PEDIATRIC KNOWLEDGE BRIEF – OCTOBER 2013

Getting off to a better start: **Pediatric Clinical Tools of Oticon Sensei**

EDITORS OF ISSUE

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ABSTRACT

When providing amplification to infants and young children, audiologists must ensure that hearing instruments are properly fit to fast growing ears. This presents practical challenges for both the clinician and parents. Fast growing ears often require frequent visits for earmold remakes and refittings. Parents must be trained in basic hearing instrument care and maintenance so that they leave the clinic feeling confident that they are capable of taking care of their child's hearing instruments. Parents need to be able to insert the earmolds properly in the child's ears, at the initial fitting and during the first period at home with the new instruments.

Oticon Sensei, a new family of pediatric hearing instruments, delivers several advanced features designed to address these challenges. Sensei offers an efficient anti-feedback system, the Inium feedback shield, and an optimized software-based feedback manager to assist in fitting amplification as ears grow. The SmartFit™ Trainer uses the LED (Light-emitting diodes) on Oticon Sensei instruments to indicate to parents that they have achieved a good earmold insertion. Both features are designed to provide the support and tools practitioners and parents need to provide optimal hearing aid rehabilitation for infants and young children.

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Introduction

The primary goal of pediatric audiology is to provide children with hearing loss with the audibility needed to support language development. Many factors need to come together to ensure a successful pediatric hearing instrument fitting (Fig. 1). Wear time for the hearing instruments must be sufficient to ensure audibility is provided over time. Sound quality without feedback should be prioritized to support auditory development and to avoid a rejection of the hearing instruments by the parents and the child. Feedback can influence the acceptance of the instruments as can a poor physical fit on the ear. The child might refuse to wear the instruments – affecting wear time and thus audibility - or the parents might lose the motivation to keep the instruments on their child's ears because of the difficulties. At the core of this work is empowering parents to engage confidently in their child's hearing care.

When developing hearing instruments for the pediatric population, these interconnected factors and many more need to be considered. This paper describes two new features in Oticon Sensei, a new family of pediatric hearing instruments. The features are designed to help audiologists and parents get off to the best possible start and thus, provide the maximum benefit to the young child with hearing loss.

Figure 1. Factors that need to come together to ensure a successful pediatric hearing instrument fitting. *At the core is the empowerment of parents in the hearing care of their child.* ***Audibility:*** *Ensuring that most sounds are within the auditory dynamic range – above the hearing threshold and below the discomfort threshold.* ***Sound quality:*** *Minimizing feedback while ensuring a clear auditory representation of the sound through the hearing instrument.* ***Wear time:*** *Delivering an audible and clear sound throughout the day across a variety of situations.* ***Acceptance:*** *Ensuring that neither child nor parents reject the instrument because of feedback or poor physical fit.*

Earmold insertion using SmartFit™ Trainer

One of the imperative aspects parents need to learn during the initial hearing aid fitting is how to insert the earmold correctly in their child's ear. Sjoblad et al. (2001) have studied parents' reactions to this first fitting appointment. The parents in the study were urged to talk freely about what they found to be meaningful and important within the context of the early audiological management of their young hearing-impaired child. The results showed that care and maintenance of the hearing aids were of concern for nearly three-fourths of the respondents. These topics encompassed a variety of aspects of hearing aid management including how to change batteries and clean earmolds. Approximately 40 percent of the parents reported concerns regarding inserting the earmolds, maintaining their placement in the ear, and preventing loss of the earmolds.

The manual skill of inserting the earmold in a child's ear is very important, as it secures the placement of the hearing aid behind the ear. This also means that transmission of amplified sound to the eardrum is ensured and the incidence of feedback is reduced. However, determining if an earmold is inserted correctly is a subtle task; often it is not visible to the eye or within the tactility of the fingers. SmartFit™ Trainer, a new LED-based tool from Oticon is designed to provide a tangible means for parents to confirm that they have inserted the earmold correctly as they practice to master the new skill. This empowers the parents to feel confident that the instruments and earmolds are properly positioned. For the audiologist, SmartFit™ Trainer provides a structured approach to train parents in earmold insertion in the office and reinforce the training at home.

