April 2019

Reduced acoustic feedback in realistic and active situations with Dynamic Feedback Canceller™

Christophe Lesimple
Martin Kuriger
Bernhard Künzle

Acoustic feedback is an unwanted artifact present in any sound amplification system comprising a microphone, an amplification unit, and a receiver. The risk of acoustic feedback is high for hearing aids because (1) the distance between the microphone and receiver is small and (2) sufficient amplification must be available to compensate for the hearing loss. Abrams & Kihm (2015) identified feedback management as one of the key factors contributing to a hearing aid user's satisfaction. Therefore, hearing aid manufacturers continually focus on improving feedback management technologies. Bernafon's patented Dynamic Feedback Canceller™ (DFC™) (US Patent No. 9,826,319 B2, 2017) introduced with Viron, falls within this context.

DFC™ was designed to handle feedback in everyday situations which can be very different from those met during fitting sessions in a clinic. The main principles and the expected benefits will be described before the presentation of our internal test results.

Acoustic feedback in static and dynamic situations

Acoustic feedback can occur in two different scenarios: static situations, without any movement around the ear, and dynamic situations with sudden and fast movements.

Acoustic feedback, as a potential artifact in hearing aids, can occur in two different scenarios: static situations, without any movement around the ear, and dynamic situations with sudden and fast movements, for example, when covering the ear with the hand. A feedback canceller's performance in static situations can be defined by the amount of added stable gain that can be given by the device without howling. Ricketts et al. (2008) and Spriet et al. (2010) compared the performance of different feedback canceller systems in commercially available hearings aids. These evaluations were done in a static condition only (i.e., gain was slowly increased until feedback occurred). This condition was used as the development guideline for Bernafon's Adaptive Feedback Canceller (AFC). AFC therefore performs quite well when changes in the feedback path are slow and gradual (Figure 1).
The feedback path (F) is the transfer function from the receiver to the microphone. It defines how much sound from the receiver is fed back and picked up by the microphone. AFC produces an estimate ($\hat{F}$) of the true feedback path (F) and applies phase cancellation to remove feedback. AFC estimators will therefore constantly update $\hat{F}$ in small steps. A small step size improves the precision of the estimate so that it can gradually converge to the true feedback path. AFC effectively removes any feedback signal without altering the useful incoming signal with an optimized estimation of F (Nordholm et al., 2018). AFC is optimized for sound quality in situations where the feedback path is stable. However, realistic scenarios like covering the ear with a hand, putting on a hat or taking a phone call are challenging. The feedback path is suddenly changed by movement and, as a consequence, the estimated feedback path no longer matches the real one (Nordholm et al., 2018). This will trigger feedback until the AFC has converged to the new transfer function.

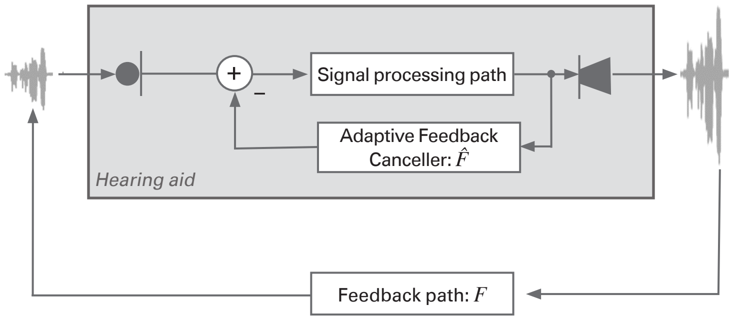

Figure 1: Block diagram of the reference system with Adaptive Feedback Canceller technology only.

DFC™ was developed to handle fast changes in the feedback path.

DFC™ was developed to handle fast changes in the feedback path. This technology is based on the AFC, which was optimized for sound quality, with additional estimators specialized to track fast changes in the feedback path (Figure 2).
Once these estimators detect emerging feedback, DFC™ removes it quickly with spectro-temporal modulations (STM) and speeds up the feedback path estimation (Guo & Kuenzle, 2017; Guo et al., 2018). The effectiveness of the system relies to a large extent on the feedback estimators. Therefore, this estimation must be fast and precise in time as well as in frequency.

