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Celebrating the Work of Dr. Mead C. Killion

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Marshall Chasin, AuD, Reg. CASLPO Editor-in-Chief

Imagine the field of audiology without Dr. Mead Killion. It brings to mind the 1946 Frank Capra movie starring Jimmy Stewart called *It's a Wonderful Life* where an angel named Clarence comes to show the Jimmy Stewart character what life would be like without him. I have asked Clarence to help me write this editorial. For those of you who have never seen this movie (which by the way requires a full box of Kleenex even for the most macho among us) sometimes a person's contributions can best be recognized if one can imagine what would happen if they had never made them.

We probably would only have had hearing aids that went out to 4,000 Hz, microphones would still be very large which would obviate the entire range of custom hearing aids, an entire generation of young musicians would have hearing loss, we would still be testing hearing with the TDH-39 earphones, RECDs would still be in their infancy, we wouldn't know how to build a hearing aid that can transduce loud music with virtually no distortion, and we wouldn't really understand the benefits of a smooth frequency response. CORFIG and "Count the Dots" would only be games sold at Christmas time, and inexpensive dosimetry and otoacoustic emissions would still be on the horizon. And oh yes, we wouldn't know the name Elmer Carlson whose innovations and inventions would have gone unrecognized. Elmer's work was instrumental in the development of the Musicians' Earplugs™, and the insert earphone.

This issue of the *Canadian Hearing Report* is not about Mead Killion. It is about the many innovations that Mead has spearheaded and convinced us that we, as a field, required. I began my working career at about the same time as Mead's 1981 *JSHD* article came out on "Earmold Options for Wideband Hearing Aids"– this introduced an entire generation of audiologists to the benefits of flared earmold tubing and the judicious use of acoustic resistance. It wasn't too long after that I purchased my first pair of insert earphones which among other things, could allow me to test people with bilateral conductive hearing losses with minimal or no masking. About this same time, a series of non-occluding earhooks were introduced that gave up to 40 dB low frequency insertion gain. This allowed our patients with mastoid cavities and other significant conductive pathologies, substantial low- and mid-frequency amplification with no occlusion of the ear canal. The late 1980s saw the introduction of uniform hearing protection that has become the mainstay for musicians. About that same time, the world's first truly high fidelity hearing aid was developed and to this day is better than the vast majority of digital hearing aids for listening to music. The past 20 years has seen the development of a range of accessible testing that go beyond the traditional measures of hearing.

Clarence Odbody, Angel, Second Class

Although this issue is about Mead's innovations and not Mead, I would be remiss if I did not mention that he has always been willing to answer questions and never once told me I was silly when I asked a silly question. The website of his company – www.etymotic.com, is a wealth of information that is available to anyone, with a series of articles (under Publications) on virtually any topic. I could envision a graduate-level reading course designed to just read through every article on the site and it would probably be voted the best course ever.

In this issue we have a range of short articles by people who over the last 30 years, worked directly with Mead to develop an innovation for the field of audiology. Each one gives the history, the reasons for the innovation, and in many cases, an inside look at how Mead likes to work. We also are fortunate enough to have received permission to reprint several of Mead's important articles. These include the first page of "Earmold Options for Wideband Hearing Aids" from the *Journal of Speech and Hearing Disorders*, and the entire articles on the ER-15 Musicians Earplugs™ and the K-AMP® hearing aid from *The Hearing Journal and Hearing Instruments.*

Thank you Mead.

Marshall Chasin, AuD, Reg. CASLPO Éditeur en chef

Imaginez le domaine de l'audiologie sans Dr. Mead Killion. Ça rappelle le film *La vie est belle* de Frank Capra sorti en 1946 dans lequel un ange du nom de Clarence montre au héros du film joué par Jimmy Stewart que serait la vie sans lui. J'ai demandé à Clarence de m'aider à élaborer cet éditorial. Pour ceux ou celles d'entre vous qui n'avaient jamais vu ce film (qui en passant exige une boite pleine de Kleenex même pour les plus machos entre nous), des fois la contribution d'une personne peut être mieux reconnue si on peut imaginer ce qui se passerait s'elle ne l'avait jamais faite.

Nous en serions probablement encore aux appareils auditifs qui portent sur 4,000 Hz, les microphones seraient encore très larges ce qui rendrait inutile la vaste rangée des appareils sur mesure, une génération entière de jeunes musiciens aurait une perte auditive, nous en serions encore à conduire des tests auditifs avec des écouteurs téléphoniques TDH-39, les différences entre l'oreille réelle et le coupleur seraient encore à leur stade infantile. On ne saurait pas comment confectionner un appareil auditif qui peut traduire la musique intense virtuellement sans distorsion, et on ne comprendrait pas les avantages d'une réponse de fréquence calme. CORFIG et "relier les pointillés" seraient seulement des jeux vendus à Noel, et la dosimétrie bon marché et émissions oto-acoustiques seraient encore à l'horizon. Et oh oui, nous ne saurions rien du nom d'Elmer Carlson dont les innovations et inventions seraient restées sans reconnaissance. Le travail d'Elmer était essentiel pour le développement des capsules protectrices pour les musiciens, et des écouteurs internes.

Ce numéro de *la revue canadienne d'audition* n'est pas sur Mead Killion. C'est au sujet des innovations multiples dont Mead a été à l'avant garde et nous a convaincu que notre domaine les exigeait. J'ai commencé ma carrière professionnelle à la même période de la sortie de l'article JSHD de Mead en 1981 au sujet des "Options d'embouts auriculaires pour les appareils auditifs à bande large" – Ceci a initié une génération entière d'audiologistes aux avantages des embouts auriculaires arrondis et à l'utilisation judicieuse de la résistance acoustique. Peu de temps après, j'ai acheté ma première paire d'écouteur interne qui, entre autres, me permettrait de tester les gens avec une perte auditive de transmission bilatérale avec minimum ou sans masquage. A la même époque, une série de crochets auriculaires non occlusifs étaient présentée qui concédait des gains en insertion des fréquences basses de 40dB. Ce qui a permis à nos patients qui présentaient des cavités mastoïdiennes et autres pathologies de transmission significatives, des amplifications substantielles des fréquences basses et moyennes sans occlusion du canal auriculaire. La fin des années 80 a vu l'introduction de la protection uniforme de l'ouïe qui est devenu le soutien principal pour les musiciens. Au même moment, le premier vrai appareil auditif haute-fidélité du monde est développé et jusqu'à date est meilleur que la vaste majorité des appareils auditifs numériques pour écouter la musique. Les dernières 20 années ont vu le développement d'une gamme de tests accessibles qui vont au-delà des mesures traditionnelles de l'ouïe.

Clarence Odbody, Angel, Deuxième classe

Même si ce numéro est dédié aux innovations de Mead et pas à Mead, je serai négligent si je ne mentionne pas qu'il a toujours été prêt à répondre aux questions et pas une seule fois m'a-t-il dit que j'étais absurde quand je posais des questions absurdes. Le site web de sa société – www.etymotic.com, est une mine de renseignements qui sont disponibles pour tous, avec une série articles (sous publications) touchant virtuellement tous sujets. J'ai la vision d'un cours de lecture de deuxième cycle universitaire conçu pour lire chaque article sur le site et il serait probablement voté le meilleur cours de tous les temps.

Dans ce numéro, une gamme d'articles courts de personnes qui, sur les dernières 30 années, ont travaillé directement avec Mead pour développer l'innovation dans le domaine de l'audiologie. Chacun raconte l'histoire, les raisons de l'innovation, et dans plusieurs cas, une vue en profondeur de la façon de travailler de Mead. Nous sommes aussi privilégiés d'avoir la permission de réimprimer plusieurs des articles importants de Mead. Parmi eux, la première page de " Les options d'embouts auriculaires pour les appareils auditifs à bande large" dans *Journal of Speech and Hearing Disorders,* et les articles au complet sur les capsules protectrices pour les musiciens ER-15 (marque de commerce) et l'appareil auditif K-AMP® dans *The Hearing Journal et Hearing Instruments.*

Merci Mead.

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By Calvin Staples, MSc

In honour of Mead Killion's contribution to our field I have selected blogs that reflect his work in music and hearing aids..

I WOULD RATHER NOT MENTION SPECIFIC HEARING AIDS FOR MUSIC … HERE'S WHY

By Marshall Chasin

I received this recent reply to my "The –6 dB rule" blog entry and thought that I would reply in some semi-specific terms…

Comment:

I'm a musician (flutist), about to purchase a new set of hearing aids. I've read several articles by Dr. Chasin and others that tell me that hearing aids are made for speech, not music, and that the peak input level should be high enough for musical sounds. But NOBODY can tell me which hearing aids, of the hundreds of available brands and models would be best for me, a musician with a mild to moderate hearing loss. I'm about to spend $5,000 on equipment with no information as to what would work best for me as a musician. My audiologist (not a musician) controls the software, so it's hit or miss on the adjustments. As far as I can see, the software is not available to me to do my own adjustments. Please tell me exactly which brand(s) and model(s) of hearing aids would be best for me.

I actually receive e-mails and phone calls such as this on a weekly basis, and I am hesitant to give explicit answers. An exact hearing aid prescription is a complex endeavour and is not just a listing of electro-acoustic features. There is the entire realm of auditory training, aural rehabilitation, and use of assistive listening devices, not to mention the personal interaction with the hearing health care professional. An exact hearing aid prescription through the Internet would do an end-run around these important aspects. I usually respond by saying that here are some general approaches that work well with music, and that if there is interest, I would be happy to work with your local hearing health care professional.

Having said this, here are several semi-specific approaches that have been shown to work well with musicians and people who like to listen to music. These two approaches are based on ensuring that the more intense components of music do not overdrive (or distort) the front end of the hearing aid. This typically refers to ensuring that the analog to digital (A/D) converter is not overdriven since most A/D converters cannot handle inputs in excess of 96 dB SPL. This is equivalent to, as our reader states, "*the peak input level should be high enough for musical sounds.*" In some sense, analog hearing aids of the 1990s such as the K-AMP®, were (and still are) much better for music than most of the modern digital hearing aids.

There are essentially two technical routes.

1. Reduce the sensitivity of the low frequency region of the hearing aid microphone. This can be implemented in a wide range of hearing aids regardless of the manufacturer. A low cut (or –6 dB/octave) microphone is less sensitive to the intense low frequency components of the music, such that intense low frequency fundamental musical energy is reduced at the level of the A/D converter. In turn, this intense low frequency energy enters the ear canal directly, by-passing the hearing aid completely. Understandably this is best for those who do not require significant amounts of gain and output in the lower frequency region, and these clients are typically fit with a non-occluding ear mold. It is a low-tech innovation that preconditions music such that we can reduce the probability of front-end related distortion.

2. Alter the operating range of the A/D converter. There are currently two approaches to accomplish this. One is to "auto-range" the front end which means that the operating range of the A/D converter keeps changing depending on what is entering the hearing aid. This technology derives from a third party manufacturer of IC circuits and is called HRX, or "head room extension." This is a trademark of a gem of a company who sells their components to virtually every hearing aid manufacturer in the world. Up until recently, it was called Gennum, then Sound Design, and has since been purchased by On Semi Conductors. This HRX technology serves as the basis behind the modern version of the K-AMP, called Digi-K, as well as many other manufacturer's products. Another "alter the operating range of the A/D converter" approach is a modification of the front-end that simply allows inputs of up to 115 dB SPL to get through the hearing aid undistorted. Most 16 bit hearing aids have a maximum capability to handle inputs of 96 dB SPL, but actually the "true" science is that 16 bit hearing aids have a 96 dB "dynamic range." Nobody said that this range needed to go from 0 dB–96 dB SPL– just that the range between the quietest and the most intense had to be 96 dB. This alternative implementation allows inputs from 15 dB SPL to 111 dB SPL- everything is shifted up by 15 dB…. Still a 96 dB dynamic range, but the range is now more appropriate for music.

Feel free to share this blog with your hearing health care professional. These two approaches are very useful for music but there is more to a hearing aid than these technical front end innovations. And I would be happy to discuss the specifics of which hearing aids have these technologies with the hearing health care professionals involved in your care.

http://hearinghealthmatters.org/hearthemusic/

ARE WE WASTING OUR TIME?

By Marshall Chasin

If you look through the literature, there are literally tons (or in Canada, tonnes) of articles about the noise levels measured in an orchestra. I am certainly guilty of this and have been doing this since the mid-1980s. But, am I wasting my time?

Does it really matter whether the sound level in a large string section is 104 dBA or 102 dBA? Our recommendations and actions will still be the same … wear hearing protection, at least while rehearsing if not all of the time; and perhaps some environmental strategies (see a recent blog on moving the entire orchestra back 2 meters from the lip of the stage). What about a sound level measurement of 106 dBA or 99 dBA – again, will this really change what we have to say? I may sound cynical but why do things that don't really matter. Further, it's not only the intensity but also the duration, hence it's the dosage of their music exposure that really counts. A 100 dBA exposure for 15 seconds is not damaging, and with proper hearing protection, 100 dBA may not contribute at all to the music exposure dose (e.g. 100 dB – 15 dB = 85 dB).

If we are lucky enough to get the attention of a large orchestra or even a rock band whose members want to protect their hearing, at most we will have one hour… perhaps during a rehearsal, or an intermission, or pre-show sound check. Hearing loss prevention is important, but it should not disturb a performing artist's pre-show routine, whatever that may be (and it can be quite odd… I have been doing this for about 30 years now and some "routines" are not all that routine).

Here is a list of priorities that I have found to be useful in the education of the musician, and you won't find a sound level assessment among them:

1. Explaining that intense music is not necessarily loud music.
2. Alleviate their fears that hearing protection will take away their music- usually when it comes to music, "less is more." A 15 dB reduction (e.g. ER-15) means that they can be exposed 32 times as long.
3. Moderation- Explain that loud music is OK from time to time – if your favourite song comes on, turn up the volume; just reduce it afterwards.
4. It's fine to relocate the amplifier/speaker, or even put the trumpet players on risers. I have it on good authority that Mozart would have done this if he were alive today.

Assessing the sound level in the horn section doesn't really add to anything. Having said this, it can be fun sitting in a professional orchestra during an actual performance if you've never done this before. Usually orchestras don't mind AS LONG AS YOU WEAR ONLY BLACK, and don't bring a tape recorder.

You want to leave the musicians (and the management) with the feeling that some simple things can be done, and in most cases, this will not be expensive. Hearing protection (and its verification) is a one-time expense and many orchestras can build that into their operating budget – it may take a year to obtain approval but your ally is the musician who needs to sit downwind of the trumpets or near the tympani.

"Politically" there may be an advantage for doing a noise assessment, perhaps to demonstrate that something needs to be done, but I have found that most musicians (classical and rock) are now pretty much aware that hearing loss is a potential issue in their job. Once your foot is in the door though, I wouldn't waste time measuring something which is well documented and whose results will not end up changing your recommendations.

Just my 2 cents worth (which I should point out is almost 2.1 cents US with the current Canadian/American exchange rate).

Etymotic Research (www.etymotic.com …. and no, I am not a share holder) has a wonderful program called Adopt-A-Band. They have a nice listing of some of the sound levels from a marching band (along with the contribution to the daily music exposure dose). Here is a sampling:
Mellophone* 92–111 dB
Flute 100–112 dB
Piccolo 102–112 dB
Snare drum 102–113 dB
Clarinet 93–119 dB
Cymbals 118–121 dB

* I have no idea what a "Mellophone" is but it sure sounds loud!

http://hearinghealthmatters.org/hearthemusic/page/4/

TK CONTROL, WDRC, AND EXPANSION (HOW THEY ARE USED AND COMPARED IN FITTING HEARING AIDS

By Wayne Staab

Of topics that are confusing to many who fit hearing aids are the distinctions between the TK Control, WDRC, and Expansion. Understanding the differences between these and how they are used for providing appropriate amplification is a critical part of hearing aid selection and consumer satisfaction.

Basics

Basic definitions to help in understanding these differences:

1. Linear Amplification: 1:1 input/output ratio. 45 degree angle.
2. Compression: Less than 1:1 amplification. Less than 45 degree angle
3. Expansion: Opposite of Compression. Greater than 1:1 amplification. Greater than 45 degree angle. One way to control the potential for circuit noise or feedback in quiet environments. It is easier to implement this action in digital than in analog.
4. WDRC (Wide Dynamic Range Compression) = input compression having a low knee point.
5. TK Control: One way to adjust the compression of a WDRC AGC aid to avoid circuit noise or to reduce feedback in quiet environments.
6. TILL: Trebel increases at low levels.[1]

WDRC vs. Expansion

Study the two graphs in Figures 1 and 2. They show Expansion versus WDRC two different ways – first with respect to output, and second, with respect to gain.

