

Active Feedback Intercept:

A State-of-the-Art Algorithm

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Active Feedback Intercept (AFI) is a state-of-the-art feedback cancellation algorithm implemented in Starkey's Destiny line of products.

Feedback cancellation (FBC) algorithms address several of the most important improvements sought by hearing aid users — better sound quality, less whistling and buzzing, more audibility for soft sounds, work better on the telephone, improved speech understanding in quiet, and better fit and comfort.

Bench testing of Destiny 1200 and flagship products from five other manufacturers showed that not all FBC algorithms are created equal (Merks et al, 2006). Furthermore, only Destiny 1200 achieved best-in-class status in all three assessments. These outcomes are summarized in the table to the left.

Clinical evaluation of the FBC algorithms revealed that, compared to Axent II:

1. Audible feedback is 5 times less likely to occur in Destiny 1200 when the feedback path changes abruptly,
2. Despite the faster adaptation rate, entrainment artifacts were 3 times less likely to occur in real-world environments with Destiny 1200, and
3. Destiny 1200 provides as much as 10 dB more stable gain (over and above that provided by Axent II), yielding up to 23 dB of added stable gain.

Further, automatic optimization of the FBC filter in the field yields added stable gain comparable to that obtained following initialization in the clinic.

Introduction

Audible feedback is among the most prominent problems with hearing aids (Kochkin, 200b). In some cases, the annoyance associated with feedback may be sufficient to negate the perceived benefits of amplification, resulting in non-use of hearing aids. The most obvious conclusion is that the whistling and buzzing associated with feedback must be minimized. Further, as shown in Figure 1, a good approach to addressing feedback also improves sound quality, makes soft sounds more audible, works better on the telephone, increases speech understanding in quiet and results in better physical fit and comfort. This is important because the overall satisfaction with hearing aids is known to increase as the number of situations in which the listener is satisfied increases (Kochkin, 2002a) (Figure 2).

Acoustic feedback occurs when the output of the receiver leaks out of the ear canal and enters the microphone of the hearing aid (Figure 3). This acoustic leakage may be through a vent or slit leaks around the edges of the hearing aid. Together, these sources of leakage constitute the acoustic feedback path. Each time sound leaks out of the ear canal and enters the microphone, it is re-amplified along with all the other sounds entering the

	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D	Manufacturer E	Destiny 1200
Added Stable Gain	Objectionable Performance			Objectionable Performance		Best-in-Class
Entrainment	Objectionable Performance		Objectionable Performance	Objectionable Performance	Best-in-Class	Best-in-Class
Path Changes	Objectionable Performance	Best-in-Class		Best-in-Class	Objectionable Performance	Best-in-Class

Bench testing of Destiny 1200 and flagship products from five other manufacturers

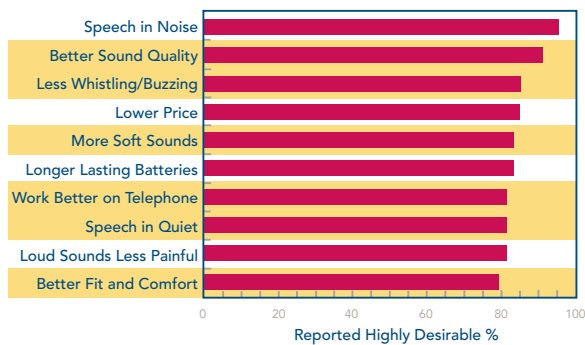


Figure 1: Top ten improvements sought by hearing aid users. The shaded regions indicate desirable outcomes of a good approach to minimizing feedback. Adapted from Kochkin (2002b).

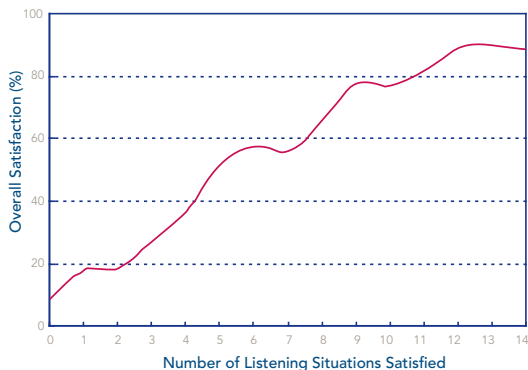


Figure 2: Multiple environment listening utility shows the relationship between the number of satisfactory listening situations and the overall satisfaction. Adapted from Kochkin (2002a).

hearing aid. This does not pose a problem as long as the physical presence of the hearing aid attenuates the acoustic leakage by more than the gain of the hearing aid. When the gain exceeds this attenuation, the feedback signal grows each time it goes around the loop and ultimately becomes strong enough to create an audible oscillation. The conditions necessary for audible feedback oscillation are met when the degree of attenuation is small and/or when the gain of the hearing aid is high.

With the advent of digital signal processing (DSP), audible feedback can be minimized without sacrificing gain, audibility, loudness and speech intelligibility. DSP-based electronic controls for minimizing audible feedback are desirable because: (1) they permit greater usable gain, (2) they allow the provision of adequate gain with an open earmold or a shell with a large vent, and (3) certain types of feedback controls can adapt to changing environments, such as when a telephone is placed close to the ear. Rather than manipulating the gain, FBC algorithms introduce an additional signal to cancel out the acoustic leakage. When feedback is detected at the output of the hearing aid, a cancellation signal is generated to mimic the feedback (Figure 4). The feedback is eliminated by subtracting the cancellation signal from the input.

