Remote Microphone Hearing Instruments

Steve Hallenbeck, Au.D.
Srdjan Petrovic, M.Sc.

The pinna carries out an important function by shaping the acoustic properties of sound entering the ear. These modifications serve to enhance the frequencies important for speech understanding as well as provide cues which allow our brain to decode, analyze and orient ourselves in the environment. When hearing is impaired, the natural boost in sounds provided by the pinna is often insufficient to ensure audibility of these essential cues. The obvious solution to this problem is to amplify those frequency regions important for speech perception to restore audibility. Hearing instruments, in general, do a good job of this, but often disrupt the cues provided by the pinna depending on the location of the sound inlet[1,2]. As a result, the altered pinna cues can add to a perception that hearing instruments provide unnatural sound.

In recent years, open fit Behind-The-Ear (BTE) hearing instruments have redefined the hearing instrument industry by providing occlusion relief and reducing the size of the BTE component. These devices have been so well received by hearing aid patients that the percentage of BTE sales relative to custom products has more than doubled between 2004 and 2007[3]. While the implementation of open products has alleviated occlusion, many patients still have an aversion towards BTE hearing aids in general and prefer an In-The-Ear device. The reason for this undoubtedly has many facets but is likely related, at least in part, to difficulties with BTE retention on the ear, wind noise reduction and cosmetic appeal.

Open fit BTE instruments have evolved further to include a new subset of devices known as miniBTEs. Many hearing instrument manufacturers have based this technology upon device component relocation resulting in instruments that place the hearing aid receiver in the ear canal. This design technique has inherent benefits related not only to the size and look of the instrument but also to the acoustic performance of the device. The success of these miniaturized instruments has ushered in a new era of design which implements component placement as a cornerstone of device performance.

Building upon the innovative development of receiver-in-the-ear miniBTEs, a new design technique which places the microphone in the external ear near the concha cymba has been implemented to utilize the natural effects of the pinna, as they relate to directivity, high frequency amplification and wind noise reduction. In addition, the body of the device is placed in the ear canal to improve device retention and cosmetic appeal relative to a BTE. This technique removes the microphone from the body of the instrument. The externalized microphone is housed in a plastic capsule attached to the body of the hearing instrument via thin wires encased in a flexible translucent plastic tube seated in the superior portion of the wearer's concha near the crus of the helix. The remaining components of the hearing instrument, including the battery, microprocessor and the receiver are encased in a plastic housing which sits in the ear canal. This design also allows for venting around the in-the-ear component to provide open comfort similar to that of an open BTE. Initial designs of Remote Microphone (RM) hearing instruments were implemented using an instant fit, one-size-fits all concept. Benefits regarding the amount of gain before feedback related to microphone location were also realized and subsequently implemented in custom hearing instruments utilizing a RM design. In the following pages, the underlying principles which guided the design process of RM hearing instrumentation are reviewed.

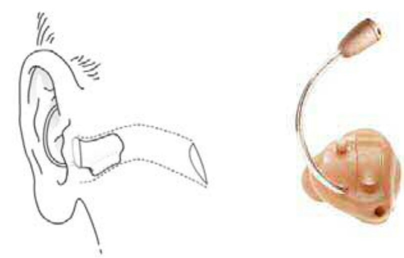

Figure 1: The placement of the microphone in the concha cymba hides the microphone not only for improved cosmetics but also for improved acoustic performance due to pinna effects.

Microphone Location Effect
Prior to reaching the ear, a sound wave interacts with the environment. Absorptions and reflections inherent in any acoustic environment provide amplification or attenuation to certain frequency regions of the sound energy. Even before a sound wave is coded in the cochlea, the structures of the outer and middle ear, as well as the listener's body and head alter the frequency response of the incoming sound. The combined effect of all these reflections adds information to the sound for the listener, providing important cues for localization and lateralization.

This phenomenon becomes extremely important during the design phase of a hearing instrument. It has been shown that when the microphone is placed in the outer ear, typical when using a custom hearing instrument, reflections and diffractions due to the geometry of the pinna result in greater sound pressure at the port of the microphone, especially for high frequencies. By contrast the microphone on a BTE instrument, which sits just above the pinna, receives cues from head and body diffraction with little to no amplification from outer ear resonances[4].