Figure 1 shows the comparison in the more traditional way, The WDRC curve shows 40 dB gain (0 dB input and 40 dB output = 40 dB gain, as does a 20 dB input and 60 dB output, etc.) up to the knee, after which amplification becomes a 2:1 compression, or 1 dB out for each 2 dB input. So, the WDRC has the same amount of gain (40 dB in this case) from soft up to the knee. Very soft inputs are amplified to 40 dB. Under these circumstances, all soft sounds are made louder, including the mic noise (about 25 dB SPL). An additional problem occurs with WDRC in that in quiet a person may experience a hissing sound, or even feedback, but not when the signal input is stronger. Again, the reason for this is because the aid has maximum gain for soft sounds (40 dB gain in our example). In hearing aids that have a TILL processor (K-AMP and almost every other aid that says it makes soft speech loud and loud sounds soft), the maximum gain is in the high frequencies, just where feedback is most likely to occur.

On the other hand, the expansion shows that at 20 dB input there is 40 dB output, or a gain of 20 dB. This is half the gain of the WDRC, and as a result, soft sounds are not amplified to the same extent as is the WDRC managed signal. At 40 dB input the output is 80 dB, which is now a 40 dB gain, the same at this point as the WDRC had from 0 dB input. So, you can see that expansion has its greatest amount of gain exactly at the knee point, and less gain for softer input signals.

Figure 2 is plotted as a result of the input to the aid. It shows the same as the above graph but is expressed in gain rather than output. The WDRC has constant gain of 40 dB up to the kneepoint.
For the example shown, the gain differences are:

Input	WDRC	Expansion
0 dB	40 dB gain	0 dB gain
20 dB	40 dB gain	20 dB gain
40 dB	40 dB gain	40 dB gain
60 dB	30 dB gain	30 dB gain

Expansion functions well with digital aids because it can be implemented fairly easily via an algorithm.

Figure 1. Comparison of compression and expansion expressed in output.

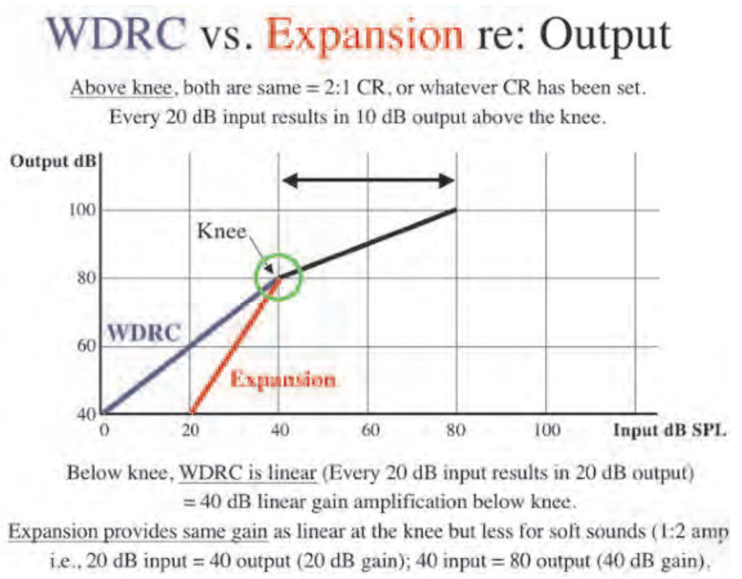
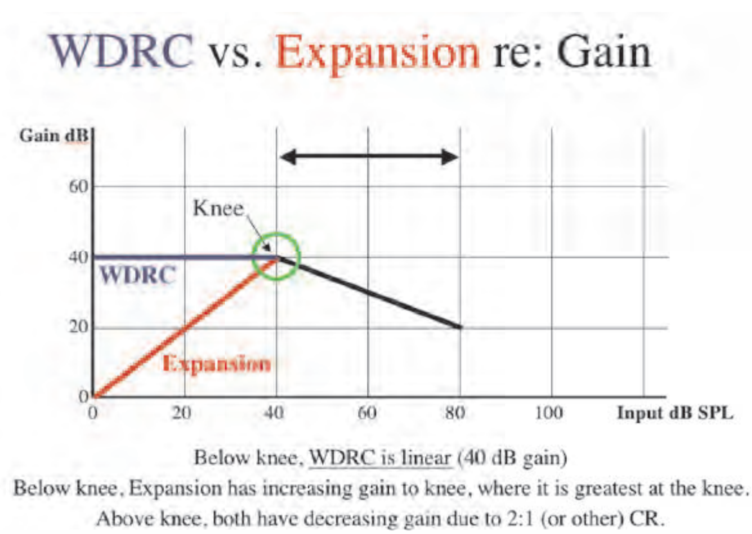


Figure 2. Comparison of compression and expansion relative to gain.



TK (Threshold) Control
A way to adjust the AGC (compression) of an aid

This controls gain for soft input sounds only by adjusting the compression kneepoint over a relatively low input level range (typically from about 40 to 55 dB).

As such, it is a gain booster for soft sounds. So, if there is too much circuit noise heard for soft sounds, move the kneepoint to a higher value, which will result in less gain for soft sounds. However, it will not affect the level of the MPO.

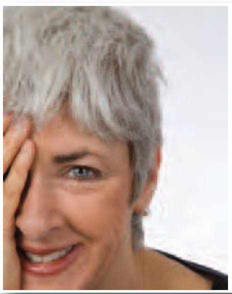
REFERENCE

1. Killion M, Preves D, and Staab W. Classifying Automatic Signal Processors, Hearing Instruments 1990:41(8):24–26.

http://hearinghealthmatters.org/waynesworld/page/4/

Enjoying Music, The Hard of Hearing Way

By Gael Hannan



Music is what feelings sound like (author unknown). *Music is poetry in the air* (Richter). And once you have experienced music, it becomes fundamental to life.

"What sound would you miss most if you couldn't hear it anymore?" I ask this to elementary students receiving Sound Sense, a presentation on hearing loss prevention.

"Music!" they yell. They are smart, these kids, because people with acquired hearing loss often mourn for the ability to enjoy music as they once did.

As a descendant of song-and-dance men and hymn-singing preachers, music is in my blood, and a source of both joy and grief. When the hearing-music gods are aligned, I can listen with pleasure. But when hearing barriers kick in, it can be emotionally painful.

I can't carry a tune. My mother said I had the unique ability to sing a four-line song in four different keys. I attributed this to my hearing loss, until I met hard of hearing people with perfect pitch (Damn them!). But I sing anyway, and I sound great, to me. And as Cervantes said, *he who sings scares away his woes.*

Singing is one thing, listening is another. Making out the lyrics is often impossible, because I can't understand words if I can't see them. Background instruments turn lyrics into soup, so through the years I have unconsciously developed my own lyrics for favourite songs, most of which are nonsense-verse and bear no resemblance to the song title.

I remember when music came alive for me; I discovered the power of print translation one glorious day when I was 10. Inside a boxed set of Gilbert & Sullivan's "The Pirates of Penzance," I found the complete libretto along with the recordings. What a treasure! For the first time in my life, I could understand the music, following along with my very own script, drinking in every note and word.

Although it would be years before I saw printed lyrics again, I soon found another way to "get the words" – through the lips of my sister Louise. We would lie on the floor by the radio, face to face, and I would make her sing along with the songs. Once I saw the words on her lips, they made complete sense from then on.
This process wasn't as meaningful for my sister, however, and I sometimes had to lie on her to make her sing. Or I'd play the poor-hard-of-hearing-kid card, and put up such a fuss that my mom would yell, "Louise, sing to your sister this minute!"

Orchestral music has always been a joy, even when my hearing can't differentiate the instruments; I need a strong melody line. If the violins or flutes carry the melody too high, the music seems to just disappear until the notes "come back down." When I go to the symphony, I find myself watching the musicians' physical movements to see who is producing which sounds – it's somewhat like reading lips. Listening to classical music in the car gives me personal surround sound, and I sometimes just drive around, soaking it up.

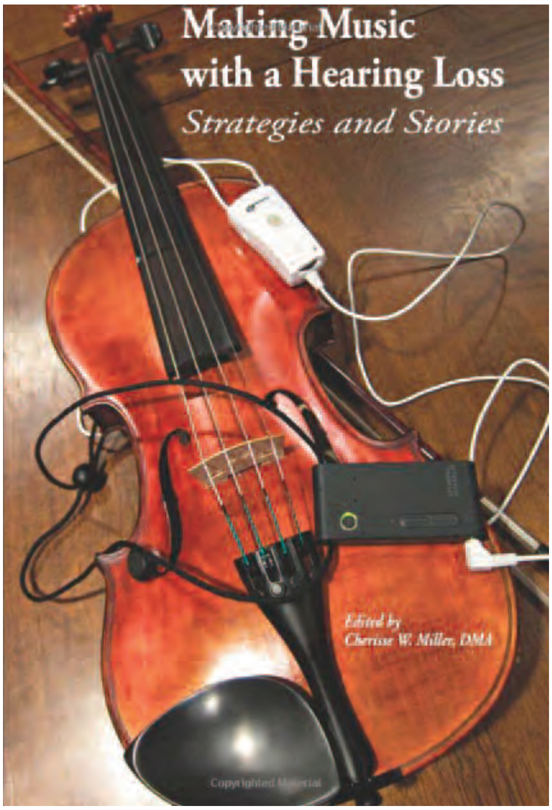
Today, hearing aids and assistive technology have given me new access to music, although discerning the lyrics and different instruments is still difficult. I can take walks listening to my MP3 player via a neckloop, avoiding hydro lines which cause buzzing.

And, with better hearing technology, I have new breath-stopping moments of music. My young son was playing classical guitar and I sat close by, watching him. I heard every note. The beauty ripped through me in waves and I was grateful, once again, for the power of music. And, once again, I grieved briefly for all the beautiful music that is just beyond the reach of my hearing.

So, along with millions of people with hearing loss, congenital or acquired, I applaud every technical advancement that can give us back.

New Book from the Association of Adult Musicians with Hearing Loss

Making Music with a Hearing Loss: Strategies and Stories



This book is available on Amazon at:

http://www.amazon.com/Making-Music-Hearing-Loss-Strategies/dp/1456586386/ref=sr_1_1?ie=UTF8&s=books&qid=1307755051&sr=1-1

There are many texts on music and hearing loss, but what makes this volume unique is that this book is a book that audiologists can share with their patients who are musicians. It is written in non-technical language for the layman, and begins by explaining how the human ear hears sound. It covers the interplay between music, speech and hearing devices and discusses hearing conservation for musicians. The final chapter contains inspiring narratives from eleven deaf or hard of hearing musicians belonging to the Association of Adult Musicians with Hearing Loss. These 11 stories describe using a variety of strategies to integrate hearing loss and music making. Musicians new to hearing loss, hearing-impaired adults wanting to learn a musical instrument, audiologists, music educators, and music researchers will also find this book a valuable addition to their library collection.

Edited by Cherisse Miller, DMA., this collaborative work is written by audiologists Dr. Marshall Chasin and Dr. Brad Ingrao, and includes stories by 11 adult musicians with hearing loss who are members of the Association of Adult Musicians with Hearing Loss (AAMHL).

The editor, **Dr. Cherisse Miller** is a pianist, organist, and Music Teacher's National Association certified piano teacher. In 2009, she obtained her doctor of musical arts in piano pedagogy at the University of South Carolina. Dr. Miller has published two online journal articles for *Pedagogy Forum* in 2002 and *The Hearing Review* in 2009, where she discusses the challenges and strategies of musicians with hearing loss. Her dissertation is titled *Musicians with Hearing Loss: A Basic Guide for Teachers and Performers*.

Dr. Marshall Chasin is the director of auditory research at the Musicians' Clinics of Canada in Toronto, the coordinator of research at the Canadian Hearing Society, and the director of research at ListenUp! Canada. Dr. Chasin has been involved with hearing and hearing aid assessment since 1981, having graduated with a master's of science from the University of British Columbia. He has authored several books on hearing, hearing aids, musicians and noise exposure and over 100 clinically based articles. In 2003, he obtained his AuD from the Arizona School of Health Sciences.

Dr. Brad Ingrao has a long history of responding to the needs of consumers, parents and colleagues through his participation on over a dozen hearing loss-related listservs and a pro-bono website for parents. As the coordinator of audiology information services of the Hearing Instrument Manufacturers' Software Association, he addressed quality and accessibility issues in software used for fitting hearing aids. Dr. Ingrao is now principal audiologist and consultant for www.e-audiology.net

EARMOLD OPTIONS FOR WIDEBAND HEARING AIDS

MEAD C. KILLION
Industrial Research Products, Inc., Elk Grove Village, Illinois

A summary of recent developments in earmold constructions for wideband hearing aids is presented. Earmold modification techniques, special earmolds, and temporary earmolds are discussed. The appendix contains the results from transmission line theory as applied to earmold acoustics and some sources for useful earmold supplies.

With the recent advances in transducer design and earmold acoustics, wideband hearing aids with high-fidelity sound quality, extended frequency response, and reduced battery drain become possible. Since many of these techniques are still evolving, this paper presents a "state-of-the art" summary of recent earmold developments.

Just how many of the special earmolds described below will have enduring value is uncertain. There are several ways to improve hearing aids; some involve earmold designs, some amplifier designs, and some internal acoustic damping in the earhook or the hearing aid itself (Carlson, 1974). The earmold options described in this report may prove useful until the final answers are in.

EARMOLD MODIFICATIONS

Several approaches to earmold modifications are possible. Two can be accomplished with tools no more complicated than a #50 (1.8-mm diameter) drill bit or a section of 1.9-mm diameter tight-coil spring for inserting damping elements and a knife or scissors for cutting tubing sections to appropriate lengths. Before discussing specific modifications, however, a word about measuring the acoustic effect of such modifications is in order. Each of the frequency responses shown in Figures 1–6 were obtained by sealing the designated earmold directly into the "HA-1" configuration of the standard 2-cm³ coupler, as illustrated in Figure 13 of ANSI S3.7-1973. In this configuration, the earmold outlet is made flush with the top surface of the coupler cavity. By way of contrast, the frequency response curves shown on a manufacturer's data sheet are typically obtained with what is properly called an HA-2 earphone coupler with entrance through a rigid tube (Figure 14 of ANSI S3.7-1973), usually a 25-mm length of 2-mm diameter tubing followed by the HA-2 configuration, which is an 18-mm length of 3-mm diameter sound channel leading into the 2-cm³ coupler cavity.

Some commercial hearing-aid test instruments are supplied only with the HA-2 coupler. Needless to say, sealing a custom earmold into such a coupler, an occasional practice of the unwary, will provide only marginally useful information because of the 18-mm long sound channel interposed between the custom earmold tip and the coupler cavity proper.

Even when custom earmold modifications are measured with the proper HA-1 configuration of the 2-cm³ coupler, the 2-cm³ coupler still is not a good simulation of the average real ear. The greater sound pressure level (SPL) developed by a hearing aid earphone-earmold combination in real ears was compared with the 2-cm³ coupler by Sachs and Burkhard (1972). As a rough rule of thumb, the higher level in real ears amounts to 3.5 dB at low frequencies, 5 dB at 1 kHz, 10 dB at 3 kHz, and 15 dB at 6 kHz.

Although the use of a realistic occluded ear-simulator such as the Zwislocki (four-branch) coupler will provide a more direct estimate of the average real-ear SPL that will be produced by a (subminiature) earphone-earmold combination, a large number of experiments conducted by the author and others have confirmed that, up to 8 kHz or so, the differences between 2-cm³ coupler and Zwislocki-coupler measurements are nearly independent of the earphone-earmold combination and are equal to the differences given by Sachs and Burkhard (1972). The only important exceptions occur when "open canal" earmolds or those with extreme venting are measured. For such measurements, a realistic ear simulator, including concha and pinna simulation, is required (Lybarger, 1980) for greatest accuracy.

Thus, an earmold modification that produces a 10 dB change in 2-cm³ coupler response can be expected to produce approximately a 10 dB change in the SPL delivered to a real ear. The greater availability of the 2-cm³ coupler was the deciding factor in the choice of coupler used to obtain response curves for this paper.

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TECHNOLOGICAL REPORT

An "acoustically invisible" hearing aid

By Mead C. Killion, PhD

For roughly a dozen years, the writer has been pursuing the goal of creating a high fidelity hearing aid. This paper is a progress report on a K-AMP custom integrated circuit amplifier designed to make such a hearing instrument possible. The "automatic signal processing" built into this amplifier differs from common practice. The first section of this paper explains the rationale for the new approach.

The second section of this paper reviews the author's earlier fidelity rating experiments. Using experimental "unity gain" hearing aids, it was demonstrated that subminiature microphones and receivers could deliver high fidelity sound according to the most stringent listening-test standards.

Finally, the input-output characteristics of traditional hearing aid amplifiers are reviewed in order to compare them to the new approach.

Rationale: Who needs it?

Despite decades of research, still not enough is known about hearing impairment to define the optimum hearing aid characteristics for many individuals. This is certainly true for the person with severe to profound hearing loss.

The person who claims: "I don't need a hearing aid most of the time," however, appears to present a problem for which a solution can be defined without further research. As argued below, such an individual probably has a mild hearing loss that is restricted to a loss of sensitivity for quiet sounds, with normal or near-normal hearing for louder sounds.

