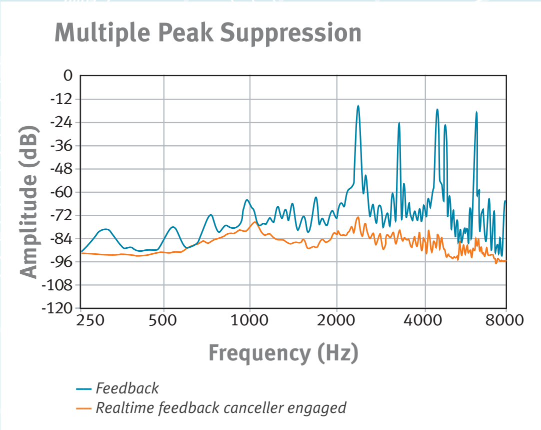
conversa™
with ClearCall

Realtime Feedback Canceller

DRAMATICALLY REDUCES MULTIPLE FEEDBACK PEAKS WITHIN MILLISECONDS



Executive Summary

Ask hearing aid wearers about the most embarrassing experience they can recall with their instruments and they will invariably describe an event involving acoustic feedback. A squealing hearing aid immediately directs everyone's attention to its owner. The oscillations responsible for the squeal can result from a hug, a hat, a telephone or a hand placed close to the ear. Even opening one's jaw to yawn can initiate an uncomfortable screech. Several methods, such as notch filtering[1,2] and phase cancelling,[3-5] may control acoustic feedback but are not completely effective at eliminating this nuisance. Realtime feedback cancellation is a more effective approach that suppresses oscillations rapidly to adapt to the dynamics of a rapidly changing feedback pathway.

unitron™ hearing

Dramatically Reduces Multiple Feedback Peak

Sources of Feedback

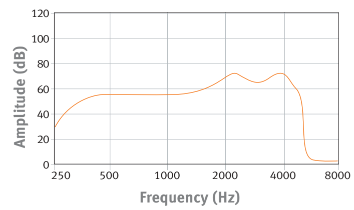
By definition, acoustic feedback is amplified sound exiting the ear canal, returning to the hearing aid microphone and passing back through the hearing aid once more. Hearing aid wearers often unknowingly tolerate low levels of feedback, as the feedback levels do not normally destabilize the amplifier or cause oscillations and squealing. However, feedback that is left unchecked can progress through different levels of intensity causing discomfort and distortion of the speech signal.

In the first stage, the hearing instrument is still considered *stable*, that is, no feedback is present in the hearing instrument or if momentary feedback occurs, the hearing instrument is able to return to its initial stabilized state (see figure 1A). The second stage in the progression of feedback is when *suboscillatory feedback*[6] occurs affecting the sound quality of the hearing instrument. These low levels of acoustic feedback may not cause squealing, but disrupt the frequency response of the hearing aid and negatively impact speech clarity (see figure 1B). Suboscillatory feedback occurs when hearing aid wearers turn up their instrument until it starts to whistle and then reduce the volume control just enough so it stops whistling when they remove their hand. This typically leaves the aid right on the edge of stability: not quite unstable enough to start whistling on its own, but a sudden impulse sound or speech in the correct frequency range will briefly drive it into oscillation. Wearers describe what they hear as an echo or reverberation more than a whistle. For example, they will often say that the /s/ sound goes on longer than it should.

Suboscillatory feedback can progress into a third stage of feedback, known as *self-sustaining oscillation*. Self-sustaining oscillation is the whistling or ringing that is most often associated with hearing instrument feedback and can be embarrassing for the hearing aid wearer (see figure 1C).

Figure 1A

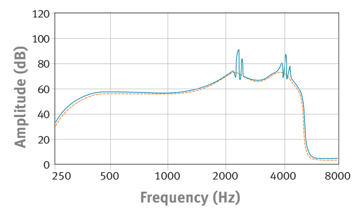
Stage 1: Stable



No appreciable acoustic feedback is present.

Figure 1B

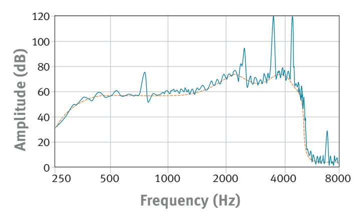
Stage 2: Suboscillatory Feedback



No sustained whistling or squealing.

