WhistleBlock Technology
The new benchmark in feedback elimination

For decades, feedback, whistling or squealing, has been a major complaint of hearing instrument users [*Kochkin, MarkTrak I-IV*]. The underlying physical mechanism of feedback is rather simple: the amplified sound from the receiver / loudspeaker leaks through the vent and is picked up and re-amplified by the hearing instrument. This causes acoustic instability which ultimately leads to a well-known and very annoying whistling, squealing or howling in the hearing aid. In the past, the major approach to handle feedback was to either limit the applied gain or reduce acoustic leakage with small vents. The introduction of digital technology has significantly improved the acoustic stability of modern hearing instruments. Modern feedback management systems enable hearing care professionals to optimally use the residual dynamic range of the individual hearing impaired person while also using acoustic coupling systems with larger vent diameters. In particular, the introduction of open fitting devices offering a much higher wearing comfort has been made possible thanks to modern feedback management systems. Despite significant improvements in the acoustic stability of hearing instruments, the performance of today's feedback management systems is still mainly driven by trading off feedback cancelling performance with sound quality and effectively applied gain. A further challenge of state-of-the-art feedback management systems is that they can cause distortions of natural signals, such as music, telephone ringing or door bells.

Physical mechanism – challenges for feedback management systems

As mentioned above, the underlying basic mechanism of feedback is rather simple. However, it is somewhat more complex when it comes to the parameters influencing the occurrence of feedback. The feedback transfer function, which is determined by the acoustic feedback path between receiver and microphone, is not stable but changes significantly during the course of the day. This is due to the fact that the wearer might move an object close to the hearing instruments (i.e. telephone), might walk along or sit next to walls or objects, wear hats, talk and yawn. [J. Hellgren (1999)] did a systematic analysis of the different parameters influencing the generation of feedback. The major conclusions from his studies were:

- There are large differences in terms of spectral, temporal and amplitude characteristics for different feedback generation mechanisms.
- Rather large differences between various subjects are observed due to different ear canal and pinna anatomies.
- Feedback is not a phenomenon occurring at a single frequency. It has complex, time varying spectral characteristics, but it is typically most prominent in the spectral range around 1.5-3 kHz.

Overall, feedback is a complex, highly dynamic phenomenon requiring complex adaptive feedback path estimation and cancellation techniques to be tackled. Besides the dynamic changes in the acoustic transfer path, other algorithms running in the hearing instruments such as the dynamic, compressive amplification schemes or adaptive noise reduction systems must also be considered. These also change the system transfer function in ways which must be taken into account by the feedback management system. Thus, feedback management requires a holistic approach: for optimum performance, the feedback canceller has to be integrated and tuned very carefully to the rest of the adaptive control and signal processing systems of modern hearing instruments.

Consequences of feedback on sound quality

An important issue to consider is the impact of acoustic feedback on the sound quality of the target signal. Commonly, the implicit assumption is that feedback equals "whistling" similar to a pure tone. However, this is only the case when the feedback signal is well beyond the critical feedback threshold, i.e. "over-critical". When the system is still "under-critical" but approaching the feedback threshold, the frequency characteristics of the hearing instrument begin to change and a marked impact on sound quality occurs: the instruments may sound rough, modulated or harsh, i.e. artifacts and distortions start to occur.

Feedback management

Different approaches to feedback management have been introduced in hearing instrument technology [*Dillon 2001*].

The most successful approach to date is the adaptive feedback cancelling system based on feedback phase inversion.

Feedback Phase Inverter

Today, state-of-the-art microprocessors allow the implementation of powerful signal processing strategies for effective cancellation of acoustic feedback. Most modern feedback cancellers are based on an "inverted phase" approach. In this approach, sound waves are cancelled out by their own 180° phase inversion. This is the only technology able to remove feedback without gain reduction.
The algorithm comprises two steps:

- Estimation and modelling of the feedback path.
- Feedback erasure.