This difference in sound energy as a function of microphone placement is referred to as the microphone location effect (MLE). Table 1 displays the microphone location effects in response to a frontal incident sound[5]. These values were obtained by comparing undisturbed free field responses to responses obtained at the microphone port when seated on the ear. These values demonstrate an increase or decrease of sound pressure level at various frequencies resulting from head, body and pinna related diffractions for BTE, ITE and CIC hearing instruments. According to the table, as the microphone is placed more deeply in the ear canal, the values increase, indicating a greater amount of sound pressure near the microphone port. When applied to the fitting of a hearing instrument, the amplifier gain can be reduced as a function of microphone placement given the natural resonances of the pinna.

Table 1: The Microphone Location Effects from Dillon[5] for frontal incident sound in dB.

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
BTE	-1	0	0	0	3	2	1	1	**2**
ITE	-1	0	1	1	3	5	7	3	**2**
CIC	0	1	1	1	5	8	10	2	-2

The newly designed RM form factors take advantage of the natural gain provided by the location of the microphone. Specifically, the MLE design reduces the necessary amplifier gain and uses the natural gain from the pinna effect. As a result, the physical device can be made smaller, utilize less power and provide open comfort to patients through instant fit RM instruments or through RM custom instruments using large vent configurations. For patients who are in need of more gain, and are not bothered by occlusion, RM custom instruments can be manufactured using minimal venting allowing room for larger more powerful receivers.

Directivity

It is known that the shape and orientation of the pinna provide directivity by enhancing sounds from the front and providing less amplification for sounds originating behind the head[6, 7]. By placing the hearing instrument microphone in the concha the MLE provides enhanced directivity. This placement can improve the perception of signals in the look direction in the presence of noise coming from behind the listener, while using an omnidirectional microphone. The following polar plots, (Figure 2) obtained on the right ear of a KEMAR, demonstrate the broad omnidirectional pattern from a BTE hearing instrument. As the omnidirectional microphone is placed more deeply into the ear, as is the case for In-The-Ear, (ITE) Mini-Canal (MC) and Completely-In-the-Canal (CIC) devices, the omnidirectional response takes on a more directional characteristic. When compared to an instant fit and custom RM instrument the directionality due to pinna effects are maintained. In this example, the null is the greatest for the instant fit RM device with the least pinna effect observed in the BTE. While the directivity of the BTE can be improved to a level similar to the RM instrument by the use of a directional microphone, limitations in directional performance can negate this technology's effectiveness for certain patients.

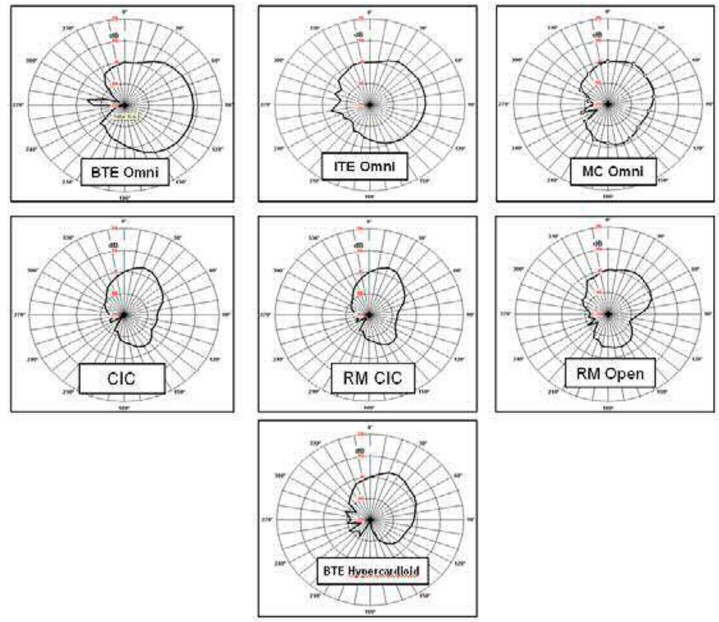

Figure 2: Polar plots Measured at 4000 Hz for instruments using an omnidirectional microphone. As the microphone is placed deeper in the ear, the pinna effect provides some directivity. Although the microphone of RM instruments is not as deep in the canal relative to a traditional CIC, pinna cues are still maintained. A BTE programmed with a fixed hypercardioid directional pattern is provided as a reference for best case directivity.

Wind Noise Reduction

Wind noise is generated from turbulent airflow over any surface. Given that this turbulence is essentially an air pressure fluctuation, hearing aid microphones are susceptible to receiving these wind fluctuations and amplifying them as they would any other sound pressure fluctuation[8]. Several solutions to reduce wind noise, such as the use of wind screens and digital algorithms, have been researched and implemented over the years. The RM design utilizes the physical and acoustic properties of the outer ear to improve performance in wind noise.

