# Beltone Boost Max S offers superior feedback management with Feedback Eraser 2

Tao Cui, AuD; Jennifer Groth, MA

## Abstract

Effective feedback management enhances the usability of hearing aids for all hearing aid users, but is especially important to hearing aid users with severe and profound hearing losses. Feedback cancellation is the gold standard of feedback management in today's hearing aids. While performance differences exist, they are difficult to quantify and not proven only by the added stable gain to a fitting. We evaluated the performance of the Beltone Boost Max S hearing aid, focusing on its feedback management capabilities using Feedback Eraser 2 technology and compared to similar premium hearing aids. The study employed two methods: recording sounds from hearing aids to analyze feedback presence and using fitting software to estimate stable gain. The findings indicate that Beltone Boost Max S with Feedback Eraser 2 demonstrates superior feedback management compared to other premium brands, allowing for better fittings for users with severe-to-profound hearing losses and reinforcing its value in modern hearing aid technology.

"No earmold, open earmold, and vented earmolds will be available to a much larger group, and the possibility for successful fitting of people with severe-to-profound hearing losses will increase considerably".[1] This prediction was made based on a study showing an added 10-15 dB of stable gain using a feedback cancellation algorithm in prototype hearing aids. A year later, this technology would become commercially available in a Super Power Behind-the-ear (SP BTE) hearing aid from a GN brand, and similar clinical findings were reported.[2] Unlike many predictions of the future, the one made in this seminal paper more than 3 decades ago has been completely borne out. Today, feedback cancellation is the gold standard for managing acoustic feedback in hearing aids in all types of fittings of all types of hearing aids for people of all ages and with all levels of hearing loss. It is so commonly used in hearing aids that communication about it is most often reduced to a checkmark on a datasheet. Although this amazing technology has taken a backseat to newer developments in hearing aids communication-wise, its importance in successful use of hearing aids has not diminished.

Feedback management techniques, including feedback cancellation, are beneficial for all hearing aid users. However, people with severe and profound hearing loss are arguably the group for whom it is most important. This is because many of them are completely dependent on their hearing aids, and high gain levels are critical to provide them with enough audibility for daily functioning. As mentioned, helping this group of hearing aid users is the origin story of feedback cancellation technology.

Because hearing aids for those with severe and profound hearing losses, such as SP BTEs, are fit with occluding custom earmolds either with no venting or a pressure vent, you might not think that feedback would be that much of an issue. This is not the case. A hearing aid user who requires very high gain may not have access to it due to feedback despite efforts to occlude the fitting. Dyrlund (1989)[3] used in situ loop gain measurements on 29 ears of people with severe-to-profound hearing loss who were fitted with high power BTE and unvented earmolds to calculate the percentage of fittings that would have feedback at different gains across frequencies. A loop gain measurement compares the output of the hearing aid in the user's ear to the signal that returns to the hearing aid microphone. Fifty percent of fittings requiring gain of approximately 58 dB would have had feedback while 90% of fittings with gain of around 65 dB would have been expected to have feedback. Given that SP BTEs typically have maximum gains exceeding 80 dB, it would not be possible to apply this much gain for many users even with occluding fittings. More recently, a study reporting on adults who were evaluated for cochlear implants suggested that a high proportion did not perceive benefit of their hearing aids, and that part of this was attributable to the gain being too low to provide adequate audibility.[4] Only 29% of the patients' own hearing aids met target audibility for 60-dB-

SPL speech as prescribed by NAL-NL2, and in all cases the hearing aid output was lower than recommended by 5 dB or more for at least one potentially audible frequency. Feedback can have been a common limitation in achieving the appropriate gains.

Feedback cancellation has been a critical component of our premium hearing aids tailored especially for people with severe and profound hearing losses. As we introduce the fifth generation SP BTE, the Beltone Boost Max S, it is relevant to revisit Feedback cancellation concepts, review the progression of this technology, and show how it compares in similar hearing aids from other brands.