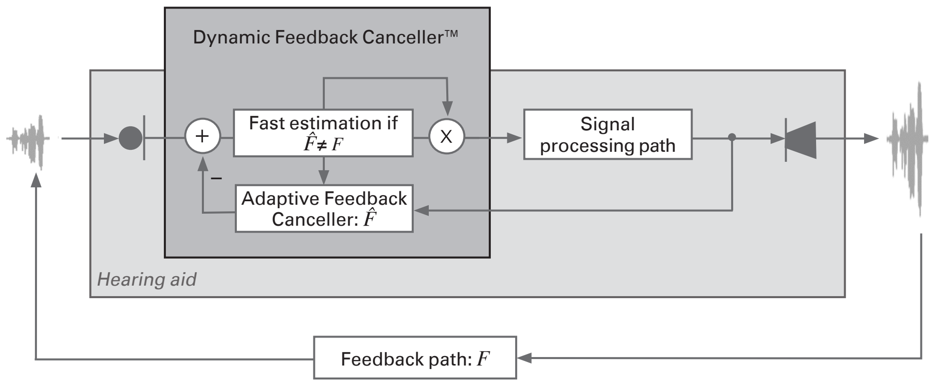

Figure 2: Block diagram of the tested system, Dynamic Feedback Canceller™ (DFC™).

AFC analyzes the feedback path in 14 frequency bands, 1,250 times per second based on the phase and amplitude from each microphone input, i.e., it already analyzes 70,000 data points per second. In addition, DFC™ detects fast and frequency-specific feedback path changes in 28 frequency bands, 1,000 times per second based on the phase and amplitude, resulting in 56,000 additional data points. Combining all the information, DFC™ adjusts feedback cancellation based on up to 126,000 data points per second. This high amount of information is necessary to enable a fast reaction. Feedback can be usually detected after 20 milliseconds (ms) and then suppressed over the subsequent 40 ms with DFC™. Fast reaction of the feedback canceller is crucial as it prevents the feedback from reaching high levels which would annoy the user or people near them.

DFC™ behavior in dynamic situations

The behavior of DFC™ in dynamic situations was measured. A test and a reference hearing aid were fitted at the feedback threshold and placed on an artificial head for the measurements. Identical fitting parameters were chosen with only the feedback cancellation system being different. The reference device had only AFC activated, while the test device had DFC™ activated. Feedback was evoked by covering the ear with a hand, waiting, and then removing the hand from the ear. The test was made with the presence of a speech signal played at 65 dB SPL. The recordings are displayed in the form of a spectrogram (Figure 3).
Feedback severeness was computed and monitored in different frequency bands in a post-hoc analysis. Figure 3 shows signal parts that are dominated by feedback in red. Without DFC™, feedback occurs with each movement of the hand. Covering and uncovering resulted in audible feedback with a duration of more than 250 ms. This time lapse is long enough for the feedback signal to reach levels above 80 dB SPL. It corresponds also to the time needed to adjust the feedback path estimation to the new acoustical configuration, i.e., with the reflections from the hand when covering the ear.

With DFC™, feedback is suppressed within milliseconds. This fast suppression doesn't leave enough time for the feedback signal to reach higher levels. STM applied by DFC™ is also visible on the spectrogram with vertical white stripes. One expected benefit is that reduced feedback duration and loudness will be preferred by hearing aid users.

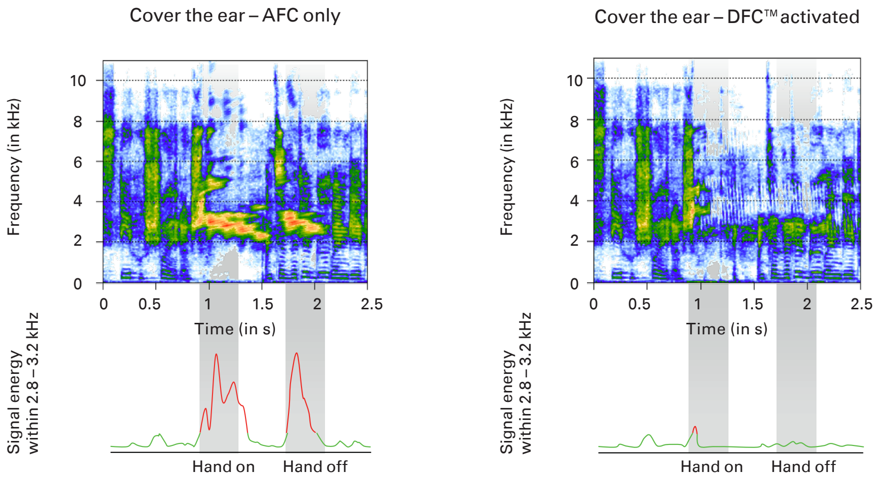

Figure 3: System test results with the reference system, AFC, on the left and the tested system, DFC™, on the right. Manipulations close to the ear are shown in gray. The signal parts that are dominated by feedback are indicated in red.