Feedback Cancellation Essentials

Although not necessary, knowledge of the characteristics of the feedback path improves the effectiveness of FBC. Feedback path refers to all the ways in which sound can leak out of the ear canal and re-enter the hearing aid microphone. Information about static feedback paths, such as vents, may be gathered by means of an initialization performed in the clinic. During initialization, a broadband noise with a known spectrum - typically white noise - is played through the hearing aid. A comparison of the frequency response of the initialization signal at the source and that detected at the microphone of the hearing aid indicates the amount of attenuation provided by the hearing aid and the frequency regions in which feedback is most likely to pose a problem. Initialization must be performed in a quiet environment to avoid contamination of the signal detected by the microphone.

Maximum stable gain (MSG) is the maximum amount of gain that can be provided without risk of audible feedback or degraded sound quality. Since FBC algorithms simply cancel out unwanted feedback, there is no gain reduction associated with eliminating feedback. On the contrary, this technique should result in added stable gain (ASG) - i.e., an increase in MSG with FBC enabled relative to that with FBC disabled. The shaded region in Figure 5 shows the ASG. Practical considerations, such as environmental acoustics and the processing capabilities of the DSP chip in a hearing aid, limit the potential improvement in MSG to 15-25 dB (Freed and Soli, in press; Kates, 2001; Merks et al, 2006).

The threat of feedback remains a real possibility even after initialization because the feedback path does not remain constant over time. Movements of the jaw and head, variations in insertion

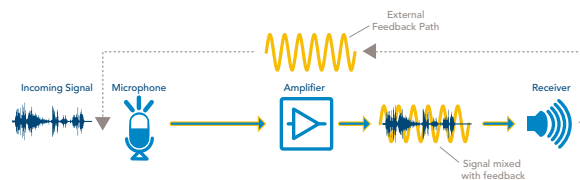


Figure 3: Schematic representation of the feedback path. The output of the hearing aid leaks out of the ear canal, enters the microphone and is re-amplified.

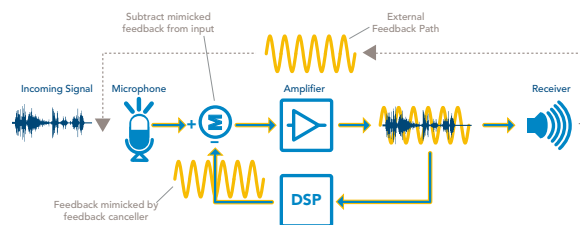


Figure 4: Schematic representation of the principle of feedback cancellation. The feedback canceller mimics the feedback signal and subtracts it from the input resulting in no audible feedback at the output of the hearing aid.

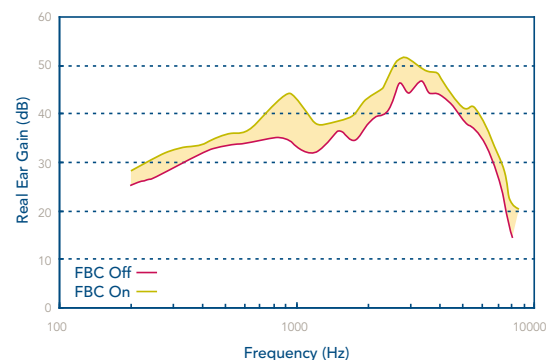


Figure 5: Example of the maximum stable gain with the feedback canceller disabled (red curve) and enabled (green curve). The added stable gain is shown by the shaded region.

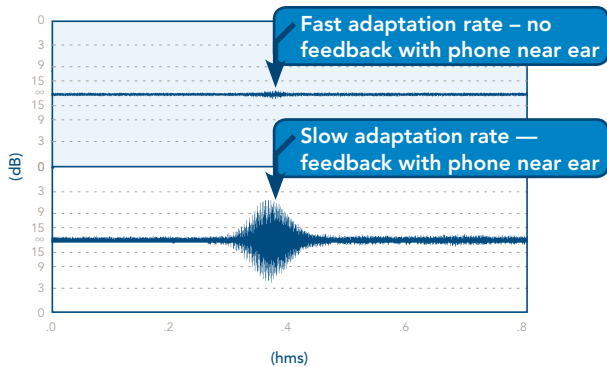


Figure 6: Impact of adaptation rate on the response of a feedback canceller to a telephone being moved close to the ear.