## The journey to Feedback Eraser 2

Feedback oscillation (squealing, whistling) occurs when the damping in the feedback path is less than the gain applied by the amplifier, and the feedback signal is in phase with the input. The feedback path is the total of all the pathways by which the amplified sound can return to the hearing aid microphones. Although this includes vibrational pathways within the device itself or the hook, tubing and even the earmold, the dominant pathways are most often via the acoustic leakage of the signal from the receiver or sound outlet of the hearing aid back to the hearing aid microphones (Figure 1). Regardless, the operating principle of a feedback canceller is to analyze the total feedback path, and to configure a cancellation filter that has the same frequency and amplitude characteristics but is opposite in phase, as illustrated conceptually in Figure 2.



Figure 1. Feedback happens when amplified sound from the ear canal leaks out and re-enters the microphone. This creates an endless loop of sound which leads to a loud, sharp whistle or squeal from the hearing aid.

Given that feedback cancellation features have become so ubiquitous in hearing aids, one might be forgiven for believing that all such features are pretty much the same. Although feedback management across hearing aid brands is generally good, it is not the same. It may also be surprising to learn that the amount of extra stable gain that can be achieved in a hearing aid fitting has not increased very much over the 10-15 dB originally reported and this holds true for any feedback canceller across hearing aid brands. While some hearing aid brands have claimed added stable gain exceeding 20 dB, this number could be attained only in limited measurement conditions and does not represent added usable gain. In other words, you wouldn't be able to send a hearing aid user out the door with an extra 20 dB of gain than is possible without feedback cancellation without them turning right around with feedback and sound quality complaints.

The main constraints for not being able to provide further stable gain have to do with the impracticality of modeling the effects of room reflections as well as nonlinearities in the hearing aid systems.[5] It is therefore unrealistic that hearing aid feedback cancellation would continue to add unlimited stable gain to hearing aid fittings while preserving sound quality. Performance improvements and differences are mainly to be found in other areas than added stable gain.

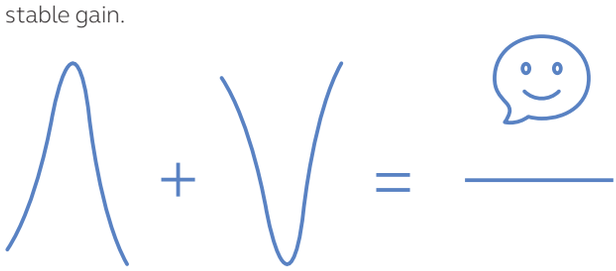


Figure 2. Feedback at the hearing aid microphones combines with a cancellation filter which models the feedback path but reverses the phase. Where the feedback and the filter meet, there is subtraction – so feedback is canceled without the need to decrease gain.

The leadership of GN in feedback cancellation technology spans more than 30 years. Development of the technology improved performance of the feature, but also the experience for both the hearing aid user and the Hearing Care Professional (HCP). Significant milestones have included:

- Feedback cancellation in a SP BTE that played a test signal during use of the hearing aids. The signal was below the user's hearing thresholds but could often be heard by others. The feature used the test signal to measure the feedback path as the hearing aids were worn, and to configure a cancellation filter to negate the feedback.
- Two feedback cancellation filters were implemented. One was calibrated at the fitting; the other was an adaptive cancellation filter that could follow dynamics of the feedback path while the hearing aids were worn without using a test signal.
- In situ feedback path calibration was done at the fitting. For dual mic hearing aids, the measurement had to be run once for each microphone at a loud level to ensure good signal-to-noise ratio (SNR) of the test signal at the hearing aid microphones.
- Maximum stable gain display in the fitting software provided valuable information to the HCP regarding available gain for each fitting.
- Feedback cancellation enabled the first specially designed open fit hearing aids and began the market shift from occluding custom hearing aids to small BTE and Receiver-in-the-ear (RIE) styles.

- 2-channel capability allowed more accurate cancellation for each feedback path of dual microphone hearing aids.
- Improved hearing aid user experience at the fitting with a shorter and softer calibration signal that only needed to be run once.
- Constrained adaptation of the adaptive cancellation filter, redesigned adaptive filter algorithm and a slower-acting option, Music Mode, all contributed to better fidelity especially with tonal inputs.
- Parallel gain restoration algorithm that relies on the in situ feedback path calibration to ensure no feedback in dynamic situations.
- Feedback Eraser 2 brought 3-channel capability for accurate cancellation in hearing aids with up to 3 microphones.