Figure 1C

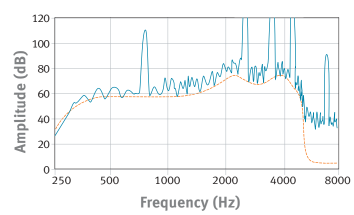
Stage 3: Self-sustaining Oscillation



Characterized by steady squeal once oscillations are initiated.

Figure 1D

Stage 4: Saturation



This results in even more distortion components between oscillation frequencies. Characterized by loud uncomfortable screeching and significant distortion

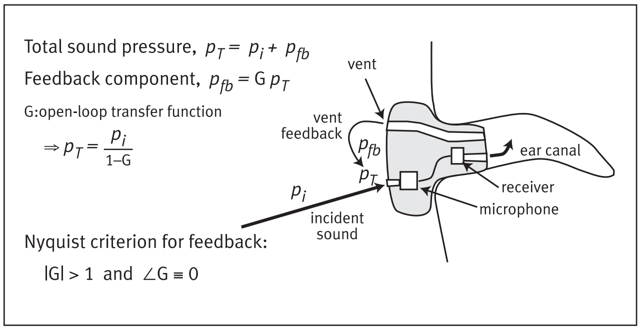
ks Within Milliseconds

Finally, the last stage of feedback involves self-sustaining oscillation progressing to the point of *saturation*. When feedback reaches the saturation stage, sound reaches the maximum possible output level and multiple feedback peaks drive the hearing instrument into intense oscillations, which can cause saturation distortion and be extremely uncomfortable for the hearing instrument wearer (see figure 1D).

While it is clear that stage 4 feedback is the most unpleasant, even the minor distortions of stage 2 feedback can reduce speech intelligibility and sound quality. Therefore the most effective feedback suppression system should rapidly detect and react to the oscillations by stage 2. It is most desirable to eliminate acoustic feedback before it becomes self-sustaining and well before the point of saturation.

Acoustic feedback can also result from changes to the sound field near the hearing aid. The near field changes when a telephone or hand is placed near the ear, altering the characteristics of the feedback pathway. The alterations to the feedback path are enough to initiate oscillations in the otherwise stable system.[7] Daigle and Stinson[8] demonstrated how variations of the acoustic near field, due to a telephone handset, lead to an increase in the open-loop transfer function across different frequency ranges. The open-loop transfer function describes the frequency response of the hearing aid receiver as its output escapes back to the microphone. They found that moving a telephone handset up to the hearing aid microphone increased the open-loop transfer by as much as 20 dB at some frequencies on linear BTE, ITE and ITC hearing aids. In other words, the presence of the telephone lowered the hearing aid's threshold for feedback onset by up to 20 dB. Earmold venting and slit leakage of amplified sound between the earmold and the wall of the ear canal are the major contributors to the feedback component of the open-loop transfer function. An object placed near the ear also increases the open-loop transfer and raises the likelihood that acoustic feedback will cause the hearing aid to oscillate and whistle.

Figure 2
Open-Loop Transfer Function



A simplified mathematical description of the open-loop transfer function[8] is shown in figure 2. In general, there are three basic components that determine its numeric value:

1. the incident sound pressure at the microphone *(p_i)*;
2. the gain of the instrument *(G)*; and
3. the amount of sound that leaks back from the receiver to the microphone *(p_{fb})*.

Raising the value of any one of the three increases the open-loop transfer and reduces the stability of the hearing aid. As the stability of the hearing aid decreases, the likelihood of oscillation and whistling increases. An increase of the transfer function by 6 dB will reduce the feedback limit *(F_L)* by 6 dB. If an instrument does not have the additional feedback reserve of 6 dB, the hearing aid will whistle. Consider the suboscillatory feedback case described above. The wearer increases volume until whistling occurs, then backs off the volume control until removing his/her hand stops the whistling. At this point, the aid is poised on the edge of stability, for example, 6 dB below the feedback limit. When the whistling stops, the gain *(G)* of any compression limiting or WDRC aid will begin to increase. A 6 dB increase in *(G)* will cause a 6 dB increase in the open-loop transfer function causing the aid to whistle. A *(G)* increase of anything less, 3 dB for example, will not increase the open-loop transfer enough to exceed the 6 dB feedback reserve. However, the introduction of any sound or speech of at least 3 dB will simultaneously increase the incident sound pressure at the microphone (p_i). Both increases, *(G)* and (p_i) are added to the open-loop transfer. A sudden increase of *(G)* = 3 dB + (p_i) > 3 dB will increase the open-loop transfer enough to equal or exceed the wearer's current 6 dB feedback reserve and oscillations will commence.