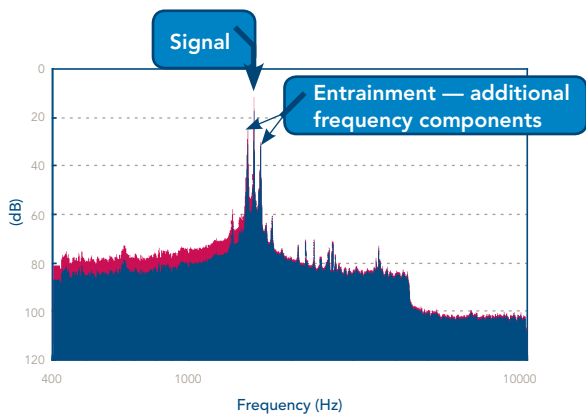


Figure 7: Impact of adaptation rate on entrainment artifacts. The blue and red shaded regions represent fast and slow adaptation rates, respectively.

of the hearing aid or earmold into the ear canal, and the presence of objects such as a telephone near the hearing aid all change the characteristics of the feedback path. Under such conditions, adaptive FBC is most effective because it can accommodate dynamic feedback path changes. How quickly should the FBC algorithm adapt to changes in the feedback path? The impact of adaptation rate on feedback path changes is shown in Figure 6. At fast adaptation rates, moving a telephone up to the ear produces no audible feedback. In contrast, at slow adaptation rates, a significant burst of feedback occurs when a telephone is placed at the ear.

A negative side effect of some adaptive FBC algorithms is the presence of entrainment artifacts. Entrainment occurs when the feedback canceller mistakenly attempts to cancel a tonal input to the hearing aid. This results in the addition of a tone to the original signal by the hearing aid itself. The hearing aid user may report hearing the additional tone, feedback after the original sound has stopped, or a modulation-type distortion of the sound. The risk of entrainment is greater at high adaptation rates. The red curve in Figure 7 shows that, at slow adaptation rates, the 2000 Hz pure tone input is the dominant frequency component at the output of the hearing aid. When the adaptation rate increases, however, additional frequency components are found in the output of the hearing aid that were not present in the input, as shown by the blue curve.

Thus, there appears to be a trade-off in performance that is related to the adaptation rate of the FBC algorithm. Specifically, fast adaptation rates handle dynamic changes in the feedback path well, but are highly susceptible to entrainment artifacts. On the other hand, feedback path changes are problematic at slow adaptation rates, which produce few artifacts. The key to optimum FBC performance is striking a balance between the two extremes.

Current State of Feedback Cancellers

A bulleted list of features on a specifications sheet suggests that there are few, if any, differences, across products and/or manufacturers. Further, because the standards for characterization of hearing aids lag their capabilities by at least 5-10 years, the performance of most advanced features is not routinely evaluated. Bench measurements can be used to shed light on the efficacy and effectiveness of advanced DSP algorithms and, in turn, accelerate innovation in hearing aid design.

Several authors have reported on benchmarking of FBC (Freed and Soli, in press; Greenberg et al, 2000; Kates, 2001). Most recently, Freed and Soli demonstrated that all FBC algorithms are not created equal. Their data showed significant differences across products in terms of ASG and entrainment artifacts. However, there are some important limitations to the methodology used in this study. Most notable is the ceiling effect. The experimental

protocol called for a broadband increase in gain until audible feedback occurred. In several cases, audible feedback could not be elicited before the maximum gain of the hearing aid was reached, especially with the FBC algorithm enabled. The second significant drawback is that entrainment artifacts were evaluated using a pure tone, a signal not typically found in real-world environments. Finally, the FBC algorithms were evaluated only under static conditions.

Starkey's benchmarking efforts aimed at extending and improving upon Freed and Soli's methods to increase the objectivity, repeatability and applicability of the measurements. Toward that end, a suite of benchmarking techniques was developed that:

1. Can be conducted on KEMAR,
2. Is mostly automated,
3. Is free from ceiling effects,
4. Allows for dynamic feedback path changes, and
5. Objectively quantifies artifacts in a perceptually meaningful way.

Six commercially available behind-the-ear (BTE) hearing aids from various manufacturers were evaluated. One of these, from Starkey's product line, is designated by its commercial name: Destiny 1200. Devices from the remaining manufacturers are arbitrarily designated A, B, C, D and E. The BTE device style was chosen for evaluation to minimize differences in coupling to the ear as a source of variability. Thus, all devices were connected to the same earmold. The hearing aids were programmed linearly with a flat frequency-gain response. All adaptive features unrelated to FBC — i.e., directionality, noise management, and expansion — were disabled. The feedback canceller was initialized whenever that option was available in the fitting software.

The measurement setup is shown in Figure 8. The KEMAR manikin is at the center with the hearing aid under test placed in the right ear. A white noise is played through a loudspeaker placed 1m in front of KEMAR, and a microphone records the sound in the ear canal. The red, cone-shaped acoustic reflector, which mimics a hand or phone, is mounted on a linear slide controlled by a computer. Together, the linear slide and acoustic reflector constitute the path change simulator (PCS) used to imitate a phone or hand approaching the ear.



Figure 8: Setup for benchmarking measurements.

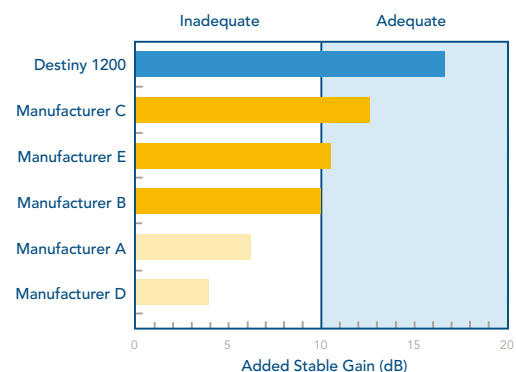


Figure 9: Summary of added stable gain of six hearing aids.

