Combating Feedback Squeal with DFS Ultra

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Abstract

All hearing instrument manufacturers include feedback cancellation systems in their devices, but not all feedback cancellation systems are equivalent. Since introducing the first feedback cancellation system for hearing instruments in the early 1990s, ReSound has continually strived to develop technology to provide hearing instrument users with feedback-free amplification in conjunction with excellent sound quality. The latest development in this technology, DFS Ultra with built-in Whistle Control, represents a significant leap forward in feedback management. DFS Ultra is unique in that it uses advanced modeling techniques of the input and feedback signals to increase the stable gain available in a fitting and combat feedback in the most difficult situations, with no compromises to the overall sound quality. What this means to the hearing instrument user is that they can enjoy the most advanced, effective feedback control on the market today while experiencing the superior sound quality that ReSound has always provided.

Introduction

According to MarkeTrak VIII survey results, one aspect of hearing instrument use with which wearers are significantly more satisfied today is feedback (Kochkin, 2010). Compared to 2004 results, consumer satisfaction ratings in this area improved by 12%. This is not to say that feedback is no longer problematic, as it remains among the most negatively ranked areas related to hearing instruments, but certainly progress in solving this vexing issue is being made and users are taking note. Nearly all hearing instruments on the market today use some type of feedback cancellation as the method to reduce feedback occurrence. As the first manufacturer to make feedback cancellation commercially available in the early 1990's, ReSound pioneered this type of sound processing and continues to set the standard for feedback cancellation that preserves sound quality.

The primary design objective for feedback cancellation is to provide added stable gain. This means that for any given fitting, more gain without feedback is possible with feedback cancellation activated than without it. As experience with feedback cancellation has grown, development has increasingly focused on a major dilemma of feedback cancellation: how to effectively eliminate internally generated feedback without affecting external sounds that resemble feedback, such as whistles, beeps and music. Continuing its industry leadership in Digital Feedback Cancellation (DFS) technology, ReSound introduces the first of such algorithms that not only keeps track of the feedback but also of the input sound. This unique characteristic allows the system to increase the amount of added stable gain without disturbing sound quality. Considering that clarity and natural sound are among the top 5 correlates with overall hearing instrument satisfaction (Kochkin, 2010), sound quality-focused developments in feedback cancellation processing are of great consequence in pleasing consumers. This paper describes the development background for a remarkable leap forward in feedback management: DFS Ultra with built-in Whistle Control.

Not All Feedback Cancellation Systems are Created Equal

All feedback cancellation systems can cancel feedback squeal, yet differences among the systems are apparent. Aside from differences in the amount of added stable gain provided, systems differ in the prevalence of artifacts, or entrainment, and the negative impact of artifacts to the overall sound quality. Artifacts are extraneous sounds such as rings, chimes or echoes emitted from the hearing instrument as a result of bias, or suboptimal performance of the feedback cancellation. Bias issues occur when the feedback cancellation system attempts to cancel out an external sound that is not feedback.

Manufacturers employ various ways of avoiding bias issues, including limiting gain. In this case, gain is "clamped" and not allowed to increase above a certain upper limit based on the calibration of the feedback cancellation system. Thus, once the feedback cancellation system is calibrated and activated, gain can only increase to a certain degree in the fitting software in an effort to prevent artifacts from occurring. This method is disadvantageous when higher gain settings are desired in a fitting, causing inadequate audibility in some cases.

Another way to manage bias is altering phase relationships between the input and output signals. In this method, the phase or the frequency of the hearing aid output is shifted to differentiate from the phase or frequency of external sounds. However, this method can be detrimental to the overall sound quality.

ReSound DFS systems have uniquely handled bias issues with the use of adaptation constraints and decorrelation methods. The constraint method works by setting limits on the adaptive feedback cancellation filter such that it is not allowed to stray too far from what was modeled by the static filter set in the calibration. This helps prevent the system from trying to cancel sounds which are not feedback but share similar tonal qualities, and does not negatively impact the audibility or the overall sound quality of the hearing instrument. Decorrelation techniques add to the robustness of the feedback cancellation system by removing tonal qualities from the input sound for the feedback path analysis. This does not affect the amplification of the input sound, but helps the system separate feedback from external sounds.