Nixon[6] reported in 1945 that "hearing loss measurements were made on a number of engineers, program producers and musicians at NBC some years ago to attempt to correlate hearing loss with ability to judge program quality. In a few cases where hearing was impaired to the extent of 40 dB at frequencies of 4000 cycles (Hz) and higher, the particular individuals were actually among the most competent of those concerned with exercising judgment of program quality." This author's more recent observation of musicians and colleagues with mild hearing impairment leads to the same conclusions: they show absolutely no indication of any abnormality in hearing for high-level sounds, even though a mild or mild-to-moderate hearing loss at threshold is measurable at the speech frequencies and is noticeable when someone talks too quietly.

As an illustration, the audiograms in Fig. 1 show the extensive regions of presumably normal hearing, inferred from the experimental complete-recruitment data of Barfod,[1] for two hypothetical subjects with mild hearing loss.

When to do nothing

Following the old adage "If it ain't broke, don't fix it," the ideal hearing instrument for someone who "doesn't need a hearing aid most of the time" appears self evident. It should do absolutely *nothing* most of the time. When no hearing assistance is required, the hearing instrument should be so acoustically transparent that it subjectively disappears; it should be acoustically "invisible." Stated another way, if an individual has normal hearing for loud sounds, the hearing instrument should, for loud sounds, neither stand in the way of the wearer's normal hearing nor give amplification the wearer does not need.

Of course, this principle is nothing more than an application in the *amplitude* domain of a principle that every dispenser applies in the *frequency* domain: Don't amplify in a region of normal hearing. The great success of the open-canal fitting for those with normal, low frequency hearing is an obvious example of the latter. But the same principle generally has not been applied in the amplitude (loudness) domain.

The prime example is in the hearing-impaired person trying to make out individual voices around a conference table. In this case, amplification tends to magnify everything, including making loud sounds too loud. What appears to be needed in this case is a hearing instrument with such fidelity that it subjectively disappears for louder sounds when it is (automatically) set to provide 0 dB acoustic gain (no gain, no loss) for louder sounds. The instrument should, of course, provide gain for the quiet sounds this person is missing. In the same way, the typical, older person with sloping, high frequency hearing loss needs more gain for high frequency sounds than for low frequency sounds, so that a substantial treble boost also is required for quiet sounds.

High fidelity transducers

A decade ago, it was popular to proclaim that the main problem with hearing aids was the "inherently low fidelity of the microphones and earphones." Partly in answer to such claims, this author demonstrated that it was possible to design BTE and ITE hearing aids which would reproduce speech and music with a fidelity comparable to that of expensive studio monitor loudspeakers.[2,4]

Fig. 2 shows a few of the results from those extensive fidelity rating experi-

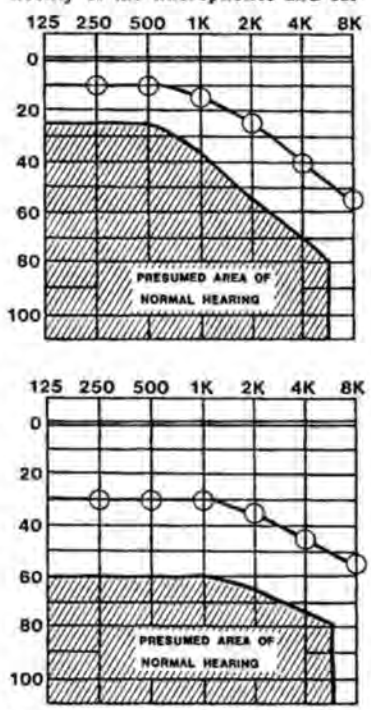

Fig. 1. Threshold audiograms for two hypothetical subjects, with areas of presumed normal hearing based on Barfod's data (reprinted with permission from Killion 1988[5]).

Mead C. Killion, PhD, is president of Etymotic Research, Elk Grove Village, IL.

ments. Experimental hearing aids were compared to popular stereo headphones such as the Koss PRO4AA, stereo loudspeakers such as the ElectroVoice Sentry V studio monitors and a speech audiometer (which was often referred to as "high fidelity" in the audiological literature). Three types of listening panels were used: Golden Ears (five high fidelity experts, the most famous of which were Julian Hirsch, who makes his living rating high fidelity systems; Hugh Knowles, who as "Mr. Loudspeaker" in the 1940s coined the term "Bass Reflex"; and Edgar Villchur, who in the 1950s developed the acoustic suspension woofers and dome tweeters); Trained Listeners (Elmer Carlson, Richard Peters, Daniel Queen, Eugene Ring, Robert Schulein and Frederic Wightman); and Untrained Listeners (12 males and 12 females aged 20 to 60), chosen to represent "man on the street" type of listeners. All three panels gave essentially similar results. Available transducers (Knowles BT- and EA-series microphones and BP-series earphones) permitted the reproduction of full-orchestra and jazz-trio selections, at original concert levels, with a fidelity equal to high-quality stereo systems.

Further evidence that the transducers are not "the problem" is the fact that a modified version of one hearing aid microphone, which the author helped design, is regularly used in broadcast and recording studios. In addition, the same basic receiver (Knowles ED-series) that is used in many hearing aids also is used in some of the highest-fidelity stereo earphones presently available. The main problem left to be solved then is one of amplifier design.

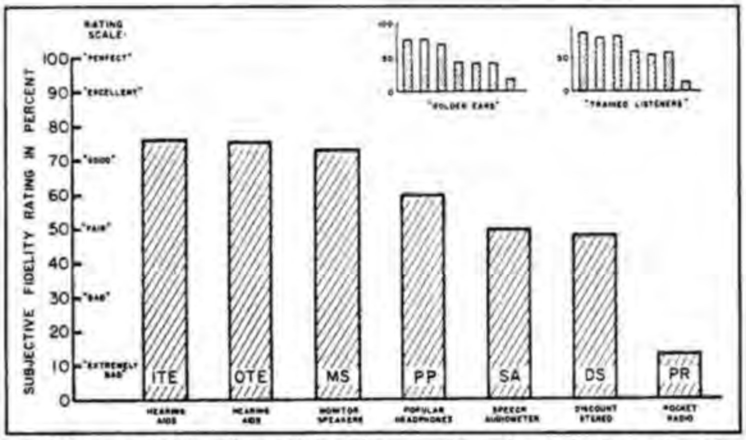

Fig. 2. Average fidelity ratings obtained for several sound reproduction systems (reprinted with permission from Killion 1988[5]):
Experimental ITE binaural hearing aids (ITE);
Experimental OTE binaural hearing aids (OTE);
ElectroVoice Sentry V studio Monitor Speakers (MS);
Koss PRO4AA Popular Phones (PP);
Simulated speech audiometer with TDH-39 earphones (SA);
K-MART special $69.95 "High Fidelity" Discount Stereo (DS);
GE $4.95 pocket radio in peak-clipping overload (PR);

The traditional amplifier

Most hearing instruments provide amplification for all sounds, even loud sounds, up to the level that peak clipping, input or output compression limiting or ASP circuits set in to reduce the gain. Many of these modern compression circuits are designed now to prevent the sounds some older hearing instruments made when driven into overload. Properly adjusted, all prevent sounds from becoming uncomfortably loud, however, only a few wide-dynamic-range-compression circuits amplify sounds up until they are *almost* at the point of being uncomfortably loud. Slightly loud normal conversational speech generally is considered to be at a hearing level of 60-70 dB, corresponding to an SPL of 75-85 dB. Such speech may not be *really* uncomfortable when amplified to 90-100 dB SPL, but it is getting there. The well-known result is that the hearing instrument wearer often turns the volume control down and consequently misses some of the quieter sounds.

The relationships described above are shown graphically in Fig. 3, which shows the gain and input-output characteristics of a hearing instrument with maximum output controlled by limiting (whether peak clipping or any-named compression with high compression threshold and high compression ratio). Note that such an instrument acts as a linear amplifier with constant gain until limiting sets in. Below the limiting level, both loud and quiet sounds are amplified by the same amount.

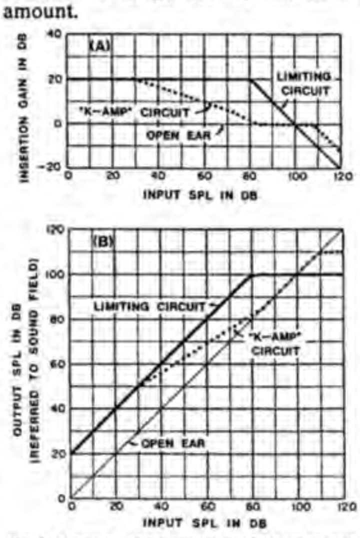

Fig. 3. Hearing instrument gain (A) and output (B) vs. input for conventional "limiting" type of amplifier (____) and for the new amplifier design (. . . . .), both set for a maximum gain of 20 dB. NOTE: The unaided open ear has neither gain nor loss "0 dB gain" for all inputs.

The new amplifier

During his PhD research, this author designed a "four-stage compression amplifier" to eliminate the problems described above.[3] This circuitry is called the K-AMP. It is designed to provide:

1. Substantial gain for quiet sounds;
2. Decreasing gain for moderate-level sounds;
3. No gain (but no loss) for loud sounds;
4. Compression limiting for the loudests sounds, to prevent output amplifier overload (peak clipping) with its attendant rasping, raucous, unpleasant sound.

AUTHOR'S NOTE: *With the high quality sound reproduction available in audio devices today, only an experienced hearing instrument wearer would be expected to tolerate the grating sound of peak clipping on a prolonged basis; although in all fairness to peak clipping circuits, some wearers get quite used to it and accept it.*

The type of input-output characteristic that results with the new approach also is shown graphically in Fig. 3. The new amplifier provides the same gain as a traditional amplifier for quiet sounds. For loud sounds, however, the new amplifier allows the hearing aid to "do nothing" (provide neither gain nor loss). For intermediate sounds, an intermediate amount of gain is provided. Combined with proper transducers and acoustic coupling and venting, the result can be a hearing instrument that comes close to being "acoustically invisible."

Note especially that the traditional discomfort-preventing output limiting is no longer needed in most cases, because loud sounds are not amplified.

With the K-AMP circuitry, intense sounds should be no more uncomfortable with the hearing instrument on than if it were removed. Only if the wearer needed hearing protection in his or her daily routine would output limiting be required for that purpose.

The need for greater gain at high frequencies, in the case of sloping high frequency loss, can be accommodated by requiring the frequency response, as well as the gain, to change with level.[7] Fig. 4 shows the frequency response characteristics, with level as a parameter, of a prototype version of the K-AMP with suitable level-dependent, high frequency emphasis. No high frequency emphasis is provided for loud sounds, because the typical individual with mild, sensorineural hearing loss does not appear to have a high frequency hearing loss for loud sounds, only for quiet sounds (recall Fig. 1).

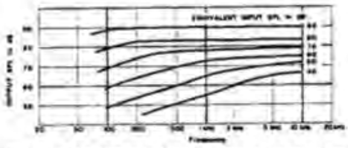

Fig. 4. Output vs. frequency of prototype amplifier adjusted for an individual who has a sloping high-frequency hearing loss for quiet sounds with normal hearing for loud sounds (reprinted with permission from Killion 1988[5]).

Antifeedback bonus

There is an additional advantage to the new design approach. Feedback squeal is an all-too-common problem which sometimes can occur even with a reasonably well-fit earmold when the wearer is eating. For most wearers, the only practical solution to date has been to turn down the gain of the hearing instrument during such times. This "turn-it-down" occurs automatically with the K-AMP circuit. As soon as feedback squeal starts to build up, but while it still is very quiet, the increasing signal at the microphone causes the gain to drop until the hearing instrument is just on the verge of squealback. In nearly every case, this will occur at a relatively low output level, so that instead of hearing a loud squeal with each chew, the wearer hears only a quiet, almost breathy, whistle that generally will be inaudible to others around the table.

What's next

As exciting as it is to see the approaching completion of a 12-year project, the real test is still ahead. When it is finished, this K-AMP circuit will be made available to manufacturers. The ultimate test of this amplifier design will be the degree of its acceptance by hearing-impaired wearers. ☐

References

1. Barfod J: Multi-channel hearing aids: experiments and consideration on clinical applicability, in *Sensorineural Hearing Impairment and Hearing Aids* Ludvigsen C and Barfod J (eds), *Scand Audiol* Suppl 6:315-430, 1978.
2. Killion MC: Design and evaluation of high fidelity hearing aids. Northwestern U PhD thesis, University Microfilms, Ann Arbor, 1979.
3. Killion MC: AGC circuit particularly for a hearing aid. U.S. Patent #4,170,720 issued Oct 9, 1979.
4. Killion MC and Tillman TW: Evaluation of high-fidelity hearing aids. *J Spe Hear Res* 25:15-25, 1982.
5. Killion MC: Principles of high fidelity hearing aid amplification, in *Handbook of Hearing Aid Amplification Vol 1: Theoretical and technical considerations*. Sandlin RE (ed), College-Hill Press, San Diego, CA, 1988.
6. Nixon GM: 'Higher Fidelity' in sound transmission and reproduction. *J Acous Soc Amer* 17:132-135, 1945.
7. Skinner MW: Speech intelligibility in noise-induced hearing loss: Effects of high-frequency compensation. *J Acous Soc Amer* 67:306-317, 1980.

Acknowledgments

Four experienced IC designers, C.M. "Kip" Brown, Bill Cole, J.B. Compton and Norm Matzen, have lent their time, experience and wisdom to the task of converting a discrete-component circuit design into a practical monolithic integrated circuit design. Steve Iseberg, Jonathon Stewart and Don Wilson spent many weeks at Etymotic Research building, testing and discarding breadboards and computer PSPICE simulations of various integrated circuit approaches. An acknowledgement of some of the writer's many intellectual debts, along with many more references to previous developments, can be found in a recent book chapter.[5]

This project was funded in part by an SBIR grant from the National Institute on Aging, which is gratefully acknowledged.

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TECHNOLOGY

An Earplug With Uniform 15-dB Attenuation

By MEAD KILLION, ED DeVILBISS, & JONATHAN STEWART

Currently available custom-earmold hearing protectors have one defect in common: They muffle the sound. Technically speaking, they give more attenuation at high frequencies than at low frequencies. Figure 1 shows representative performance of a well-sealed and of a poorly sealed custom-earmold type of hearing protector with solid construction, based on data from E. H. Berger.[1]

Another type of custom-earmold hearing protector includes a small vent channel, often with a stepped diameter. If the vent channel is very small (0.5-mm diameter, for example), such devices give a real-ear attenuation that is generally similar to the curve labeled "Leaky Earmold H.P." in Figure 1. If the vent channel is a little larger, an undesirable resonance peak is created, and the earplug actually provides *amplification* instead of attenuation at the resonance frequency. A 1-mm diameter vent, for example, gives a peak of about 5 dB near 250 Hz.

Mead Killion, *PhD and* **Ed DeVilbiss,** *MBA are President and Vice President, respectively of, and* **Jonathan Stewart,** *BS/EET is Engineer with, Etymōtic Research, Inc. (manufacturer of the ER-15 earplug). Correspondence to: Etymōtic Research, Inc., 61 Martin Lane, Elk Grove Village, IL 60007.*

Regardless of their exact construction, a reasonable generalization is that existing custom-earmold hearing protectors produce 10 dB to 20 dB of excessive high-frequency attenuation. A hearing protector with more uniform response—a high-fidelity earplug, if you will—seems needed.

A NEW EARPLUG

The curve labeled "15 dB Earplug" in Figure 1 shows the expected real-ear attenuation of the ER-15™ earplug, based on KEMAR measurements. The trick in producing this high-fidelity response is to reproduce the shape of the natural frequency response of the open ear, but at a reduced level. Figure 2 shows the response of the normal open ear, plotted as the eardrum SPL developed in a diffuse sound field, and the response of the ear with a properly constructed ER-15 earplug in place. The *difference* between these two curves represents the real-ear attenuation of the ER-15 earplug, which is a nearly uniform 15 dB as shown in the solid curve of Figure 1, based on KEMAR measurements.

The ER-15 earplug is a novel development by Elmer Carlson, who added acoustic elements into the sound channel in order to accomplish this result. Figure 3 shows a cross-section drawing of the ER-15 earplug, along with the electrical analog equivalent circuit (included for those who enjoy reading schematics). A flexible plastic diaphragm acts as a compliance, and is labeled C1 in the equivalent circuit. The sound channel (L1 in Figure 3) acts as an acoustic mass, so that a Helmholtz resonator is formed between the inertance of the sound channel and the combined compliance of the flexible diaphragm and the ear-canal volume. With the proper combination of diameter and length for the sound channel, the Helmholtz resonator will resonate at 2.7 kHz, providing the desired boost at that frequency as illustrated in the lower response curve of Figure 2.