$F_L = 6$ dB, $|G|$ increase $= 6$ dB, $P_i = 5$ dB

a) Use $|G| + 6\text{ dB} = F_L$, oscillation

b) Use $|G| + 3\text{ dB} = 3\text{ dB} < F_L$, no oscillation

c) Use $|G| + 3\text{ dB} + P_i^{(5\text{ dB})} > F_L$, oscillation

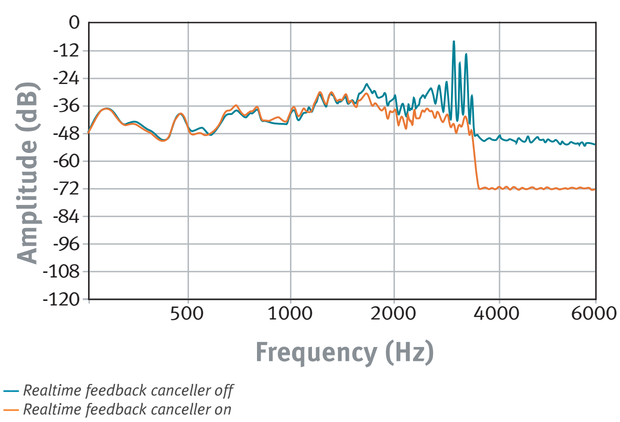
If the increase of (p_i) is brief, the open-loop transfer may drop back below the feedback reserve limit before the oscillations become self-sustaining. In that case, the wearer may perceive the echo or perseveration of /s/ described above. If the feedback reserve is exceeded for too long, the oscillations will drive the hearing aid into saturation and become self-sustaining. The oscillations can then only be stopped by breaking up the feedback pathway. This requires disabling the hearing aid or blocking the microphone and/or receiver port. More detailed descriptions of this phenomenon have been written by others such as Egolf and Daigle.[8-10]

Once the feedback reserve is overcome, the system begins to oscillate. The oscillations, heard as a whistling sound, create sharp amplitude spikes in the frequency response of the hearing aid. These spikes will occur at frequencies where the incident signal at the microphone (p_i) and the signal being fed back from the ear canal (p_{fb}) are in phase with one another.[7,8,11] Secondary spikes may also occur at harmonic multiples of the primary spikes.

Methods for controlling acoustic feedback typically focus on breaking up the feedback pathway or on the detection and suppression of the spikes. For example, when disabling the hearing aid microphone using a telecoil, the feedback pathway is broken and the size of the open-loop transfer no longer matters. Since the hearing aid no longer picks up an acoustic signal, acoustic feedback is eliminated. Unfortunately, this creates obvious limitations for the effectiveness of the aid wherever a microphone is required. Therefore, the most common approach to feedback suppression is the detection and suppression of oscillatory spikes. The blue line in figure 3 shows the output of a hearing aid in full self-sustaining oscillation. This was a recording of speech through a telephone as measured in the ear of an individual wearing a Conversa Behind-the-Ear aid. Note the four primary feedback peaks from 2700 Hz to 3400 Hz. Saturation distortion can also be seen in the high frequencies above 3400 Hz. The orange line shows the output of the same hearing aid for the same speech signal with feedback suppression engaged. The frequency response is normal and both feedback oscillations and the saturation distortion are gone.

Figure 3

Effective Feedback Suppression

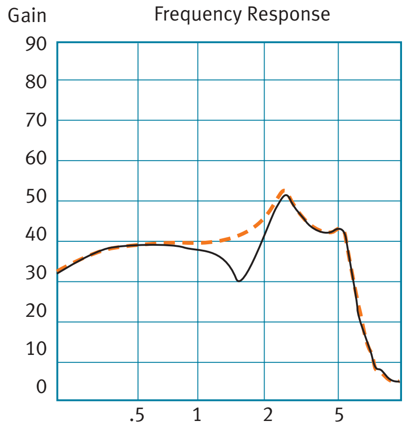


Recorded telephone speech with and without realtime feedback suppression.