The last decade in particular has seen the development of feedback management algorithms aimed at completely eliminating feedback, even in extremely dynamic, difficult situations. Hearing instrument manufacturers approach this from two main perspectives; some focus on cancelling feedback squeal in all situations and employ gain reduction in order to do so, while others prioritize audibility by preserving gain at all costs. Each of these approaches may have drawbacks, however. Feedback cancellation systems that try to eliminate feedback in all situations may have poor sound quality as a result. On the other hand, feedback cancellation systems that preserve gain at all costs may not effectively cancel feedback in the most dynamic conditions. In sum, achieving a high amount of added stable gain while preserving good sound quality and minimizing sound artifacts remains the ultimate goal. DFS Ultra strives for optimum performance in each dimension by utilizing the most advanced feedback control system available today.

Digital Feedback Suppression, the ReSound Way

ReSound DFS technology works by introducing a phase inverted signal relative to the feedback pathway into the signal pathway of the hearing instrument. The result is reduction of the intensity and occurrence of feedback squeal. The feedback cancellation system for a single-microphone hearing instrument consists of two filters, both static and adaptive, as illustrated in Figure 1. For dual-microphone directional hearing instruments, a separate, additional set of static and adaptive filters is required to accurately model the feedback paths created from the receiver to each of the two microphones.

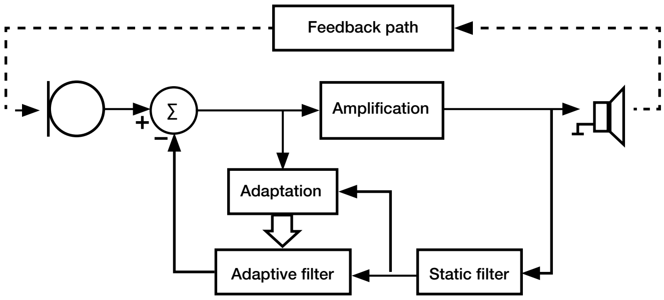

Figure 1. The feedback path (solid red line) and the adaptive constraints (dotted red lines), with frequency on the X axis and gain on the Y axis. The solid grey line represents a tonal input beyond the adaptive constraints that would be incorrectly targeted by the system as feedback if not for the adaptive constraints.

The first, static filter is set up by a calibration procedure during fitting of the hearing instrument. The purpose of this filter is to represent relatively stable characteristics of the feedback path, such as vent size and position, hearing instrument microphone and receiver orientation, and ear canal size and shape. This static filter allows the user to wear the hearing instrument without feedback squeal in most normal wearing conditions. The system's second filter is adaptive and is also activated following the calibration of the static feedback cancellation filter. The second filter accounts for changes in the feedback path. Feedback path changes can occur gradually, such as when cerumen builds up over time, or rapidly, such as when the user holds a phone close to the hearing instrument. The adaptive filter better allows the end user to use the hearing instrument actively and to engage in dynamic everyday situations without feedback. The adaptive filter is constrained to prevent it from straying too far away from what was modeled by the static filter (10 dB range), in order to prevent artifacts from occurring. Figure 2 illustrates a typical feedback path as modeled by DFS calibration, with frequency on the X axis and gain on the Y axis. The adaptive filter constraints prevent the system from trying to cancel sounds which are not feedback squeal. The combination of the static and adaptive filters with constraints provides added stable gain and preserves sound quality by minimizing artifacts.

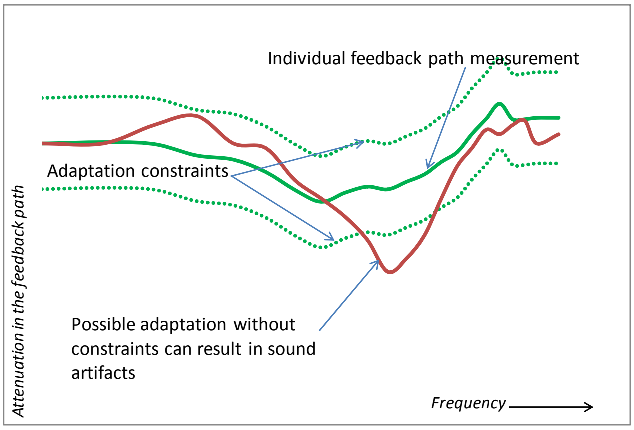

Figure 2. The feedback path (solid green line) and the adaptive constraints (dotted green lines), with frequency on the X axis and gain on the Y axis. The solid red line represents a tonal input beyond the adaptive constraints that would be incorrectly targeted by the system as feedback if not for the adaptive constraints.

DFS Ultra

A new generation of feedback cancellation, DFS Ultra, represents a major breakthrough in feedback cancellation processing. This algorithm models both the feedback path and the input (or external sound), to improve the accuracy in identification of feedback from other tonal input sounds. In addition, improvements to the precision and scaling in the models result in a more accurate feedback cancellation signal. These advancements improve upon the identification and differentiation of feedback from other tonal input sounds, thereby reducing artifacts to a greater degree than was previously possible.