CONSTRUCTION VARIATIONS

Figure 4 shows the medium depth ER-15 earmold with the ER-15 attenuator button snapped in place. The "canal-aid" style construction should make for a nearly invisible earplug in most ears. The right and left earmolds must be color coded.

A version designed to produce less occlusion effect (i.e., fewer "my own voice sounds hollow" complaints), shown in Figure 5, is suitable for persons with larger-diameter ear canals. The reduction of occlusion effect is a result of the deep seal of the plug.[2,3] The standard 3.5-mm diameter sound channel can be drilled with the same .142" drill used for #13 super-thick tubing. Some ear canals will be so flattened that such a hole, extending for 10 mm down the canal, will not be practical. A roughly oval hole may be used in these cases to obtain the desired acoustical results, as suggested years ago by H.S. Knowles. Figure 6 shows elon-

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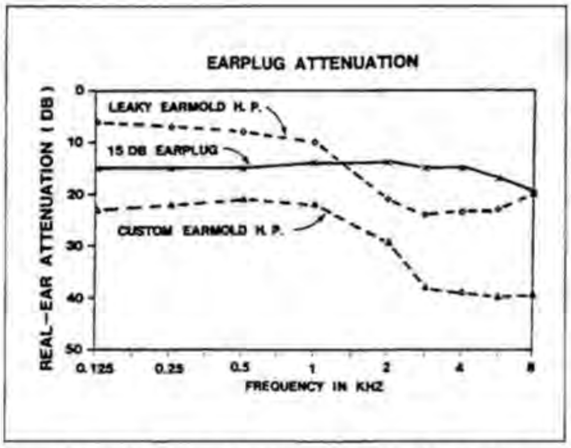


Figure 1. Performances of a well-sealed and of a poorly sealed custom-earmold-type hearing protector with solid construction.[1]

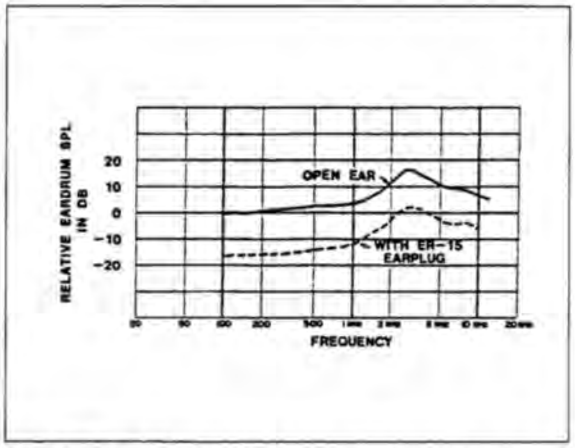


Figure 2. Expected eardrum SPL in diffuse (random incidence) sound field with ear open or occluded.

gated holes, equivalent to 3.5-mm and 4-mm diameter sound channels, with flat-side dimensions of 3 mm. In order to check the accuracy of the frequency response and/or the amount of occlusion effect on an individual ear, a 1-mm o.d.

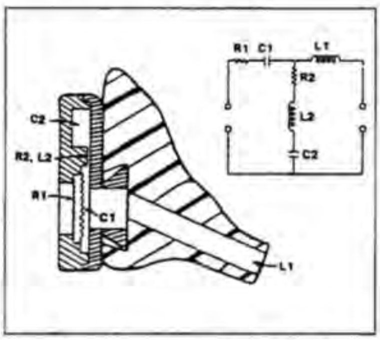


Figure 3. Construction of 15-dB earplug.

probe-tube hole can be ordered with the earmold. Figure 7 shows the preferred and alternate locations for the probe-tube channel, which should be *sealed completely* after testing is completed.

Despite the best of intentions, earmolds occasionally will be badly made. The effect of two likely errors, lack of seal and undersized sound channel, is illustrated below with specific examples. Figure 8 shows the effect of a leak or an undersized sound channel (2-mm diameter instead of 3.5-mm diameter) on the *eardrum SPL* generated in a diffuse sound field. Figure 9 shows the resulting real-ear attenuation expected for these errors.

EARMOLD MATERIAL

From an acoustic standpoint, any earmold material can be used, but we recommend soft vinyl or silicone for two reasons: (1) It eases the task of obtaining a good seal; (2) It permits a deep seal with good comfort. The disadvantage of soft (30- to 40-durometer) materials is their reduced durability compared to acrylic.

APPLICATIONS

Two potential applications for the ER-15 earmold stand out: First, for the musician who wants some protection but needs good fidelity (proper spectral balance) in order to perform properly; and second, for the factory worker who has a high-frequency hearing loss and refuses to wear conventional hearing protection because he needs to hear more clearly. Figure 10 shows the expected sound-field audiograms for a person with normal hearing, and for a typical 50-year-old man using either conventional custom-earmold hearing protectors or ER-15 custom-earmold hearing protectors. The audibility of important high-frequency speech sounds is clearly im-

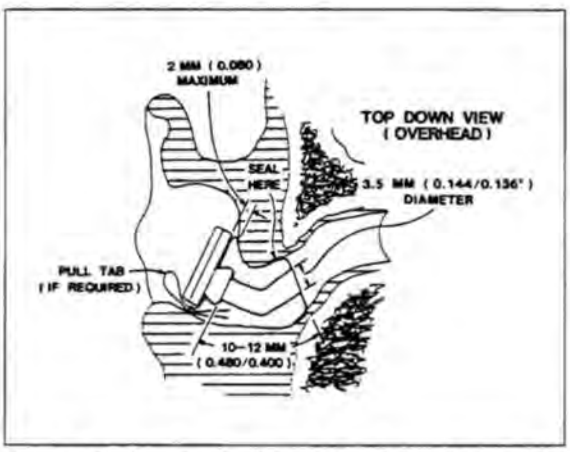


Figure 4. Medium (First Bend) Depth. (Standard ER-15 earmold for ER-15 attenuator.)

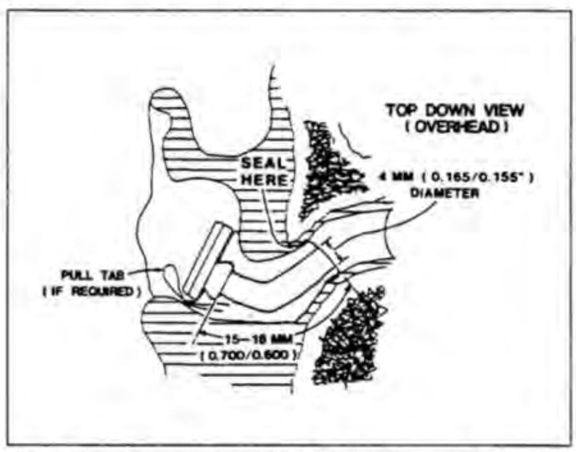


Figure 5. Long (Second Bend) Depth. (Low-occlusion-effect version of ER-15 earmold for larger ear canals.)

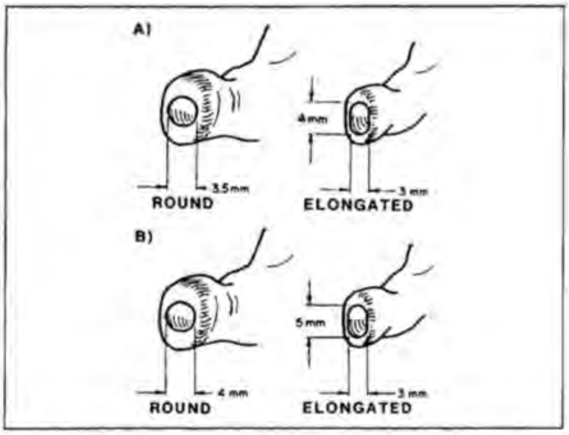


Figure 6. Sound channels for round and flattened ear canals: (A) 3.5-mm equivalent diameter; (B) 4-mm equivalent diameter.

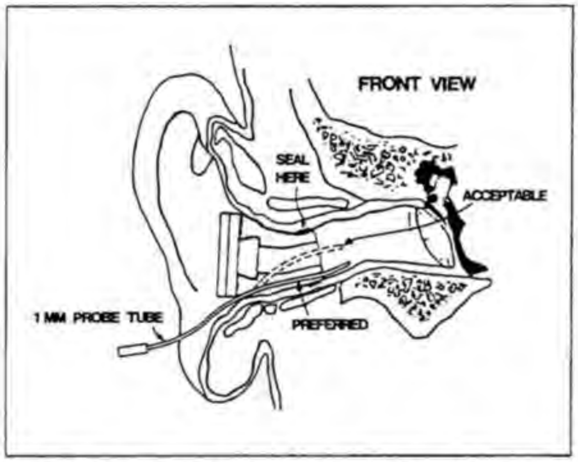


Figure 7. Preferred and alternate probe-tube channel locations.

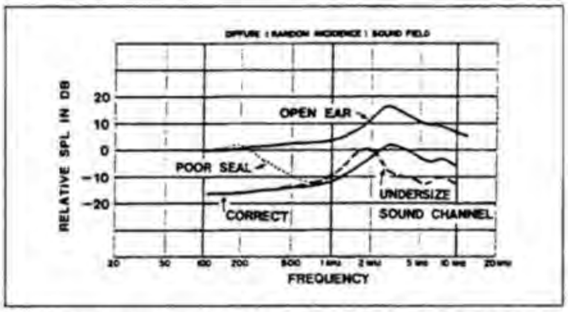


Figure 8. Expected eardrum SPL with ear open and with three constructions of ER-15 earmold.

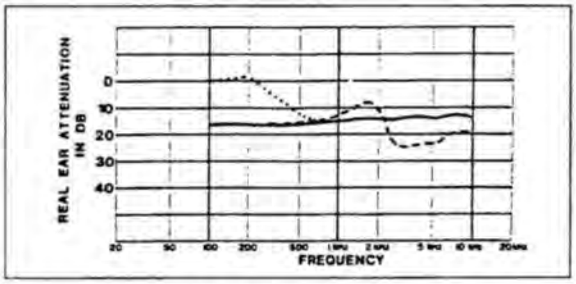


Figure 9. Calculated ER-15 performance vs. earmold construction: (—) correct (3.5 mm) sound channel, well-sealed; (. . .) poor seal, equivalent to 0.028" vent hole; (- - -) undersized sound channel (2-mm dia.).

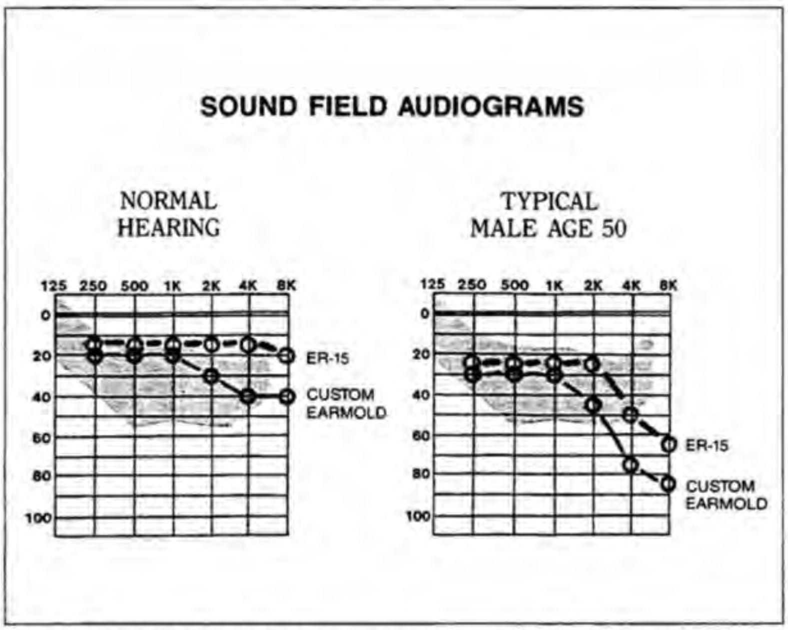


Figure 10. Expected sound-field audiograms, using conventional or ER-15 hearing protectors, for a normal-hearing person (left) and for a typical 50-year-old man (right).

proved with a flat attenuator. Note: this is a low-attenuation earplug with an estimated noise reduction rating (NRR) of 5 dB to 8 dB,* and is not meant for prolonged use in high levels of industrial noise or with gunfire.

Another potential application is for the person whose hearing probably is not really at risk, but who would prefer to hear without discomfort at amplified-music concerts. The authors also find that these attenuators make travel by both automobile and airplane more enjoyable. Production quantities will be available in the third quarter of 1988.

* The NRR estimates the A-weighted noise exposure from a C-weighted sound level meter reading under worst-case (- 2 sigma) conditions. The calculation of NRR is laborious and not simply related to the actual attenuation of an earplug at any frequency.

REFERENCES

1. Berger EH: Can hearing aids provide hearing protection? *Hear Instr* 1987; 38(3):12–14.
2. Killion MC, Wilber LA, Gudmundsen GI: Zwislocki was right . . . . *Hear Instr* 1988; 39(1):14–18.
3. Berger EH, Kerivan JE: Influence of physiological noise and the occlusion effect on the measurement of real ear attenuation at threshold. *J Acous Soc Am* 1983; 74:81–94.

Interview with Dr. Mead C. Killion, PhD

By Marshall Chasin, AuD
Editor-in-Chief

Marshall Chasin: The first time that I heard your name was when I was reading the 1981 *JSHD* article on "Earmold Options for Wideband Hearing Aids" (*Journal of Speech and Hearing Disorders* 1981;46[2]:10–20). Was that part of your PhD?

Mead Killion: No that was before my PhD. I was interested in earmold acoustics for years to achieve a sufficient amount of gain in the high frequencies, and most of the hearing aids at the time clipped badly in the higher frequencies so the distortion with louder inputs such as a cocktail party, would significantly reduce speech intelligibility. I became interested in this back in the 1960s about the same time that Dr. Keller (a German researcher) wrote that it was too bad that the Knowles transducers of the time had so many peaks in them because that degraded the sound quality of the hearing aids. I had already shown that the peaks were not in the hearing aid but in the tubing (tubing related resonances) and Hugh Knowles and I were sufficiently concerned about this at the time that we co-authored a paper ("Frequency Characteristics of Recent Broad Band Receivers." Knowles HS and Killion MC. *Journal of Audiological Technique* 1978;17:136–40) showing that with sufficient damping and an acoustic flaring (plumbing) or horn, we could obtain a flatter frequency response. I wanted to call it acoustic plumbing but Hugh thought otherwise: He didn't like the image it evoked.

MC: Starting with the 1981 *JSHD* article and with the subsequent advent of earmolds with great names such as the 8CR, and 6R12, you seemed to feel that an acoustic high frequency amplification was probably better than an electrical one. Do you still feel that this is the case?

MK: It was only true when most hearing aid amplifiers clipped badly at high frequencies. That problem was solved in the late 1980s with the advent of the class D amplifier, and continues to be solved with the switching output stage in digital hearing aids. Before that, the common class A amplifier required either an excessive amount of battery drain or they use receivers with so many turns on the coil that they "voltage clipped" when even a moderately loud high-frequency sound came along. (If you recall, with a Class A amplifier, half of the peak current is on all of the time, continuously draining the battery even in a quiet environment. That's why one could predict exactly the battery life of these old-style hearing aids regardless of the level of the input and the volume control used). Back in those days, it was always better to have the acoustic plumbing pick up 8–10 dB, which required only one-third the output voltage (roughly one-tenth the power) at high frequencies. I always enjoyed Hans Bergenstoff's answer to an audience question in Chicago in 1980: "You could get the same response with electrical equalization, but that would be like driving a car with one foot on the brake and one on the gas." Switching amplifiers are so efficient that you could (and still can) afford to do that, although some modern hearing aids could still use the response smoothing of a good horn earmold.

MC: Most people know you as an audiologist, but prior to that they would have known you as an engineer. Yet, I understand that you were a mathematician and never took any engineering classes.

MK: That's true in terms of formal classes. I have an undergraduate and a master's degree in mathematics. For my master's thesis my professor gave me what I thought was an interesting problem and I solved it in two weeks. I brought it back and was told that it wasn't very interesting. He then gave me what I thought was an impossible problem involving two-dimensional surfaces in four-dimensional Euclidean space. I worked on for five years, at the end of which I finally found a way to solve it. My professor liked it so much he had me defend it twice before the faculty. There were two parts to the problem – an easy part and a difficult one. He suggested I use the easier part for my master's and the more difficult part for my PhD dissertation. I might have become a mathematician, but in the course of solving that problem, I realized that I didn't like pure mathematics nearly as much as engineering and its applied mathematics.

MC: What led you to discover our field?

MK: I found a technical job working for an engineer's engineer named Elmer Carlson, director of engineering at Industrial Research Products (a Knowles Company). He was a wonderful inventor and mentor, and even more of a mathematician than I was. After 21 years under his teaching, in 1983 I decided to try my own wings and started Etymotic Research. I started it knowing that 80% of new businesses did not succeed, but only later found out later that those were mostly restaurants; and in fact 80% of new businesses started by engineers who had previously designed saleable products, succeeded.

