and phase compensation filters, while D_{ff} and D_{fb} are delays introduced due to the speaker and microphones in the system.

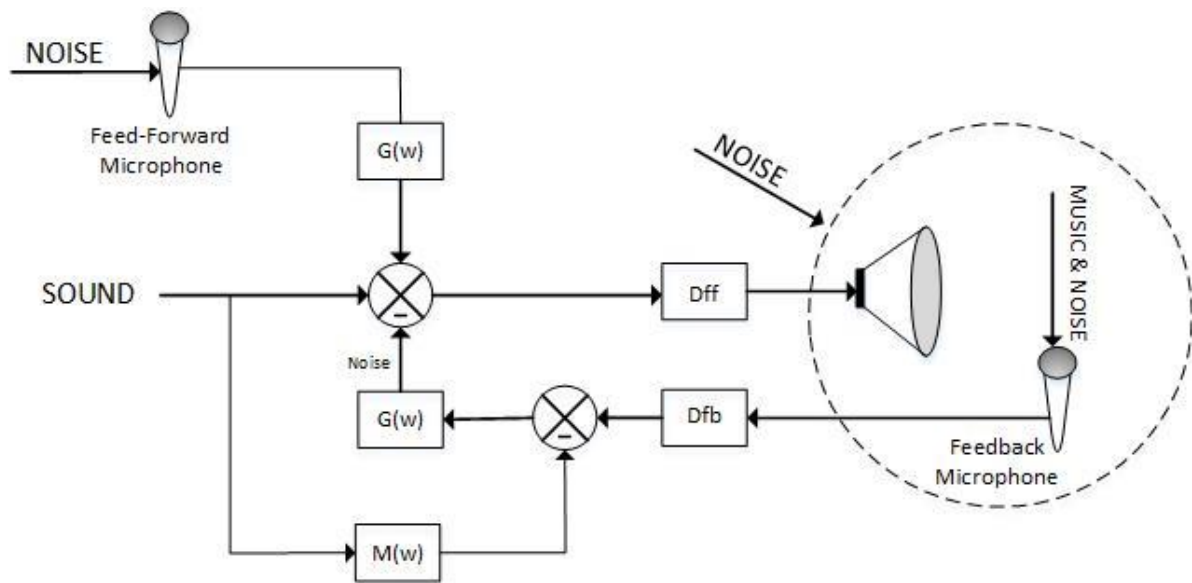


Figure 5. Hybrid ANC topology: block diagram

The hybrid ANC headset design has the capability to provide the best ANC performance and widest noise cancellation bandwidth of the three topologies. However, it is not widely used due to the added cost and complexity of the design. This type of architecture is preferred in high-performance ANC headset designs, where keeping the cost low is not the primary concern. Even in this configuration, the ANC performance beyond 2 kHz is not satisfactory. Hence, headset designers typically use passive noise cancelling techniques as well to improve high-frequency noise cancellation performance.

The headset design can also be classified based on its placement around the human ear such as in-ear, on-the-ear and over-the-ear headsets. For over-the-ear and on-the-ear headset designs, passive and active noise cancelling techniques can be employed in combination to provide excellent ANC performance over the entire audio bandwidth. For in-ear headset designs, where there is no luxury of physical space around the earbuds, implementing typical passive noise cancellation techniques to remove high-frequency noise gets challenging. Hence, the microphones used in such in-ear ANC headsets will need to aid in cancelling high-frequency noise signals as well. If the microphones have lower group delay and have a relatively flatter phase response over frequency, then the high-frequency performance can be improved. The tolerance of the phase response is also very important. A tight distribution of this spec will help in optimizing the ANC algorithms effectively and in turn make the high-frequency noise cancelling behavior better and consistent.

4 Solution provided by Infineon microphone

Infineon Technologies' digital microphone, IM69D130, possesses a rare combination of the best-in-class SNR of 69dB and an incredibly high AOP of 130dB SPL. This microphone is a great choice for noise cancelling headset applications since its specs and tolerances meet all of the criteria discussed in previous sections of this document.