For feedback path estimation, a high resolution correlation analysis between hearing instrument input and output is performed. The amount of sound leaking from the receiver back to the microphone is indicated by the result of this correlation analysis. To achieve cancellation, a phase inverted signal with the same frequency content as the feedback signal is generated. Due to destructive interference, the feedback signal is efficiently eliminated without gain reduction. Feedback phase inversion or cancellation has become an accepted and proven method of removing feedback. However, feedback management systems should only be active where and when needed. In programs where feedback is less likely, the feedback phase inverter setting should be less aggressive than in programs where there is greater chance of feedback. While effective at suppressing feedback, many algorithms may be subject to artifacts if the feedback path estimation mechanism falsely identifies other sounds as feedback. This is affected by the degree of feedback phase inversion. As some listening situations have a greater chance of feedback than others, traditional feedback cancellers must have an effective means of ensuring the right balance between feedback suppression, sound quality and effective gain applied by the hearing instrument. The major design criterion for a traditional feedback management system is to find the optimum balance between these three performance dimensions. Different optimized settings should be applied in different listening conditions in order to achieve optimal performance of the entire hearing instrument system. For example, feedback suppression might be given greater priority over sound quality when used together with a telephone as the likelihood of feedback occurring in this situation is greater. On the other hand, when the music program is activated, the adaptive feedback phase inverter ensures optimum sound quality by reducing feedback suppression settings as there is less likelihood of feedback occurring is less. Modern feedback management systems may alleviate feedback, but most will incorrectly identify naturally occurring tonal or correlated signal components ("entrainment") as feedback and subsequently create unpleasant artifacts. This not only has an impact on the sound quality of the hearing instruments but also limits the amount of applicable gain in the system. Existing systems could be parameterized to reduce feedback more effectively and faster if hearing instrument wearers could tolerate more artifacts and thus a much poorer sound quality. In order to overcome the system performance limitations, it is necessary to precisely identify and distinguish feedback from other tonal signal components.

WhistleBlock Technology – revolutionary feedback identification and elimination

WhistleBlock Technology is a significant step forward in feedback phase inversion by enabling feedback cancellation with much higher effectiveness and precision. It profits from a state-of-the-art feedback identification and tagging module. This module is able to instantly differentiate between true feedback and naturally occurring tones, such as music. Figure 1 shows the trade-off between performance of feedback cancellation systems in terms of added stable gain vs. sound quality. With existing feedback cancellers, increased feedback suppression results in decreased sound quality. The feedback canceller applying WhistleBlock Technology eliminates this trade-off. Higher stable gain is achieved with the same sound quality. Accurate identification of sounds that have re-entered the system as true feedback allows for a precise feedback cancellation strategy, blocking feedback without impacting speech clarity or sound quality (see figure 2). By distinguishing feedback components from other correlated tonal components in the signal, it is possible to apply significantly more aggressive feedback cancellation techniques without creating unwanted artifacts.

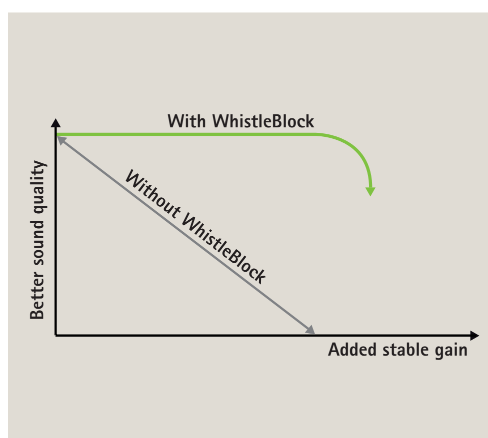


Figure 1:
Qualitative representation of the trade-off between sound quality and added stable gain in existing feedback cancellers. Thanks to WhistleBlock Technology, significantly more gain can be added without compromising sound quality.

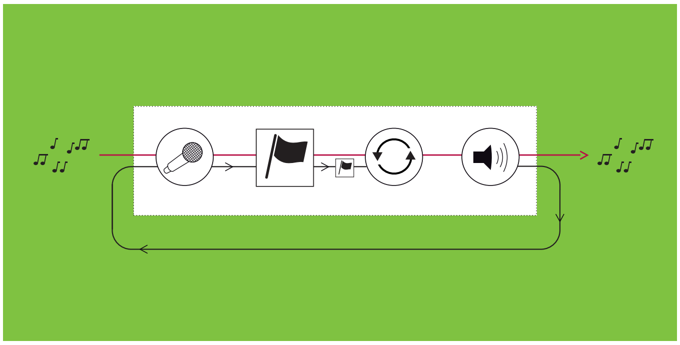


Figure 2:
WhistleBlock Technology profits from a state-of-the-art feedback identification and tagging module. This technology is able to instantly differentiate between true feedback and naturally occurring pure tones, such as music. Accurate identification of sounds that have re-entered the system as true feedback allows for a precise feedback cancellation strategy which eliminates the correlation between input and output signals, blocking feedback without impacting speech clarity or sound quality.