The SmartFit™ Trainer concept

The SmartFit™ Trainer in Oticon Sensei builds on the integrated LED introduced in Oticon Safari. In Sensei, one function of the LED is to alert parents and caregivers when the earmold is not in the correct position. Table 1 provides additional information about how and when the SmartFit™ Trainer works and benefits the child and parent.

Proper earmold insertion is determined by comparing the leakage out of the ear with a fixed, frequency dependent pass criteria in the instrument. SmartFit™ Trainer makes a quick leakage measurement at seven frequencies within the 1400-4000 Hz range at approximately 73 dB SPL. To determine if a good insertion is achieved, the SmartFit™ Trainer will run up to seven measurements. During this time the LED is lit continuously. The LED switches off as soon as all seven tones are above the pass criteria, indicating a good insertion (Fig. 2a).

Fitting tips	Hearing loss dependencies	Benefits and limitations
• The SmartFit™ Trainer works only with closed earmold fittings in BTE style instruments and is by default enabled in Sensei. This feature can be disabled as desired in the Genie fitting software. • The start-up jingle and SmartFit™ Trainer cannot be selected at the same time, since both are start-up features. • Similar to other hearing instrument-based measurements, the environment should be fairly quiet in order for the measurement to be valid. Talking at normal conversational level at close proximity to the ear will disturb the measurement. If there is too much noise, SmartFit™ Trainer will most likely show the rapid warning blinks.	• For mild hearing losses, reduced amplification due to leakage of sound is a bigger issue than the risk of feedback. The pass criteria are thus set so that the warning is triggered when there is a risk of reduced audibility even though there is no risk of whistling. The warning will be less frequent in this case. • The leakage measurement by the SmartFit™ Trainer is done within the 1400-4000 Hz frequency range. Beyond this range, it will not detect leakage of sound. Thus, for steeply sloping hearing losses with significant high frequency gain prescriptions, the SmartFit™ Trainer might indicate a good insertion despite there being leakage at higher frequencies.	• As soon as the parents master the skill of inserting an earmold, the instrument will behave as if Smart Fit™ Trainer was absent. The pass criteria will be fulfilled within the early leakage measurements, thus not prolonging the hearing instrument start-up relative to not having SmartFit™ Trainer. • Leakage is only measured during start-up of the instrument. SmartFit™ Trainer can thus not detect leakage that occurs when the instruments are used during the course of a day. • While SmartFit™ Trainer is running measurements, no gain is applied in the hearing instrument. This ensures that the child and parent will not experience feedback as the instrument is put in place. This has the potential benefit of preventing uncomfortable feedback that could lead to initial rejection of the instrument by the child or parent.

Table 1. Additional information about the SmartFit™ Trainer.