When considering the auditory system, the fact that the middle and inner ear structures are placed deeply relative to the pinna provides a level of natural wind noise reduction. Therefore, a deep microphone placement, such as that used in CIC instruments, can reduce the annoyance of wind noise. In situ measurements[9] indicate the greatest amount of wind noise turbulence typically occurs in the areas behind the pinna while little turbulence is measured in the superior portions of the concha. The placement of the microphone behind the cartilage of the helix and concha inherent in the RM design provides a physical barrier protecting the inlet of the microphone from turbulent air flow.

Gain before Feedback

Undoubtedly, one of the most important lessons learned in the development of mini-BTE devices was to think out of the box, or rather out of the hearing aid case, when deciding where hearing aid components should be placed relative to the design. The design concepts implemented for very small cosmetically appealing RIE hearing instruments were made possible once the receiver was relocated in the patient's ear canal. While the initial act of moving the receiver initially provided benefits related to the size of the device, other benefits regarding the amount of available gain before feedback were also achieved. Specifically for RIE technology, the placement of the receiver in the ear canal reduced the transmission of structurally born acoustic energy. While this phenomenon is typically masked in an open configuration[10], it is clearly demonstrable when RIE devices are fit with an occluding earmold. The closed configuration hearing instruments provide a reduction in the mechanical transmission of acoustic energy and may increase the fitting range of a given technology.

The "out of the case" design process utilized in RM hearing instruments builds upon these same concepts. Given that the microphone is placed outside of the hearing aid case in the upper portion of the concha of the outer ear, the same benefits related to gain before feedback possible with closed RIE devices can be achieved using this design. When custom devices are constructed with the receiver and microphone in the same housing, mechanical feedback pathways exist for the structural transmission of sound energy. By removing the microphone from the instrument case, the mechanical feedback pathway is reduced due to the increase in distance between components and decrease in points of contact between microphone, shell and receiver. Similar to RIE devices, the benefits in terms of microphone externalization in RM open configurations will be masked by the direct feedback pathway of sound leaving the ear canal. However, the closed RM configuration reduces the primary acoustic feedback pathway by occluding the ear canal and decreases the transmission of structurally transmitted feedback via external microphone placement. This manifests itself most notably in the closed configurations with no or minimal venting. To that end, a tightly sealed custom shell RM device can provide power comparable to an ITE device in the size of a CIC.

This concept was investigated during the development of RM CIC products. Twenty-six ears were fit with custom RM CIC products and traditional CIC products. The devices were closely matched in terms of the shape, size and the fit of the shell. A measurement of maximum stable gain was obtained by setting the gain handles of the fitting software to a flat level and gradually increasing the gain until the point of feedback. Both the traditional CICs and RM CICs were tested using this technique. A baseline insertion gain measure was obtained to ensure that differences in device calibration did not influence the data. These findings suggest that, on average, one might expect a 9 dB increase in maximum gain before feedback in RM CIC compared to traditional CICs. (Figure 6).

While the increase in gain before feedback is related to the microphone relocation, it was considered that other factors such as the fit of the device and the venting of the device are probably also factors. The data previously presented contains information for various power levels and vent configurations. When these groups are separated into two smaller groups the difference is slightly larger for high power closed configurations and slightly less for lower power devices with larger vents. While some difference between RM CICs and traditional CICs might be expected in devices with large vents, the amount of the difference actually observed was somewhat unexpected and not readily explained.

To reduce variability due to fit suspected to influence the differences between RM CIC and traditional CICs measured on real ears, a second experiment was completed using a device made for a KEMAR with 2 microphones. One of the microphones was located in a position typical for standard CIC instruments. The other microphone was placed in a position consistent with the design of the RM CIC. These 2 microphones could be switched off and on using development software without disturbing the placement of the instrument in the KEMAR ear. Devices were constructed with a variety of vent sizes. Results from this laboratory test consistently demonstrated that the RM position provided more gain before feedback in comparison to traditional microphone location. It is also interesting to note that as vent size increased, the amount of available gain before feedback decreased.

