EARMOLD DESIGN: THEORY AND PRACTICE

Mead C. Killion

ETYMOTIC RESEARCH
61 Martin Lane
Elk Grove Village, Illinois   60007
USA

ABSTRACT

The sound channel in the earmold has a suprisingly large effect on both the real-ear and the coupler response of a BTE hearing aid at high frequencies. Audible demonstrations, both live and pre-recorded, dramatize the effect of the horn cutoff frequency, quarter-wave resonance frequencies, and the amount of increase or decrease in SPL produced above the cutoff frequency by the combination of horn action and quarter-wave resonances. Three simple mathematical formulae predict these effects quite well, and the application of these formulae to some intentional and unintentional BTE earmold constructions provides an illustration of their use.

INTRODUCTION

When Stig Dalsgaard told me he wanted me to speak about earmolds I was both honored and puzzled, because   speaking about earmolds at the Danavox symposium struck me as similar to bringing fish to Denmark: Many of the classic papers on real ear earmold acoustics have come out of this Symposium. I could not disagree with his reply, however, that despite the wealth of available information, the sound channels in all too many earmolds were still carelessly specified and/or fabricated. The consequence is that many hearing aid wearers are obtaining much less help from their hearing aids than they should be. So after

briefly summarizing the dramatic way in which the ear mold controls the <u>entire</u> frequency response of the hearing aid, I will concentrate on the high-frequency effect of earmold modifications.
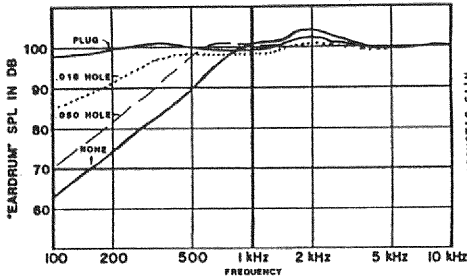

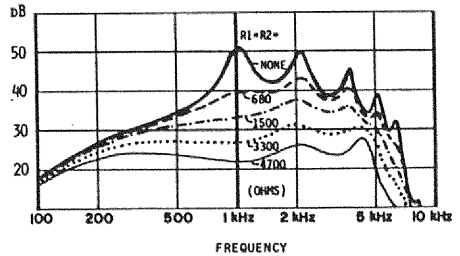Figure 1. Effect of "SAV" insert on low-frequency response of hearing aid.

Figure 2. Effect of damping on mid-frequency response of hearing aid (from Killion, 1981)

Figures 1 thru 3 illustrate the low-frequency, mid-frequency, and high-frequency control these earmold constructions have over the frequency response of a behind the ear (BTE) hearing aid. In the illustrated examples, this control can be obtained right in the dispensing office with almost as much ease as adjusting the bass and treble controls on a high fidelity amplifier. All of the variations shown were obtained with an on-the-spot change of inserts or dampers. The earmold constructions that permit this flexibility are described in the sections below.

VENTING

The curves in Figure 1 are what Sam Lybarger has called the "vent response" curves (Lybarger, 1980). They show the large amount of change you can obtain at low frequencies if the earmold has been properly prepared for "SAV" inserts. "Properly prepared" in this case means that the vent channel itself is short enough and fat enough so that the vent response will be

controlled by the hole in the selected SAV insert rather than by the vent channel itself. For the curves of Figure 1, the short, fat vent was 3 mm in diameter and only 5 mm long.
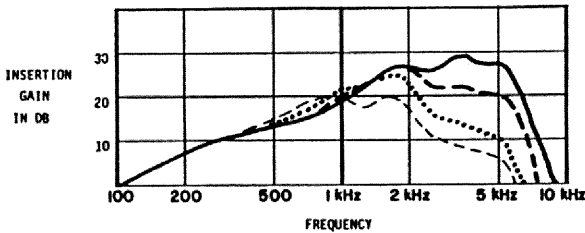

Figure 3. Effect of "Select-A-Boost" inserts on high frequency response of hearing aid (From Killion, 1984).

If, on the other hand, the vent channel is long and thin, then changing from one SAV insert to another will make little difference: all curves will look similar to the one labeled ".018 hole" in Figure 1. The same considerations apply to the "PVV" type of insert, of course.

DAMPING

Placing some damping in the earmold tubing to smooth the frequency response or reduce the maximum output of a hearing aid was a common method employed by the more sophisticated dispensers even when the only readily available damping material was wool from a sweater. Quite similar results, with improved predictibility, can now be obtained with the Knowles fused-mesh dampers which are available in resistances of 330, 680, 1000, 1500, 2200, 3300, and 4700 cgs acoustical Ohms.