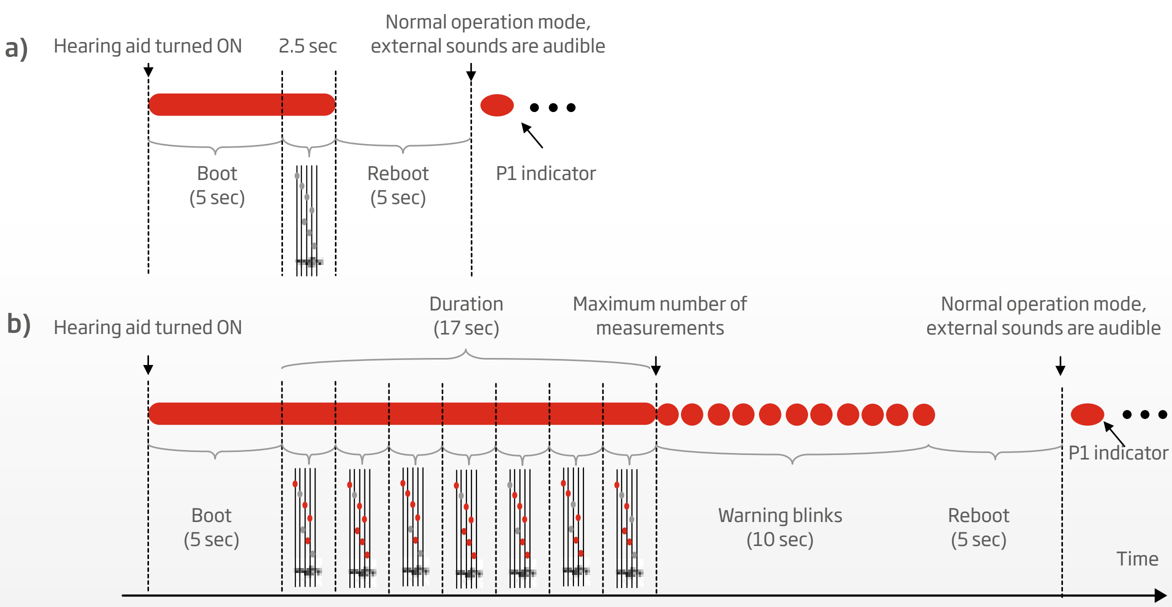


Figure 2. The SmartFit™ Trainer's LED function. *The figure illustrates the process from the moment when the hearing aid is turned on, boots up, evaluates earmold insertion, reboots and finally goes into normal mode of operation in Program 1 (P1). The red areas show the corresponding LED sequence, visual to the parent.* ***Scenario a)*** *illustrates a quick and successful earmold insertion;* ***b)*** *illustrates an unsuccessful insertion. When seven measurements at seven frequencies do not pass the success criteria, SmartFit™ Trainer produces a fast sequence of warning blinks.*

An insufficient earmold insertion or a poorly fitting earmold initiates a rapid series of blinks, as one or more measurement tones fall below the pass criteria. Whether or not a proper earmold insertion is achieved using the SmartFit™ Trainer, the instrument will always start up normally and go into the general program (Fig. 2b). If the parent wishes to have one more attempt at inserting the earmold, SmartFit™ Trainer can be re-started by turning the instrument off and back on again via opening and closing the battery door.

The pass criteria is set to guarantee that the earmold is correctly inserted when indicated. The primary objective of proper earmold insertion is to prevent the hearing aid from whistling. The secondary objective is to prevent leakage that can result in the loss of amplification in the low frequencies. Because the pass criteria is fixed within a fitting, the risk of a leakage warning will be higher as the ear grows. The SmartFit™ Trainer is set so that the LED warning is given prior to audible feedback. This enables parents to arrange for the remake of earmolds as needed, limiting periods of suboptimal amplification or down time.

The growing ears of young children

Acoustic feedback is a cause for concern to parents, particularly as infants and young children outgrow their earmolds. McCracken et al. (2008) investigated the experiences of parents in the early audiological management as part of the emergence of Universal Newborn Hearing Screening. Eighty percent of the parents reported that "the weakest link in the amplification chain was the custom made earmolds". This was based on their experience with poorly fitting earmolds as well as the lengthy waiting period for an initial appointment to have ear impressions taken and then, waiting for the new earmolds to be ready.

Comments presented in the study indicate that parents experienced some frustration due to acoustic feedback issues. Quotes reveal challenges in parent-child interaction and more practical day-to-day issues. These quotes have both an intimacy and a practical angle:

"In some ways it would have been nice to know a bit later 'cause I would have had a chance to enjoy him without all the issues of, I can't put him on my shoulder because ...I can't cuddle him too close 'cause he'll get feedback off his hearing aids and those sorts of things that you want to do with a child... and they're harder with a child whose younger."

"you have a lot more practical issues like they have their head down a lot and that makes, when they thrash around their heads, that sets off feedback, to holding them a lot cause problems, and hats and coats and all that causes problems associated with newborns... so there's definitely more problems associated with newborns than there are with older children."