Detection and Suppression of Feedback

Notch filtering is the most basic approach for suppressing feedback spikes. Notch filtering sharply reduces the gain at the frequencies where the spikes occur.[1,2] This narrow band gain reduction creates a notch in the frequency response of the hearing aid at each point where the gain is decreased, hence the name "notch filter". This can be implemented by using "static" notches that have a constant depth and frequency or "roving" notches that can change frequencies adaptively. An example of the notch filtering is shown in figure 4.

Figure 4
Notch Filtering



Hearing aid frequency response with and without 1600 Hz 1/2 octave notch.

Static filtering is uncomplicated, constantly available, and consumes little or no digital processing power or battery life. However, each notch is set at only one frequency. Notches do not adapt when the feedback spikes change frequencies due to alterations of the sound field near the hearing aid. In other words, the feedback pathway *(p_{fb})* is dynamic and changes to that pathway, due to a moving hand or telephone handset, will alter the frequencies at which the spikes occur. Static notch filters cannot adapt to such changes and are, therefore, of limited effectiveness. In contrast, roving notches can adapt to dynamic feedback spikes; however, they consume more digital processing power and battery life. Furthermore, using more than two or three such notches at once will have a detrimental effect on the frequency response of the amplified signal. Even when using as many as three notches, this approach is slow to adapt to rapidly changing feedback pathways, requiring more than 200 milliseconds (ms) to converge on feedback spikes. Consequently, roving notches are more effective than static notches, but they are limited to controlling no more than approximately three feedback peaks.

A third type of feedback suppression system is called phase cancelling. In this case, the incoming signal is modeled. When acoustic feedback is detected, it is subtracted from the signal pathway at the microphone. The subtraction is accomplished by generating a second internal signal that is 180˚ out of phase with the feedback signal.[3-5,12-14] This approach is highly adaptive and may control several feedback spikes simultaneously without sacrificing sound quality. Given enough battery life, sampling time, and processing power, phase cancelling could be used to thoroughly suppress feedback for nearly any conceivable hearing aid application. Consequently, battery life, sampling time and processing power are the key factors that define the limits of effective phase cancelling for feedback spike suppression.

Considerable amounts of battery and processing power must be allocated to build computationally intensive models of the incoming signal. The precision of the model is dependent upon the number of samples used to build it. A time frame of at least 400 – 500 ms may be needed to converge upon a rapidly changing feedback pathway. Coloration artifacts around narrowband signals[5] and reverberation in the hearing aid near field can further limit the effectiveness of phase cancellation.[15] Therefore, adequate time must elapse to build a precise enough model to react to feedback spikes, but not so much time that the system lags behind the dynamic changes in the hearing aid near field. This technical challenge has limited the effectiveness of phase cancelling in currently available hearing aids.

Conversa's realtime feedback canceller: Dramatically reduces feedback even during phone use

Suppresses several narrowband feedback spikes without distorting the frequency response

Conversa's realtime feedback canceller uses 12 independent narrowband detectors, each covering a bandwidth of only 500 Hz. Each detector reacts to the presence of acoustic feedback within its own designated band.

Rapid and dynamic feedback detection and suppression

Rather than using a single model of the entire bandwidth of the hearing aid, multiple narrowband detectors are used to monitor the presence of oscillations. Independent detectors can react to feedback oscillations in as little as 60 ms and suppress as many peaks as there are detectors.

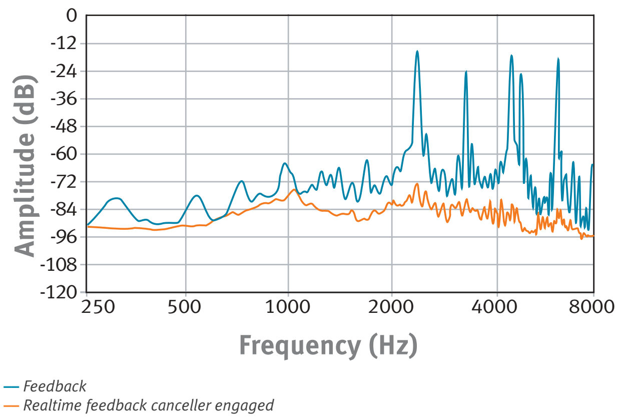
Diminishes audible oscillations immediately and suppresses peaks before they maximize

Changes in the open-loop transfer due to jaw movements or objects such as a telephone, can initiate dynamically changing, multi-peak oscillations that build to saturation in as little as 200 ms. Conversa's realtime feedback canceller suppresses oscillations in under 100 ms to adapt to the dynamics of a rapidly changing feedback pathway.