Figure 2 shows the effect of increasing resistance, using

either a long piece of wool yarn or a pair of appropriately spaced dampers. Note that the first result is a smoothing of all response peaks, followed by a broad-band reduction in overall output.

The problem with placing dampers in the tubing itself is that the very warm, moist air found in some earcanals will often condense on the cooler tubing walls and damper elements, much as droplets of water collect on a cold can of beer on a warm damp day.

Moisture is much less of a problem with the dampers in the earhook ("tone hook"); it is nestled over the ear and tends to stay warm. Most BTE hearing aids are now available with damped earhooks, so the use of dampers to smooth the response is pretty much taken care of by the manufacturer. The higher values of resistance can still come in handy to reduce the maximum output of an "overfit" BTE hearing aid, however, and the dampers can often be installed in the earhook: One located at the tip and another located at the threaded end will generally give the smoothest response. A simultaneous reduction of 15 dB or more in gain and maximum output may be obtained in this way.

"HORN EFFECT"

Figure 3 shows the roughly 20 dB range of treble-boost control afforded in a BTE earmold using what we can loosely call the "horn effect", a term I will use to include the effect of quarter-wave resonances formed in the earmold sound channel.

I brought two examples of simple horns (see Figure 4). These are the true "Killion horns", made up of increasing diameter sections of tubing coupled together, starting with a 1 mm diameter tube and ending with a 40 mm diameter section of pipe. This construction was intentionally chosen to illustrate that a horn doesn't have to be shiny and goldplated and look as though it belonged in the symphony in order to work. All that is required to get horn action is that you start small and increase the tubing diameter gradually until you get to the size you want. How do you determine how big to go? To answer that, we need to know a little about how a horn works.
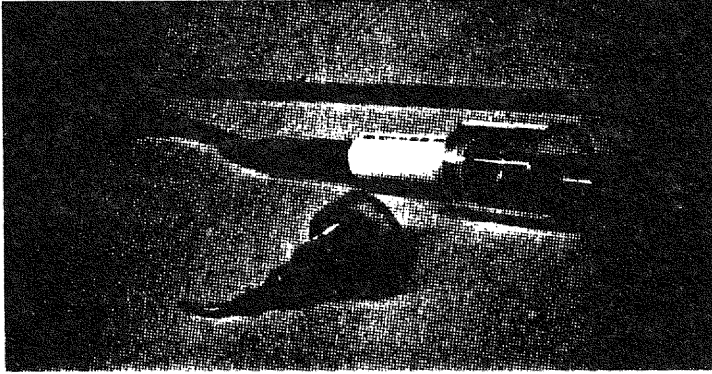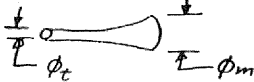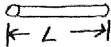
Figure 4. Stepped-diameter horns providing 25 to 30 dB of gain for hearing aid earphone acting as a loudspeaker.

Formula 1.   Gain $(P_m/P_t) = \emptyset_m/\emptyset_t$ (Pressures and diameters at mouth & throat)

Formula 2.   Cutoff frequency $f_c = 120/DDD$ (kHz, mm)

DDD is Diameter Doubling Distance

Formula 3.   Quarter-wave frequency $f_{1/4} = 86/L$ (kHz, mm)

L is Length from open end back to beginning or to partial wall (at diameter change).

or   Also: $f_{3/4} = 3*f_{1/4}$; $f_{5/4} = 5*f_{1/4}$; etc.

Pressure Gain

The pressure gain of a horn is simply the ratio of the diameter of the mouth to the diameter of the throat. In the case of the long horn, where we start with a one millimeter tube at the throat and end with a 40 millimeter mouth opening, we can expect a gain of 40/1 = 40, or approximately 32 dB. I

once measured the gain of this horn operating on output of a hearing aid earphone radiating into the open air, and obtained a figure of 25-28dB. (In practice, a certain amount of loss can be expected in any horn.)

The gain of this horn above its cutoff frequency is easily demonstrated in a large lecture room using a hearing aid receiver (earphone) such as the Knowles CI-1955 connected to the output of a tape recorder. Even though this is the most powerful of the Knowles receivers, and will produce some 140 dB SPL at the eardrum with a closed earmold, the amount of sound it can produce by itself in a large room is almost inaudible because the distance its small diaphragm can move is only about the thickness of a human hair. The addition of a horn, however, makes its output quite audible.