This example demonstrates the effectiveness of DFC™ in one test condition. However, other factors might also play a role in the perceived feedback. The movement's amplitude and speed might produce different changes in the feedback path. It can potentially affect the behavior of the feedback cancellers. This might be the case with different types of movement like inserting the hearing aid or holding a phone to the ear. These aspects were covered in a live feedback test in a controlled environment.

Less feedback annoyance and sensitivity with DFC™

One expected benefit is that reduced feedback duration and loudness will be preferred by hearing aid users.

The idea of testing feedback in dynamic situations was introduced by Marcrum et al. (2018). Indeed, hearing aid users are more likely to report experiencing feedback in dynamic and active situations. It implies that the evaluation of feedback canceller technologies should not be carried out in static or optimal situations only. Selected test manipulations for the evaluation should ideally reflect challenging and realistic situations. A live feedback test was designed to address this use case.

The main outcome of our test was about the annoyance of feedback. Feedback annoyance is a composite score combining the duration and loudness of feedback. The most direct way to measure annoyance after each manipulation is to explicitly ask for and get the result on a visual analog scale (VAS). If the manipulation elicited feedback, then the participant marked the level of feedback annoyance on the VAS. The scale is adjusted to fit on a 10 cm line and VAS scores can be interpreted as follows:

- low values indicate less annoying feedback or positive results (Not annoying = 0 cm),
- high values indicate extremely annoying feedback or negative results (Extremely annoying = 10 cm).

The main outcome of our test was about the annoyance of feedback. Feedback annoyance is a composite score combining the duration and loudness of feedback.

The protocol was designed to reproduce a subset of everyday manipulations, for example, hearing aid insertion, covering the ear with the hand or with a hat, simulating a phone call, and removing the hearing aid. These manipulations were performed with each of the test devices, combining the device with AFC, the reference condition, or with DFC™, the test condition, at three different levels of gain. The devices were not distinguishable other than with a small colored dot.

Each participant was asked to do the above-mentioned manipulations on an artificial head, while at the same time, monitoring the audio/feedback through headphones. The participants were asked to perform the manipulation in a similar way (similar distance from the ear) with each test device independent of the experienced feedback. The participants evaluated feedback annoyance for each test device and each manipulation. A training run was made with a device without any feedback canceller activated so that each participant could experience feedback in a worst-case scenario.

Another factor, gain, was expected to play a role in evoked feedback, more gain makes the device more prone to feedback (Marcrum et al., 2018). The baseline fitting was defined for the reference device for a severe high-frequency hearing loss (S2 standard audiogram from IEC, Bisgaard et al., 2010) with the NAL-NL2 fitting rationale, 85-Speaker, and Open Dome. The insertion gain, for 50 dB input levels, between 3 and 5 kHz was exactly at the feedback threshold with this configuration. This gain configuration was defined as 0 dB gain above the feedback threshold. For the two other conditions, the broadband gain was increased by 6 dB and 10 dB to create more challenging test conditions.

To summarize, feedback annoyance was tested with the reference AFC against the developed DFC™ using five different manipulations and three gain levels. For this test, fourteen participants with normal hearing were recruited. The average annoyance scores were reported on a VAS scale and are shown in Figure 4.

The average results show a large variability in perceived annoyance across the programmed gain, the manipulations, and the tested system. Manipulation evoked different feedback annoyance with both tested systems. Covering the ear with the hand is the most sensitive manipulation while putting on the hat is less capable of evoking feedback. It is therefore interesting to include the type of manipulation as an independent variable to explain one part of the observed variation in the perceived annoyance. Manipulations were grouped into two categories: (1) low feedback risk (insertion, cover with the hat, and removal) and (2) high risk (cover with the hand and the phone).

Average feedback annoyance also increased with additional gain above the feedback threshold from M = 1.3 cm, 95 % CI [0.9, 1.7] at 0 dB, to M = 3.9 cm, 95 % CI [3.2, 4.6] with 6 dB added gain, and finally M = 5.6 cm, 95 % CI [4.9, 6.3] with 10 dB added gain. These changes can be expected as the feedback risk directly depends on the amount of programmed gain. Testing different systems also changed the perceived annoyance from M = 5.3 cm, 95 % CI [4.6, 6.0] with the reference AFC to M = 1.9 cm, 95 % CI [1.5, 2.2] with the tested DFC™.