Added Stable Gain

The signal recorded in KEMAR's ear canal has three components: acoustic leakage, hearing aid response, and feedback. By performing the measurement at different gain settings of the hearing aid, the feedback component can be distinguished from the other two. MSG is estimated as a function of frequency; ASG is calculated as the difference between MSG with FBC disabled and MSG with FBC enabled. The ASG determined in this manner is exactly the same (Merks et al, unpublished data) as that measured using the traditional method (Freed and Soli, in press; Greenberg et al, 2000; Merks et al, unpublished data). In the traditional method,



Figure 10: Perceptual meaning of overall entrainment level.

MSGs are determined by gradually increasing the overall gain of the hearing aid until audible feedback occurs.

Figure 9 shows the results for single measurements on all six devices. ASG values range from 3.5 dB for Manufacturer D to 16.3 dB for Starkey's Destiny 1200 hearing aid. In fact, only four of the devices tested had ASGs of at least 10 dB. ASG maybe limited if the FBC algorithm is not active at low frequencies. This is usually done to avoid entrainment artifacts.

Two noteworthy points should be added. First, in reality, the maximum gain that can be applied varies as a function of frequency. This signifies the inverse relationship between MSG and the magnitude of the feedback path. That is, the smaller the feedback path, the more gain that can be achieved before audible feedback oscillation. And, second, MSG with FBC disabled and FBC enabled is summarized as the gain at the peak of each response, regardless of the specific frequency at which it occurs. From a practical point of view, feedback is most likely to occur at a frequency where the feedback path is largest, as indicated by the peak. Moreover, when feedback occurs, its frequency characteristics make no difference to a hearing aid user.

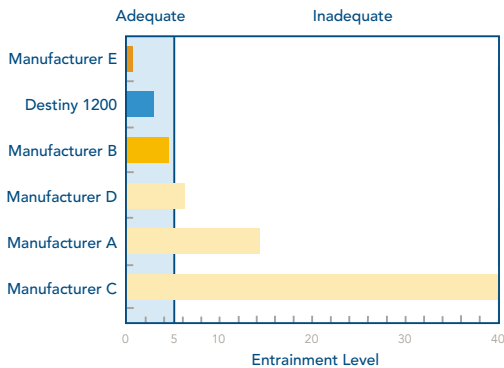


Figure 11: Entrainment level of six hearing aids.

Entrainment Artifacts

ASG is the primary yardstick used to quantify the adequacy of an FBC algorithm. However, high ASG is valuable only if the hearing aid retains good sound quality and does not produce entrainment artifacts in response to tonal input signals. Unlike the pure tone signal used to assess entrainment in previous studies (Freed and Soli, in press), realistic signals were selected for this benchmarking effort. The input contained segments of music (opera, flute concert, rock guitar), machine noise (vacuum cleaner, stationary car, hair dryer), tonal sounds (car horn, siren, telephone ring, pure tone at 4 kHz), human sounds (child's voice, finger snapping), and water (toilet flushing). All stimuli were presented at 75 dBA.

The hearing aids were programmed with 25 dB linear gain across the frequency range. Care was taken to ensure that this was at least 5 dB below the MSG in the FBC off condition. The output of the hearing aid in KEMAR's ear canal was recorded with FBC disabled and enabled. The difference between the short-term spectra of the FBC off and FBC on signals was calculated using a technique described by Boll (1979). The overall entrainment level was then calculated based on the loudness and sharpness of this difference (Zwicker and Fastl, 1999). Entrainment level is interpreted in perceptual terms as shown in Figure 10.

The overall entrainment level of one recording for all six hearing aids is shown in Figure 11. Manufacturer E showed the lowest level of entrainment (<1), which suggests that FBC is non-adaptive. At an entrainment level of 3, the artifact in Starkey's Destiny 1200 would be audible only in a paired comparison between FBC disabled and FBC enabled. The entrainment artifact for Manufacturer B occurred at the end of the audio fragment, when the hearing aid lingered on for a quarter of a second after

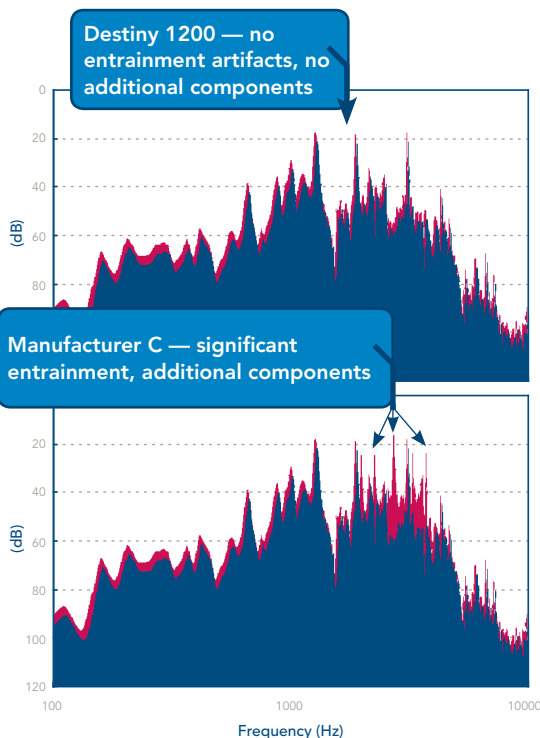


Figure 12: Frequency analysis of the output of Destiny 1200 (upper panel) and a device from Manufacturer C (lower panel). In each panel, responses are shown with the feedback canceller disabled (blue curve) and enabled (red curve).