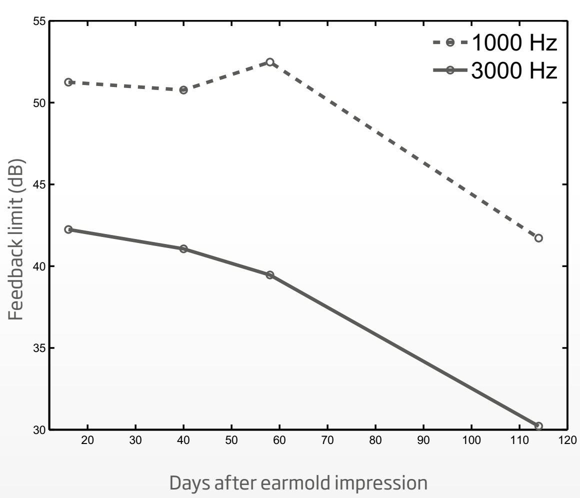


Figure 3. Impact of the growing ear on the feedback limit as a function of time. *The feedback limits at 1000 Hz (dashed line) and 3000 Hz (solid line) are shown as a function of time for the left ear of a 16-month-old child. The feedback measurement was repeated during four visits over 110 days. A higher feedback limit allows more gain in the instrument.*

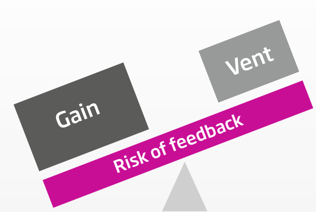


Figure 4. The balance between vent and gain. *A correct balance between the amount of venting and gain in a fitting will keep the risk of feedback in check. The assumption is that both large venting and high gain are desirable. However if one goes up, the other most come down.*

Fast growing ears present a practical challenge when providing amplification to infants and young children. In essence, the parent and audiologist need to join forces and keep up with earmold remakes and instrument refittings so that feedback issues in turn will be minimal.

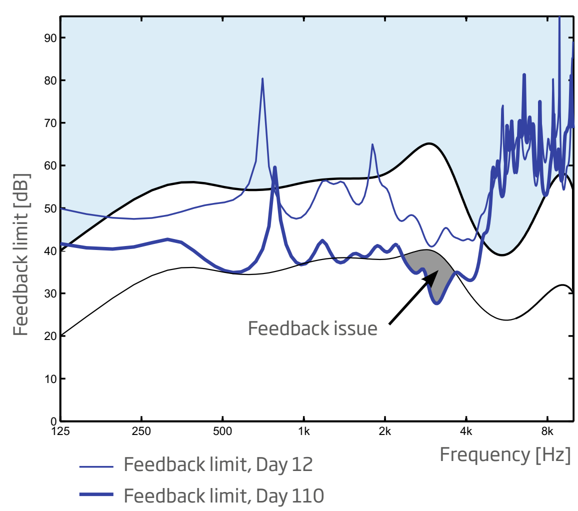
Figure 3 shows the impact of the growing ear of a 16-month-old child on the feedback limit at two frequencies. The feedback paths have been measured and feedback limits calculated using the Automatic Feedback Manager (AFBM) tool in Oticon Genie fitting software. Measurements were done at 2-3 week intervals starting from two weeks post ear impressions. Figure 3 displays the frequency limit at 1000 Hz (dashed curve) and 3000 Hz (solid curve). These two frequencies were selected to represent an area where feedback can be an issue. The 3000 Hz curve is consistently around 10 dB below the 1000 Hz curve across the four visits and more susceptible to the occurrence of feedback than the 1000 Hz curve. Within the first two months, the feedback limit is close to constant, varying only a few dB for both curves in Figure 3. However a clear, rapid decline occurs in the following two months as the feedback limit drops in total approximately 10 dB, from 53 to 42 dB at 1000 Hz and from 40 to 30 dB at 3000 Hz. Use Case 1 presents the fitting use case for the growing ear of this particular 16-month-old child and the effect on the gain margin (the span between the feedback limit and the insertion gain curve for soft input levels) for a moderate hearing loss.

Use Case 1: Effect of growing ears on gain margin

A 40-60 dB HL hearing loss at 500 and 2000 Hz respectively has been selected to illustrate the effect of growing ears on gain margin and how this is affecting the prescription of desired gain. Gain margin is the range between the feedback limit and the insertion gain curve for soft input levels (45 dB SPL). Because of amplitude compression, the soft-input gain represents the maximum gain of the prescription, thus the level that is most affected by feedback issues.