Unlike other systems which only attempt to model the feedback path, the new input signal modeling incorporated in the DFS Ultra system (Figure 3) maintains a representation of the sound entering the hearing instrument and uses this information to prevent the feedback cancellation filters from attacking desired sounds. The advantage of this signal model component is that the system more easily can distinguish between feedback and non-feedback sounds, vastly improving the dynamic behavior of the system. Important everyday sounds like phone rings, alarm beeps and music can be amplified to desired levels without being mistaken for being feedback squeal.

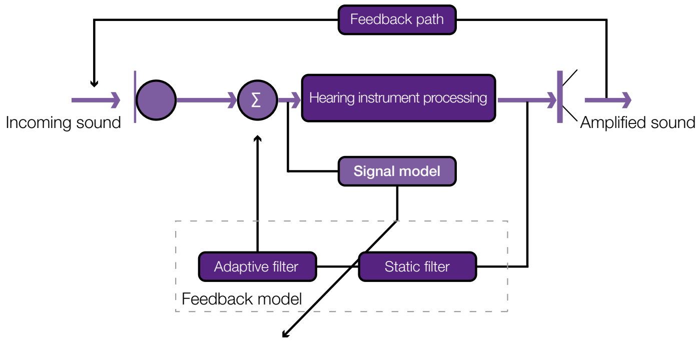

Figure 3. DFS Ultra analyzes and models the incoming sound and uses this information to prevent the feedback cancellation filters from attacking desired sounds.

The product of more accurate feedback path modeling is evident in significantly more added stable gain as compared to the legacy DFS algorithm ($p < 0.05$). Figure 4 shows the distribution of added stable gain with legacy DFS and DFS Ultra. The added stable gain is higher with DFS Ultra as compared to legacy DFS.

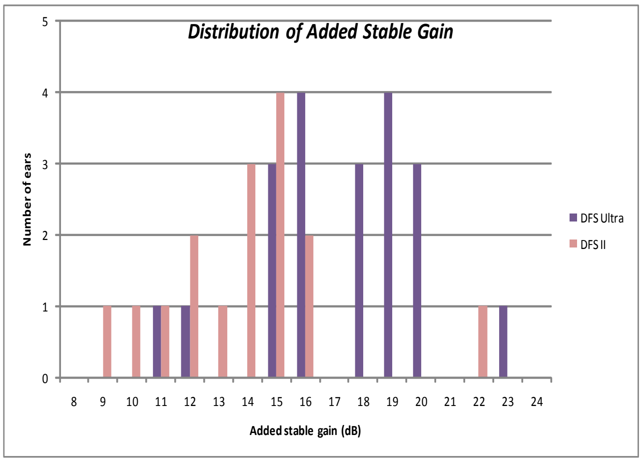

Figure 4. DFS Ultra provides more added stable gain than legacy DFS.

Whistle Control

Whistle Control serves as an additional layer of feedback control in DFS Ultra, by reducing the occurrence of feedback that arises from dynamic, transient situations. Even with adaptation constraints and the improved signal modeling accuracy, it is possible for occasional feedback to occur in situations like holding a phone to the ear while wearing a hearing instrument. With Whistle Control, feedback that manages to elude the DFS system is controlled via gain reduction in the frequency range of the feedback. The signal itself is unaffected while the extra gain from the feedback spike is reduced. Thus, Whistle Control serves as an emergency option, for the most difficult feedback-provoking events which are not completely resolved through the feedback cancellation alone.

The combination of feedback cancellation and Whistle Control ensures that it is possible to provide sufficient, undistorted high frequency gain without feedback squeal.

DFS Ultra as it is available on the market today in the ReSound Alera family has Whistle Control built into the system. When selecting DFS Ultra in Aventa 3.0 fitting software, functional options include mild, moderate, and strong levels. These levels correspond to the aggressiveness of the Whistle Control system to reduce gain for the feedback spike. The stronger the level of DFS Ultra chosen, the more likely the system is to reduce high-frequency gains for sounds it identifies as feedback. For most end users who participated in clinical trials, a "mild" setting was been found to be an appropriate default level.

Evidence-Based Design and Development

ReSound relied on evidence-based design to ensure that DFS Ultra and Whistle Control met the ambitious objectives that were set. First, a sophisticated measurement system with a specially designed robotic arm was used to evaluate and tune the feedback cancellation algorithm in the laboratory. The robot can be programmed for evaluating different scenarios. For example, it can replicate precisely the movements made by a human putting a telephone up to the ear and removing it again. This measurement setup can be used to collect and analyze data on minute changes in parameters in a controlled and repeatable way.