The almost magical operation of the horn in this case (it has no moving parts!) comes about because the CI-1955 receiver can produce enough sound power to fill the room, but it is so badly mismatched in impedance that it can't deliver the power. Most of you have experienced an exactly comparable situation riding a ten speed bicycle and trying to go fast in 1st gear. No matter how hard you pedal you can't go very fast. Your legs have plenty of strength for the task but you can't get them moving fast enough; you can't get enough velocity out of your legs. The solution of course is to shift into high gear, where the mechanical impedance transformation of the gears produces a better match between your legs and the load, taking more force but less motion from your legs for a given bicycle velocity.

A horn is simply an acoustic impedance transformer that can produce a better match between a high-acoustic-impedance source (in this case the hearing aid receiver) and a low-acoustic-impedance load (the soft air in a lecture hall or in an earcanal). It is an acoustic lever.

The "throat" and "mouth" of a horn are named after one of the acoustic horns we are born with: The one from our throat to our mouth. The other one (for each ear) is formed by the pinna, concha, and earcanal. In each case, greater sound power is delivered to the load because the horn is hooked up correctly: The small end, the throat of the horn, is connected to the high impedance (vocal cords as source or eardrum as load) while the large end, the mouth of the horn, is connected to the low impedance (air in the sound field).

What if we hook a horn up backwards? Any good transformer works both ways.   Just as turning the binoculars around and looking through the   wrong end of them makes things look smaller,   so also using a horn backwards will cause a drop in output instead of a boost in output above the cutoff frequency. In earmold construction, such a reverse horn is obtained by inserting a smaller section of tubing near the eartip.   This explains the treble cut curves in Figure 3, which use small inserts to effectively choke off the highs above the cutoff frequency.

Cutoff Frequency

The second thing we need to know about a horn is the characteristic that determines its cutoff frequency, which is the frequency below which the horn action starts to lose effect. Below the cutoff frequency, horn action drops to no gain, while above the cutoff frequency the horn gives roughly the gain predicted by Formula 1.   Similarly, the reverse horn produces a drop in output only above its cutoff frequency; below that frequency it has little effect (no loss).

The cutoff frequency of a horn is determined by what is called the "rate of flare", the rate at which the diameter increases with distance along the length of the horn.   Formula 2 gives a simple approximation for the cutoff frequency of a horn: 120 divided by the average distance over which the diameter doubles, which I call the "Diameter Doubling Distance" DDD.   To give an example, the long horn in Figure 4 works as well as it does over a reasonably wide band of frequencies because it is fairly long in relation to its throat diameter, nearly one meter or 1000 mm.   From a starting diameter of one millimeter, after a certain distance the diameter becomes two millimeters, or double the diameter.   A little bit farther along it gets to four millimeters, a second doubling in diameter.   Continuing, it gets to eight millimeters (three doublings),   then 16 mm (four doublings), 32 mm (five doublings) and finally finishes at a diameter of 40 mm.   The diamater doubles a little over 5 times over the roughly 1000 mm length of the horn, which gives an average diameter doubling distance of a little under 1000/5 = 200 mm.   From Formula 2, we would expect a cutoff frequency of 120/200 = .6 kHz, or 600 Hz, above which nearly the full gain of the horn could be expected and is obtained.

The other horn shown in Figure 4 is a short horn,

constructed so that each section has the same diameter but 1/5
the length of the long horn. If you think in terms of the rate
of flare, the short horn has a 5 times more rapid rate of flare.
Similarly the DDD, the diameter doubling distance, is only 1/5
as large, or about 40 mm. The cutoff frequency for the short
horn, therefore, would be about 120/40 = 3 kHz. As can be
readily heard when coupled to the CI-1955 receiver in
demonstration, the short horn has a tinny sound (even though it
is made mostly from plastic tubing) because its roughly 30 dB of
boost is restricted to the region above 3 kHz.

This latter design is quite similar to the one in BTE
hearing aids, where the total sound channel from the receiver to
the eartip is roughly 80 mm, and going from the typical 1 mm
diameter receiver tube to a 4 mm "horn" earmold gives two
diameter doublings in 80 mm, or DDD = 40 mm.   The resulting
cutoff frequency of 3 kHz represents a typical result for BTE
hearing aid earmolds: The horn effect can produce about 6 dB
gain in output (compared to a 2 mm constant-diameter earmold
sound channel), but only above about 3 kHz.