4.1. Magnitude and phase response

As discussed earlier, the tolerances of cut-off frequency and phase response play an important role in selection of the microphone for a noise cancelling headset design. Figure 6, Figure 7, Figure 8 and Figure 9 show the mean and standard deviation of the magnitude and phase response of the IM69D130 microphone. Their 6 sigma limits are also provided for reference. The temperature was kept at 25°C.

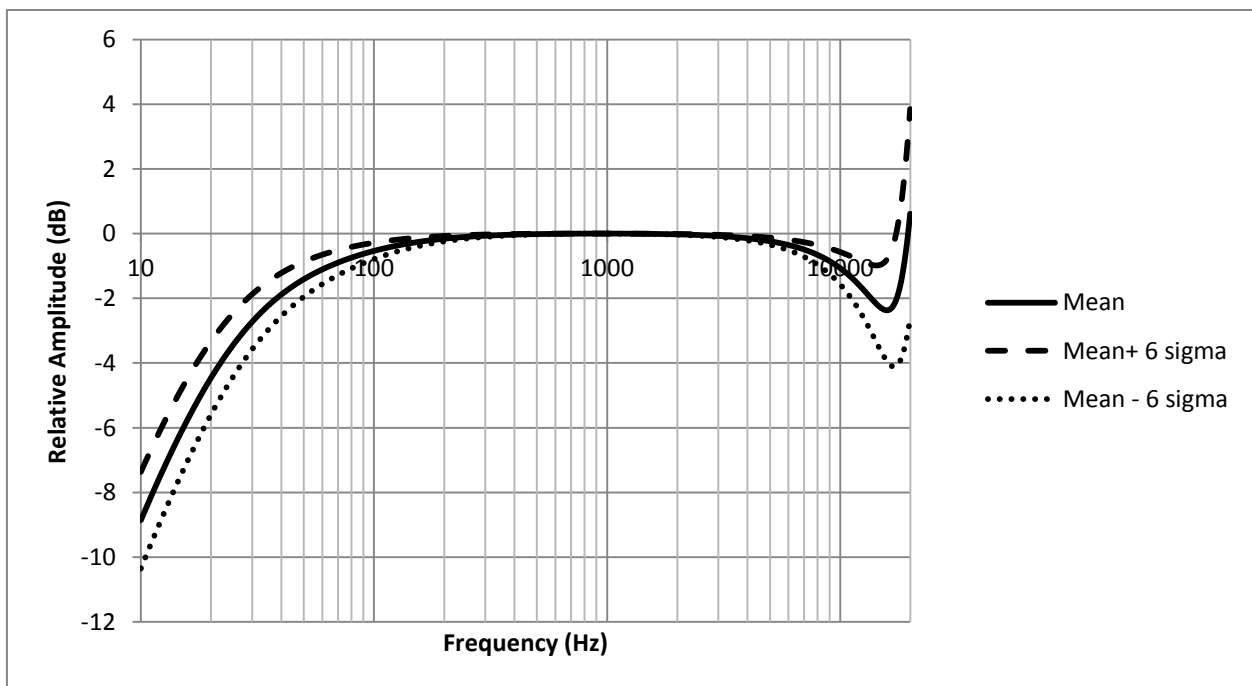


Figure 6. Magnitude response with tolerances

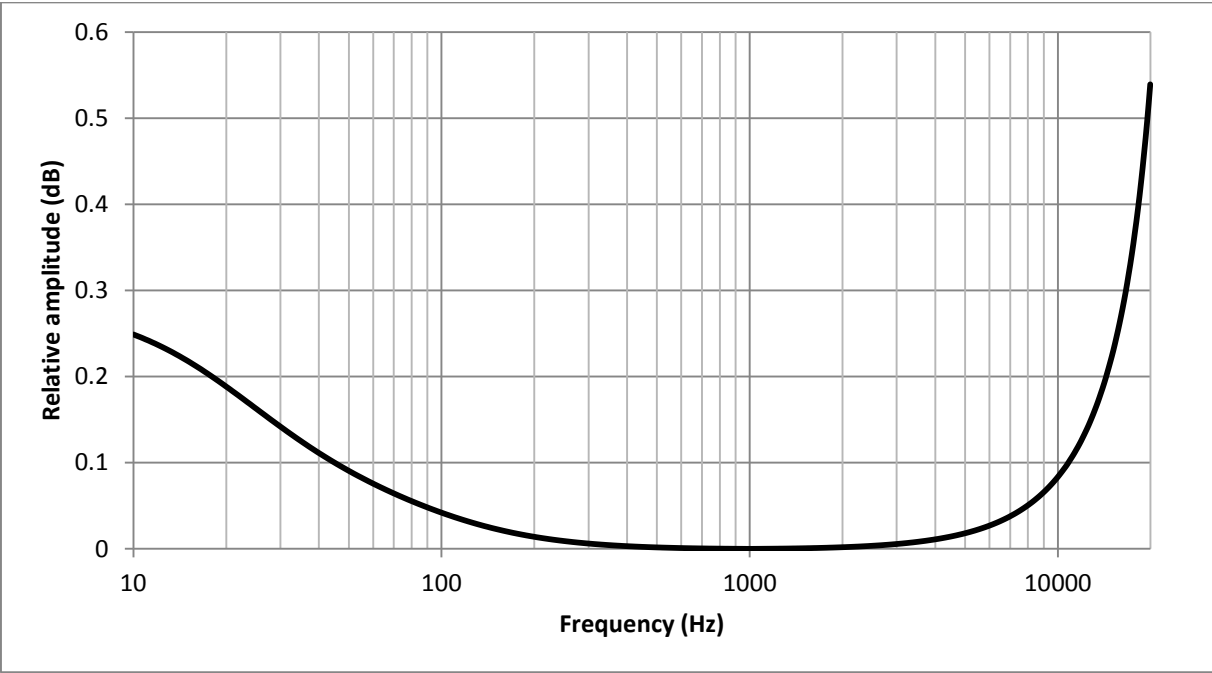


Figure 7. Standard deviation – Magnitude response

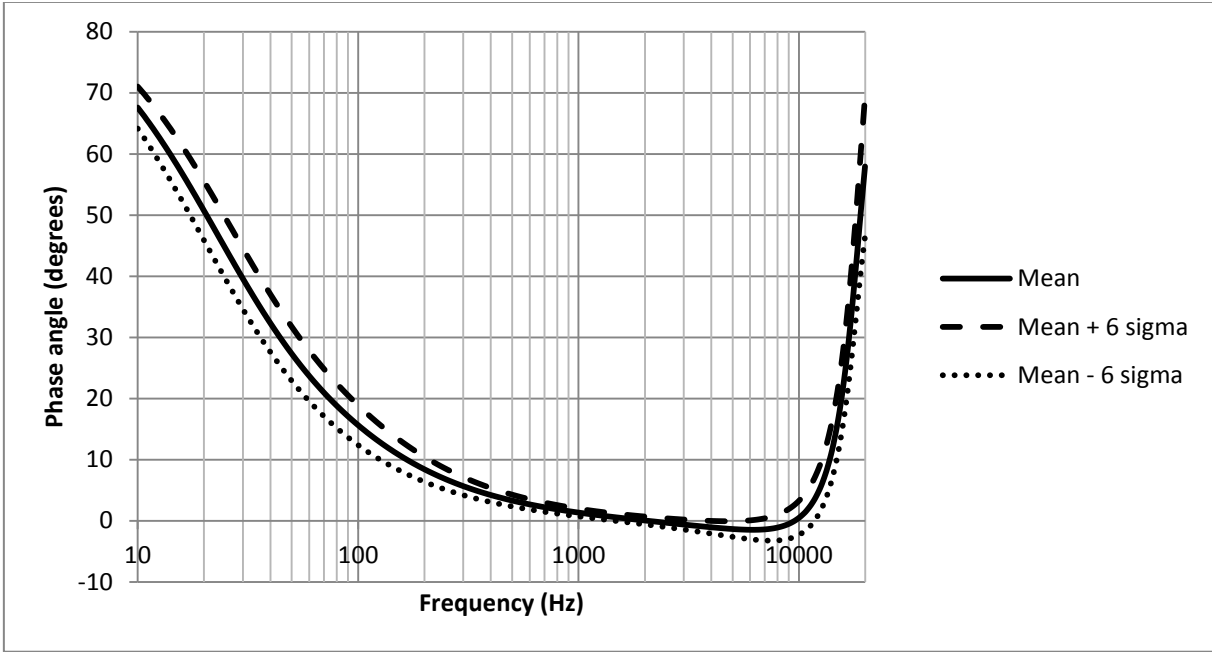


Figure 8. Phase response with tolerances

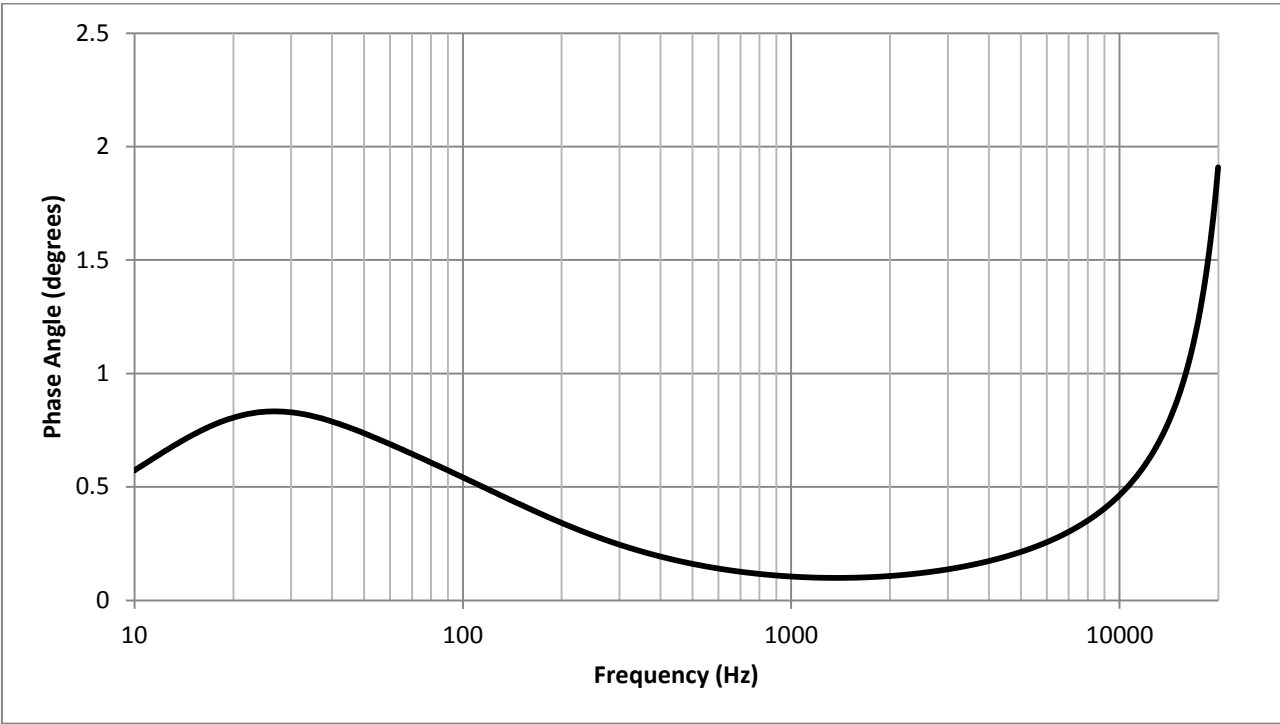


Figure 9. Standard deviation – Phase response

Based on these plots, it is clear that the magnitude and phase response tolerances are very tight for IM69D130. This ensures that the part-to-part variations of corner frequency and phase response remain minimal. This in turn helps to make sure that the ANC algorithm implementation is more accurate.