WhistleBlock Technology performance assessment

For assessing the performance of feedback management systems, several different aspects and quality dimensions have to be taken into account. Freed and Soli (2006) and Merks et al. (2006) suggest: (i) added stable gain / effective gain, (ii) effective gain applied, (iii) reliability and speed of feedback detection mechanism, (iv) sound quality.

The performance of a feedback management system can be assessed by answering the following questions:

- How effective is the algorithm at preventing feedback?
- How effective is the algorithm at reducing sub-oscillatory peaks in the frequency response?
- Does the algorithm sacrifice gain in any frequency bands?
- How robust is the algorithm when presented with tonal input signals?

In order to answer these questions and assess the performance of feedback management systems, it is necessary to use a reproducible and realistic test set-up. This can be done by placing an artificial head in a sound treated box and using a linear motor to move an object reproducibly close to the ear and the hearing instrument (figure 3). This allows for a realistic and reproducible simulation of different feedback conditions. Using this test set-up, the performance of the new WhistleBlock Technology was compared to other commercially available products with respect to:

- Added stable gain or excess gain. This measure shows how much more gain can be applied with the feedback canceller turned on versus feedback canceller turned off.
- Sound quality: considers the amount of artifacts occurring.
- Robustness in terms of distinguishing real feedback sounds from tonal signal components.

Added stable gain

Figure 4 shows the added stable gain or excess gain measured for five different devices with the test set-up described above. The instruments were equalized to produce the same amount of gain. It is clearly visible, that the new feedback management system provides significantly more stable gain. Especially in the frequency range most susceptible to feedback, between 1.5-3 kHz, this new technology provides the largest amount of added stable gain.

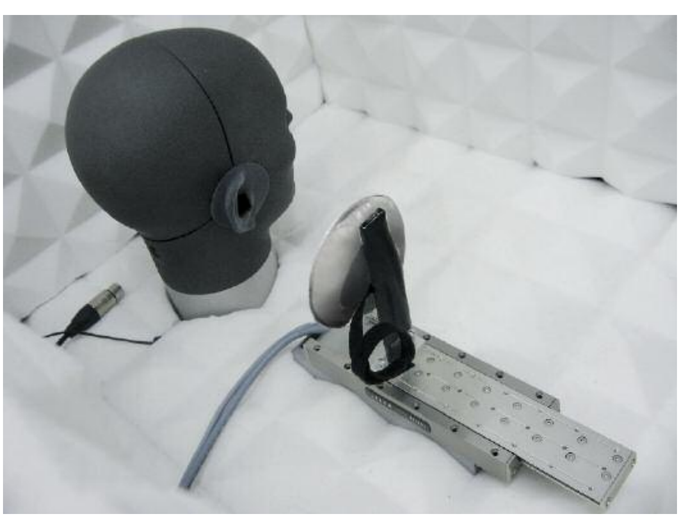


Figure 3:
Test set-up for assessing the performance of feedback management systems under reproducible conditions.