One final example may be useful.   A friend of mine
published a paper on ITE hearing aids in which he reported the
failure of "Killion's horn techniques" to provide any
measurable improvement in the output of the ITE aid. The reason
for the failure became obvious after we calculated the expected
cutoff frequency of his experimental devices.   He had tapered
the sound channel from the 1 mm tubing out to a 4 mm "bell"
mouth at the eartip over a total distance of about 8 mm. Two
doublings in diameter in 8 mm gives one doubling in 4 mm (DDD =
4 mm), and a cutoff frequency of 120/4 = 30 kHz!   The horn
effect presumably worked beautifully above 30 kHz, where it
undoubtably gave the expected 12 dB gain ($\emptyset_m/\emptyset_t = 4/1 = 4$ from

Formula 1).   The only problem was that he didn't measure the
hearing aid at a high enough frequency!

From a practical standpoint it is difficult, in an ITE aid,
to use horn action to obtain more than a couple of dB of gain
below 6 kHz or so without coiling some tubing up inside the aid.
If you are interested in extending the bandwidth of ITE hearing
aids out to 16 kHz, however, as I am, you can use a combination
of horn action and the quarter-wave resonance boost described in
the next section to provide a very nice assist above 8 kHz.
Such a combination will be included in the high-fidelity hearing
aid design we plan to recommend to customers of our new, soon-

to-be-in-production high fidelity hearing aid amplifier circuit.
With a full 16 kHz bandwidth and low distortion, no one need
apologize about advertising such a hearing aid as "high
fidelity". (Besides which, it sounds better.)

RESONANCE

    If you connect a high impedance source to a low impedance
load through a piece of tubing, and don't use any damping,
you'll find peaks in the transmission such as shown in Figure 5.
Those resonances are caused by standing waves set up between the
ends of the tube. With one end open and the other end blocked,
resonance occurs at frequencies where the tubing length equals
an odd multiple of a quarter wavelength. This is the case of
interest to us, because the volume of air in the earcanal
presents a relatively low impedance to any practical hearing aid
tubing, so the earcanal end of the tube is effectively "open",
while the high acoustic impedance of the miniature hearing aid
receiver effectively blocks the other end. Formula 3 gives the
frequency of the first quarter-wave resonance, and also of the
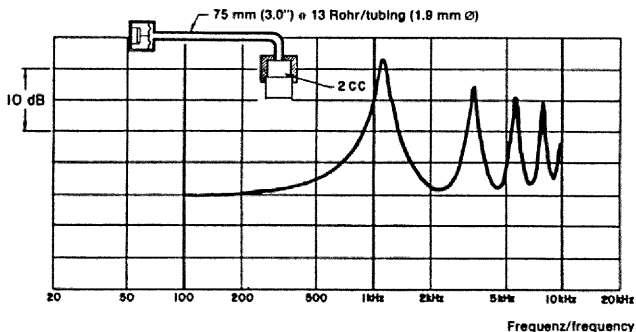third (3/4-wavelength) and fifth (5/4-wavelength).

Figure 5.   Resonances in tubing coupling an
idealized hearing aid receiver (no resonance below
20 kHz) to a 2cc coupler thru 75 mm of 1.93 mm
tubing.   (From Knowles & Killion, 1978)

    In the case of the typical BTE hearing aid the total
distance from the receiver to the eartip is usually 70 to 80
millimeters.   In the 75-mm example of Figure 5, the first

resonance should occur at 86 divided by 75, or about 1.1 kHz. The 3/4-wavelength resonance should occur at 3 times that frequency, or about 3.3 kHz. The 5/4 resonance should occur at roughly 5.5 kHz, etc. (If you do the arithmetic carefully, the numbers are 1.15, 3.44, and 5.73, but if you are going to be that careful you need to take into account the fact that sound travels a little slower in a tube than in free space, the fact that if a horn coupling is used the first-quarter-wave resonance will appear at a higher-than-expected frequency, and the fact that the acoustic impedance hooked to each end of the tube will affect the resonance frequencies somewhat. The numbers obtained from Formula 3 are simply good first approximations.)

Damping the bad peak

If you don't see a prominant peak near 1 kHz in the response of a BTE hearing aid, it is because the manufacturer has abandonded the "numbers game" (sometimes jokingly referred to as the "horsepower race") and mercifully damped that peak. Although damping the peak will reduce the HF-average gain and SSPL-90 specifications on the data sheet by about 5 dB, it has several advantages for the user. I'm sure they are all familiar to everyone here, but since my assignment was to repeat what you already know about earmold acoustics for reinforcement, lets review them.