MC: Tell me about Elmer Carlson and what was to become known as the ER-15 musicians' earplug.

MK: Elmer became interested in the fact that a lot of people required less attenuation and a flatter frequency response. I believe that it was Larry and Julia Royster that were quoted as saying that only about 1/3 of the workforce needed any hearing protection at all, and that 3/4 of those needed less than 10 dB of attenuation. So, Elmer thought a moderate-attenuation, say 15 dB reduction, earplug would be useful for almost everyone, even in industry, but especially for musicians. Being the superb acoustician that he was, he designed such an earplug. When Elliott Berger tested it in his EAR-CAL laboratory years later, he found that it was indeed flat, within 1–2 dB dB or so from 80 Hz to 16,000 Hz: What we now call the ER15 Musicians Earplug reduced the pressure at the eardrum by almost exactly 15 dB, compared to the open ear, at all frequencies. It stayed on the shelf because it appeared that the market for such an expensive earplug would be too small to justify the cost of introducing it. Fortunately, one of the viola players in the Chicago Symphony Orchestra ended up with a frightening temporary threshold shift after a concert where 200 musicians and singers were so crowded on stage that his head was almost in the bell of the trombone player behind him. He and a couple colleagues formed a "sound level committee" which resonated (sorry) across the county. I was invited to be a consultant, and once attended a meeting with the orchestra directors and union representative from the six major U.S. symphonies. After that meeting I approached Knowles about the Carlson earplug, and they very generously licensed it to us to produce under the Carlson patent. He himself was quite modest, and strongly declined to have it called the "Carlson Earplug," so we decided to call it the Musicians Earplug. Oddly enough, some viola players who thought that that was too *much* attenuation, and we later came out with the ER-9 following Elmer's basic approach. Still later, several drummers said that for jazz and orchestral work the ER-15 was fine, but it wasn't enough for rock. (Even unamplified, a drum can be beaten within an inch of its life to produce 135 dB peaks, as demonstrated to us recently by one of our engineers!)

MC: Before continuing on with the "ER" or "K"-prefaced other innovations, I recall in the mid-1980s you came out with a series of odd looking ear hooks, one of which was called the K-Bass (or Low-Pass) ear hook, which would allow significant (40 dB) low frequency gain with a non-occluding fitting. I have used it often for those with chronic middle ear dysfunction who require both low frequency amplification and a non-occluding vented hearing aid fitting.

MK: It's ironic because we are now seeing people lecturing that we can only get high frequency gain and output with a non-occluding tube fitting. The "K-Bass" hearing aid was our first product in 1983, designed for someone with normal *high frequency* hearing which you didn't want to interfere with. We started with an old Zenith power behind the ear hearing aid that could deliver 135 dB at 125 Hz. Even with the 20 dB loss for an open mold fitting, that still left 115 dB undistorted output at that frequency (which is more than some aids have now). We then coiled a long, small, tube inside the hearing aid to resonate the low-frequency response. An open-ear fitting naturally rolls off the low-frequency response at 6 dB per octave. In the final K-Bass design, the 2 cc coupler response rises at 6 dB per octave to compensate, with the result that a nearly constant 20 dB of gain was obtained from 150 to 1,500 Hz with a non-occluding tube fit. Chuck Berlin and I joked that it should have been called the Killion/Berlin ear hook since he asked if it could be done for one of his patients. The idea of a low frequency fitting with an open canal seems to have been lost but it's entirely practical, even now.

MC: Would this be able to be redesigned to give you a broadband signal with an open mold tube fit, using today's feedback management systems?

MK: Yes. It wouldn't be able to fit into something as small as a pea, but if you had any of the broadband high-gain, high-power, behind the ear hearing aids commonly used for children, this can be done. With digital equalization it would be trivial to shape the frequency response in order to compensate for the roll off in the lower frequency region.

MC: Moving to 1988 you had developed the K-AMP® hearing aid (with the invaluable assistance of fellow Canadian Bill Cole of Etymonic Design). What led you to this when there were already many hearing aids available for almost any use? Specifically what led you to design a hearing aid that could reliably transduce inputs of 115 dB SPL- the limit of modern hearing aids microphones- when the most intense components of speech was around 90 dB?

MK: We invited about eight people to help consult and design various parts of the K-AMP©, including Bill Cole, Norm Matzen and some semi-conductor people. The ability of a hearing aid to handle an input of 115 dB such as many forms of music has always been a design criterion at Etymotic Research, right from the breadboard stage. If it couldn't handle my piano playing or violin playing, it wasn't even considered. Even speech is misunderstood, I believe. The typical (even now) 90 dB maximum input in many hearing aid designs is enough for conversational speech, but not for many social gatherings. I recall Margo Skinner lecturing in Texas that the maximum speech levels were about 80 dB. That night at a Country and Western dance, she was talking across a picnic bench to a colleague and I held a sound level meter to the colleague's ear. It measured peaks of 95 dB. (Mild mannered Margo, indeed!) A 95 dB peak on a SLM corresponds to 105-110 dB instantaneous peak on an oscilloscope. A hearing aid that clips at 90 dB is wildly distorted at 110 dB inputs. A wonderful study by Naidoo and Hawkins in the *Journal of the American Academy of Audiology* (Monaural/Binaural Preferences: Effect of Hearing Aid Circuit on Speech Intelligibility and Sound Quality" 1997;8[3]:188–202) uncovered the reason many users reported they took off one hearing when they were in high-level noise: they heard better with only one distorting hearing aid! When there was not distortion, they preferred two.

MC: If you'll forgive me, we started talking about music levels and ended talking only about speech levels.

MK: You are quite right. Marshall, you yourself have repeatedly reported that many modern hearing aids are totally unacceptable to musicians, and your reports go back 10–15 years and still continue. Just last month we at Etymotic tested three digital aids at the request of a friend at a hearing aid company. The most recent design distorted the most on simple piano playing. Similarly, we sent some electronic BlastPLG earplugs to members of the National Symphony Orchestra, after I confirmed that they didn't distort on my own loud-as-possible playing. The orchestra musicians liked them but complained that they distorted on loud passages. (Which shouldn't have surprised me: It seems only fair that musicians in a world-class orchestra can play a violin or trumpet much more loudly than an amateur can!)

MC: That is interesting and consistent with my own experience fitting musicians at our Musicians Clinics of Canada here in Toronto, but I was hoping you would talk about what you did in the K-AMP design that changed that.

MK: I believe we were the first in the industry to use a balanced-input operational amplifier for the input stage (similar to mixing boards) that could handle 200–300 mV peaks at the input. That corresponds to 116–120 dB instantaneous peak into a typical microphone. (By the way, that input cancelled cellphone interference, so when digital cellphones came into use the K-AMP amplifier was already immune. We didn't plan on that, but it was a nice bonus.) But in order to make use of that input capability, it is important not to throw it away by amplifying loud sounds. Since most people need little or no amplification for loud sounds, the basic K-AMP design carried the undistorted reproduction from input to the ear.

MC: I would have thought you would also have mentioned that you and your design team did all that with only 300 A of battery drain, so hearing aid batteries could last for weeks. Are you as happy with the Digi-K as you were with the K-AMP?

MK: I'm happier with the modern Digi-K in the sense that it allows you to come as close to perfection as possible. In 45 seconds after it is placed in a 16 kHz soundbox, the Digi-K software measures the response, flattens all the microphone, receiver, and tubing peaks within a dB or so, and then introduces the appropriate BTE, ITC, or CIC CORFIG. Whatever goal you set for the frequency response, this approach does it better.

MC: I want to return to something that you just touched on regarding microphones. Electret microphones were invented by G.M. Sessler and J.E. West. (*Journal of the Acoustical Society of America* 1966;40[6]1433). But we don't think of Mead Killion when it comes to electret microphones – I understand that you were involved in the miniaturization of the electret microphone that makes it useful for modern hearing aids.

MK: Yes, and I am a friend of Jim West and followed his work. The first wideband microphone I helped design at Knowles was a ceramic microphone that had an 8,000 Hz bandwidth. This doubled the bandwidth of many magnetic microphones. We chose ceramic at first because that was a known technology and knew we that we could make a reliable microphone. It had the disadvantage of having a greater sensitivity to vibration. As soon as that was in production we started on the development of a stable miniaturized electret microphone. Usually when I had a design problem I showed it to Elmer Carlson who turned the problem around and clarified it and made it simple. That's why Elmer Carlson's name was usually first on any patent. In this particular case the problem was to get a stable structure for the microphone that would not be temperature and humidity sensitive. Instead of stretching the diaphragm it almost was a free-floating one sitting on a bunch of bumps. That structure allowed the microphone function to be essentially free of temperature and humidity. This was a very stable structure and if you put it in a case that was slightly larger, one could show that the internal noise was lower than that of the human ear. The much smaller microphones that are made now come close: Masking level equivalent to about 5 dB HL, which we have extensively confirmed with our BlastPLG earplug units.

MC: If you open up one of your insert earphones that are used for audiometry and research, you see Elmer Carlson's handiwork staring out at you. He invented the twin tube approach, didn't he?

MK: It's nice to have someone remember that innovation, perhaps Elmer's most brilliant. The hearing aid problem he was thinking about at the time was that you can't damp those nasty tubing resonances completely unless you put the damper at the end of the tube, which is the worst possible place to put it in an earmold from the standpoint of earwax (more about that problem below). His hero, Oliver Heaviside, had solved the electrical problem of resonances in telephone lines by realizing that a resistance placed at the end of an electrical transmission line could smooth the frequency response completely if the resistance equalled what he calculated as the "characteristic impedance" of the line. (Incidentally, Heaviside was kicked out of the British Royal Philosopical Society after demonstrating that those who said he was wrong were dunces. He also patented coaxial cable whose advantages can be viewed with a quick Google or Yahoo search.)

MC: That is interesting but what does it have to do with Elmer Carlson and his twin-tube damping method.

MK: Sorry, but you are the first one who has shown an interest in this great stuff. Anyway, Elmer knew all of Heaviside's mathematics and also understood they applied to acoustics as well. The characteristic impedance of an acoustic tube is 41/area cgs Ohms. Thus the ubiquitous #13 tubing, which has an I.D. of about 0.2 cm (0.193 cm to be exact), can be readily seen to have an acoustic impedance of 1,400 Ohms. A common damper of 1,500 Ohms is close enough to smooth the response beautifully if placed at the end of the earmold.

MC: Mead, you are usually direct. Have you forgotten the original question about twin-tube damping.

MK: Patience, my Canadian friend. I just stated that 1,400 Ohms at the tip of the earmold would smooth the response beautifully. But I also stated earlier that a damper in that location would be exposed to earwax: The hearing aid might sound beautiful for a while and then quit sounding at all! What Elmer realized, in a wild burst of intuition, was that you could add an auxiliary tube, so you have *two tubes*, the normal sound tube that is open at the (earcanal) end, and a "peak cancellation tube" blocked at its end. If you used two 1,400 Ohm dampers (in the example of #13 tubing) one damper at the beginning of the sound tube and one at the beginning of the blocked tube, *the combination would have a perfectly flat response.*

MC: What if that damper is right for smoothing the tubing resonances but is the incorrect value for smoothing the receiver response?

MK: Wonderful question. Here we see Carlson's total brilliance: Since you can choose any tubing you want (look at the wide variety of tubes used with open-canal hearing aids today), you are free to choose the tubing diameter, and thus the damper value, that gives the best damping and shaping of the receiver response. Pretty neat, huh?

MC: How has Etymotic Research exploited Elmer's invention, and didn't you need to obtain a license on his patent.

MK: Second question first: We were using Knowles transducers exclusively at the time, and that carried an implied license to such inventions – which we confirmed, of course. Our first use of the Carlson twin-tube damping was in the ER-1 and ER-2 earphones. The ER-2 is the most fun to describe, because it delivers sound to the ear at the end of 10 inches (254 mm) of tubing, and yet produces an eardrum-pressure response on the average ear (as measured on KEMAR and confirmed with probe-microphone measurements) that is flat within 2 dB from 200 Hz to 12 kHz (and 5 dB from 20 Hz to 16 kHz). It uses a #16 sound tube (1.35 mm I.D.) and thus a 1.35 mm pre-formed stainless steel cancellation tube of exactly the same length wound inside the case. The reader can readily calculate the dampers we use. By the way, it is unlikely that the sound tube will become clogged with earwax because the foam eartip is replaced with each use.

MC: What other uses has the twin tube approach been put to, and how have you been involved in them?

MK: The second twin-tube product was our ER-7C probe microphone, which also uses a coiled cancellation tube inside the case. The ER-7C uses a 0.5 mm ID tube with 0.97mm O.D., so it will fit in the smallest vent holes or around the earmold. In this case, the dampers are so tiny that the manufacturer who makes them calls them "no see ums," but this allows us to provide a flat response (with some simple electrical equalization to compensate for the attenuation of sound in small tubes) from 200 Hz to 10 kHz. We continue to provide these units for hearing research and hearing aid research.

MC: You really like Carlson's idea!

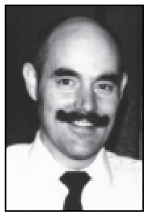
MK: Absolutely. We used basically his approach in the ER-3 insert earphone, which was our first product that anyone wanted. Indeed, we were looking at closing the doors until Nicolet placed a large order for ABR applications. With the ER-3 earphone we needed more power, but not as much fidelity because we only wanted to mimic the TDH-39 audiometric earphones. In that case we found we could produce more output (less loss) by using a "lumped element" version of the twin tube. Elmer has taught that you could use acoustic mass elements (tubing) and acoustic compliance elements (volume) to give a close approximation to the pure twin tube transmission line. The result looks like sausages (volumes) strung on tubes (masses) inside the ER-3 earphone case. Not as pretty, but highly efficient in smoothing the resonances. By the way, the twin tube approach has been used by progressive hearing aid manufactures as well.

MC: Speeding forward to the 1990s, you (and Etymotic Research) had been involved in otoacoustic emissions, dosimetry, blast plugs, hi-fidelity earphones, insert earphones. Is there anything that you haven't been involved in?

MK: We had the company evaluated several years ago and the evaluator said that "You are the most difficult company to evaluate I have ever seen. You are involved in almost everything. You are not just consumer products; you are not just diagnostics; you are not just hearing protection." But to answer your question, we don't make ABR units and have no intention to do so.

MC: And the most important question of all, in the K-Bass, the K-AMP, and the Digi-K, what does the "K" stand for?

MK: Before I answer that question, I want to state that it was the board of directors who urged me to use my own name whenever possible. It didn't take much encouragement, of course. The answer to all of those is "Killion," but in the case of the K-Bass aid Chuck Berlin was largely responsible for making such a hearing aid in the early 1980s, and so that might be considered the Killion-Berlin hearing aid.



Mead Killion, Ph.D.
(circa 1983)

FIRST PRESS ANNOUNCEMENT (July 1983)

Killion Launches Etymotic Research Inc.

FOR IMMEDIATE RELEASE....

Elk Grove Village, IL. Mead Killion, Ph.D., has announced the formation of Etymotic Research, Inc., a new company to do research and product development in the hearing instruments field. "We have been extremely fortunate," says Killion, "that Knowles Electronics has granted us the development rights to three important new products on which I worked. We hope to bring out the first one early in 1984."

Killion has spent 21 years in the hearing aid industry. He helped develop the first subminiature ceramic microphone, the subminiature electrets microphone, and subminiature directional microphones. He is probably best known for developing earmold coupling systems to improve both the useful bandwidth and the sound quality of hearing aids. He has been granted eight U.S. patents, either as sole inventor or with co-inventors, and has two more pending.

Killion is an Adjunct Professor of Audiology at Northwestern University. He has written and lectured extensively on hearing aids and earmolds, with papers published in the field of electroacoustic, psycho- and physiological acoustics, and audiology.

The corporate name ETYMOTIC is pronounced et-im-OH-tik. It is a newly coined "ancient Greek" word, which here means "true to the ear." The corporate name reflects Killion's commitment to unflawed sound reproduction for the normal or impaired ear.

The Board of Directors of Etymotic Research includes Charles I. Berlin, PhD, Jack Clemis, MD, Barbara Kruger, PhD, E. Robert Libby, Edgar Villchur, and Laura Wilber, Ph.D.

MISSION We develop products for the ear. We are a product development group.

GOALS • To be the leader in product development for the ear. • To earn sufficient profit to reach and maintain that leadership.