## Evaluating feedback performance with Feedback Eraser 2

Feedback management technology has clearly been a continual area of focus and has come a long way. But how does it compare to other brands' systems? As discussed, measuring added stable gain does not tell the whole story about how well the overall system works. Objective metrics have been used to capture other performance aspects,[6,7] but the perceptual relevance of these is not determined and an accepted benchmark approach to evaluating feedback cancellers has not been established. We decided to try simpler methods that would have clearer relevance to HCPs and hearing aid users. We used two methods; one involved recording the sound from the hearing aids so we could analyze presence of feedback, whether the system could manage it and how long that took. The other method was to use each brand's fitting software to estimate the added stable gain. We know that gain might be limited because of carrying out the feedback test that is offered as a fitting tool in fitting software. We tested Beltone Boost Max S and 4 other SP BTEs from premium brands.

The procedure for the sound recordings was to fit the hearing aids to a KEMAR ear with size 13 tubing and no earmold. This was done to ensure that it would be easy to evoke feedback. A recording microphone was also placed in the ear canal. Hearing aids were programmed with all special features disabled and an omnidirectional response. The gain was set to be linear and increased to 10 dB above the point where feedback occurred without feedback cancellation activated. The 10 dB increase in gain was chosen because all feedback cancellers today should be capable of providing at least this much added stable gain under the given conditions. Because of the non-occluding fitting, the feedback pathway was dominated by the sound leaking from the unoccluded ear canal. Thus the point at which feedback occurred was approximately the same across all the hearing aids.

First, recordings were made without performing the feedback test (calibration) in the fitting software. All brands can apply feedback cancellation without running their feedback test. For these recordings, the hearing aids were muted, and the feedback cancellation feature was turned on. A 65 dB SPL white noise was played and the audio recording was started. Finally, the hearing aids were unmuted and the audio output was recorded. All hearing aids converged to a certain performance in well under 5 seconds. Therefore, the data presented in this paper are for the first 5 seconds after the hearing aids were unmuted.

Next, the feedback test was run with the hearing aids on KEMAR and the same procedure for recording was followed as without the feedback test. We plotted 3D spectra of all the recordings and sought to answer the following questions for each condition:

1. Was feedback present when the hearing aids were unmuted?
2. Did the feedback canceller eliminate the feedback if there was any?
3. How long did it take the feedback canceller to eliminate the feedback?
4. Using the Beltone Boost Max S output as the reference, was the output reduced?

For Beltone hearing aids, the feedback calibration serves multiple purposes. It initializes the static cancellation filter which accounts for relatively stable elements of the fitting. This filter's settings then provide a reference point from which the adaptive cancellation filter operates. Because it is a loop gain measurement, the feedback calibration also provides the reference for the adaptive gain restoration algorithm. This feature predicts feedback spikes in dynamic situations and corrects the gain preemptively such that the feedback does not occur and the delivered gain is as prescribed.[8] Finally, the feedback test estimates the maximum stable gain available in the fitting. In Beltone Solus Max fitting software, the HCP can choose only to view this information on the display, or to also apply a safety cap on the amount of gain that is available for the fitting so that feedback will never occur during use of the hearing aids. The other brands tested also use their feedback tests to estimate maximum stable gain and to cap the amount of gain available for the fitting, but it is not known whether they use the information in other ways.

# Results

## When the feedback test was not run

Some examples of the 3D spectra are shown in Figures 3 through 5. Figure 3 shows the output from Brand A without running the feedback test but with feedback cancellation turned on. The red peak indicates audible feedback oscillation between 2 and 3 kHz. It continued throughout the duration of the recording.

