Frequency response control of hearing aids is achieved by electrical control in the hearing aid or, more commonly, by the coupler system, which includes the earmold, the tubing and the earhook. The earmolds and tubing have received the majority of coverage by researchers and reporters. This article concentrates on special earhook designs.

Response-Modifying Earhooks For Special Fitting Problems

By Mead C. Killion, Ph.D. and Donald L. Wilson

SPECIAL EARHOOK designs can be used to modify the frequency response of a hearing aid. Existing designs include the "high pass" earhook[5] with a small hole near the tip, Bergenstoff's "E-Hook" earhook[6] with a small plastic insert, and the "KBASS earhook" with two filter chambers.

There are three newly designed earhooks to be used with hard-to-fit clients:

1. A KBASS earhook that by itself provides the same low-pass response that had previously been obtained only with the help of internal modifications to the hearing aid circuitry and plumbing.
2. A 2-kHz notch-filter earhook that, when used with a conventional earmold, provides the equivalent of Macrae's special notch-filter earmold.
3. A high-pass earhook that, when used with Lybarger's dual-diameter open-canal earmold, provides a more effective suppression of output below 3 kHz.

This article describes these new earhooks and their application. Also included is a summary of some surprising results from recent experiments on feedback in open-canal fittings: The optimum tube insertion depth is quite different for low-frequency and high-frequency fittings.

The Revised KBASS Earhook

A year ago we reported on a new low-frequency emphasis, open-canal hearing aid somewhat whimsically called the "KBASS" (*K*illion-Berlin *B*ass *A*mplified unob*S*tructed *S*ound) hearing aid.[1] Since that time, 68 such aids have been supplied on a 60 day trial basis for those rare individuals with normal or near-normal high-frequency hearing but 40-65 dB of low-frequency sensorineural hearing loss. Of these, 52 aids (76%) have been accepted as providing useful hearing assistance and 16 aids (24%) have been returned.

The success rate with this especially difficult-to-fit type of loss is good, but the high cost of the KBASS hearing aids as we had been producing them meant that binaural candidates often chose to use only one aid.

Original attempts to obtain the proper frequency response with only earhook modifications were blocked by the difficulty of including 3 inches (75mm) of tubing plus a damper and two filter chambers inside an earhook. After a year of making KBASS aids the hard way, and after some 75 computer simulations and a dozen or so experimental earhooks, we finally realized what should have been obvious much sooner; We could eliminate the damper and reduce the 75mm of tubing to a very short length by changing to a small enough tube diameter.

(The acoustic mass varies inversely with the square of the tubing diameter, while the resistance varies inversely with the fourth power of the diameter, so when wavelength resonances are not required a smaller-diameter short tube can often replace the combination of a larger-diameter long tube and a separate damping resistance. In the case of a low-pass filter, the normally troublesome frequency dependence of the resistance of a tube turns into a bonus: The acoustic resistance is proportional to the square root of the frequency at high frequencies, which assists in rolling off the highs.)

Figure 1 shows a prototype of the new earhook in place on a BTE hearing aid.

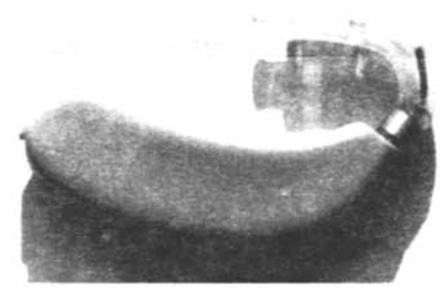


Figure 1. Prototype KBASS earhook on BTE hearing aid.

Figure 2 shows the SSPL-90 and frequency response of two versions of the KBASS hearing aid. The solid curve shows the original version, which used a modified Zenetron ZP-70 hearing aid with the earhook described last year. The dashed curves show the response

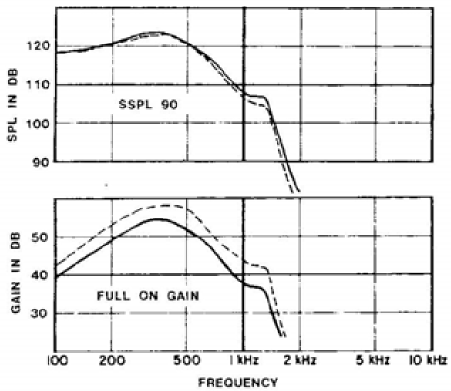


Figure 2. Comparison of 2cc coupler measurements.:
(——) original KBASS aid
(– – –) new change-earhook-only version

with the new earhook added to an *unmodified* ZP-70. The only disadvantage to the new approach is that we no longer reduce the gain by internal modification to prevent oscillatory feedback at full-on gain in a typical open-canal fitting, so the user must be a little more careful of the volume control setting.