VALUES

1. We put the customer first. Without satisfied customers we can't achieve our goals.
2. We are a high-integrity group of people. We value that.
3. We design products that solve real problems, and are proud ofi t.
4. We build products that help people hear now and hear later.
5. We are glad you are here. We welcome your energy, talent, sense of humor, decision-making ability, and insight into our strengths, weaknesses, and blind spots. If you find someone who doesn't welcome these things, point out this paragraph to them.
6. We trust your judgment. If no one is around to check your decision, please take your best shot.
7. We value risk-taking. We learn from our mistakes; when we realize we have made a mistake, we admit it and try to do better next time.
8. We don't like a lot of rules and authority. We avoid them by insisting that each person take personal responsibility for getting the job done.
9. We are committed to keeping our promises.
10. We measure results, not actions.
11. We work hard and value the work ethic.
12. We try to have fun. It makes our jobs more enjoyable.
13. We commit to long-term relationships; with our customers; with our suppliers; and with each other. This commitment helps carry us past the inevitable frustrations with others (who are, naturally, likely to be less perfect than we are) to the mutual trust and confidence that comes from surviving the hard times together.
14. We realize that people come in packages, usually with a ding or two (sometimes several). We can't keep the parts we like and discard the parts we don't like.
15. We believe that once the goals are set, the enlightened supervisor is more servant than boss, providing the information, supplies, equipment and training required by the task to be performed.
16. We believe that the best return on shareholder investment will follow from concentrating on the successful introduction ofi mportant new products, and not from focusing on "making money. " That's not why we do it, but it is pleasant that it usually works out that way.
17. We treat everyone, even competitors, as friends.

Development of the E-A-RTONE™ / ER-3A and ER-5A Audiometric Insert Earphones

By Allan H. Gross, MA

About the Author

Allan Gross completed his undergraduate work in speech pathology and audiology at Kent State University, and received his MA in audiology from Case Western Reserve University. He has worked as a clinician, a medical service corps officer and head of an Occupational Health and Preventive Medicine Directorate for the US Navy, a hearing conservation specialist in the civilian sector, and as a consultant in assistive technology to public school systems. He is presently the manager of 3M Auditory Systems, the licensed manufacturer of the E-A-RTONE 3A and 5A Insert Earphones.

The Telephonics Corporation Model TDH-39 supra-aural earphone was the standard headset for the US Air Force during WWII. Ironically, after the war, it also served our veterans and others, in quite a different way; as the standard audiometer transducer for the then nascent field of audiology. Waning in popularity, but still provided along with some new equipment by audiometer manufacturers today, the supra-aural style earphone in an MX-41/AR or similar rubber "noise occluding" cushion has changed hardly at all since its early contribution both to the war effort itself, and in the subsequent understanding and remediation of the auditory consequences associated with that combat. Unfortunately, the persisting limitations of the supra-aural earphone continue to frustrate hearing health care professionals to this day. The limitations include; poor ambient noise exclusion particularly at the lower frequency range, poor inter-aural separation increasing the need for masking of the non-test ear, a limited bandwidth, inaccurate real-ear frequency response, and a headband force that reduces comfort and may collapse the external auditory canal of some test subjects, resulting in falsely elevated threshold responses.[1] In addition, as the nature of audiological procedures requires direct and indirect contact with multiple patients and multiple objects, infection control has become more of a critical issue in health care.[2] As such, supra-aural cushions need to be cleaned for each patient, or disposable earphone covers must be employed to provide hygienic protection. Finally, the supra-aural headband, although adjustable, will not always provide an appropriate fit to insure that the test signal is appropriately directed towards the eardrum without reliance on an awkward accommodation for some patients.

For approximately the same number of years that Moses wandered in the desert of Midian, audiometer manufacturers continued to provide TDH-style supra-aural earphones with their audiometers as the only readily available transducer for audiometric testing. A technological corner was turned, however, on July 5, 1984, when US Patent Number 4,677,679; "INSERT EARPHONES FOR AUDIOMETRY" was filed by Mead C. Killion, PhD. It was undoubtedly just one of many worthy of note inventions for which patents had been filed during that year, including the battery driven golf cart, and the Aerobie™ flying ring. This particular development, however, that expanded on the work of the late Elmer V. Carlson and Ross Gardener Jr., and facilitated by the development of wideband subminiature receivers, was the dawn of an evolutionary change in the way audiometric testing would be administered in the US, and across the globe. The "Method", "Stimuli," or "Procedures" sections of published audiological research gradually began to

Figure 1.The E-A-RTONE 3A Insert Earphone.

Figure 2.The E-A-RTONE 5A Insert Earphone.

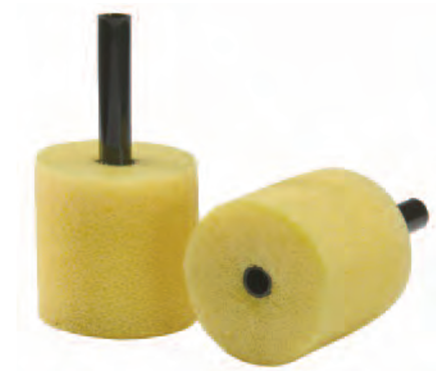


Figure 3. E-A-RLINK™ 3A (standard adult size) foam eartips.

specify not only the audiometer make and model used, but also the earphone.

Initially introduced as the ER-1® and ER-2® Tubephones – high-fidelity, reference-quality insert earphones for research applications - those versions were followed by a standard audiometric ER-3A® Tubephone version which, primarily by virtue of the way it coupled to the ear, resolved or mitigated most of the vexing limitations of the supra-aural earphone noted above. The ER-3A Insert Earphone was designed specifically to mimic the limited real-ear frequency response of the TDH-39 device so that the two transducers could be used interchangeably.[3]

In 2001 Killion's company, Etymotic Research, in a co-development project with Aearo Technologies, (now a part of 3M Company, and still the sole licensed manufacturer of the identical but re-branded E-A-RTONE™ 3A), introduced the "next generation" insert earphone – the E-A-RTONE/ER-5A Insert Earphone. Utilizing the existing foam coupler system of the tubephone insured that the same basic calibration procedures applied, and that all the advantages of the original device would be maintained. The E-A-RTONE 5A Insert Earphone provides the additional benefits of no front tubes to replace, an extended high frequency range, increased output capability, and greater ease of foam eartip insertion. The E-A-RTONE 3A Insert Earphone and E-A-RTONE 5A Insert Earphone, as currently produced, are illustrated respectively in Figure 1 and Figure 2.

The published research to date investigating the relative performance of supra-aural earphones and insert earphones has confirmed that the problems encountered with supra-aural earphones can be resolved or diminished by switching to an insert earphone. Here's why:

REDUCTION OF BACKGROUND NOISE

With a properly inserted E-A-RLINK (Figure 3) foam eartip as the coupler, the E-A-RTONE Insert Earphone can be expected to provide 30 to 40 dB of ambient noise attenuation; a reduction sufficient to permit testing to audiometric zero in typical office noise levels, and considerably greater than supra-aurals with or without an added circumaural enclosure.[4] The greatest difference is in the frequency range below 1,000 Hz, where the effect is most critical. Table 1 shows the difference in decibels between the ears covered ambient attenuation for supra-aural and insert earphones. Reliable thresholds on normal-hearing listeners (to 0 dB HL) can be obtained under field-testing conditions with insert earphones if the ambient noise levels are known to be below 40 to 45 dBA.[5]

Table 1

Earphone			Frequency in Hertz						
Type	125	250	500	1,000	2,000	3,000	4,000	6,000	8,000
SA	6.0	4.0	5.0	12.5	19.5	25.0	25.5	24.0	23.0
IE	29.9	31.4	33.7	34.0	34.1	37.9	38.6	40.7	42.7

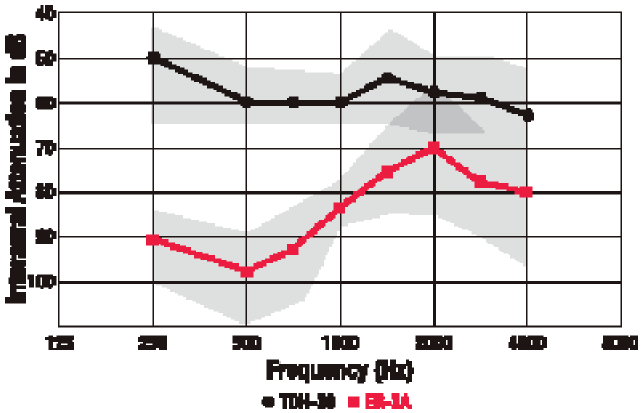


Figure 4. Comparison of the interaural attenuation of the TDH-39 and ER-3A insert earphone.

GREATER INTER-AURAL ATTENUATION

Arguably, the most valuable advantage to clinicians is the E-A-RTONE Insert Earphone's high inter-aural attenuation characteristic. Insert earphones significantly reduce testing time and complexity by limiting the situations where clinical masking is necessary, and reducing the masking level required when the potential for crossover does exist. When masking is needed, the lower levels that can be employed with insert earphones will reduce the chance for errors.[6] Figure 4 illustrates the inter-aural attenuation advantage of the insert earphone compared to the TDH-39 (supra-aural) earphone.

ELIMINATION OF COLLAPSED CANAL ARTIFACT

With an insert earphone's foam eartip properly placed in the earcanal, holding it open rather than collapsing it, the problem of canal collapse artifact is eliminated.[7]

HEARING AID SELECTION

Because an insert earphone is calibrated via a 2-cc coupler, and interacts with the ear much like a hearing aid, both maximum output and 2-cc coupler gain requirements for amplification can be determined in less time and with greater confidence compared to an earphone that is calibrated via a 6-cc coupler.[5]

IMPROVED HYGIENE / LESS MAINTENANCE / BETTER SUBJECT FIT AND COMFORT

The disposable foam eartips used with the E-A-RTONE Insert Earphone prevent any cross contamination from one ear or one patient to another. There are no headbands or cushions to adjust, clean, and periodically replace, and most subjects are likely to be more comfortable with a lightweight insert earphone connected to the appropriate size foam eartip in their earcanal than with a supra-aural earphone.

For the above and other advantages. including improved test-retest reliability, reduced occlusion effect in bone conduction testing, and stimulus artifact resolution in auditory evoked response evaluations that space limitations rule out describing in more detail herein, those who test hearing with insert earphones, and those who are tested with them, owe Dr. Killion their greatest esteem and appreciation.

REFERENCES

1. Killion MC. New Insert Earphones for Audiometry. Hearing Instruments 1984;35:45–46.
2. Bankaitis AU. Infection Control in the Audiology Clinic: Frequently Asked Questions. Audiology Today 2005;17(5):17–19.
3. Killion MC. Earphones in audiometry. Journal of the Acoustcal Society of America 1988;83:1688–89.
4. Berger EH and Killion MC. Comparison of the Noise Attenuation of Three Audiometric Earphones, with Additional Data On Masking Near Threshold. Journal of the Acoustical Society of America 1989;86(4):1392–403.
5. Clemis JD, Ballad WJ, and Killion MC. Clinical Use of an Insert Earphone. Annals of Otology Rhinology and Laryngology 1986;95(5):520–24.
6. Killion MC, Wilber LA, and Gudmundsen GI. Insert Earphones for More Interaural Attenuation. Hearing Instruments 1985;36:34–36.
7. Killion MC and Villchur E. Comments on 'Earphones in audiometry (Zwislocki et al., Journal of the Acoustical Society of America 1988;83:1688–89)" Journal of the Acoustical Society of America 1989;85(4):1775–78.

The ER-15 – Development of a Good-Sounding Earplug

By Elliott H. Berger, MS

About the Author

Elliott H. Berger, MS, is a division scientist for 3M's Occupational Health & Environmental Safety Division. For over 35 years, Elliott has studied noise and hearing conservation with an emphasis on hearing protection. He has numerous text book chapters and over 60 published articles in the topic area, and chairs the ANSI working group on hearing protectors. Among his favourite sounds is his terrier, Sophie, munching on a sesame brittle treat.

Throughout the first 40 years or so of hearing protector research following World War II, the developments were all about hearing protection, that is, the more the better. This was natural – after all wasn't protecting hearing what such devices were intended to do? It wasn't until the early 1980s that authors began to ask whether the frequency dependence of the attenuation characteristic, and its amount, might be affected so as to provide better sounding protection and the "appropriate" level of protection, too. By that was meant an attenuation characteristic that was relatively uniform across the primary portion of the audible frequency range, and designed for the right value of protection – as opposed to simply the most attenuation possible. This type of attenuation would avoid the muffled sound typical of passive (i.e., non-electronic) hearing protection.

At about this same time Mead Killion was working with the Chicago Symphony orchestra to address their concerns regarding noise exposures of their musicians. He realized that a promising solution to the exposure issue would be a flat-attenuation hearing protector providing a natural-sounding music spectrum. Fortuitously, Mead's mentor, Elmer Carlson (Figure 1), had already conceived of and described such a hearing protector in the late 1970s. It incorporated acoustic elements into a sound channel through an earplug, but Carlson had never produced or marketed the product. Mead was able to license the Carlson patent[1] from his employer, Knowles Electronics, and turned the concept into a commercially viable product in 1988 – the ER-15 Musicians Earplugs™.

A drawing of the product embodied in a custom earmold, and its equivalent circuit, appear as Figure 2, and a photograph of the earplugs appears as Figure 3. As Killion et al.[2] succinctly describe, an acoustic button at the entrance to the earplug incorporates a flexible plastic diaphragm that acts as a compliance (C1) and a sound channel (L1) that provides an acoustic mass to form a Helmholtz resonator between the inertance of the sound channel, and

Figure 1. Mead's mentor, Elmer Carlson.

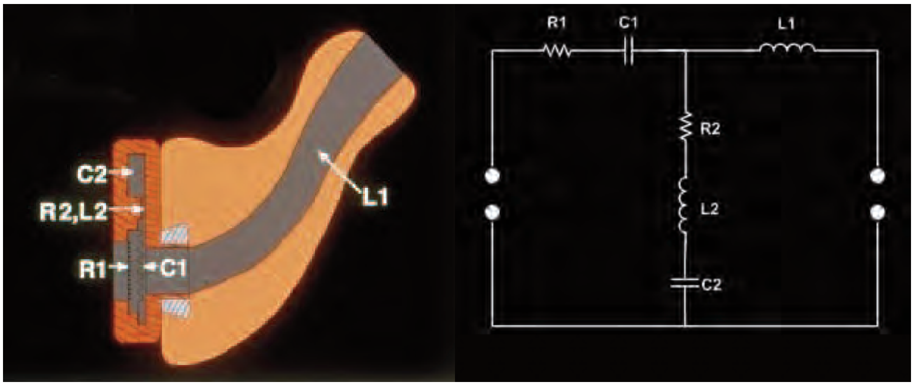


Figure 2. Cross sectional diagram (left) and electrical equivalent circuit (right), of the ER-15 custom molded earplug.

Figure 3. Photograph of ER-15 earplugs.

the combined compliance of the flexible diaphragm and the earcanal volume. The resonance can be tuned to about 2.7 kHz, providing the desired boost to offset the loss of the ear's natural resonance at that frequency which occurs whenever the ear is occluded by an earplug. Another feature of the earplug is that it includes a sound inlet to the button (R1 in Figure 2) that is recessed and near the concha floor. This advantageously utilized the ear's natural high-frequency amplification to further offset the earplug's built-in tendency to block more high-frequency sound than low-frequency sound. And finally, the R2/L2/C2 side branch corrects for a minor dip in response near 6 kHz to provide the flattest possible attenuation.

The elegance of the Musicians Earplugs was well suited to the original intended audience, symphony musicians, but many others both within and outside the music industry, from bar tenders at loud clubs to NASA astronauts on the International Space Station (Danielson 2011, personal communication) have adopted it as well. Whenever modest attenuation and an earplug that sounds natural is required, i.e., just as though the sounds of the world were slightly attenuated instead of unpleasantly filtered, the Musicians Earplugs are a perfect fit. Another valuable application is for those experiencing tinnitus and hyperacusis who need modest good-sounding attenuation to be able to comfortably hear the world.[3] They substantially benefit from the ER-15, which provides protection yet lets in enough sound to help mask the tinnitus and make it more tolerable. Conventional earplugs not only distort sound, but can also block so much ambient noise that one perceives that the tinnitus is worsened while the plugs are worn.

To make the product more affordable and universally available, Mead's company, Etymotic Research, teamed with the E•A•R™ brand of Cabot Safety Corporation (now the E•A•R™ brand of 3M Company) in a joint-development effort. That work resulted in a premolded eartip version of the Musicians Earplugs dubbed the ER-20 earplugs, today called the HiFi™ earplugs as sold by 3M, and the ETY•Plugs™ earplugs as sold in two sizes by Etymotic (Figure 4). The ER-20 provides much of the performance of the ER-15 at less than 1/10 price and, thus, makes it available to a larger audience.

Figure 5 shows the response curves of the two products compared to the attenuation of well-fitted conventional earplugs. Note how both the ER-15 and the ER-20 provide lower levels of protection and, especially in the case of the ER-15, more uniform levels of protection across frequency. My response, when as an experienced user of hearing protection in the late 1980s I fitted a pair of ER-15 earplugs for the first time, was "it sounds like there is nothing in my ear." It took me a moment to confirm that I was actually getting protection since the muffled and distorted characteristic common to other hearing protection of that era was absent.