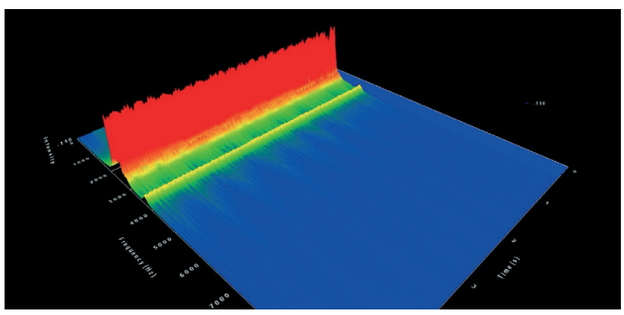


Figure 3. The output of Brand A with the feedback cancellation feature active, but without running the feedback test in the fitting software. Time is on the x-axis, frequency on the y-axis, and intensity is indicated by the height and color of any peaks. Red is most intense and blue is least intense. The output is normalized to the gain settings, which were 10 dB above the point of stability without feedback cancellation. Brand A showed intense feedback throughout the recording. It was not at all effective in cancelling feedback in this condition.

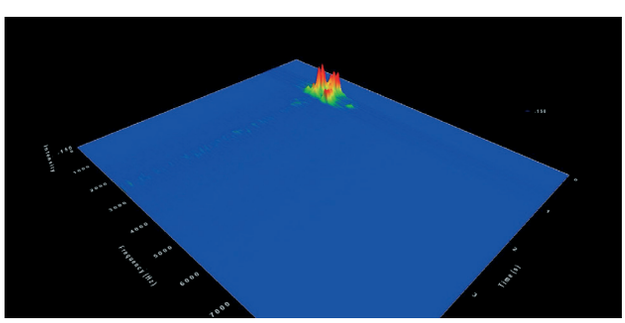


Figure 4. The output of Beltone Boost Max S with Safeguard Feedback Control under the same conditions as Brand A in Figure 3. A spike of feedback occurred when the hearing aid was unmuted, but it was quickly cancelled and no longer audible.

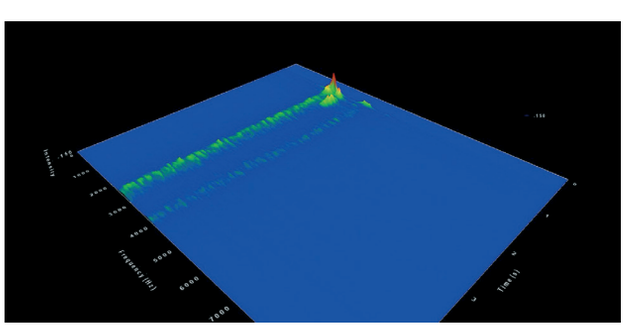


Figure 5. The output of Brand C under the same conditions as in the recordings shown in Figures 3 and 4. This hearing aid showed a spike of feedback between 2 and 3kHz when unmuted. It quickly reduced level of the feedback but did not eliminate it. Feedback is audible for the duration of the recording although not nearly as loud as the feedback from Brand A.

Table 1 summarizes results for the condition where the brand's feedback test was not run but feedback cancellation was active. In Beltone hearing aids, the feedback management feature that doesn't require running the feedback test is called "Safeguard Feedback Control". The color-coding in the table indicates performance with green signifying good performance, gold acceptable or neutral performance, and blue showing undesirable performance. All hearing aids tested had feedback when they were unmuted, and only Beltone Boost Max S and Brand B were able to eliminate the feedback. Although Brand B achieved this faster than Beltone Boost Max S, it did this by also reducing the output slightly relative to the Beltone hearing aids. Overall, Beltone Boost Max S performed best in this condition with Brand B also doing well. Brand C was able to reduce the level of feedback within a short period of time but did not eliminate it.

| | Beltone Boost Max S | Brand A | Brand B | Brand C | Brand D |
|---|---|---|---|---|---|
| Feedback present? | Yes | Yes | Yes | Yes | Yes |
| Eliminate feedback? | Yes | No | Yes | No | No |
| Response time (ms) | 46 | n/a | 18 | 40 | n/a |
| Reduce output? | No | No | Yes | No | no |

Table 1

## When the feedback test was run

Performance was better for all the tested hearing aids. Only Brand A and Brand D had feedback when the hearing aids were unmuted. Of the two, only Brand A eliminated the feedback. Beltone Boost Max S, Brand B and Brand C did not have feedback when the hearing aids were unmuted in this condition and none of these showed feedback during the recording.

