# Opening Ears: The Scientific Basis for an Open Ear Acoustic System

**by Mark C. Flynn, PhD**

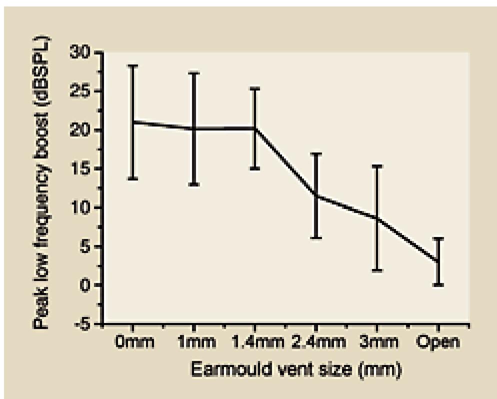
**A technical review on the dynamics of DSP systems using special vented earmolds.**

For users of modern hearing instruments, one of the unexpected disappointments is the distortion of the their own voice (ie, the occlusion effect).[1] There has been much discussion about the origins and effects of occlusion, but the reality remains that there are only two ways to remove the occlusion effect.[2-4]

1. To allow the low frequency sounds to escape via the ear canal through increasing the vent size (ie, open ear acoustics).
2. To create an earmold that completely fills the cartilaginous portion of the external auditory meatus.

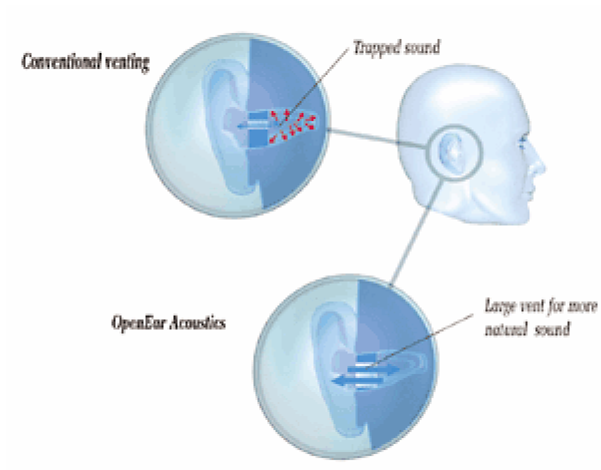
The latter solution is often impractical because it can lead to physical discomfort.[5] Hence, the only method to remove the occlusion effect is through increasing the vent size.

*Figure 1. The increase of the occlusion effect as a function of earmold vent size.*




While hearing instruments offer many benefits, occlusion can be a source of immediate and even lasting annoyance.[1,6] The user's annoyance with occlusion can range from the perceptual—such as the sound of one's own voice, bodily functions (eg, chewing) or an uncomfortable sensation of pressure blockage in the ear—to the physical, such as itching and skin irritation. Any of these perceptions can verge on the unbearable and result in dissatisfaction and rejection of a hearing instrument. Figure 1 shows that, when the ear canal is occluded with an unvented earmold, low frequency sounds can increase by up to 30 dB. We should remember that the magnitude of the occlusion effect varies greatly between people,[3] as the skull shape, size, bone-plate strength, and other qualities vary from person to person.

*Figure 2. Comparison between conventional venting and open ear acoustics system.*




The occlusion effect arises from two sources. The first source is the unvented earmold which traps the user's bone-conducted voice between the occluding earmold of the hearing instrument and the tympanic membrane (Figure 2). This sensation is also apparent with jaw movements (eg, chewing) and when walking/running on hard surfaces. Normally sound waves can escape from the ear canal so they are not perceived. Unfortunately, an unvented earmold results in a build-up of sound pressure in the low frequencies.