Damping smooths the frequency response, which makes the hearing aid sound better. That is not so bad.

Damping allows more broadband gain without feedback: If you encounter a hearing aid that is whistling and you find out where it's whistling, it is always at a peak in the response. (Even internal mechanical feedback will show up as a peak in the response as the whistling condition is approached.)

A more subtle advantage of damping is that it increases the dynamic range of acceptable sounds for the user. If you have a large peak in the hearing aid frequency response, each time one of the wearer's own vowel formants coincides with that frequency it bangs him on the head with an unexpectedly loud sound and he's likely to turn the gain down. (In most cases, the wearer's own voice will be the most intense sound arriving at the hearing aid microphone.) Edgar Villchur has prepared an excellent recorded simulation (played for the Symposium participants) of the problems of recruitment acting alone and recruitment combined with a peak in the hearing aid frequency response at

1.5 kHz where most ITE aids once had their maximum peak.   The
strong peak exacerbates the problem;   the hearing aid sounds as
if it contains an __expander__ instead of a compressor circuit.
That is not so good.

But a gentle peak can be a good thing
Tubing resonance can be put to good use under some
circumstances, however -- most often to increase the high
frequency output of the hearing aid.   Used in moderation, and
combined with horn action to fill in the valleys, resonance can
be an asset rather than a liability.

The second sketch next to Formula 3 shows a condition in
which a   potentially useful secondary resonance occurs: a
standing wave is set up between the open end of the tube and the
partial wall formed at the junction of the small tube and the
large tube.   If the inside diameter of the small tube is
extremely small, the partial wall is nearly a complete block,
and a full resonance peak will be developed.   In the more common
case where the inside diameter of the small tube is a
significant fraction of inside diameter of the large tube, a
gentler peak is developed.   In any case, the peak occurs at the
frequency at which the distance from the partial wall to the
open end is equal to 1/4 wavelength (and 3/4, 5/4, etc.,
although the latter resonances will often be above the passband
of the hearing aid).

HORNS AND RESONANCE COMBINED

In practice, it is sometimes difficult to decide how much
of the high frequency boost obtained in a stepped-diameter
"horn" earmold is caused by horn action and how much is caused
by a resonance boost.   Experimentally, the length of the large
tube   required for good horn action in such an earmold will
generally also create a quarter-wave resonance at a frequency
not too far from the calculated cutoff frequency of the horn.
With Formula 3 in mind, however, the length of the final section
(or sections) can be chosen to place the quarter-wave (and
perhaps 3/4-wave) resonance where it is most needed, to fill in
a valley in the overall response or boost the response at a
particular frequency.

By the same token, simply pulling the tubing back 6 mm from
the tip of a BTE earmold will generally not provide much

improvement. In this case, L = 6 mm in Formula 3, so the
frequency of the first partial resonance will be 86/6 = 14.3
kHz, which is above the passband of most hearing aids. Only a
small amount of horn action will be obtained in this example,
even though the 3-mm diameter of the resulting 6-mm length would
predict a roughly 4 dB increase (by Formula 1, 3mm/2mm = 1.5).

On the other hand, the 22 mm length of 3 mm diameter
"earmold simulation" that is included in the standard 2cc
coupler measurements provides a substantial boost in the
response of most BTE hearing aids as reported on data sheets;
typically 5 to 8 dB over the entire octave between 3 and 6 kHz
due to the combination of horn action and the quarter-wave
resonance centered at 86/22 = 3.9 kHz (by Formula 3).

The "6LS" earmold: resonance & horn action combined.

Some time ago, Floyd Rudman and Dan Ling found that when
severely-hearing-impaired children were fit with "8CR" earmolds
(Killion, 1981) they were able to detect the "S" sound at 5
meters instead of 12 cm. (You are probably familiar with the
utility of Ling's 5-sound test--EE, AH, OO, S, SH--as a simple
and ready check for appropriate amplification in children.) The
problem, Floyd told me, was that only a small fraction of their
youngsters could accomodate an earmold with the large 4 mm bore
used in the 8CR. He asked if there was anything that could be
done to give the same boost in the 3 to 6 kHz range using a
smaller earmold bore. After some experiments, I re-invented Sam
Lybarger's 1970 earmold design, described in the 1970 Radioear
Model 1010 Dealer bulletin. This version, which I called the
"6LS" (Lybarger Style) construction, is shown in Figure 6.