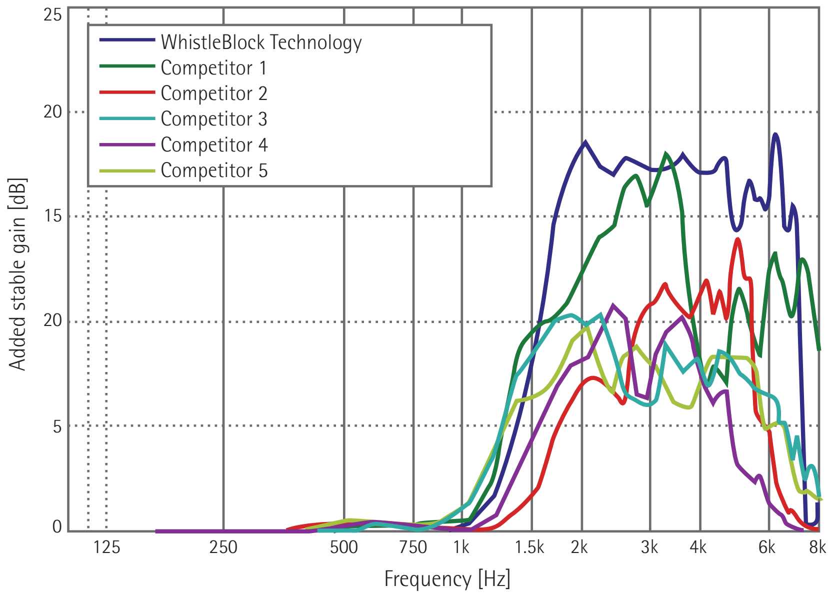
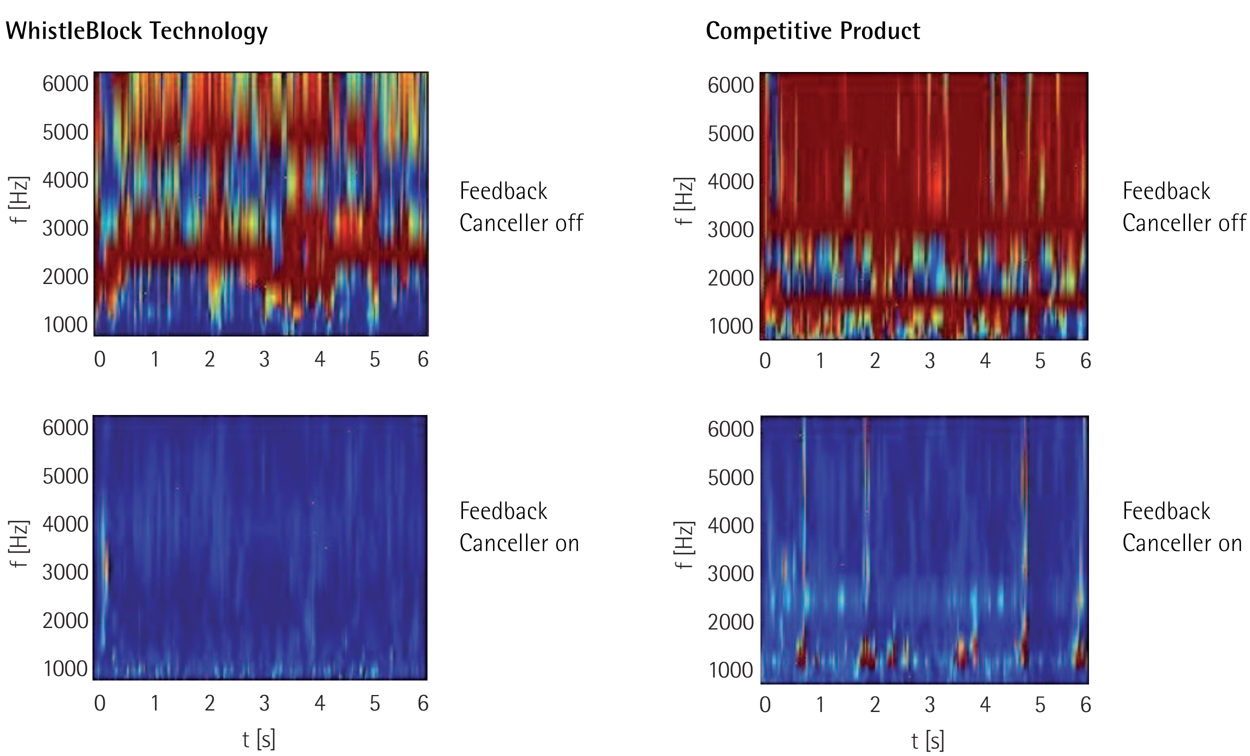


Figure 4:
Added stable gain for different hearing instruments. WhistleBlock Technology available in the Exélia and Naída product lines shows by far the greatest or added stable gain especially in the most critical spectral region between 1.5 kHz and 3 kHz.

Sound quality

Figure 5 compares the amount of artifacts, i.e. the sound quality, of a hearing instrument equipped with WhistleBlock Technology with a competitive device that uses another modern feedback cancellation scheme. The left graphs show the results of the device with WhistleBlock Technology. Two sets of spectrograms of the amplified output signals were measured: the first with no object close to the ear and the second one where a solid object was held about 2 cm away from the pinna. The top row shows the results with the feedback management systems turned off, the bottom row shows the results with feedback management turned on. The red areas in the graphs indicate the occurrence of feedback components or artifacts. With WhistleBlock Technology, hardly any artifacts occur while for a popular competitive system significant artifacts are still present.



Red = feedback
Blue = no feedback

Figure 5:
Comparison of the presence of artifacts, i.e. the sound quality, of two different feedback suppression systems: left graphs are for WhistleBlock, right graphs for a competitive system.
Top row: feedback management turned off.
Bottom row: feedback management turned on.