the stimulus stopped. Although Manufacturer D showed a small entrainment artifact throughout the stimulus, it was clearly audible during the music segment. It is particularly remarkable that Manufacturer D showed a lot of entrainment despite the fact that FBC is non-adaptive at low frequencies. Finally, Manufacturers A and C became unstable and loud oscillations were audible during the pure tone segment of the stimulus.

Figure 12 shows frequency analysis of the outputs of the best and worst performing devices in response to an ambulance siren. The blue curves show the response of the devices with the FBC algorithm disabled. This reflects the processing of the hearing aid itself and serves as the reference condition. The response of the Destiny 1200 with the FBC algorithm enabled (red curve) is very similar to that in the FBC off condition and there are virtually no audible entrainment artifacts. In contrast, for Manufacturer C, there are several prominent frequency components in the FBC on condition that were absent in the FBC off condition. This is consistent with the distinctly audible entrainment artifact.

Path Changes

Jaw and head movements, improper insertion of the hearing aid, wearing a hat and using a telephone are some examples of everyday activities that alter the feedback path. In addition to dealing with tonal input signals, a good FBC algorithm also eliminates feedback in the presence of sudden changes in the acoustic feedback path.

Figure 13 shows the PCS used to simulate an acoustic path change. Prior to initiating the path change, the MSG of the test hearing aid was calculated for FBC on with the PCS at the start (away from the ear) and final positions (near the ear). To ensure stability of the device under static conditions with an object near the ear and at a distance, the gain of the hearing aid was then set 1 dB below the lower of the two MSGs. A white noise was played at 50 dBA while the output of the hearing aid was recorded. During the recording, the PCS was moved quickly towards the ear.

For analysis, the recorded output was scaled to account for differences in gain with the object near the ear and at a distance. The loudness and sharpness of the scaled output were calculated. This information was used to derive an overall annoyance level based on the psychoacoustic annoyance (Greenberg et al, 2000). The annoyance level, which can take values between 0 and 140, is interpreted as shown in Figure 14.

Only five out of the six hearing aids were assessed for robustness of the FBC algorithm to changes in the acoustic feedback path. It was not meaningful to test the non-adaptive FBC from Manufacturer E because, by definition, a non-adaptive FBC algorithm does not respond to changes in the acoustic feedback path. Thus, once the gain is set just below the lower of the two MSGs, feedback cannot be elicited by changing the acoustic feedback path.

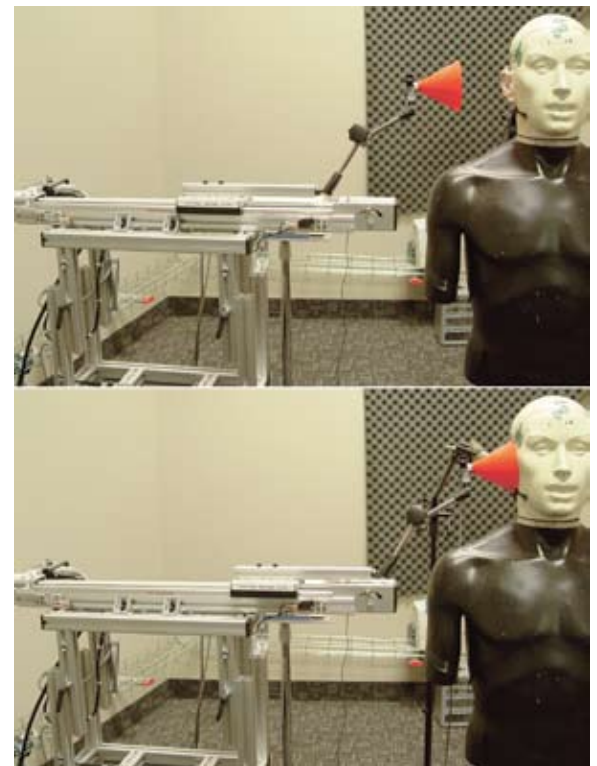


Figure 13: Path change simulator away from the ear (top panel) and near the ear (bottom panel).

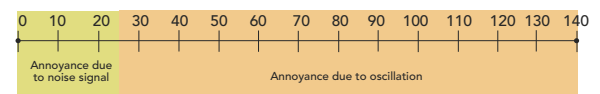


Figure 14: Interpretation of annoyance level.