The prescribed gain margin (before a feedback limit was measured) was approximately 20 dB across the frequency range in the figure to the right, but slightly less in the 4000 Hz area. The prescribed feedback limit and insertion gain curve in the graph was derived from the fitting software Genie, and is depicted by black lines. Feedback measurements, completed on day 12 and day 110 after the ear impressions were made, are depicted with blue curves in the figure (not visible in Genie).

The feedback measurements after 12 days displayed a reduced gain margin in the 2000 to 3000 Hz area for this particular fitting, but were still not compromising the desired gain. However, after 110 days, the impact of the growing ear had a great impact on the gain margin. Noticeably, the feedback limit was below the insertion gain curve at around 3000 Hz, causing a feedback issue. If new earmolds were not refitted or gain reduced, the risk of getting feedback would have been markedly increased for this fitting.



Impact of the growing ear on the feedback limit as a function of frequency. *The picture illustrates the growing ear's influence on a feedback limit for a 16-month-old child. The thick black line is displaying the prescribed feedback limit. The thin black line corresponds to the desired insertion gain curve for soft input levels (45 dB SPL). The thin blue curve illustrates the feedback limit that was measured 12 days after earmold impression, whereas the thick blue curve is measured after 110 days. When the ear grows, the earmold is no longer fitting the ear, thus causing more sound to leak and the feedback limit is lowered. This is compromising the gain and causing a feedback issue (marked out in the figure) if the fit is not improved/ new earmolds are made or if the desired gain is not reduced.*

Depending on the hearing loss, selected instrument and prescribed amplification, the decline of the actual feedback limit affected by the growing ear will increase the risk of running into audible feedback issues. This in turn will compromise gain and sound quality. In the intermediate periods between earmold remakes, the anti-feedback system needs to deal with the slowly but continuously changing feedback path of the acoustic coupling to the ear. This is where efficient feedback management comes into play.

Feedback management

Current amplification guidelines (American Academy of Audiology, 2013; Bagatto et al., 2010; Foley et al., 2009; King, 2010) supply a range of strategies for managing earmolds and feedback issues. Feedback suppression strategies need to be carefully considered before introduced in children's hearing aids and the feedback suppression strategies should not be used as a substitute for the regular provision of good fitting earmolds. Figure 4 illustrates the constantly present balancing of gain and venting and its impact on the risk of feedback. The amount of gain influences the size of the venting in an inverse manner, i.e. when gain goes up vent size must go down.

Access to high frequency information is of particular importance in pediatric hearing device fittings to support speech perception and language development (American Academy of Audiology, 2013; McCreery, 2011). A typical feedback path provides less attenuation at high frequencies than at low frequencies. Therefore, the risk of audible feedback is greater in the 2500 to 4000 Hz range as well as in the 8000 Hz area. To provide gain in as broad a frequency bandwidth as possible, Oticon deploys Dynamic Feedback Cancellation (DFC) technology.

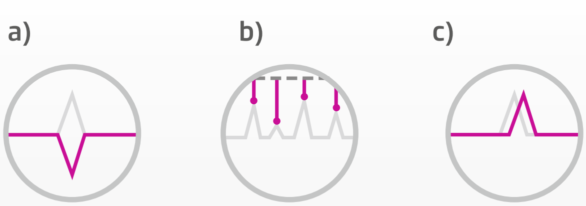


*Figure 5. The Oticon symbols illustrating the three core elements of the Inium feedback shield: **a) Phase inversion** – The use of destructive interference to cancel the feedback signal. **b) Gain Control** – The use of continuous feedback limit estimation to temporally limit the gain to eliminate feedback. **c) Frequency shift** – To introduce a shift in the frequency response to allow more frequent updates of the filter. In Sensei the frequency shift is only applied when it is called for.*

Phase inversion

Phase inversion means that the hearing instrument uses destructive interference to eliminate the feedback signal. It is the job of the anti-feedback system to calculate a model of the feedback path from the receiver to the microphone and also to track changes to this path. This is done by comparing the microphone signal to the amplified signal. The modeled feedback path is inversed (thus it contains the same frequency content as the feedback signal), and imposed on the amplified signal (Fig. 5a). An effective DFC system does this almost instantaneously and without introducing audible artifacts or compromising high frequency gain or speech intelligibility.