One of the difficulties of promoting a product like the ER-15/20 is that so much of the hearing protection business is driven by the Noise Reduction Rating (NRR), the Environmental Protection Agency required noise rating that appears on all hearing protection in the U.S. Most

Figure 4. Photograph of the original size (large) and the new smaller size (standard) ETY•Plugs™ high-fidelity earplugs.

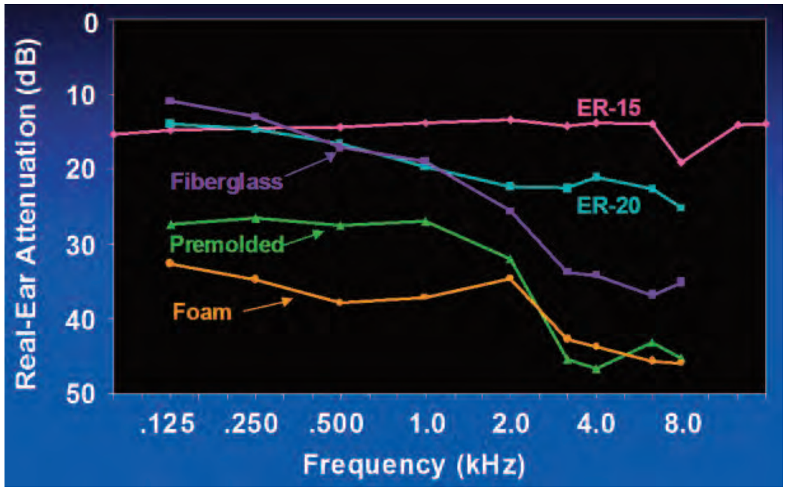


Figure 5. Attenuation of the ER-15 and ER-20 earplugs compared to well-fitted conventional style earplugs.

buyers want as high an NRR as possible, which the ER-15/20 does not provide since it is not intended for high attenuation. Mead responded to this unfortunate more-is-better model of thinking by following the dictum that any self-respecting fallacy should be voiced in Latin. He coined the phrase *Parvum bonum, plus melius*, meaning "a little is good, more is better," and proceeded to argue strenuously against that notion, both in word ("If two aspirin are good for your headache, should you take the entire bottle?") and indeed (by purveying the Etymotic line of flat and moderate attenuation earplugs).

As an early adopter of the ER-15 earplugs, I have been personally grateful to Mead for commercializing this invaluable product as it has immeasurably increased my listening enjoyment and auditory safety for over 20 years. Thank you, Mead, for an elegant engineering solution, and the willingness to risk the introduction of, what was at the time, such an unusual product.

REFERENCES

1. Carlson EV. Passive Ear Protector. U. S. Patent 4,807,612. 1989.
2. Killion MC, DeVilbiss E, and Stewart J. "An Earplug with Uniform 15-dB Attenuation. Hearing Journal 1988;41(5):14–17.
3. Berger EH. Life Can Be Loud – Remember Your Hearing Protection. Tinnitus Today 2003;28(1):20–22.

Killion and the K-AMP®

By Bill Cole

About the Author

William A. Cole is the president of Etymonic Design, a manufacturer of the Audioscan and Verifit. Bill has been involved in the hearing aid industry for more than 40 years and has been responsible for many of the standards and technologies now in use.

Somewhere on my desk is a small box awaiting my attention. It was sent to me by an old friend along with a note reading "I have been informed that this hearing aid can no longer be repaired. I am hoping that you can help because it works better in noisy situations and at the opera than any of the new digital aids I have tried."

In the box was a very old K-AMP® hearing aid and its story begins in 1975. In that year, Mead Killion began work on a 2-year PhD in audiology at Northwester University. His research project was the design and evaluation of high-fidelity hearing aids. Considering that the best hearing aids of the time had very limited bandwidth, a mountainous frequency response and high distortion, this was a very ambitious and challenging project. In the 4 years that followed, Mead was able to demonstrate that it was possible, using available hearing aid microphones and receivers and a wearable amplifier, to make a hearing aid that was judged by listeners with normal hearing to be as good, or better, than expensive studio monitor speakers.

Mead had already solved part of the frequency response problem when he and Elmer Carlson invented a miniature electret microphone, suitable for use in hearing aids, with a broad, smooth frequency response (US patent 4151480). Smoothing and broadening the response of available wideband hearing aid receivers required the application of known acoustic principles to the coupling system between the receiver and the ear canal. Applying these principles, Mead demonstrated that it was possible to achieve a variety of smooth, wideband responses in both BTE and ITE configurations, including one ITE with nearly flat insertion response from 50 Hz to 16 kHz. The ear-level assemblies were coupled to low distortion body-worn amplifier packs which Mead designed. The "how-to" information needed to achieve smooth wide-band response was widely disseminated through publications and lectures and Knowles Electronics made available a damped coupling assembly (BF-1743) to encourage manufacturers to improve the response of their products.

In the course of his PhD studies, Mead came to the conclusion that there was a large class of people who had near-normal hearing for loud sounds but had lost sensitivity for soft sounds – particularly those in the high frequencies. He postulated that, for these people, a high-fidelity hearing aid would be one that provided unobtrusive (i.e., low distortion) high frequency amplification for soft sounds and do absolutely nothing for loud sounds. Mead disclosed the amplifier circuit for such a hearing aid in US patent 4170720.

Aside from skepticism of the need for a high-fidelity hearing aid, there were two significant problems preventing hearing aid manufacturers from building such hearing aids – fitting in the necessary circuitry and finding a place for the AA battery.

Work to solve the first of these problems was begun by Etymotic Research in

1986. It was a task that frequently pushed the limits of technology and human endurance but never compromised the goals Mead had established. I recall arriving at O'Hare at 11:00pm and being invited to join the crew for Mexican food at Etymotic where nobody was thinking of calling it a night. And while marvelling at how fresh Mead was at 2 pm the next day, discovering that he had been power napping on the couch in the listening room. It took 3 years and a team of more than 10 designers to develop the K-AMP microchip and its associated circuit module but by the fall of 1989, Etymotic was able to introduce what truly was a breakthrough in hearing aid technology.

The solution to the second problem evolved from Mead's interest in Class D amplifiers dating back to 1963. Because of space limitations, the ITE hearing aids of the time used Class A amplifiers which consume a constant battery current. The current required to produce a given undistorted SPL increases with frequency. A hearing aid battery powering a class A amplifier capable of delivering the undistorted high frequency SPL required by Mead's postulated hearing aid would last about 1 day. The Class B amplifiers of the time were much more efficient but were too large to fit the available space. Class D amplifiers were potentially more efficient than Class B and much smaller but nobody had ever designed one for hearing aids. In 1988, Mead Killion did so, under contract to Knowles Electronics, and was granted US patent 4689819. The amplifier was small enough to fit entirely inside the hearing aid receiver and efficient enough to produce the undistorted output needed for a high-fidelity hearing aid.

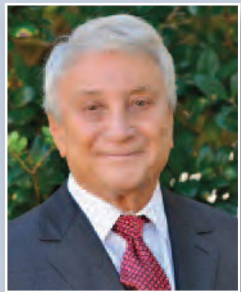
After wearing prototype K-AMPs for 3 months, Mead felt something was missing and was convinced by Harry Teder of Telex that the answer was something called "Adaptive Compression" (a Telex trademark). This patented compression scheme provided a release time that varies with the level and duration of loud sounds – and it was indeed the missing piece. It was licensed from Telex (patent 5144675 was obtained for its use in wide-dynamic range hearing aids) and it became part of every K-AMP circuit.

By 1989, all the elements necessary to build the high-fidelity ITE hearing aids that Mead had envisioned a decade earlier, were available to every hearing aid manufacturer. In the months that followed, with tireless enthusiasm, Mead delivered the K-AMP message to dispensers and the hearing impaired through countless lectures and numerous papers and articles. And demand grew. At its peak, the K-AMP hearing aid accounted for nearly 20% of hearing aids sold in the US and Europe.

Why was the K-AMP hearing aid so effective? Its smooth, wideband frequency response ensured that much-needed audibility was not compromised by limited bandwidth and discomfort-causing peaks. This also ensures that the effects of room reverberation were not exaggerated and (for CIC aids) that important localization cues were not masked by hearing aid peaks. Its low distortion over a wide frequency range for input levels up to 115 dB SPL ensured that the high frequency components of speech and music (often at low levels) were not masked by distortion products. The provision of (usually) high frequency gain for soft sounds and a zero gain (usually) flat response for loud sounds compensated for the loss of outer hair cell function. Also important was a compression threshold curve that was the inverse of the gain curve which meant, when adjusted for a high frequency loss, that frequencies that were not being amplified did not cause the gain to be reduced at frequencies where it was needed. All of these features combined with the adaptive-release time contributed to its legendary performance in noise. But, above all, the K-AMP was effective because Mead refused to make the compromises that others were prepared to live with.

Mead Killion and Chuck Berlin

By Charles I. Berlin



About the Author

Charles I. Berlin, PhD, retired on 9/1/02 as professor of otorhinolaryngology, head and neck surgery, and physiology, and director of the world-renowned Kresge Hearing Research Laboratory at LSU Medical School in New Orleans. He is the recipient of the American Academy of Otolaryngology, Head and Neck Surgery's highest award, the Presidential Citation; the recipient of the Honors of the Association as well as the Frank J. Kleffner Award for Lifetime Clinical Achievement from the American Speech Language and Hearing Association; and the recipient of the Lifetime Career Research Award from the American Academy of Audiology.

He is currently coordinator of the Auditory Neuropathy Spectrum Disorders Program at All Children's Hospital, St. Petersburg, FL and clinical professor of otolaryngology head and neck surgery at the University of South Florida.

When I went to professional meetings, I often sought out a piano in order to stay in practice for my (all too infrequent) paying jazz gigs. At the time I was living in New Orleans and playing at least twice a week, sometimes more often on Bourbon Street and at the Fairmont Hotel. When I found the backstage piano my first night there, and played a few notes on it, I found it to be in tune and looked forward to a long and pleasant practice session over the next few days. What was especially appealing about backstage pianos at hotels was that the sound didn't travel very far past the heavy curtains and one was almost always alone….allowing reverie, introspection, risk-taking and mistakes…lots and lots of mistakes.

Mead and Chuck first met at a piano backstage at the ASA Headquarters Hotel (maybe the Hilton) in San Diego at the Acoustical Society of America meeting in November of 1969.

So there I was hoping to indulge in a reverie and make lots of "innovations." I was frankly put out when I went back stage the next day and found this bald dude with a mustache playing on MY piano, and without permission! But he was pretty good, so I listened a bit and then sort of easily slid into a four hand piano playing mode, where he played the bass and I the treble, and then we switched. The hours just flew by and we had a great time. I told him my name was Chuck, and he said something than sounded to me like "Mead" and I said to myself "That's a drink made of honey, we should play Honeysuckle Rose." And we did. I excused myself to go to a meeting, and he did the same.

Then we both sat in the front row to hear a talk on …whatever…which is when we found out we were in the same profession and field. However, it was the piano and jazz that made us fast friends forever. The collaborations on hearing projects were just icing on a delicious cake. (And when Mead married Gail, it was a startling friendship because our spouses bonded as well. So both Mead and Gail are among our best friends and Gail is my special link to the Basics in my life.)

Mead was working at Knowles at the time and I learned a lot about his work on wide band hearing aids. Fortuitously we soon thereafter discovered a form of hearing loss where hearing was normal at 10 kHz while it was very poor in the more commonly tested frequencies. How were we going to manage that?

Well, some talented people in my lab (Henry Halperin and the late Jack Cullen) hatched an idea to build a frequency shifting aid that moved low frequencies up to high. But what were going to be the tranducers?

Killion to the rescue with Knowles B-1912 transducers! He made the first shells and mounted the transducers in them which went out to 16 kHz. A remarkable technical achievement for the 1970s and even today.

It was a huge success with these patients and we soon published some germinal, but now mostly ignored papers, on ultra audiometric hearing. Mead, Linda Hood, and I also published a FUN paper on an open ear fitting for LOW frequency losses! It was called the K-Bass aid where the high frequency output of a power aid was muffled by a special ear hook, the open ear allowed the high frequencies through which were heard normally, and there was a comfortable but not overpowering low frequency amplification for the 10 or so patients who were candidates. One of those patients, the only one who rejected the aid, actually had auditory neuropathy/dys-synchrony which I only discovered long after the paper was published!

It should come as no surprise that Mead, Gail, and my wife Harriet and I travel together from time to time. We especially enjoy a magical place called Chautauqua in upstate New York, where the lectures, the music, and the zeitgeist are just perfect for a group of music-and-science-loving eccentrics like us.

ETYMOTIC RESEARCH: THE FIRST 25 YEARS OF RESEARCH & DEVELOPMENT - 1983-2008

The early 1980s represented a new electronic age which saw the introduction of numerous technical devices to assist consumers in telephone communication and increase their access to and appreciation of music. Products such as personal portable radio/cassette players, FAX machines, cell phones and compact disc technologies were introduced. This time frame was also a period of advancement ofi n-ear technologies and greater public acceptance of hearing aids. On September 7, 1983, during a routine press conference, the news media observed that President Reagan was wearing a hearing aid in his right ear, which proved to be a priceless endorsement of hearing aids and helped boost sales to record levels. In fact, in 1983, hearing aid sales surpassed the one million mark for the first time in history.

This atmosphere ofi nnovative technology set the stage for the establishment of a new company that would focus on the design of high-fidelity products that measure, improve and protect hearing. Armed with two and one-half degrees in mathematics, a PhD in audiology, and more than 20 years of experience in electronic component manufacturing, Mead Killion took the giant step forward to initiate his own commercial enterprise during the summer of 1983.

When Mead established Etymotic Research, a friend told him that starting and sustaining a business was like being on a roller coaster: Many highs and many lows, but you are strapped in and might as well enjoy the ride. Mead believes that the success of a company is never due to just one person. Etymotic is defined as much by its team players as by its founder. Mead is proud of the fact that while he participated in all developments, taught the art or mentored the individuals involved, 17 of Etymotic's (almost 100) patents do not have the name Killion on them. Most projects are a complex blend of art and science. Novel ideas are as likely to germinate at the lunch table as at the boardroom table. Mead is quick to give credit to others and he takes delight in their accomplishments. He advocates celebrating the small things: Etymotic has toasted a new company sign, the first $1-million month, shipping the 1000th ERO-SCAN, and countless other events and successes. A summer BBQ in the parking lot is as meaningful as a formal holiday party.

The success of Etymotic Research is nothing short of remarkable. Etymotic Research has developed insert earphones for audiometry and auditory brainstem response testing; otoacoustic emissions screening and diagnostic devices; directional and array microphones; a real-ear probe microphone for research; K-AMP and Digi-K hearing aid circuitry; Companion Mics; a multi-talker noise-reduction system; Musicians Earplugs; non-custom high-fidelity earplugs; personal dosimeters and a sound level meter.

Never losing sight ofi ts mission, Etymotic Research has expanded from audiology-based products to innovative devices for the high-growth consumer electronics and telephony markets. Etymotic has almost 60 employees and many consultants and colleagues who contribute to research and product development. Etymotic is rich in relationships with passionate people from all over the globe. This amazing group shares a common goal: To make the world a better place.

Digi-K and Mead Killion

By David Preves

About the Author

David Preves, who is currently a senior staff engineer at Starkey Laboratories, was a consultant at Etymotic Research in 2001-2002. He is a life member of the International Institute of Electrical and Electronic Engineers, Audio Engineering Society and the American Auditory Society, and is chair of the Acoustical Society of America (ASA) accredited working group on hearing aid standards.

It has been my pleasure to know Mead Killion as a friend, brilliant engineer, and highly talented musician. If there could ever be a modern day renaissance man, it would be Mead. I have often thought how fortunate our hearing health care industry has been to have the interest and attention of such a talented and caring person.

When I began working as a consultant at Etymotic Research in the fall of 2001, Mead and several of his engineers had already begun working on the development of a programmable digital hearing aid circuit that would ultimately become known as the Digi-K.

The Digi-K high fidelity hearing aid circuit was an extension of Mead's PhD dissertation work at Northwestern[1] and his lifelong belief about the need and feasibility of hearing aids having a smoothly-extended high frequency bandwidth. Mead has long held the belief, which is somewhat controversial, that persons with hearing loss can make use of extended high frequency sounds and can distinguish whether they are present or not. Therefore Mead advocated long ago that hearing aids should amplify at frequencies above 10,000 Hz after he demonstrated 30 years ago that hearing aid microphones and receivers could produce frequency responses out to 16kHz.[2]

In the early 1980s, Mead advocated extending hearing aid high frequency response while he worked as an engineer at Industrial Research Products, Inc.– the research division of Knowles Electronics. Mead promoted, in concert with hearing industry earmold labs (National Association of Earmold Laboratory Manufacturers), a system of stepped earmolds for behind the ear hearing aids as a way of extending their high frequency response. Perhaps some readers will remember how the individual stepped earmold designs were distinguished in this unique system of earmolds – for example, 8CR,6R12, 16KL. These devices were essentially miniature megaphones for the high frequency output of hearing aids, working in conjunction with a damping screen placed within the earmold tubing or earhook to damp out peaks to provide a wideband, flattened frequency response. (Mead's 1970's dissertation work involved blind comparative listening tests by hundreds of people at various conventions and speaking occasions rating recordings made on KEMAR of hearing aids with these earmolds against recordings made with high fidelity components. The wideband hearing aid was judged superior in sound quality every time.) One of the main difficulties with the stepped earmolds was the damping screen would become clogged with moisture and debris. Ultimately, the demand for these earmolds waned, and they no longer are being manufactured.