Figure 15 shows the annoyance level for the five hearing aids evaluated. Three of the hearing aids had no oscillation in the output signal: Starkey's Destiny 1200 (Figure 16, upper panel), and Manufacturers B and D. Manufacturer A had loud and annoying oscillation but achieved stability after three seconds (Figure 16, lower panel). It is generally expected that hearing aids that handle tonal inputs well score poorly on handling path changes, and vice-versa. While it is true for Manufacturer E, this expectation clearly does not hold true for the other devices evaluated here. Specifically, Starkey's Destiny 1200 performs well on the entrainment and path change tests; Manufacturer C does rather poorly on both measures.

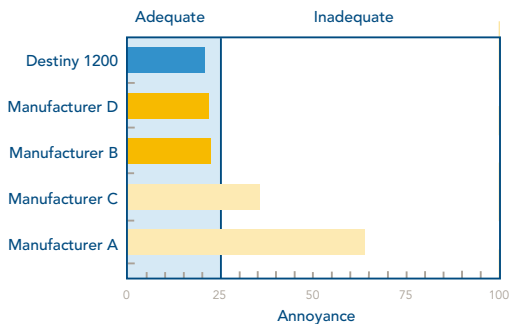


Figure 15: Annoyance level at the output of five hearing aids after a change in the acoustic feedback path.

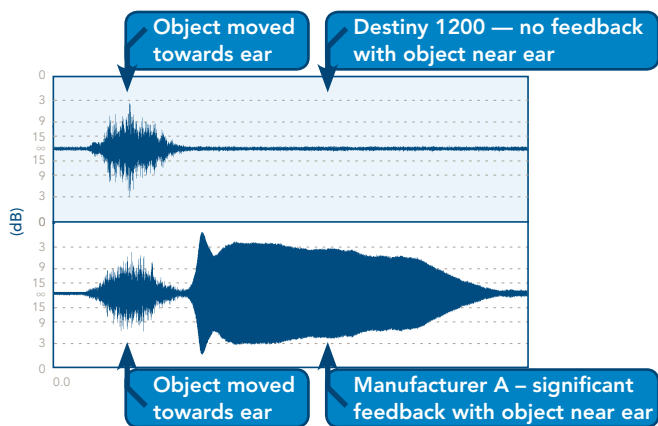


Figure 16: Output of Destiny 1200 (upper panel) and a device from Manufacturer A (lower panel) in response to dynamic changes in the feedback path.

Summary and Implications

A new test methodology was developed to objectively characterize FBC in terms of ASG, susceptibility to entrainment, and sensitivity to acoustic feedback path changes. The method was used to assess hearing aids from six manufacturers. The outcomes of each assessment are summarized in Figure 17 and may be described as follows:

- (1) Added Stable Gain: There is a substantial range across manufacturers, from 3 to 16 dB. The ASG often depends on the lowest frequency at which the FBC operates. FBCs that operate only at higher frequencies will offer no ASG for patients with significant acoustic leakage at low frequencies. Small ASGs offer little advantage in delivering necessary gain. Further, operating a hearing aid close to its MSG results in poor sound quality.
- (2) Susceptibility to Entrainment: Three of the six hearing aids evaluated demonstrated objectionable entrainment artifact. This poses a problem because it distorts the quality of the sound. Further, because the FBC is attempting to cancel the desired signal, it may actually cause continued feedback once the desired signal stops. One hearing aid had extremely low levels of entrainment because it used non-adaptive FBC. Entrainment levels were acceptable for the remaining two hearing aids.
- (3) Sensitivity to Changes in Acoustic Feedback Path: Only five hearing aids were evaluated because one used non-adaptive FBC and could not be tested. Two of the devices evaluated showed objectionable levels of annoyance due to audible feedback oscillation. The obvious implication is that individuals using these devices at or close to the MSG are prone to feedback with jaw and/or head movements, when putting on a hat, etc. They are also apt to remove their hearing aid before putting a telephone up to the ear.

Clinical Evaluation

There were four primary design goals for AFI: (1) improved feedback path analysis, (2) robust entrainment prevention, (3) excellent added stable gain, and (4) minimal dependence on initialization.

In order to evaluate whether or not these objectives had been achieved, ten individuals performed head-to-head comparisons between Axent II and Destiny 1200. All participants had bilaterally symmetrical, mild to moderately-severe sensorineural hearing loss (Figure 18). In addition, five of these individuals had previous research experience evaluating FBC algorithm. Participants were fitted bilaterally with BTE devices, programmed to match the gain targets prescribed by NAL-NL1 (Dillon, 1999). A randomized cross-over design was used to ensure that all participants evaluated Destiny 1200 and Axent II, but not necessarily in that order. Further, participants were blinded to the identity and expected performance of the devices. Each pair of devices was assessed in the field for one week; in addition, laboratory tests were conducted during each visit. For the most part, the clinical data discussed here were obtained during this evaluation; data from previous studies are shown in green.

Feedback Path Analysis

The prevalence of feedback with Axent II and Destiny 1200 during field trials is shown in Figure 19. Facial movements, such as smiling and jaw movements, placing a telephone at the ear or moving it away produce changes in the feedback path. Under such conditions, feedback was approximately five times more likely to occur with Axent II than with Destiny 1200.