The second source of occlusion is the effect of the hearing aid amplifier itself and the amplification of low frequency sounds. The input of the hearing aid at the microphone relative to the speaker's own voice is higher than the conversational partner talking at a normal distance (eg, 1 meter). In this situation, the speaker's own voice is 15 dB-20 dB louder, particularly in the low frequency region. This situation has been labeled ampclusion.[7]

It is possible in advanced hearing instruments to reduce the low frequency gain. This provides some relief from the perception of ampclusion.[8] Systems which decrease low frequency gain reduce the occlusion effect in two ways: 1) They reduce the amplification of low frequency sounds, and 2) The client, through fine tuning, is counseled about the occlusion effect.4 Because ampclusion depends on the insertion gain in the low frequencies, reducing the low frequency gain reduces the occlusion effect. The result on speech recognition of reducing amplification in the very low frequencies (80-500 Hz) will be minimal.[7]

Unfortunately, decreasing the low frequency gain of the hearing aid does not reduce the physiological contribution (eg, own voice, chewing, etc) to occlusion. The optimum solution is one where the contribution of the user's own body and the amplifier-generated sounds are both reduced. It has been recognized for some time that venting is necessary to maximize the user's sound quality rating of their own hearing aid and hence to increase the user's acceptance of their hearing instrument.[9] Research has recommended that the largest vent size possible should be used.[9,10] The traditional constraint to providing increased vent size has been the unwanted side-effect of increased susceptibility to feedback.

**Challenges to Increasing the Vent Size in Earmolds**

An increase in vent size requires a complex method of digital feedback control that can work without decreasing the overall gain of the hearing aid. Unfortunately, the issue is complex; opening up the vent in the earmold brings additional problems, such as increased awareness of signal processing time in addition to needing to compensate for the low frequency sounds that are lost through the open earmold.

1. Short time delay (Digital Processing Time). Unfortunately, digital signal processing (DSP) instruments do not work in absolute “real time”; it takes time for the DSP to act on the signal. Typically, this time period is very short and the user will not notice the slight delay. If the time lag is perceived, however, the sound of the user’s own voice becomes irritating and can lead to lack of acceptance of a device. In the case of binaural fittings, it can even lead to dizziness.

When examining open ear fittings, the issue of time delay becomes even more important. There is an increased possibility that the speech signal will be heard through the vent before the amplified signal is delivered via the receiver, resulting in an objectionable echo. Therefore, as a guideline, any device that has a vent (especially open ear acoustics) should have a digital processing time of less than 10 ms.[11-13]

This “echo sensation” is another reason why some engineers and dispensing professionals may recommend closing the earmold. If the signal is only heard through the instrument, rather than through the vent as well, the echo effect is eradicated at the expense of resolving occlusion. If, on the other hand, we wish to have an effective open fitting, the hearing aid should have an extremely short processing time. Once the signal processing is sufficiently fast enough to ensure no dissatisfaction with listening to both the direct and amplified signal, then the next problem needs to be solved: the well known problem of feedback.

2. Dynamic Feedback Cancellation. Acoustic feedback plays a part in limiting the overall gain of the hearing instrument and determining the vent size before the client complains of audible feedback. As the hearing instrument approaches the threshold of feedback, a ringing or metallic sound quality will be produced. The hearing aid will start to oscillate or howl if the gain is increased beyond this limit. It is crucial that, when providing for a larger vent size, the hearing aid is able to quickly control any resulting feedback without decreasing the gain of the hearing aid or exposing the client to the uncomfortable sensation of feedback.

Digital hearing aids provide a number of different solutions to reduce feedback (eg, notch filtering and feedback management). These strategies have the common feature that they change the characteristics of the hearing aid and reduce the gain at the problematic frequency. While this solution will attenuate the feedback, it will also reduce the speech signal that we want to amplify. Therefore, it is not an ideal solution and, in this situation, the manufacturer will generally recommend reducing the vent size and using the feedback control in the unlikely event of any further feedback. In fact, with modern digital hearing instruments, feedback is even more of a concern because the client often has no volume control and therefore cannot turn down the volume to reduce feedback. This is not ideal if we wish to create a situation where the earmold is opened with a larger vent, increasing the potential for feedback.