An advantage is that a similar response was obtained when we tried the new earhook with a ZP-78 compression power aid (and would presumably obtain a roughly similar response with any high power hearing aid that can be adjusted to provide low frequency emphasis), solving a year-old frustration in trying to find a compression aid with enough room in the case to allow us to make an input-compression version of the KBASS hearing aid. The most important advantage, of course, is the reduced cost.

The Notch-Filter Earhook

Two years ago John Macrae of Australia described another type of hearing loss that he said "may occur too rarely to justify the production of a model of hearing aid designed especially for it." The person in this case had normal hearing in a narrow frequency band centered at 2000 Hz, with a mild to moderate loss at other frequencies.

Macrae went on to describe an acoustic notch filter that could be incorporated into a special earmold that used an ITE shell to house the filter components. We have recommended this earmold in several cases where the initial inquiry was about a KBASS hearing aid, but where the region of normal or near-normal hearing was so narrow that both low- and high-frequency amplification seemed advisable. (By design, the KBASS aid provides only low-frequency amplification, leaving the normal open-canal high-frequency hearing unaffected.)

While working on the new KBASS earhook, we realized that the acoustic volume we were using in that earhook should permit the construction of a notch filter similar to the Helmholtz resonator version described by Macrae. Figure 3 shows the frequency response of the ZP-78 BTE hearing aid measured under two conditions: with the regular earhook combined with a closed earmold consisting of 43mm of #13 tubing (solid curve), and with the new notch-filter earhook and the same earmold (dashed curve). The results are similar to those shown by Macrae.

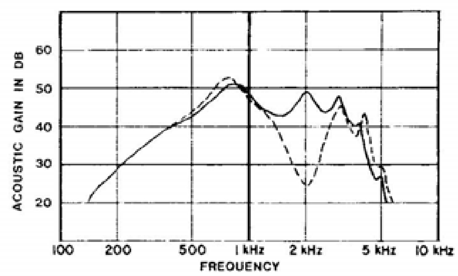


Figure 3. 2cc coupler response of power aid with:
(——) standard earhook
(– – –) notch-filter earhook

The advantage of the special earhook in this case is that it can be kept on hand and used with any conventional earmold (or a foam-earplug trial earmold). A custom earmold does not have to be fabricated before an evaluation is performed.

The High-Pass Earhook

Five years ago Sam Lybarger described a dual-diameter earmold system "especially effective for open canal fittings on persons whose hearing remains fairly normal up to 1500 or 2000 Hz and then drops off markedly." As he pointed out, "the usual open-canal fitting, even using #16 tubing, gives too much amplification in the middle frequencies in such cases."[3] I have tried the Lybarger earmold with a high-pass hearing aid on a friend with normal hearing thru 2 kHz, a 30 dB loss at 3 kHz, 35 dB at 4 kHz, and 45 dB at 6 kHz, and have confirmed Lybarger's observations with KEMAR measurements. The improvement in insertion gain with the Lybarger earmold compared to a "Killion 6EF earmold" is shown in Figure 4. (Libby's acoustically equivalent "3mm horn" was used for the comparison.)

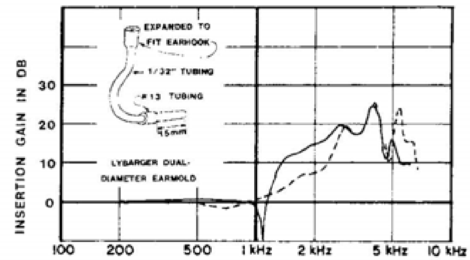


Figure 4. Insertion gain (KEMAR) of open canal fitting of high frequency emphasis BTE hearing aid with:
(——) 3mm Libby horn
(– – –) Lybarger dual-diameter earmold

Although the Lybarger dual-diameter earmold made possible a response I didn't know how to get any other way, there was still a bit too much gain at 2000 Hz. Even with the addition of a piece of #20 tubing in the earhook, I was unable to reduce the insertion gain measured at 2 kHz on KEMAR to less than 5-8 dB when the volume control was set for 25 dB gain at 4 kHz. This led to a third earhook design, which provided additional attenuation below 3 kHz when used with the Lybarger earmold.