4.2. Group delay

The group delay was measured on IM69D130 samples in the lab and Figure 10 provides the typical group delay observed across the frequency band. It can be observed from the data that the group delay at 1 kHz is <10µs. Such a small group delay will aid in better ANC algorithm implementation.

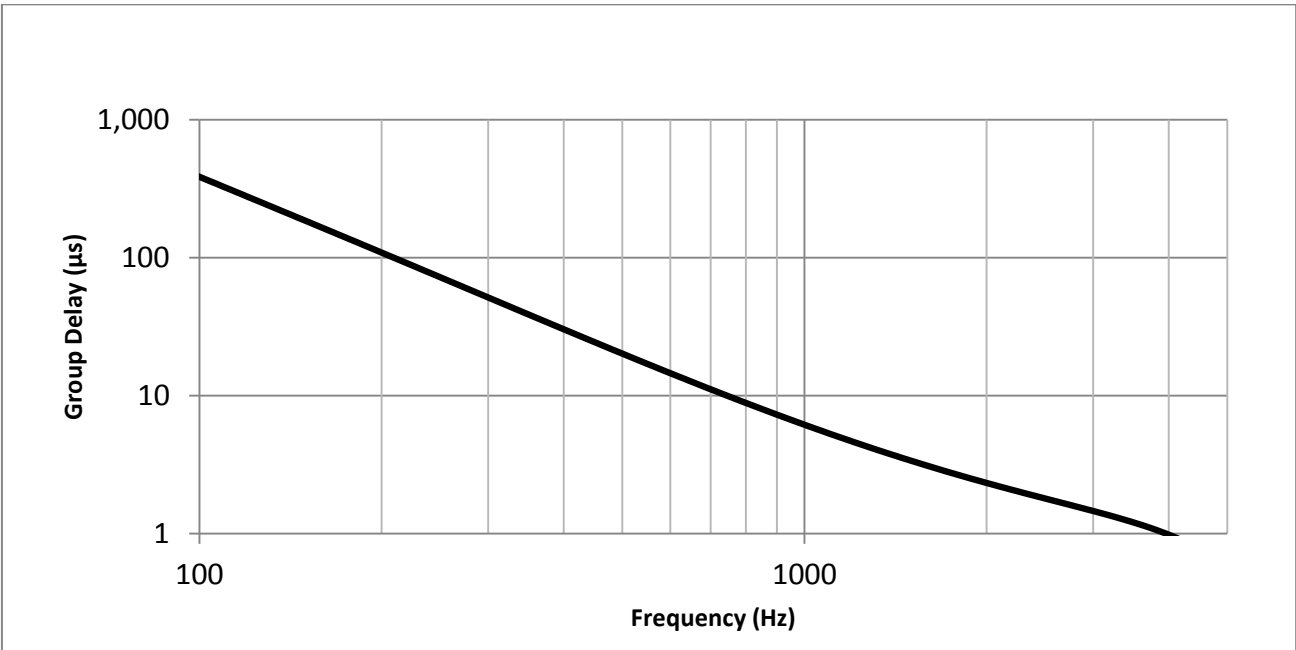


Figure 10. Group delay vs. Frequency

4.3. Total Harmonic Distortion

Another key microphone specification is the AOP. Figure 11 shows the THD vs. SPL plot for IM69D130 along with two competing products. The 10% THD limit is reached at 130dB SPL for IM69D130, which is the AOP spec of this microphone. However, one of the standout features of this microphone is that the distortion remains well within 1% THD up to ~128dB SPL. This greatly helps in capturing loud noise signals reliably with minimal distortion, and hence makes the ANC algorithm implementation much more effective. The competitor microphones represented in Figure 11 have a marginally better AOP spec compared to IM69D130, but it is very clear from the figure that IM69D130 exhibits much lower THD up to ~128dB SPL compared to the other two microphones.