Gain control

In addition to the phase inversion, Sensei makes use of gain control based on continuous feedback limit estimation to eliminate feedback (Fig. 5b). A static feedback limit is set in Genie during the fitting to ensure that the instruments are fitted within the fitting range of the instrument. The continuous feedback limit estimation gives an opportunity to dynamically apply a new temporary feedback limit in extreme acoustic conditions. At instances when an abrupt and dramatic change in the feedback path occurs, this dynamic feedback limit serves as an interim gain control to attenuate the feedback. This might occur in the situations described by the parents previously in the text, such as when cuddling a child or when covering the instruments with a hat or sitting in a car seat with a closely fitting headrest.

Frequency shift

The DFC system is also supported by a range of signal processing schemes including frequency shift to break auto-correlation between the output and input signal. A Fourier transformation is included to give a detailed insight into the frequency contents of the signal. Oticon's symbol illustrating frequency shift is depicted in Figure 5c. The DFC system is supplemented by the ability to introduce a 10 Hz upward frequency shift of the input signal above 900 Hz. This enables the DFC to differentiate between sounds from the environment and actual feedback, creating a more robust anti-feedback system. The frequency shift is only applied when it is called for:

1. When audible feedback needs to be eliminated.
2. When the input to the instrument resembles tones.

Furthermore only the frequency region in which feedback is likely to occur, i.e. above 900 Hz, is shifted. The strategy around applying the frequency shift is consolidated in an effort to preserve the best sound quality possible and ensure the best possible estimation of the feedback path.

The anti-feedback system in Sensei is termed Inium feedback shield (Oticon, 2013). Inium is the name of Oticon's current hearing instrument platform and is used in all Sensei instruments. How the entire system is controlled and adapts to the environment to effectively reduce feedback and at the same time carefully preserve good sound quality is the core of the anti-feedback management strategy in Sensei. In addition, fitting the instrument to individually-set feedback limit will optimize the operation of the anti-feedback system (see "Setting individual feedback limits" later in this text).

Controlling the Inium feedback shield

The Inium feedback shield effectively runs in three modes (Fig. 6). The modes distinguish themselves from one another by how often the anti-feedback system updates the phase inversed filter. The application of modes is controlled by two detectors. The howl detector is the first order detector. If howl or audible feedback is detected, **Fast Mode** is applied.

- In **Fast Mode**, the DFC imposes a fast updating filter to the input signal. To ensure the most robust estimation, frequency shift is applied enabling the anti-feedback system to make a precise estimate of the new feedback path.

If audible feedback is not present, the second order tonal detector determines whether Inium feedback shield should use **Stable** or **Dynamic Mode,** based on the presence of tonality in the environment. Tonality is characterized by repeatable, harmonic content such as acoustic stimuli like speech and music. This type of content can be mistaken for feedback by the anti-feedback system, so extra care needs to be taken to avoid suppressing any valuable information or creating a loop in phase with the input, causing additional feedback.

- When the content of the input signal is tonal, the Inium feedback shield will be in **Stable Mode**. The DFC behaves in a stable manner in the sense that the last updated feedback path filter is applied to the input signal. The assumption is that the acoustic properties around the hearing aid will not have changed and thus this filter will still be applicable. When the DFC is not being updated, the frequency shift is not relevant and will be disabled.