Figures 6 and 7 show examples of the 3D spectra in this condition. Beltone Boost Max S results are shown in Figure 6, where feedback elimination was instantaneous. As shown in Figure 7, Brand A shows a small chirp of feedback before quickly eliminating it.

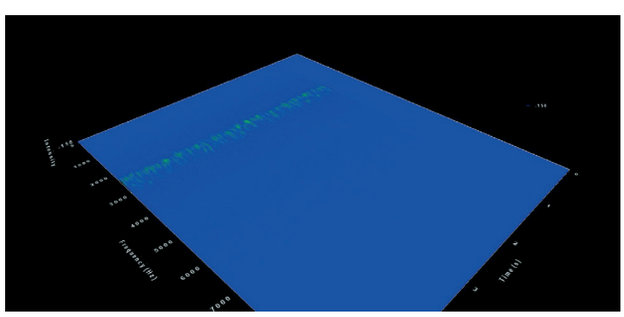


Figure 6. 3D plot of the recording of Beltone Boost Max S when the feedback test was run (Feedback Eraser 2). There was no audible feedback at any time during the recording.

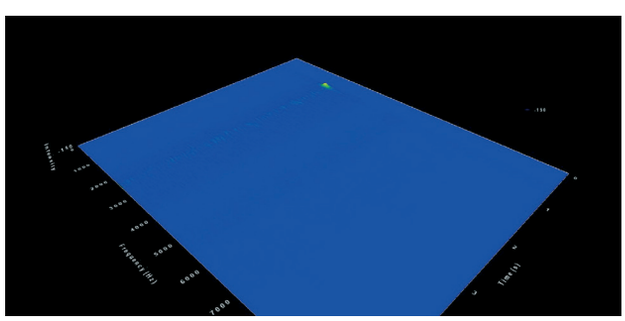


Figure 7. 3D plot of the recording of Brand A when the feedback test was run. There was a brief burst of feedback that was quickly eliminated. However, gain was also reduced by 7 dB as shown in the fitting software.

Table 2 summarizes results after each brand's feedback test was run, answering the same questions as in Table 1.

While Brand B and Brand C showed good performance, they both reduced gain due to running the feedback test. Therefore, it was not the feedback canceller performance alone but also less gain that contributed to performance. Beltone Boost Max S was the only hearing aid that could eliminate the feedback instantaneously without reducing the gain.

| | Beltone Boost Max S | Brand A | Brand B | Brand C | Brand D |
|---|---|---|---|---|---|
| Feedback present? | No | Yes | No | No | Yes |
| Eliminate feedback? | Yes | Yes | Yes | Yes | No |
| Response time (ms) | 0 | 15 | 0 | 0 | n/a |
| Reduce output? | No | Yes (-7) | Yes (-4) | Yes (-2) | No |

Table 2

## Available gain for fitting

The in situ feedback test offered by all brands in the hearing aid fitting software is used to measure the feedback path and to estimate the level of stable gain in the fitting. As mentioned, the available gain in the fitting may be reduced based on this measurement to prevent feedback from occurring. This is a double-edged sword; on the one hand, it helps the HCP to ensure sound quality and listening comfort while the hearing aids are in use in the real world. But it also means that the provided audibility and benefit of the hearing aids may be limited. For this test, the hearing aids were again fit to KEMAR but with putty to partially seal the ear canal.

The feedback test was run in each brand's fitting software. Like in the previous test, gains were set linear and increased until the point where feedback occurred without feedback cancellation active. The gains where feedback occurred differed more among the hearing aids than in the non-occluding fitting condition due to less consistency in the seal with the putty. The maximum stable gain without feedback management was 30 dB for Beltone Boost Max S and Brand D, 24 dB for Brand A, 23 dB for Brand B, and 17 dB for Brand C. Then the feedback management feature was turned on, and gain was increased further until feedback occurred or until the gain cap was reached at any frequency.