The FBC filters in both devices update every 0.5 ms. However, the adaptation rate for Destiny 1200 is ten times faster than that for Axent II. Thus, although the two filters update at similar intervals of time, a larger step size is used in Destiny 1200. As a result, Destiny 1200 is better able to respond quickly to large changes in the feedback path. The difference between walking up an escalator versus a flight of stairs is a useful analogy in understanding this distinction between the two FBC algorithms. In both cases, the start (i.e., telephone away from the ear) and end (i.e., telephone at the ear) points are the same. The rate of walking (i.e., filter update) is also the same. However, one would reach the destination more quickly by walking up an escalator because one travels a greater distance (i.e., faster adaptation rate) for each step (i.e. filter update) on the escalator.

Entrainment Prevention

Entrainment was evaluated in the laboratory using six stimuli known to cause entrainment - ambulance siren, car horn, choir music, 3kHz pure tone, telephone ring and whistling. The stimuli were presented at 50 dBA through a loudspeaker placed 3 feet in front of the listener. For each stimulus, participants were asked to rate, on a 7-point scale, whether they preferred the quality of the sound in memory 1 or memory 2. The FBC algorithm was randomly disabled in one of these memories. If necessary, overall gain was adjusted in both memories so that feedback did not occur in either condition. Under such circumstances, the best possible performance is a rating of "no difference" between the two memories. The mean preference ratings (Figure 20) were

	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D	Manufacturer E	Destiny 1200
Added Stable Gain	Objectionable Performance			Objectionable Performance		Best-in-Class
Entrainment	Objectionable Performance		Objectionable Performance	Objectionable Performance	Best-in-Class	Best-in-Class
Path Changes	Objectionable Performance	Best-in-Class		Best-in-Class	Objectionable Performance	Best-in-Class

Figure 17: Summary of the outcomes of bench assessment of feedback cancellation algorithms.

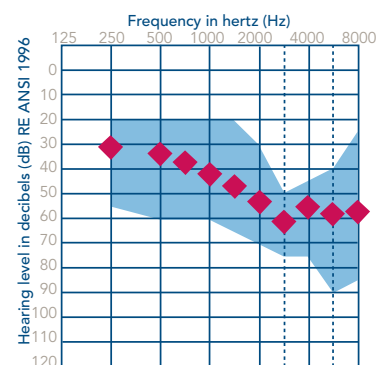


Figure 18: Average audiometric thresholds. The range from minimum to maximum is shown by the shaded region. Data are collapsed across ears.

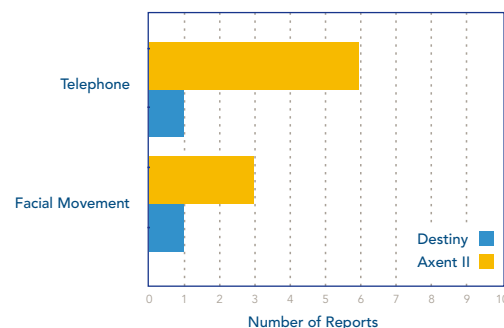


Figure 19: Prevalence of feedback due to changes in the feedback path during field trials.

found to be similar for Axent II and Destiny 1200. Further, both products received the best possible score on the laboratory evaluation.

The prevalence of entrainment artifacts was determined over the course of a 1-week field trial with Axent II and Destiny 1200. Figure 21 shows that entrainment artifacts were three times more likely to occur with Axent II than with Destiny 1200.

Participants described the entrainment artifacts in Axent II as an echo or as a burst of feedback after the sound had stopped; the terms “pulsing” and “warbling” were used to describe entrainment artifacts in Destiny 1200. Entrainment is addressed in Axent II only after the FBC filter has been affected. In contrast, entrainment is prevented proactively in Destiny 1200. The results of the laboratory evaluation and field trials indicate that, in spite of the faster adaptation rate, Destiny 1200 is better at preventing entrainment artifacts than Axent II.

Added Stable Gain

The broadband gain of the hearing aid was increased until audible feedback occurred, and then decreased until feedback disappeared. The real-ear aided gain (REAG) was measured for composite noise presented at 60 dB SPL. This procedure was repeated for the right and left ears, Axent II and Destiny 1200 devices, with the FBC algorithm disabled and enabled. MSG was calculated as the average gain at 1000, 1600 and 2500 Hz. ASG was calculated as the difference in MSG between the FBC off and FBC on conditions.

Figure 22 shows the ASG plotted as a function of MSG in the FBC off condition. Two key observations can be made from these data. First, Destiny 1200 provides as much as 10 dB more ASG than Axent II. This can be attributed to the sub-band method in Destiny 1200 which uses 16 independent filters to model the feedback path more accurately than the broadband approach used in Axent II. And, second, Destiny 1200 shows a marked trend toward decreasing ASG as the MSG in the FBC off condition increases. This highlights the primary limitation of the traditional method of measuring MSG - viz., ceiling effects. That is, when the MSG is high with the FBC algorithm disabled, the maximum gain of the device is frequently reached before feedback can be elicited with the FBC algorithm enabled. A similar trend is seen in the data obtained from a previous clinical evaluation of Destiny 1200 (shown by the green triangles in Figure 22), which included both custom and BTE styles. The fact that the Axent II data show no such trend indicates that the best possible ASG provided by the FBC algorithm is about 10 dB. In contrast, ASG values as high as 23 dB are seen in Destiny 1200.