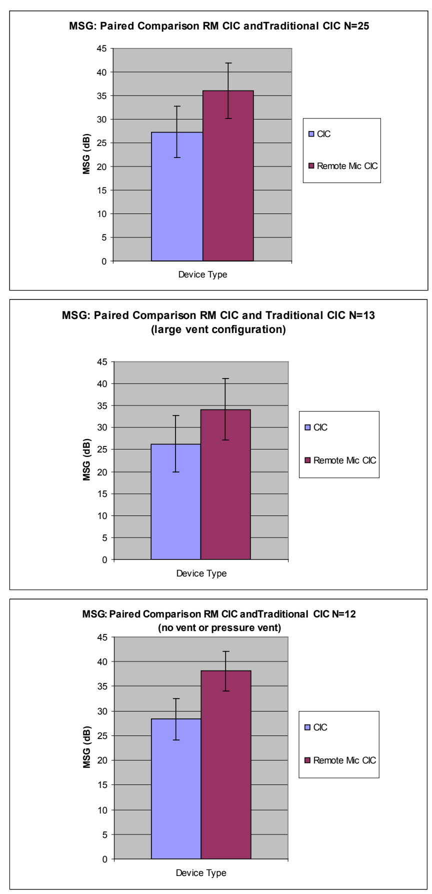

Figure 6: Comparison of the amount of gain before feedback between traditional CICs and RM CICs measured in real ears. Secondary graphs are grouped based upon power level and venting.

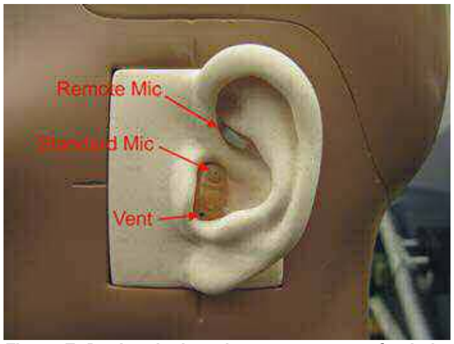

Figure 7: Device designed to test amount of gain before feedback controlling for the effect of fit and venting.

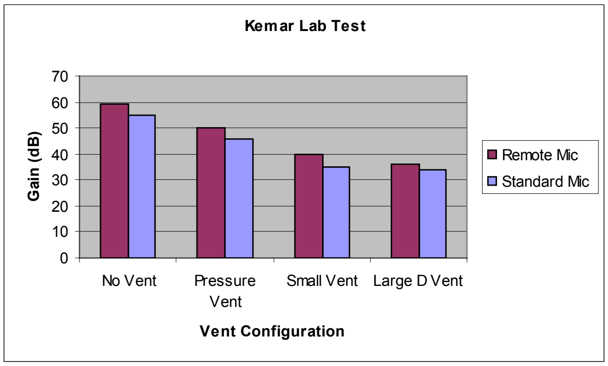

Figure 8: Results comparing the amount of gain before feedback as it relates to microphone location.

Conclusion

RM hearing instruments provide a myriad of benefits to a wide range of hearing-impaired patients. These benefits include decreased wind noise, improved cosmetic appeal and directivity based upon pinna effects. Additionally, design characteristics due to receiver placement facilitate the device fitting for clinicians.

References

1. Franks JR, Feth LL, Daniloff RG. Hearing aid microphone location effects on speech discrimination in noise. *Ear and Hearing.* 1981; 2(6):241-50.
2. Gartrell EL, Church GT. Effect of microphone location in ITE versus BTE hearing aids. *Journal of the American Academy of Audiology.* 1990; 1(3):151-3.
3. Hallenbeck SA. The Mighty Mini. *Advance for Audiologists.* 2008; 10 (5) 41-47.
4. Bentler RA, Pavlovic CV. Transfer Functions and Correction Factors Used in Hearing Aid Evaluation and Research. *Ear and Hearing.* 1989; 10, 58-63.
5. Dillon H, *Hearing Aids.* Thieme: New York; 2001.
6. Wightman, F., & Kistler, D.. Headphone simulation of free-field listening, I: Stimulus synthesis. *Journal of the Acoustical Society of America.* 1989a; 85: 858-867.
7. Wightman, F., & Kistler, D. Headphone simulation of free-field listening, II: Psychophysical validation. *Journal of the Acoustical Society of America.* 1989b; 85: 868-878.
8. Kates, J. *Digital Hearing Aids.* San Diego: Plural Publishing; 2008.
9. Dillon H, Roe I, Katch R. Wind noise in hearing aids: mechanisms and measurements. National Acoustics Labs Australia: Report to Danavox, Phonak, Oticon and Widex, January 13 1999.
10. Hallenbeck SA, Groth J. Thin-Tube and Receiver-In-Canal devices, Positive Feedback on Both! *Hearing Journal.* 2008; 61: 28-34.