For SP BTE devices, maximum gain in the high frequencies is lower than in the mid-frequencies due to the receiver response, so the gain around the frequency where feedback usually occurs - between 2 and 3 kHz - was the main limitation. The maximum gain for Beltone Boost Max S is 56 dB at 3 kHz which is similar to the other hearing aids. Figure 8 shows the added gain, which is the difference between the maximum stable gain with feedback management on versus off. The gains were the same across frequencies because the hearing aids were set to flat linear gain and the gain increase was stopped at the lowest frequency where feedback occurred or where a gain increase was no longer possible due to capping of the gain.

Feedback occurrence was the limitation for Brands B, C and D. Brand A capped the maximum gain before the point of feedback was reached, and Brand A also showed the lowest added gain of all the hearing aids. Brands B and C showed 17 dB added gain before feedback occurred and Brand D showed 20 dB added gain. Beltone Boost Max S did not reach the point of feedback at 26 dB of added gain. The gain was not capped at this level but rather it reached the maximum gain of the hearing aid at 3 kHz.

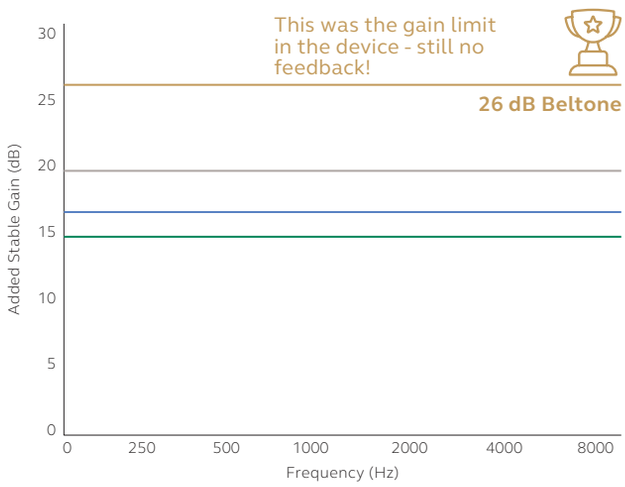



Figure 8. The maximum stable gain settings in the fitting software for a linear, flat response were determined with and without feedback management for each brand and the difference is presented here as "added stable gain". Feedback Eraser 2 in the Beltone Boost Max S allowed for the greatest added stable gain. Brand A is green, Brands B and C are blue, and Brand D is grey in this graph..

As discussed, the expected added stable gain in this test would probably be around 15 dB for a well-designed feedback canceller, yet we saw values exceeding this, especially for Beltone Boost Max S. One explanation could be that the gain in the hearing aids was reduced in some hearing aids, and therefore the values indicated in the fitting software did not match the achieved gain. While this is unknown for the other brands, it is known that the adaptive gain restoration contributed to the result with Beltone Boost Max S. This feature does not reduce gain below the prescribed level. In addition to the effect of the feedback cancellation, it helps to break the endless loop of amplification that leads to feedback. Although this processing is intended and recommended to prevent feedback occurrence in dynamic situations where the feedback path changes can be sudden and large, it can also add benefit in stable situations when the applied gain is higher than what the feedback cancellation can eliminate by itself, as illustrated in the current test. The aggressiveness of this aspect of feedback management is configurable by the HCP in the Beltone Solus Max software. This is what the "Mild", "Moderate" or "Strong" setting for Feedback Eraser 2 controls, and it was set to the default "Mild" level for the current test.

## Conclusions

- Feedback cancellers in premium brand SP BTEs can be used with or without doing a feedback test in the fitting software, but performance is best for all if the feedback test is performed.
- Beltone Boost Max S showed the best feedback management performance among the premium brand SP BTEs tested in that it eliminated feedback instantaneously and without reducing gain.
- Beltone Boost Max S showed the highest added gain without feedback occurrence.

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Worldwide Headquarters
Beltone A/S
Lautrupbjerg 7
DK-2750 Ballerup
Denmark
Tel.: +45 4575 1111
beltone.com

CVR no. 55082715

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