Note that in this earmold Sam used tubing of only 1.5 mm
inner diameter instead of the conventional 2 mm (actually 1.93
mm is the standard in the U.S.). The smaller tubing provides a
more complete reflection of sound for the standing wave in the
final 3 mm section, and thus gives a greater boost from the
secondary quarter-wave resonance than would be obtained with 2
mm tubing. Sam had obviously been interested in boosting the
output in the same frequency region as the "S" sound occurs,
choosing a length similar to the 20 mm I finally chose
experimentally. That length gives a quarter-wave boost in the
region around 86/20 = 4.3 kHz.

The 6LS earmolds worked well, providing an improvement in
the "S distance" similar to that of the 8CR earmold for children
whose small ears would not accept an 8CR construction. The 15

dB improvement I obtained relative to these children's previous conventional earmolds is shown in Figure 7. That much improvement was a bit puzzling, however. Even combining the horn effect with the secondary resonance, an improvement of at most 8 dB would be expected, not 15 dB. Where was the other 7 dB coming from?
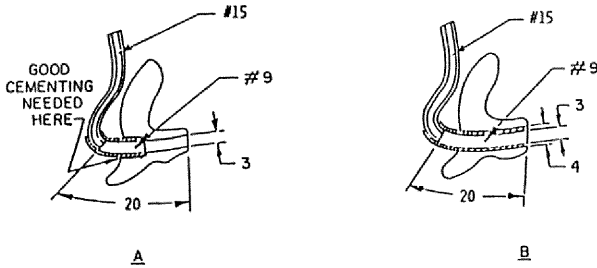
ALTERNATE CONSTRUCTIONS FOR 6LS (LYBARGER STYLE) EARMOLD

Fig. 6. Construction of the "6LS" earmold using 1.35 mm and 3 mm tubing. Note that the alternate construction can be used for any ear that can accept conventional earmolds, whose 2 mm i.d. tubing has a 3 mm outside diameter.
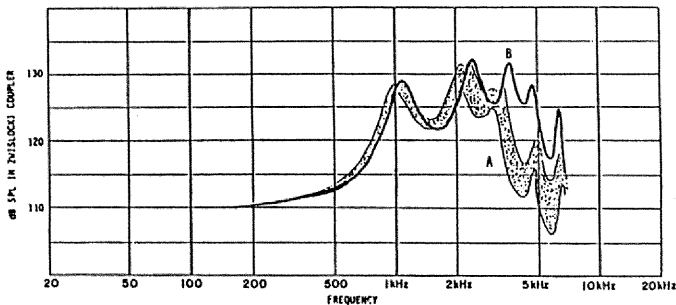
RESPONSE OF SIMULATED HIGH POWER, WIDEBAND HEARING AID WITH:
A) FOUR CHILDREN'S CONVENTIONAL EARMOLDS
B) LYBARGER-STYLE "6LS" EARMOLD

Fig. 7. Frequency response of power aid measured with 6LS earmold. Shaded response area includes the response measured with 4 different "conventional" children's molds, all of which had choked off the sound channel.

When I examined the original earmolds more carefully, I saw the explanation. The earmold laboratory that made those earmolds had adopted the practice of using a very small hole in the earmold, as a way of making a tighter fit between the glued-in tubing and the earmold, in order to keep the tubing from pulling out when the kids yanked on it. As a result, the nominally 1.93 mm tubing was under so much compression that its inside diameter was squeezed down to 1.4 mm in the earmold channel. The high frequencies were being choked off by the reverse horn effect!

That particular defect is one to watch for. We have seen "horn molds" that gave no better high frequency response (measured with a probe microphone in a real ear or with the ITE version of the 2cc coupler) than a conventional earmold. Examination of such molds usually reveals a squeezed down tube in the earmold channel. The reverse horn effect cancels the horn action of the large-diameter final section.

Similarly, Lyregaard (1982) shows the several-dB loss in high-frequency gain caused by the use of an earmold angle piece with only a 1.5 mm bore. In the U.S. this problem is avoided using the "CFA" angle piece, which has a 1.93 mm bore.

Select-A-Boost inserts
Now I want to talk about what I consider to be my finest hour even though it has universally not been adopted anywhere as far as I know. This is the "Treble Response Selector" or "Select-A-Boost" earmold shown in Figure 8. If you order a BTE earmold with 22 mm of 3 mm diameter for the final sound channel (what I called the "6EF" construction, available as the 3-mm "Libby Horn"), you will begin with roughly 6 to 8 dB of high frequency boost compared to a conventional (in the U.S., at least) BTE earmold with the 2-mm tubing going nearly all the way to the eartip.