Does not cause increased battery drain

Time consuming and computationally intensive models are not required thereby minimizing digital processing power. This in turn provides better battery life than other advanced feedback management approaches.

Figure 5
Multiple Peak Suppression

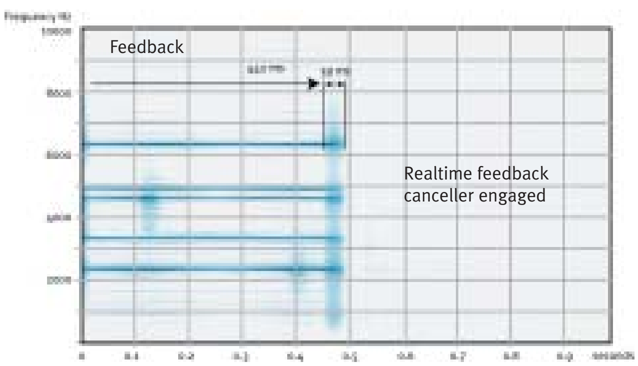


The advantage of deploying multiple narrowband detectors to diminish several peaks simultaneously can be seen in figure 4.

Figure 5 shows a Fast Fourier Transform (FFT) of two recordings made through a Conversa Behind-the-Ear (BTE) aid worn by a mannequin in an audiology test suite. The BTE, with a 2 mm vent, was programmed using NAL-NL1 targets to fit a moderately severe hearing loss. A telephone handset was placed next to the hearing aid microphone, as it would be for a normal conversation. The blue line in figure 5 shows the presence of significant oscillating acoustic feedback when the real-time feedback algorithm was disengaged. Primary oscillations occurred at five frequencies: 2400 Hz, 3400 Hz, 4600 Hz, 4900 Hz and 6300 Hz respectively. Numerous smaller secondary peaks are also visible. The orange line demonstrates how Conversa's multiple detectors eliminated every feedback peak once the algorithm was engaged.

The FFT in figure 5 shows the effectiveness of using multiple detectors. The speed at which the algorithm can suppress multiple oscillations can be seen spectrographically in figure 6. This spectrogram provides a different view of the same data used in figure 5, as frequency response over time instead of intensity over frequency (as in the FFT). The blue line in figure 5 is an FFT taken from the first 442 ms of figure 6. The orange line in figure 4 is taken from the last 500 ms shown in figure 6. During the first 442 ms in figure 6, the blue lines show the five primary peaks prior to deployment of the feedback suppression algorithm. At 443 ms the algorithm was engaged. Thirty-nine ms later all acoustic feedback was completely suppressed. Taken together, figures 5 and 6 show how real-time feedback suppression should work, simultaneously eliminating multiple peaks almost instantaneously, and in this case, in less than 40 ms.

Figure 5
Multiple Peak Suppression



Suppression of self sustaining feedback oscillations in real-time.

Conversa's realtime feedback canceller reacts rapidly, simultaneously attacking multiple feedback peaks at different frequencies without diminishing the clarity of the speech signal. The realtime feedback canceller maintains excellent sound quality without reducing gain at conversational speech levels. Hearing healthcare professionals can also fit feedback-prone losses, such as steep high-frequency losses or severe losses, more effectively while maintaining adequate gain without feedback.

Summary

Acoustic feedback is one of the most frequent complaints of hearing aid wearers. The oscillations responsible for the squeal can result from everyday occurrences such as a hug, putting on a hat, placing a telephone or hand close to the ear or even chewing. Notch filtering and phase cancelling can control acoustic feedback; however, roving notches are limited to controlling no more than three feedback peaks, while the success of phase cancelling is dependent upon sampling time, processing power and battery life. Conversa's realtime feedback canceller has multiple narrowband detectors that can be deployed to monitor the presence of oscillations. During real-time feedback suppression, each detector reacts to the presence of acoustic feedback within its own designated band without draining digital processing power and battery life.

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