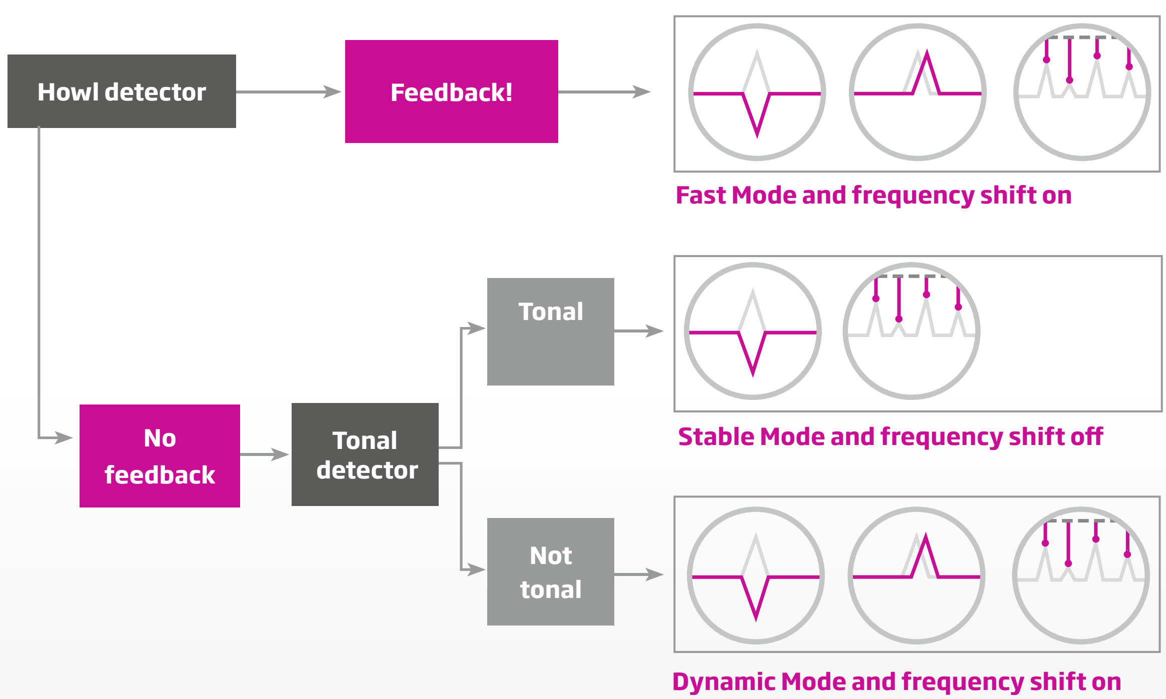


Figure 6. The flow chart of how Inium feedback shield is controlled. *Depending on the outcome of the Howl detector, different modes are applied. If feedback is present in the input,* ***Fast Mode*** *is applied; fast updating DFC and frequency shift is on. If no feedback is present, the Tonal detector is activated. If the input is tonal,* ***Stable Mode*** *is activated; the last updated feedback path filter is applied to the input signal and frequency shift is not needed. If the input is not tonal* ***Dynamic Mode*** *is activated; frequent update of DFC and frequency shift is on. Note that gain control by continuous feedback limit estimation is always present.*

- When the content of the input signal is NOT tonal, the Inium feedback shield will be in **Dynamic Mode**. The risk of degrading either speech or music is no longer present, and therefore, the DFC will allow more frequent update of the filter according to the subtle changes in the feedback path. Frequency shift is enabled in **Dynamic mode** to ensure robust feedback path estimation.

Regardless of mode, feedback limit estimation is ongoing, so that gain control can be provided when warranted.

Setting individual feedback limits

The prescription of feedback limits is determined by factors known to the fitting software such as instrument style, vent size and gain prescription. If the feedback limit is set conservatively, gain is compromised unnecessarily. If the limit is set optimistically and the instrument is fitted close to the upper fitting range, the amplified sound is more susceptible to changes in the feedback path and thus to the occurrence of audible feedback. However, the physical properties of an instrument and its coupling to the ear will be unique for every given fitting. To ensure that the instrument can provide sufficient amplification given the specific physical condition of the fitting, setting individual feedback limits is recommended. For Oticon instruments, this is done using the Automatic Feedback Manager tool in Genie.

With the introduction of Sensei and Oticon's latest anti-feedback system, Inium feedback shield, the Automatic Feedback Manager will allow a higher feedback limit than previously. Figure 7 shows how the feedback limit is set today in Sensei as compared to how it was set previously with Oticon's earlier anti-feedback system. Across frequencies, this amounts to around a 3 dB broader gain margin. Use Case 2 illustrates the effect hearing loss will have on the gain margin.