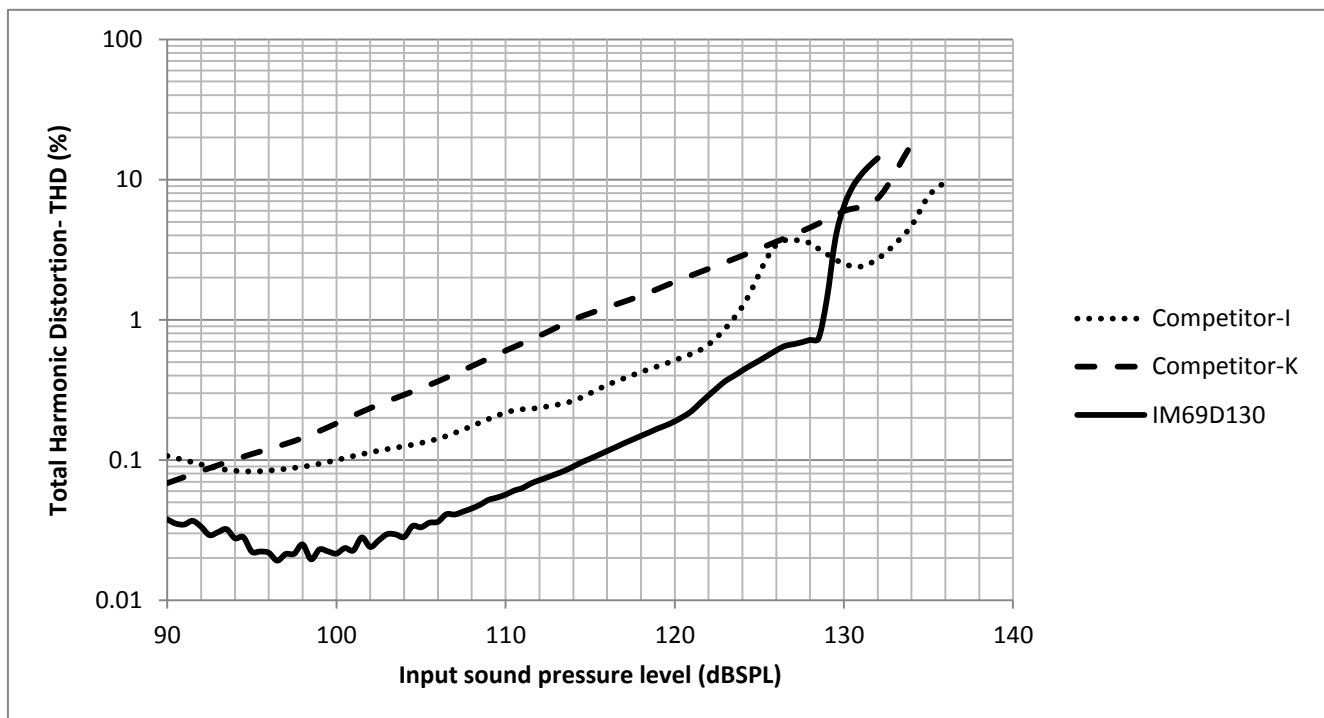


Figure 11. THD vs. SPL

For further specifications and details on IM69D130 microphone, refer to the datasheet. The results shown in this section along with the datasheet specifications of IM69D130 make a compelling argument that IM69D130 will help overcome the challenges addressed in the Section 3 of this document.



Revision History

Major changes since the last revision

Page or Reference	Description of change

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