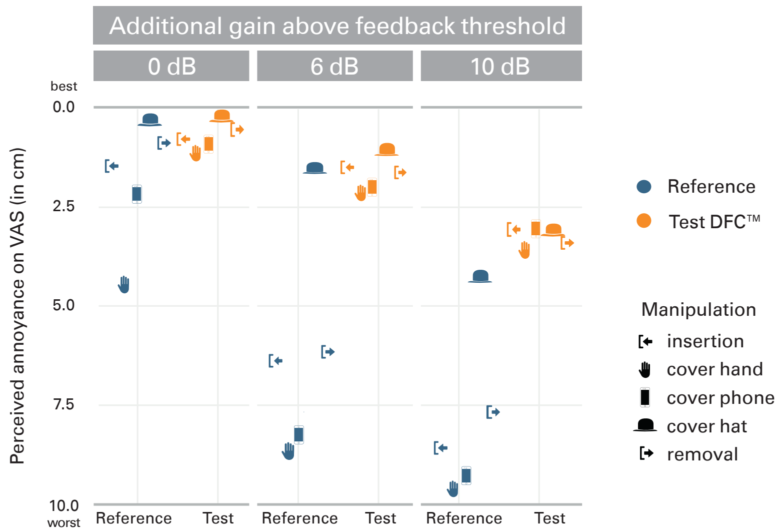

Figure 4: Average feedback annoyance measured with the reference system in blue, AFC only, and with the test system, DFC™, in orange at three gain levels and five different manipulations. Low annoyance scores are displayed toward the top of the figure and indicate better performance.

While the summary data shows positive and coherent results, it is challenging to interpret a change in centimeters on the visual scale. These values represent a relative evaluation of perceived annoyance and not absolute values. It is therefore appropriate to describe the effect of each factor as a percentage. To estimate a change of annoyance in percent, the different explanatory variables were modelled with a mixed-effect regression on a log transformed score of feedback annoyance (Feng et al., 2013). The model's coefficients are shown in Table 1, however, a backward transformation is needed to get the effect in percent. For a coefficient $\hat{\beta}$, the change in percent equals $100 \times (e^{\hat{\beta}} - 1)$. The coefficient for the feedback canceller effect is estimated at -0.331 which corresponds to a reduction of 28 % of feedback annoyance with the tested DFC™ over the reference AFC.

The first part of the test investigated the feedback canceller in some realistic situations with a set of selected manipulations. The test was pushed further to challenge the feedback canceller system to its limit. At the end of the manipulation routine, each participant was asked to hold the device in their hand and try to trigger feedback. They had to rate the effort needed to produce feedback with the different systems and the different programmed gain. This measure, made in a blind test condition, evaluates the sensitivity of each test condition towards feedback (Figure 5).

High effort to trigger feedback was rated with low values on the VAS. These values indicate that the tested device could withstand sudden changes in the feedback path. Low effort, rated with high values, indicates that the test device was more sensitive to changes in the feedback path and was more likely to produce acoustic feedback. The analysis of feedback sensitivity scores was treated similarly to the analysis of the feedback annoyance scores.

Feedback sensitivity was found to be significantly reduced by 36.3 % when DFC™ was enabled. The amount of gain above the feedback threshold was also a significant factor; more gain made the tested system more sensitive to evoked feedback.

The coefficient for the feedback canceller effect corresponds to a reduction of 28 % of feedback annoyance with the tested DFC™ over the reference AFC.

Fixed effects	Coef.β	SE.(β)	t	p
Test system				
From Reference to DFC™	-0.331	0.022	-15.0	<0.001
Additional gain				
From 0 db to 6 dB	0.479	0.027	17.8	<0.001
From 0 db to 10 dB	0.290	0.027	10.8	<0.001
Manipulation risk				
From high to low	-0.178	0.022	-7.9	<0.001

Table 1: Result summary coefficient estimates **β**, standard errors (**β**), associated **t** values (**β**/SE(**β**)), and significance level **p** for all the fixed effects in the linear mixed model with log transformed VAS scores as the outcome.