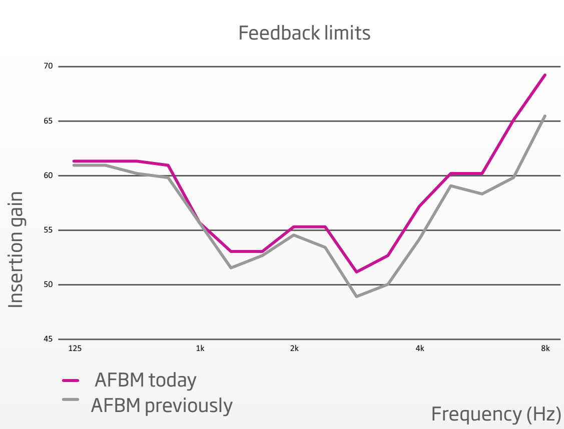


Figure 7. Oticon's new anti-feedback system compared to the previous one. *Feedback limits are shown as a function of frequency. The magenta curve shows how the Automatic Feedback Manager (AFBM) sets the feedback limit with the Inium feedback shield, and the grey curve how it is set for Oticon's previous anti-feedback system.*

It is important to apply an individually measured feedback limit in order to set a trustworthy gain margin. By running the Automatic Feedback Manager and applying the new feedback limit, the actual physical properties of the instrument's coupling to the ear will be factored into the fitting, optimizing the operation of the anti-feedback system.

Conclusion

In the development of the new Oticon Sensei pediatric family of instruments, the focus has been on the needs and challenges of the parents of infants and young children with hearing loss. With SmartFit™ Trainer, a new clinical concept to help parents achieve a proper earmold insertion has been introduced. SmartFit™ Trainer builds on the ongoing effort by audiologists to empower parents to confidently engage in the hearing care of their child.

Fitting instruments to fast growing ears presents a practical challenge when providing amplification to infants and young children. As the ears grow, leakage of sound will increase the risk of feedback and eventually negatively affect audibility and sound quality. In addition, the occurrence of feedback can play an undesirable part in the intimate interaction between parent and child, as close physical contact might be compromised. In essence, the parent and audiologist need to join forces and keep up with earmold remakes and instrument refittings so that feedback issues in turn will be minimal. However, in periods between earmold remakes, the anti-feedback system needs to reduce the occurrence of feedback in an effective way. For this reason Oticon Sensei offers Oticon's newest and most efficient anti-feedback system, Inium feedback shield.

Use Case 2: Effect of hearing loss on gain margin

In essence, the feedback limit sets the maximum insertion gain allowable in the instrument, effectively also defining the fitting range of the instrument. As explained in Use Case 1, the prescribed gain margin is given by the the difference between maximum allowed insertion gain (i.e. the feedback limit) and the insertion gain for soft input levels (45 dB SPL). The figure below displays the impact of two degrees of hearing loss on prescription of gain for soft input levels and consequently the width of the gain margin. It is apparent that as the hearing loss increases the gain margin narrows.

An example of the effect of hearing loss on gain margin. *Different hearing losses require different gain prescriptions, thus affecting the gain margin. The prescribed feedback limit (blue curve) as a function of frequency determines the maximum insertion gain for a given fitting. The soft gain curves for two degrees of hearing loss: 20-40 dB HL (red) and 50-70 dB HL (green) are displayed. The range between the feedback limit curve and the prescribed soft gain curve gives the available gain margin for the fitting. The difference between the blue curve and green curve is smaller than the range between the blue curve and red curve, thus the gain margin (and the ability to give more amplification) is also reduced.*

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People First is our promise
to empower people
to communicate freely,
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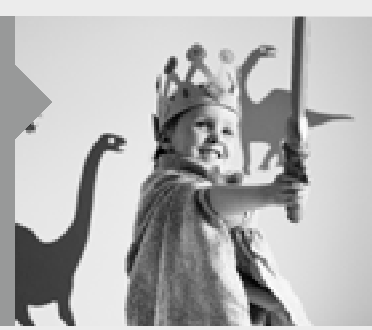
child friendly hearing care

Our pediatric audiological mission is to ensure a better future for every child with hearing loss. We will deliver solutions, tools and techniques that optimize auditory and cognitive habilitation, embrace the complexities of growing up with hearing loss and empower you to adapt solutions to each child's developmental stage on their journey to adulthood.



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