Maxim – He/Nigam – Contributed Article

Enhancing PSAP Audio Performance and Power Efficiency in Hearables with Antinoise

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Teaser:

Today's hearable devices improve a user's listening experience even in the most challenging environments. How does a PSAP amplify only the desired ambient sound?

What you'll learn:

- What are personal sound amplification products (PSAPs)
- Understand the root cause of comb effect
- Basic building blocks of a PSAP system
- How an antinoise solution mitigates comb effect

Body:

Introduction

Hearable devices are designed to improve a user's listening experience by reducing ambient noise. This is done by using passive and active noise cancellation (ANC) and amplifying the desired ambient sound. Hearables that support amplification of desired ambient sound are commonly referred to as personal sound amplification products (PSAPs). In this article, without loss of generality, PSAP is considered an assisted listening feature in hearables. Used to enhance hearing in challenging environments, PSAP is meant for individuals with and without hearing impairments. Basic building blocks of a PSAP system may include, but are not limited to:

- one or few external microphones to capture the ambient sound.
- one or few internal microphones to capture residual sound inside the ear canal.
- a headphone speaker to playback augmented sound.

- digital signal processing (DSP) blocks, such as beamforming, feedback suppression, ambient/wind/impulse/mic noise suppression, gain amplification, equalization, dynamic range compression, limiters, etc.

A simplified view of the typical audio system for PSAP is illustrated in Figure 1, where the analog microphone signal is converted to digital, decimated in the audio codec, and transmitted to the Bluetooth® system-on-chip (SoC) or DSP core through a buffer. It is then processed in the DSP blocks, transmitted back to the codec through a buffer, and interpolated before converting to analog for the amplifier to drive the speaker output.

Figure 1. Typical audio system view for PSAP

When PSAP is enabled, two types of sounds reach a user's eardrum, as illustrated in Figure 2. Sound S1 is the residual ambient sound (and/or user's own voice). This is a result of the hearable device occluding the ear opening, blocking the sound from reaching the inside of the ear canal and escaping outside of the ear canal. Sound S2 is the PSAP output of the ambient sound captured by the microphone and processed by PSAP DSP blocks. It is finally generated by the speaker, where an inherent delay caused by the audio system may be involved, depending on the audio processing chain design. These two sounds sum at the user's eardrum (i.e., acoustic wave superposition) to create a complete sensation of PSAP experience.

Figure 2. Two sounds reaching the eardrum in PSAP

Problem of Comb Effect

To understand the consequence of the summing effect of two sounds in the presence of a relative delay and gain amplification, Figure 3 represents a simplified signal model. Based on this model, Maxim performed a study to understand how delay and gain affects sound output. Two values of delay were used at 3ms and 0.4ms, with gains at 0, 15, and 30dB.

Figure 3. Simplified signal model for two sounds

Figure 4 illustrates the normalized frequency response of the sum of two sounds, where both delay and gain affect the output significantly. With a 0dB gain, clear distortion in the form of multiple notches can be observed. This distortion is known as comb effect and may degrade the sound quality and create an echoic or reverberation effect. A longer delay (e.g., 3ms) creates more notches, including notches at a much lower frequency than a shorter delay (e.g., 0.4ms). With increased gain, the comb effect is greatly alleviated and forms a ripple of 2-3dB at a 15dB gain or an almost flat response at a 30dB gain, indicating minimal difference in the two delays.

Maxim examined the comb effect of a conventional PSAP solution in typical hearables use cases. As depicted in Figure 5, sound S1 is usually the result of the passive attenuation that shows attenuation (e.g., 15dB) at only high frequencies. Sound S2 is the PSAP output. Two cases of PSAP are shown with 0dB and 15dB gain, respectively. The simulation results of the comb effect are represented in Figure 6, indicating that long latency (e.g., 3ms) can incur comb effect when the gain is low (e.g., 0dB), resulting in audio distortion and an inferior listening experience.

Figure 4. Frequency response of the sum of two sounds based on the simplified signal model

Figure 5. Conventional PSAP solution

Figure 6. Results of conventional PSAP solution

Maxim's Solution to Mitigate Comb Effect Using Antinoise

Mitigation of the comb effect in PSAP can be achieved in two ways: by reducing delay and/or by increasing the gain difference between the two summing sounds, as implied in the above study. Reducing delay in audio systems (see Figure 1) usually requires the use of a very high sampling rate and small buffers in audio conversion (analog-to-digital and digital-to-analog), audio data transmission between codec and SoC/DSP cores, and DSP blocks. Such requirements incur a higher computation load, poor power efficiency, and degraded audio performance, or limited system design and tuning flexibility.

To overcome these issues, Maxim proposed an antinoise based solution that allows a PSAP system to manage gain levels between two sounds, in particular, reducing the level of S1 in low frequency. Introducing the MAX98050, the first low-power, high-performance audio codec designed for continuously active hearables, enabling differentiating features, such as noise cancellation and voice/ambient enhancement. Maxim's patent pending antinoise solution for PSAP is enabled by utilizing the integrated low-power, low-latency digital filter chain configured to generate antinoise. This is done concurrently with sending the microphone record and playback audio data to the host processor (e.g., Bluetooth SoC) at typical audio sampling rates and buffer schemes for flexible and optimal PSAP algorithms design and tuning.

As illustrated in Figure 7, the MAX98050 generates antinoise C1 that interacts with the original passive ambient sound to form a new sound S1 with a reduced level at low frequencies. Figure 8 illustrates a simplified block diagram of this solution based on the simulated comb effect results of a 15dB reduction in low frequencies. As illustrated in Figure 9, Maxim's antinoise solution creates more gain difference between S1 and S2, leading to similar performance between long and short delays in both PSAP gain cases. In addition to the simulation, measurements based on real form factor and a real-time evaluation system have been validated for the proposed antinoise solution.

Figure 7. Two sounds reaching the eardrum in PSAP with antinoise

Figure 8. Maxim's PSAP solution with antinoise

Figure 9. Results of Maxim's PSAP solution with antinoise

Summary

This article explains the comb effect issue that plagues PSAP systems for hearables. The consequences of long delays for PSAP processing is studied in the presence of different gain levels. Reducing delays in PSAP systems leads to poor performance and higher power. Built upon the first low-power, continuously active codec MAX98050, Maxim introduces an antinoise based solution to mitigate comb effect in PSAP, leading to improved audio and power performance, as well as flexible system design for next generation hearables.

For More Information

Learn more about Maxim's Hearable Audio Codec solution: MAX98050

References

- Bluetooth is a registered trademark of Bluetooth SIG, Inc.
- Video: Introduction to the MAX98050 Low-Power, High-Performance Audio CODEC
- Video: Getting Started with the MAX98050 Evaluation System