Suppose you discover that less high frequency gain is desirable. Perhaps your real ear probe measurements show excessive high frequency gain. Or perhaps your patient says, "I don't want to hear all those highs. I'm retired now and I've listened to shrieks and whistles all my life; I kind of like it nice and mellow now." Whatever the reason, you can simply put in a piece of 2 millimeter tubing and obtain 6 to 8 dB less high frequency boost just as if you had ordered a regular earmold in the first place. (A millimeter or so of gap between

the end of the 2 mm tubing insert and the regular 2 mm tubing will have little effect on the response.)
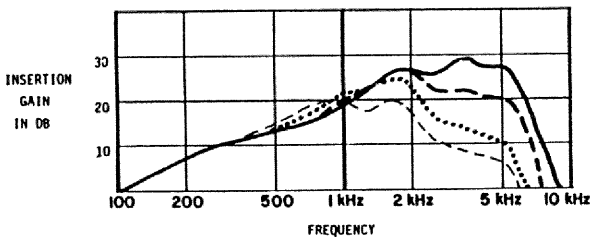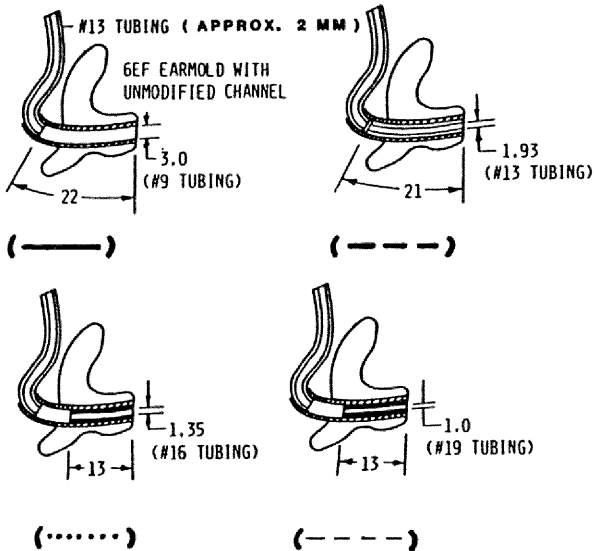

Figure 8. High-frequency response control obtained with "Select-A-Boost" inserts in 6EF earmold. (From Killion, 1984)

If you find you still have too many highs, you can change to a 10 mm length of 1.35 mm tubing as an insert (in the U.S. one of the standard earmold tubings has a 1.35 mm inside diameter and a 3 mm outside diameter, and I assume you have such

tubing here), and you'll drop the highs another 10 dB.

And if you find you still have too many highs, you can
stuff a 13 mm section of 1 mm tubing inside 13 mm of 2 mm
tubing, insert that as shown in Figure 8, and you can roll the
highs off as much as anyone could possible want.

If you prepare these inserts in advance, you can quickly
adjust the high frequency gain and maximum output of a BTE
hearing aid while your patient watches you admiringly.   I still
think that's not such a bad idea, although Hans Bergenstoff sent
me a   copy of a paper describing a hearing aid that provides
similar adjustment of high frequency response electronically
(Bergenstoff, 1987).

Either of these approaches offers a solution to the dilemma
presented by the experienced hearing aid user   who says he
doesn't want to hear all the highs, but at the same time is
complaining about having trouble understanding people talking.
You know that highs are necessary for best speech understanding,
but you can start out with a restricted high frequency response,
perhaps similar to the one he is used to, and bring him back in
a week or two for an increase. Perhaps over a period of a few
weeks you can end up having him satisfied with the sound   of a
hearing aid that gives sufficient treble boost for him to obtain
maximum intelligibility.

My favorite story along this line is one that used to be
told   by Harvey Fletcher, who in the U.S. is considered the
father of speech and hearing research. Back in the 1940s when
good console high fidelity radio-phonographs were just becoming
available, the only phonograph records were 78 rpm, and
inherently scratchy. Dr Fletcher brought home one of these
consoles   and played it for his wife, and she said something
like: "My goodness, that is awful. Listen to all that scratch.
I don't want to listen to that."   So Dr. Fletcher went to the
radio parts store and bought 20 one-uF capacitors and soldered
all 20 across the loudspeaker terminals (much as we do in
hearing aids to roll off the high frequency response for
"feedback controls"). She was happy. Once a week for twenty
weeks   when he was home alone, Dr. Fletcher clipped one
capacitor. At the end of twenty weeks they were both happy!