Figure 5 shows the 2cc coupler response of a simulated wideband hearing aid (using the Knowles ED-series receiver) measured with the new high-pass earhook plus a Lybarger dual-diameter earmold, compared to the aid's response with a conventional earmold. Note that in an open-canal fitting the response below 1 kHz would be attenuated well below the natural sound entering the ear canal, so that no amplifica-

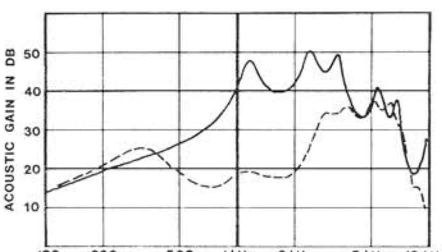


Figure 5. 2cc coupler response of simulated wideband BTE hearing aid with:
(——) Regular earhook and conventional earmold
(– – –) High pass earhook and Lybarger earmold

tion would be heard below 2 kHz. With this earhook and the Lybarger earmold in an open canal fitting, a wideband hearing aid becomes a high pass aid with little output below 3 kHz.

The high-pass earhook may also prove useful in fittings where a closed mold with minimal venting is used. The calculated insertion gain for the 2cc coupler response of Figure 5 is shown in Figure 6. To the best of our knowledge, that amount of high frequency boost above 2 kHz is not otherwise available in current hearing aids.

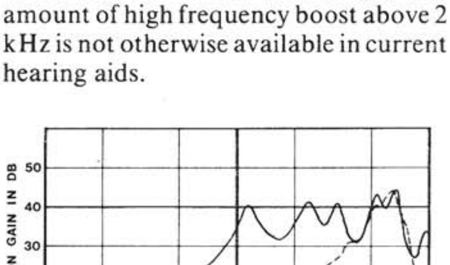


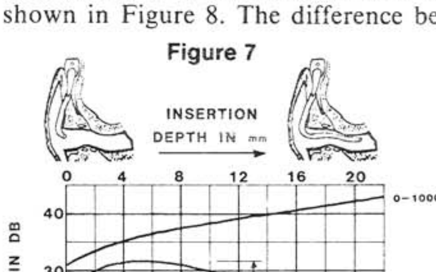
Figure 6. Insertion gain of simulated wideband BTE hearing aid with two minimally vented earmolds:
(——) Regular earhook and conventional earmold
(– – –) High pass earhook and Lybarger earmold

Other Considerations for KBASS and High-Pass (Open-Canal) Fittings

During the earlier measurements of the high-pass hearing aid, an unexpected result was observed: The deeper I inserted the earmold tubing in my open ear, the more trouble I seemed to have obtaining much gain before the aid whistled. This led to a series of experiments reported last fall, and results that can be summarized as follows: For maximum gain before feedback at *low* frequencies (as in a KBASS fitting), the tubing should be inserted as deeply as is comfortable. For maximum gain before feedback at *high* frequencies (3 kHz and above), on the other hand, a *shallow* insertion is better, with 4 to 8 mm (roughly ¼ inch) being about optimum.

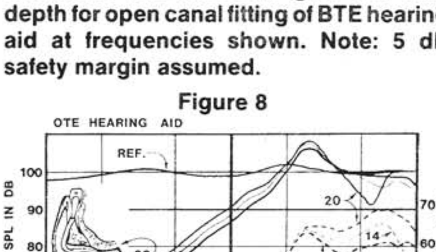
Figure 7 shows a graphical summary of a series of measurements such as shown in Figure 8. The difference between the *eardrum* pressure produced by a hearing aid and the *vent leakage* pressure that gets back to the hearing-aid microphone determines the maximum gain that can be obtained before oscillation occurs. The measurements shown in Figure 8 are similar to those reported by Lybarger in 1975,[4] except that an ER-2 insert earphone was used to simulate the hearing-aid output, and an Etymotic Research ER-7 probe microphone system was located either at the eardrum position of a KEMAR manikin or at the microphone inlet of a BTE hearing aid mounted on the manikin. Thus the mesaurements shown here extend out to 10 kHz.

Figure 7



Maximum safe insertion gain vs. tube depth for open canal fitting of BTE hearing aid at frequencies shown. Note: 5 dB safety margin assumed.

Figure 8



Vent response (——) and feedback SPL at hearing aid microphone (- - -) for three tube insertion depths.

Summary

Several new acoustical devices have been described. Each opens up fitting possitilities that did not exist or were more costly in the past. Earhooks to produce other hearing aid frequency responses are being considered.

Acknowledgements

A well argued phone call from Roy Sullivan supplied part of the impetus to try again on the KBASS earhook. Jon Stewart assisted us with the other two earhooks.

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Mead Killion is an Adjunct Professor of Audiology at Northwestern University and President of Etymotic Research in Elk Grove Village, Illinois. He has spent 21 years in the hearing aid industry and is probably best known for developing earmold coupling systems to improve the useful bandwidth and the sound quality of hearing aids. He has been granted eight U.S. patents.

Don Wilson is presently finishing a Bachelors of Science degree in Electronics Engineering Technology at DeVry Institute of Technology, Chicago. He has had primary responsibility for computer simulation and mechanical design of the new earhook.