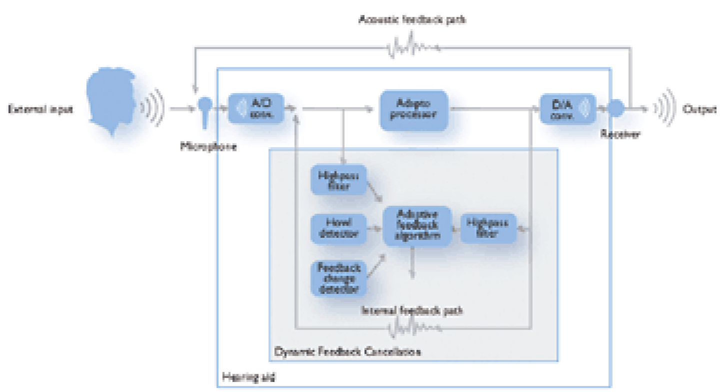



*Figure 3. Schematic of digital feedback control in system.*

Feedback cancellation systems for open ear acoustics should have two characteristics. First, the system requires fast and slow-acting components to allow for rapid identification and elimination of feedback without the noticeable sound quality degradation common in older systems. For example, the Oticon Adapto hearing instrument has a feedback cancellation system that allows the implementation of Open Ear

Acoustics (Figure 3). The feedback control works in one of two modes, whichever is most appropriate for the specific situation. Usually, it functions in the “slow” mode. In this mode, the adaptation of the adaptive filters is very slow, ensuring low power consumption. Whenever feedback occurs, it is immediately detected by the “howl detector” which classifies the signal as being a puretone or not. If it is a tone with certain properties and with a frequency over a certain lower limit, it assumes that the hearing aid is howling and the fast adaptation is then used. The frequency range in which the adaptation takes place is determined by two HF-filters in the signal-processing path. These filters are applied to safeguard against its reacting to an artifact that is not feedback.

Second, the processing time should be fast (<10 ms). When signal processing times are slow and a vent is utilized, dissatisfaction might arise due to the unpleasant mixing of the direct and amplified sounds. A fast processing time allows the mixing of the processed sound with direct sound entering through a large vent without any annoying echo effects that could be experienced in digital systems with longer processing times.

While most modern hearing instruments contain some mechanism of feedback control, the objective of any digital feedback control is to cancel feedback in a way that neither increases processing time nor results in any distortion of the speech signal. In this way the user is not exposed to processing delays and the gain of the hearing instrument is not reduced. Once this situation is acheived, the potential exists for increasing the size of the vent, and therefore opening up the ear canal, reducing the annoying occlusion effect, and preserving the benefits of a more natural hearing system.

3. Low-frequency gain compensation. With a short time delay and digital feedback control, it is possible to provide the client with an open fitting. However, opening the ear canal via a larger vent has consequences in terms of low frequency amplification provided to the client.