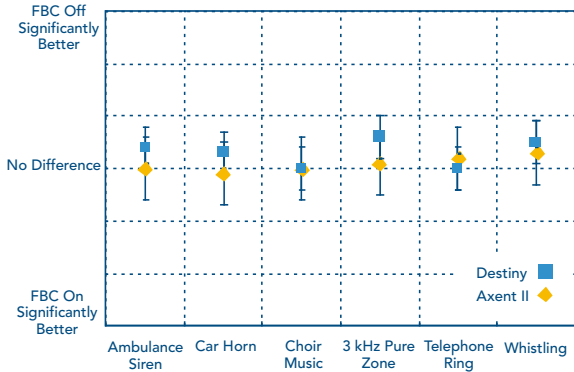


Figure 20: Mean preference rating during laboratory evaluation of entrainment.

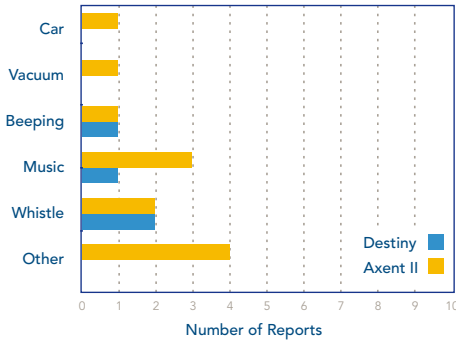


Figure 21: Prevalence of entrainment during field trials.

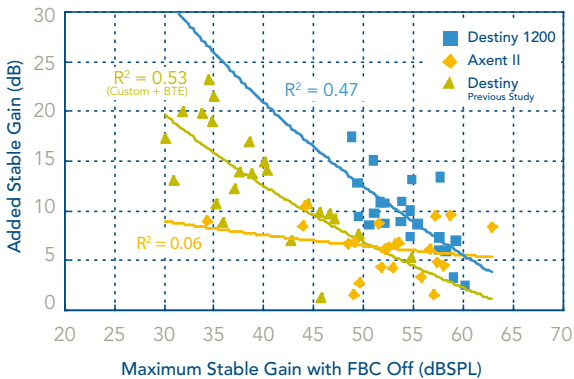


Figure 22: Added stable gain measured in the laboratory using the traditional method.

Need for Initialization

The FBC algorithm is capable of optimizing the filter to the individual ear within 10-25 hours of use. This self-learning may obviate the need for initialization in the clinic. It should be noted that, self-learning occurs only if an initialization has not been performed.

Figure 23 shows the ASG obtained with and without initialization. ASG for the uninitialized condition was measured after a week of hearing aid use to allow time for customization of the FBC filter. The black line denotes perfect self-learning under ideal conditions; the region to the right of the black line indicates that the ASG measured following initialization is greater than the ASG resulting from self-learning. In reality, a slight advantage is noted for initialization. However, for more than 80% of the ears tested, the uninitialized ASG was within 5 dB of the ASG obtained with initialization.

Conclusions

FBC algorithms are a useful, and often necessary, addition to hearing aids. Directly or indirectly, they address several of the most important improvements sought by hearing aid users - better sound quality, less whistling and buzzing, more audibility for soft sounds, work better on the telephone, improved speech understanding in quiet, and better fit and comfort.

Adaptive feedback cancellation is essential to accommodate changes in the acoustic feedback path, such as placing a telephone by the ear or putting on a hat. However, adaptive systems are prone to entrainment artifacts. Thus, the goals of adapting to changing feedback paths and minimizing the occurrence of artifacts are contradictory. The hallmark of good FBC is striking the right balance between the two extremes.

The results of the benchmarking effort highlight the fact that all FBC algorithms are not created equal. Only one hearing aid, Starkey's Destiny 1200, achieved best-in-class status on all measures of the assessment: added stable gain, entrainment, and path change.

Clinical evaluation of AFI reveals that design objectives have been attained. Compared to the FBC algorithm of the previous generation, AFI offers: (1) improved feedback path analysis, (2) more robust prevention of entrainment, and (3) excellent added stable gain. In addition, reliable and automatic customization of the algorithm reduces the need for initialization.

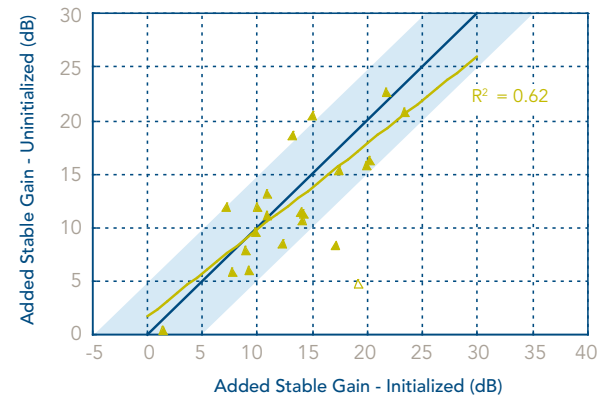


Figure 23: Added stable gain achieved with and without initialization. The shaded region marks a ± 5 dB deviation from the ideal result. An outlier not included in calculation is shown by the unfilled symbol.

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