Entrainment

The last parameter to discuss is entrainment. This phenomenon creates unpleasant artifacts when the feedback cancellation system falsely identifies highly correlated tones as feedback and generates a phase inverted signal. Figure 6 compares the artifacts created due to entrainment of a device with and a device without WhistleBlock Technology. A ring tone was played through a hearing instrument with the respective feedback cancellers turned on. The competitor's feedback canceller (lower panel) produces modulation artifacts, which results in sidebands around the spectral peaks. When using WhistleBlock Technology (upper panel) no entrainment artifacts occur. WhistleBlock Technology can correctly identify tonal input signals and does not take any disturbing counter actions.

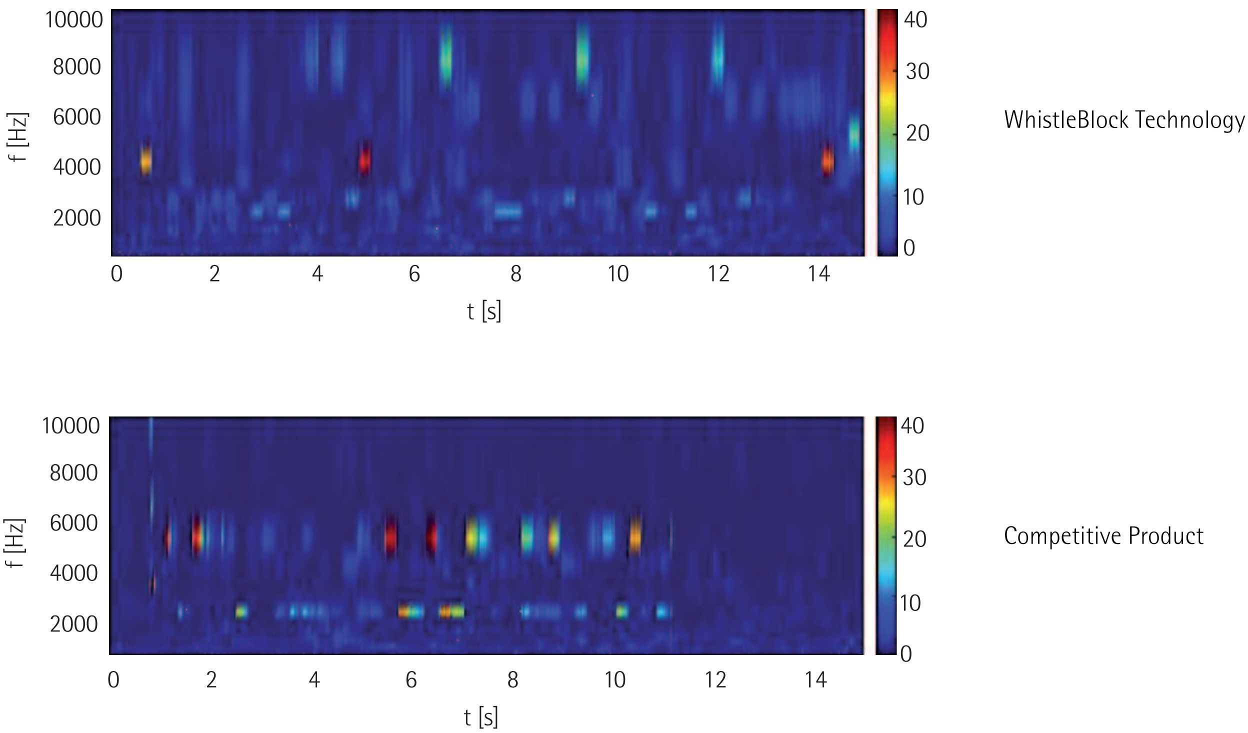


Figure 6:
Spectrogram showing the amount of artifacts in products with and without WhistleBlock Technology. A ring tone is played and the output of the hearing instrument recorded. The top graph shows the measurement results of a device with WhistleBlock Technology. The yellow and red areas indicate the presence of artifacts that lead to poor sound quality. It is clearly visible, that WhistleBlock Technology leads to significantly less artifacts due to entrainment.

Summary

WhistleBlock Technology, now available in Exélia and Naída products, will yield optimal performance for many different hearing instrument families and styles. WhistleBlock Technology achieves significant improvements for added stable gain, improved sound quality and reduced entrainment effects when compared to other competitive schemes of feedback cancellation.

WhistleBlock Technology achieves unprecedented amelioration of one of the major complaints of hearing instrument users, effectively eliminating feedback without introducing annoying artifacts.

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