Laboratory testing with the robotic arm was conducted using an Alera 61 receiver-in-the-ear (RIE) hearing instrument and the KEMAR acoustic manikin (Figure 5). Both static and dynamic measurements were obtained over the course of the testing, which lasted 31.5 hours and generated more than 9600 measurements and sound files. In the static measurements, gain was increased when a plate was positioned 1mm from KEMAR's ear in a quiet environment. For the dynamic measurements, the robot held a phone and moved it rapidly to KEMAR's ear while background speech was present and gain was incrementally increased.

Figure 5. Robotic arm lab testing of DFS Ultra with a KEMAR manikin.

Once the best proposed combination of parameter settings were established for DFS Ultra, ReSound carried out in-house and external clinical testing to evaluate real-world performance. A double-blind field trial was conducted at the University of Oldenburg clinic to compare DFS Ultra with legacy DFS. Twenty-six end users were fitted with two sets of identical open fit thin tube BTE instruments. The only difference between these two sets of instruments was that one set was programmed with legacy DFS and the other set was programmed with DFS Ultra. Both the end users and the audiologists were blinded to the DFS version used in each set. The end users kept logs of situations they encountered, rating "occurrence of feedback," "occurrence of artifact," and "sound quality." As compared to existing DFS technology, which in itself is a leader in feedback cancellation on the market, small improvements in the absolute ratings were observed. For example, when rating the occurrence of feedback on the phone for the devices with legacy DFS, the median response corresponded to "seldom." For the devices with DFS Ultra, the median rating was about 1 scaling unit better. What is striking about the results of this trial is not the size of the absolute differences in the ratings, but the fact that the DFS Ultra was consistently rated just a bit better than technology that is already well-respected in the industry. The results showed lower occurrence of feedback squeal and artifacts along with better sound quality for DFS Ultra as compared to legacy DFS, as shown in Figure 6. When looking at "feedback occurrence" in particular, every single situation was rated better with DFS Ultra than with legacy DFS. This is compelling evidence of true added benefit provided by DFS Ultra (Henriksen, 2008).

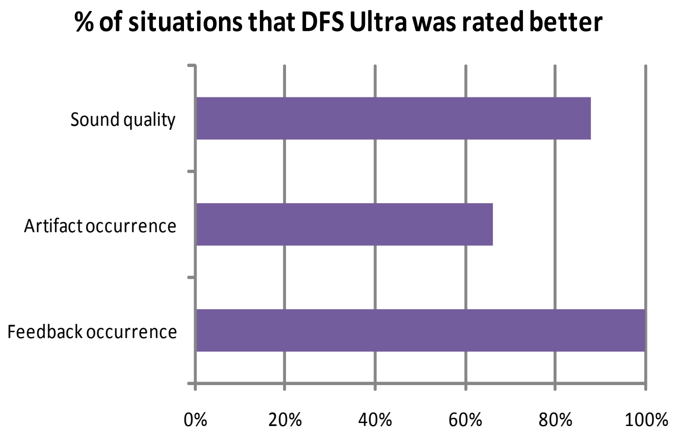

Figure 6. Percentage of situations where DFS Ultra was rated as better than legacy DFS.

In another external clinical trial, the ReSound Alera RIE was compared to six other competitive RIE devices in terms of feedback performance. The hearing instruments were programmed to their first-fit defaults for 40 participants with mild-to-moderate hearing losses, and the feedback management systems were activated according to manufacturers' recommendations. Occurrence of feedback was noted when a phone was held up to the ear, and is shown in Figure 7. Device C had no feedback at all. However, it is important to note that the first-fit average high frequency gain was found to be only 5 dB in these 40 ears, whereas the Resound Alera and all other devices tested averaged 12 to 17 dB in the high frequencies. Apart from Device C, ReSound Alera displayed the best performance with only 2 of 40 ears experiencing feedback in this situation. Other devices, such as D and F, not only had a high occurrence of feedback, but a degradation of sound quality was also reported by some participants.