More fitting options with DFC™

This test investigated different aspects of measuring feedback performance in dynamic situations (i.e., when the feedback path changes quickly). All the test results are consistent, and we can conclude that Bernafon's DFC™ implemented in the tested device reduces feedback annoyance by 28 % and feedback sensitivity by 36 %.

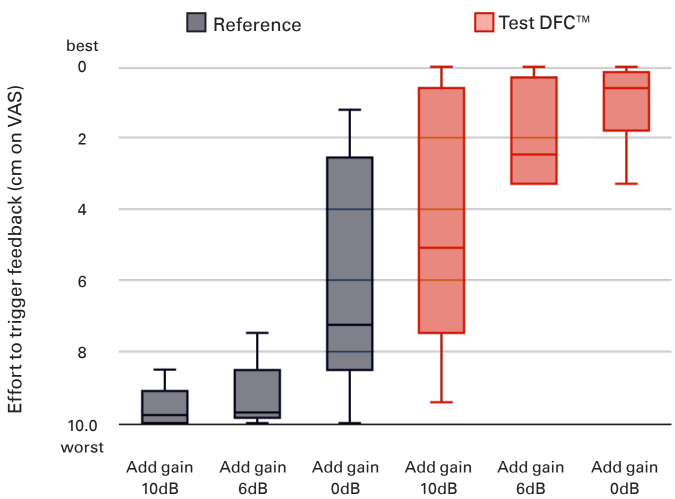

Figure 5: Feedback sensitivity measured with the reference system in gray, AFC only, and with the test system, DFC™, in red at three added gain levels. High effort, with small values on the top of the figure, shows good performance of the tested system.

Improving the feedback performance has the potential to provide more gain with more open acoustics without worrying about feedback issues. It should extend the fitting range of the devices and give more headroom if additional gain is required. Finally, it is anticipated that experiencing less feedback should improve hearing aid user's satisfaction.

Feedback sensitivity was found to be significantly reduced by 36.3 % when DFC™ was enabled.

References

Abrams, H.B., & Kihm, J. (2015). An Introduction to MarkeTrak IX: A New Baseline for the Hearing Aid Market. *Hearing Review, 22*(6), 16.

Bisgaard, N., Vlaming, M. S. M. G., & Dahlquist, M. (2010). Standard Audiograms for the IEC 60118-15 Measurement Procedure. *Trends in Amplification, 14*(2), 113–120.

Feng, C., Wang, H., Lu, N., & Tu, X. M. (2013). Log transformation: application and interpretation in biomedical research. *Statistics in Medicine, 32*(2), 230–239.

Guo, M., Kuriger, M., Lesimple, C., & Kuenzle, B. (2018). Extension and Evaluation of a Spectro-Temporal Modulation Method to Improve Acoustic Feedback Performance in Hearing Aids. In 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE.

Guo, M., & Kuenzle, B. (2017). On the use of spectro-temporal modulation in assisting adaptive feedback cancellation for hearing aid applications. In 2017 51st Asilomar Conference on Signals, Systems, and Computers. IEEE.

Kuenzle, B. & Guo, M. (2017). U.S. *Patent No. 9,826,319 B2*. Washington, DC: U.S. Patent and Trademark Office.

Marcrum, S. C., Picou, E. M., Bohr, C., & Steffens, T. (2018). Feedback reduction system influence on additional gain before feedback and maximum stable gain in open-fitted hearing aids. *International Journal of Audiology, 57*(10), 737–745.

Nordholm, S., Schepker, H., Tran, L. T. T., & Doclo, S. (2018). Stability-controlled hybrid adaptive feedback cancellation scheme for hearing aids. *The Journal of the Acoustical Society of America, 143*(1), 150–166.

Ricketts, T., Johnson, E., & Federman, J. (2008). Individual Differences within and across Feedback Suppression Hearing Aids. *Journal of the American Academy of Audiology,* 19(10), 748–757.

Spriet, A., Moonen, M., & Wouters, J. (2010). Evaluation of feedback reduction techniques in hearing aids based on physical performance measures. *The Journal of the Acoustical Society of America, 128*(3), 1245.

World Headquarters
Switzerland
Bernafon AG
Morgenstrasse 131
3018 Bern
Switzerland
www.bernafon.com

Imported and
Distributed by:
Audmet Canada Ltd
1600-4950 Yonge St
Toronto, ON M2N 6K1
www.bernafon.ca

2019-04-15/CA-US/subject to change/Ver 1.0

SOUND OF SWITZERLAND

bernafon
Your hearing • Our passion