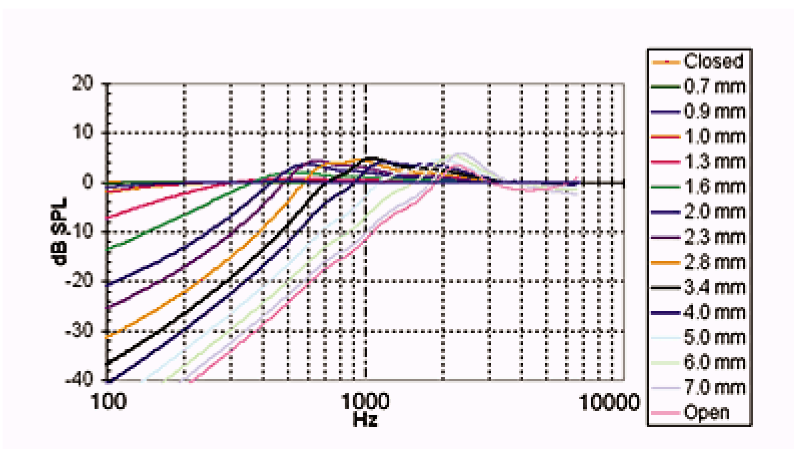



*Figure 4. Amount of leakage from a series of different vent sizes.*

If the earmold is opened, the low frequency energy (<1000 Hz) tends to dissipate, resulting in a loss of low frequency amplification (Figure 4). This reduction can be as great as 30 dB. Often, this is of no consequence—especially when the client has normal or near-normal hearing in the low frequency regions. For people with a more severe hearing loss, a closed earmold is often considered essential to avoid a sensation of “thin” sound. In this situation, the fitting rationale should compensate for the loss of low frequency energy and prevent the hearing aid from sounding excessively tinny due to the increased high frequency emphasis. Clinical trials of Open Ear Acoustics found the best result was to add 50% of compensation for the lost low frequency sounds.[14]

Of course the fitting rationale should determine the ideal vent size for the hearing loss and the amount of compensation required. In this situation, it is imperative that the dispensing professional either uses the ideal vent size or informs the fitting software of the actual vent size so that the appropriate amount of compensation is used. For example, if a 3 mm vent is required, the fitting rationale will increase the low frequency gain; however, if the actual vent size is only 1 mm, then too much low frequency gain will be provided by the software. Given that the low frequency gain is now dependent on the degree of low frequency hearing loss and the vent size, we need to ensure that the fitting software is using the correct vent size. This strategy differs from previous hearing aid fitting strategies and is a part of a more holistic approach to the fitting, where all individual aspects—such as vent size—are part of the gain calculation.

| Own HI Vent (mm) | Adapto vent (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 0.8 | 1.4 | 1.8 | 2.4 | 3.0 | 4.0 |
| No vent | 1 | -- | -- | -- | 2 | -- |
| 0.8 | 1 | 4 | 5 | -- | 4 | 1 |
| 1.4 | -- | -- | -- | -- | -- | 4 |
| 1.8 | -- | -- | 2 | -- | 6 | 2 |
| 2.4 | -- | -- | -- | 1 | 9 | 2 |
| 3.0 | -- | 1 | -- | -- | 1 | 5 |
| 4.0 | -- | -- | -- | -- | 1 | -- |

**TABLE 1.** Matrix of previous ear vent size and the vent size of OpenEar Acoustics implemented in clinical study.

**Clinical Results When Implementing These Concepts**

The above describes a need for a short processing delay, digital feedback control, and subsequent low frequency compensation in open ear fittings, but what are the results of Open Ear Acoustics for the client? As part of a clinical trial, 52 clients were upgraded from a well-fitted advanced digital hearing instrument to the Adapto which implements Open Ear Acoustics.[14] Table 1 shows that 47 of the 52 users obtained an increased vent size. It should be noted that 2 participants were upgraded from a BTE to an ITE instrument, and the larger vent size could not be accommodated. The table shows that open ear acoustics led to an increase in vent size of 85%, or an average vent increase from 1.7 mm to 3.2 mm.

An interesting comparison was made by Schum & Pogash[15] with respect to new users' versus old users' interpretations of open ear acoustics in this study. The new users did not rate the performance of a hearing instrument with open ear acoustics as positively as the experienced users. It was concluded that new users did not appreciate the benefits of open ear acoustics because they had no comparison with traditional technologies that provided the unwanted occlusion effect. Conversely, experienced users responded much more positively because they had experienced the effects of occlusion and greatly appreciated the benefits that open ear acoustics provide. In a follow-up blinded study with three different levels of technology, Schum & Pogash[16] found that, when new users had experiences of an occluding earmold versus open ear acoustics, they rated open ear acoustics just as highly as experienced users on the dimensions of physical comfort and sound quality. Therefore, a user's previous hearing instrument experience will affect their positive ratings of open ear acoustics, but it will not affect the overall satisfaction of open ear acoustics for new and experiences users. Consequently, the OpenEar Acoustics system may result in greater acceptance of hearing instruments by both new and experienced hearing aid users.

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