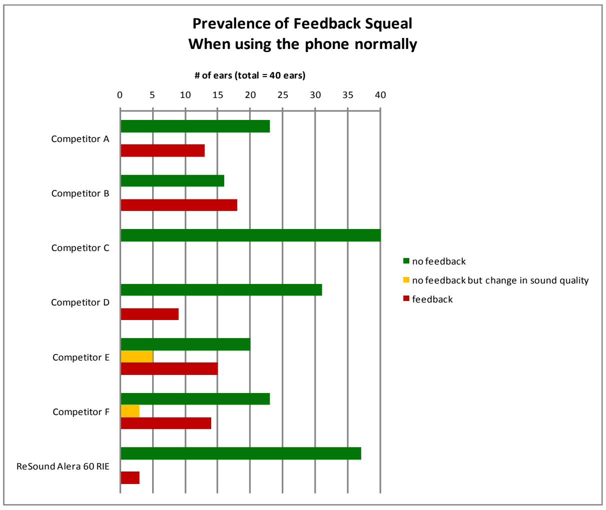

Figure 7. Trial participants held a telephone up to the test devices programmed to the manufacturers' first-fit gains, and it was noted whether feedback occurred. Although no feedback was experienced with Device C, this particular hearing instrument prescribed on average 10 dB less high frequency gain than the others. The ReSound Alera with DFS Ultra and Whistle Control demonstrated the lowest occurrence of feedback compared to devices with similar gain.

Feedback calibration

DFS Ultra, like ReSound legacy DFS systems, is activated by calibration during the fitting. This measurement is used to determine the static feedback path for the individual fitting. An accurate feedback path measurement requires an adequate signal-to-noise ratio (SNR) of the test stimulus at the hearing instrument microphone. The calibration for DFS Ultra in ReSound Alera is the first calibration procedure which monitors the SNR during the calibration and stops the test when an adequate level has been reached and sufficient data collected for a precise analysis of the feedback path. In addition, the duration of signal presentation is reduced markedly. The average calibration tone length observed in clinical trials was only 1-2 seconds (Figure 8).

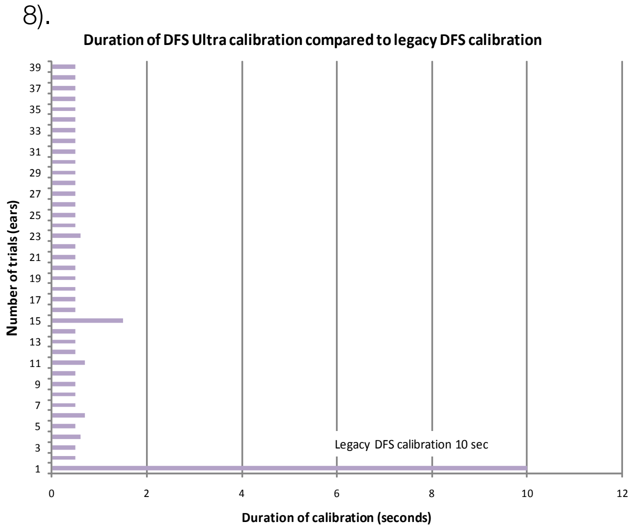

Figure 8. DFS Ultra calibration tone duration for 38 ears in clinical trials. The duration of the legacy DFS calibration signal is represented by the bar at the bottom of the graph.

Evaluating Feedback Cancellation

As discussed previously, not all feedback cancellation systems available today on the market are created equal. Thus, it may be useful to evaluate the robustness and sound quality of the feedback cancellation system in the clinic. There are several ways to evaluate different feedback cancellation systems in a typical clinic setting. First, one can evaluate the amount of added stable gain available for a given patient. With the patient wearing the instruments in a quiet, the level to which the gains can be increased before feedback occurring indicates the amount of added stable gain available in static, unchanging conditions.

Usable gain takes into account dynamic changes in the feedback path that occur from patient movements, speech and other everyday activities. The amount of usable added stable gain available will often be less than the added stable gain for static conditions. The degree and severity of artifacts produced by a feedback cancellation system can be evaluated through playing sounds that would typically cause artifacts to occur in some feedback cancellation systems, such as a mobile phone ringing or a grandfather clock chiming. Finally, the effectiveness of dual feedback cancellation for two-microphone hearing instruments can be evaluated by increasing gains in the fitting software in each of the omnidirectional and the fixed directional modes.

Summary

For nearly 20 years, ReSound has strived to develop technology to provide hearing instrument users with feedback-free amplification in conjunction with excellent sound quality. Now, with DFS Ultra with built-in Whistle Control, there is a solution that addresses static and dynamic feedback, with safeguards to combat feedback even in the most difficult situations of daily life. This means that even while engaging in the most feedback-prone activities, such as talking on a cell phone, hearing instrument users fitted with DFS Ultra can enjoy state-of-the-art feedback control without sacrificing audibility or superior sound quality.

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