SUMMARY

The sound channel and vent channel in a BTE earmold <u>control</u> the delivered response of the hearing aid. Fortunately, the acoustics of earmolds are relatively easy to understand and apply. With a basic understanding of earmold acoustics, the hearing aid dispensor is equipped to explain some of his or her unexpected results, and is provided with an important tool for matching the hearing aid response to the needs of the user.

FURTHER READING

Lybarger's (1985) handbook chapter on Earmolds is must reading for anyone interested in earmold acoustics: It is a superb summary of almost everything one needs to know.

Lyregaard's (1982) Figure 3e and Lybarger's (1985) Figure 44.12 is especially recommended to anyone that believes "just pull the tubing back a little and you'll get good horn action."

ACKNOWLEDGMENTS

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DISCUSSION

Ludvigsen: Do you have any advice for the "fitter" - who is not an acoustician - about how to make a good ear mold ?

Killion: If you intend to get a high-frequency boost in a BTE-ear mold, it's important that you don't constrict your tubing as it goes into the earmold for in that case you don't get the horn effect that you are looking for.

The second pitfall: The horn ear mold uses both the increasing diameter and the quarter wave resonance so the length of the last large diameter portion must be close to a quarter wave length at the frequency where you want to get the boost - typically we are talking about 4 kHz - so you devide 120 by 4 (formula 2).

Looking at the quarterwave resonance, you devide $86/4 \approx 20$ mm. If you have an earmold with only about 10 mm tube it's likely to be very effective up at about 8 kHz which is bad when you are shooting for 4 kHz.

Third pitfall: If you use a large-bore earmold in combination with a wideband hearing aid you must get a very good amplifier and some sort of compression limiting to keep it from distorting in the overload condition or it may be totally unacceptable from a sound quality standpoint.

Leijon: How do you compromize if you want to have a wide sound channel bore and a vent and there is not enough room for both.

Killion: I deny the statement. Every ear mold that I know of has a 3 mm hole all the way through it, se every ear mold is basically capable of at least a 3 mm horn.

Leijon: If your ear canal measures 3 mm by 4 mm in total and you want a 3 mm sound channel ?

Killion: I don't have an answer to that. But you can sometime-as has been done in canal aids a little bit - use the canal wall for half of the vent.

If it's 3,5 by 6 mm you can make an oval hole, which has the same cross section area. The born does not have to be round.

Pascoe: The simple procedure I use for checking the efficiency of a Libby-horn earmold is to make a measurement on a HA-2 coupler without the earmold and a measurement on a HA-1 coupler with the earmold in question. This is a quick way to check the efficiency of the tubing.

Killion: Thats an excellent suggestion. The HA-2 coupler has a build-in horn mold and a coupling cavity, the HA-1 has only the coupling cavity. If you seal the earmold in question to the HA-1 coupler and test that and you see that the hearing aid has no high frequency output but it had when tested on the HA-2 coupler you know, that the earmold is not good.

OPEN MOLDS

Jean Courtois, Palle Angaard Johansen, Bodil Vendelbo Larsen,
Per-Henrik Christensen and Joel Beilin, Department of Audiology
and Technical-Audiological Laboratory, Odense, Denmark.

Since the sixties everything has been said and demonstrated
regarding the question of open fittings, but it seems that the
explosive development of hearing aid techniques hypnotizes many
people and makes them consider ear molds a relic from the past
and the manufacturing of ear molds a negligible part of hearing
aid fitting. This is a big error. The ears that we fit today have
exactly the same anatomic and acoustic characteristics as ever
before, and electronics cannot eliminate this fact.

Fitting patients with hearing aids requires still more knowledge
of ear molds, more technique, and manual capacity than ever
before.

Therefore I will repeat the basic rules of open mold fittings
described in broad outlines and the clinical indications and
limits of the method illustrating with some practical cases.

As a medical audiologist I started using I.R.O.S. in 1970. Today
with 18 years of experience I am even more convinced of the
absolute necessity of using well open molds in most cases with
mild or moderate hearing loss.

WHY DO WE USE OPEN MOLDS IN THESE CASES?

First of all to spare the patient from the noisy effect of the
disturbing bass sound, the external bass sounds amplified by a
hearing aid, as well as the internal bass sounds from the
patients' own body amplified by occlusion of the ear canal due to
closed or insufficiently open ear mold.

This occlusion effect has been described in several papers (1)
(2), but it is my conviction that it is not a problem that all of