For the DigiK introduction (AAA, Philadelphia 2002), Etymotic Research prepared an audio CD containing binaural KEMAR recordings that compared the sound quality of various types of music in the open ear against processed music through seven digital

Figure 1.

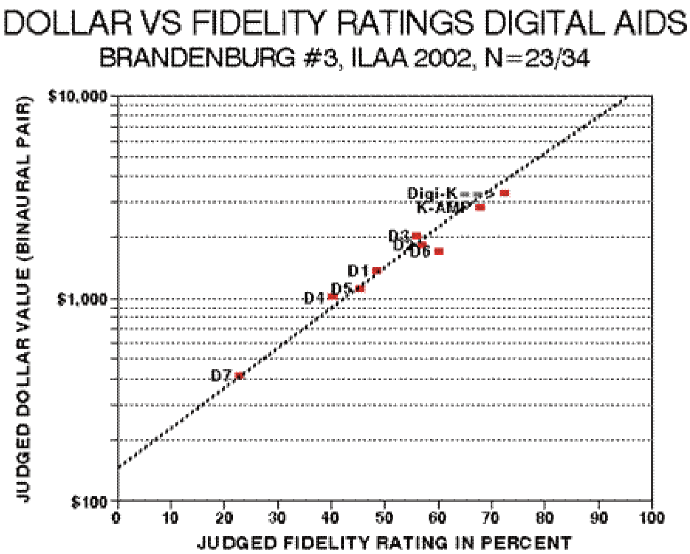
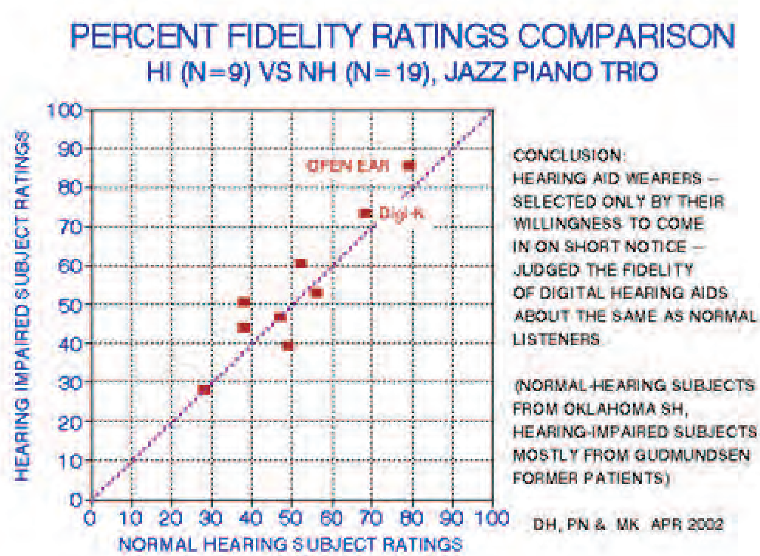


Figure 2.



hearing aids and hearing aids having Digi-K and analog K-AMP® circuits. These same recordings were also used in juried listening tests performed by both normal and hearing impaired listeners. The listeners were also asked to assign a dollar value to the sound quality they perceived for each listening trial. Figure 1 shows results obtained for 23 normal hearing listeners at the 2000 Illinois Academy of Audiology meeting. The Digi-K and K-AMP had the highest fidelity ratings and corresponding dollar value. Figure 2 shows that ratings for the 7 digital and Digi-K hearing aids made by hearing impaired and normal hearing are very similar, with the Digi-K again coming out with the highest rating, close to that obtained with the music played through the open KEMAR ear.

Unfortunately, at the time of the DigiK introduction, many of the larger hearing aid manufacturers were already developing their own hearing aid integrated circuits and did not, in general, perceive the need for wideband hearing aids or the DigiK.

However, time has ultimately proven out Mead's vision of over 30 years ago: finally, the need for wideband hearing aids has been firmly established, and hearing aid manufacturers are responding with devices extending well into the higher frequencies, well beyond the upper frequency limit achieved previously.

For those readers that are interested in more design details, some of the unique concepts that went into developing the Digi-K circuit were ultimately patented in the Etymotic Research US patent 7697705.

REFERENCES

1. Killion M. Design and Evaluation of High Fidelity Hearing Aids, Northwestern University, PhD dissertation. 1979.
2. Killion M, Preves D, Scicluna R, Niquette P. Hearing Aid Fidelity Ratings: 25-Band Accuracy Scores and Compression Characteristics. IHCON Conference, Lake Tahoe, CA. 2002.

I Can't Think of Any (Reasons)

By Gregory Flamme, PhD

About the Author

Greg Flamme is an associate professor in the Department of Speech Pathology and Audiology at Western Michigan University in Kalamazoo, Michigan. He was a co-developer of the Etymotic ER-200 Personal Noise Dosimeter, and his research focuses on the prevention and treatment of hearing impairment due to noise and other exposures.

An airplane seat, pencil, and a notepad are a powerful set of tools. For me, flights are a period of uninterrupted time to assemble and examine thoughts that might poke their heads out during regular days but then get whacked down by the figurative mallet of the next telephone call, meeting, e-mail, or other daily crisis. Over 10 years ago, as I sat on a flight with my trusty notepad and pencil, I had the modest idea that people benefit from knowing about their noise exposure, and that the necessary technology probably existed. Eventually, I shared this idea with Mead Killion, and the years and discussions led to the ER200 Personal Noise Dosimeter.

I grew up in a rural area, where hearing loss due to noise exposure and poor overall health is all too common. And, the people I remember from my childhood were not ignorant in matters of safety. Indeed, they spent a great deal of effort trying to find ways to get work done safely. However, their personal experiences with injuries and death from dangerous work takes the focus away from the chronic problems presented by such things as noise exposure, particularly when there are no available tools to help you judge the risk.

Some people have jobs or hobbies that incidentally put their ears at risk and these things take their toll over time. They might elect to jeopardize hearing in order to avoid what they perceive to be a more immediate or severe problem. They also might put themselves at risk unknowingly out of habit and the unfortunate examples others provide. But whether the sacrifice results from the choice made on a menu of bad options, or through lack of awareness, it is my perspective that nobody wants to sacrifice his or her hearing.

There were lots of different types of hearing protection available at the time, and there are even more now, but how is a normal person supposed to know when they should be used and how much protection is needed? Sound survey data can be used in industrial environments with active hearing loss prevention programs. But what about the millions of people who don't work in environments where these programs are in place? People in small business, musicians, farmers, those with noisy hobbies … what about them?
You have to know your risk before you can respond appropriately. Simple rules

have their place, but the person whose days are marked with a huge variety of exposures and listening needs quickly uncovers the flaws of simple rules. Furthermore, we haven't the necessary time or personnel to expound upon the virtues of the logarithm, decibel, A-weighting, or the roles of exposure duration and exchange rate. Neither can we expect to convey successfully the pregnant concept of "excess risk of material hearing impairment." Even if we managed to do all this, people are still left with the problem of obtaining a device that actually measures the sound levels!

Regular people can, however, understand the concept of a percentage. Further, the percentage could be expressed using the language of the traffic light, where you only need to know you're okay if it's green, you're treading close when it's yellow, and red means you're in the danger zone. Why not develop a personal noise dosimeter that speaks a language that is useful to a layperson?

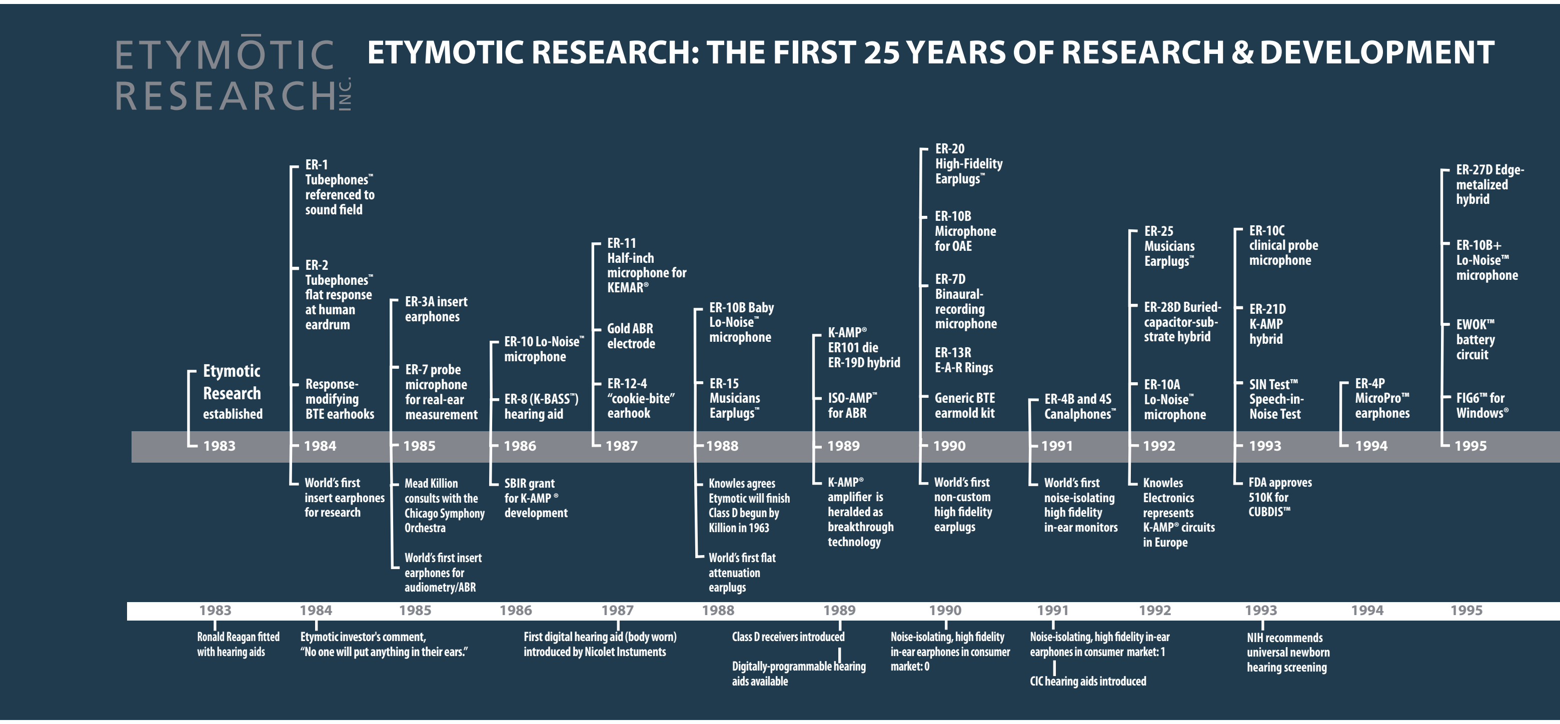
The function of a noise dosimeter is really very simple. All it has to do is measure sound levels and add them up over time, ultimately leading to a ratio of observed sound exposure to a maximum permissible exposure. Consumer electronics have developed to the point where much more complex operations are performed, and at a reasonable cost.

Thus the idea of a consumer's personal noise dosimeter emerged. But an unexpressed idea has no potency, and I didn't have the technological skill or resources to convert my vision into a tangible tool. I needed a partner. I needed a person who would look critically at this idea and give an honest opinion. A partner with the experience of transforming all those things that *could be* into things that *are*.

I had spoken with Mead Killion on perhaps half a dozen occasions at this time in my life, and all of my interactions were the kinds of chatter that one can expect at a professional meeting. I couldn't presume that he knew anything about me, but I knew a few things about him.

- He shares his opinion – using both barrels as necessary
- He can change how people think about what they do
- He is a masterful engineer
- He gets things done

I ruminated on the idea of the consumer noise dosimeter for a while, eventually convincing myself that it wasn't one of the crackpot schemes that many ideas turn out to be. Finally it was time to let someone else in on it. I ran into Mead in the hallway at a convention and told him I had an idea that I'd like to run by him.



My question: *Is there any reason why it would be impossible to make an inexpensive noise dosimeter for consumer use?* He paused and thought. I took this as a good sign. The longer he paused, the more optimistic I became.

Bad ideas are easily recognized by the person whose trade it is to turn ideas into reality. In the first few moments of the pause, I figured he was finding a gentle way to tell me I had a crackpot idea and enumerate the reasons why it wouldn't work. I was ready for this. But as the pause grew longer, and my mind stretched the time, I could only conclude that he either thought it a workable idea, or that the reasons it was unworkable extended well into the horizon.

Mead's reply: "I can't think of any. Let's talk later."

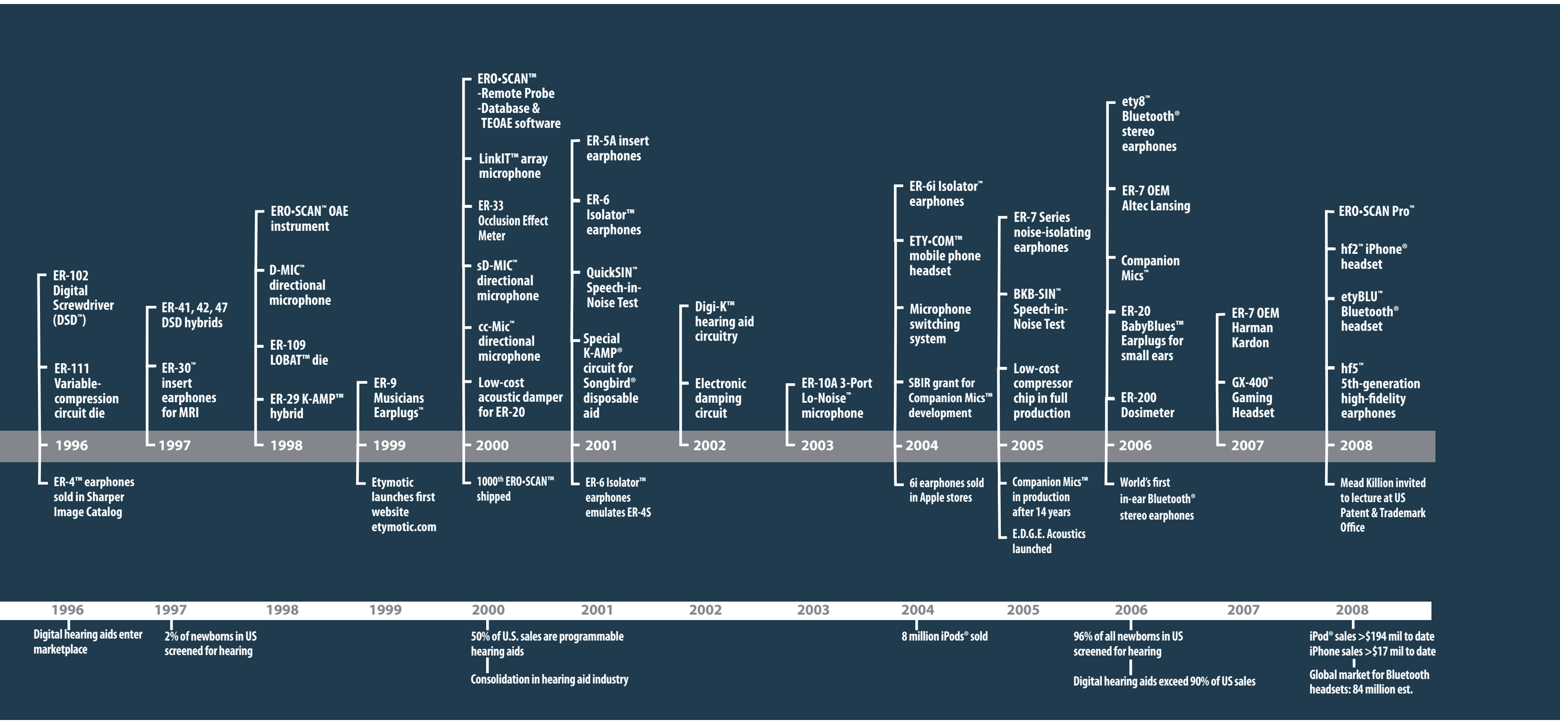
This response exceeded any expectations.

The decade since that response has been amazing. A thought has been made tangible. I have worked with some of the brightest and most capable professionals I've encountered. The device, the ER200 Personal Noise Dosimeter has two versions. The ER200D allows download and subsequent analysis; the basic unit, the ER200, is designed for the layperson who simply wants to know his or her noise dose. These devices provide information that would have been otherwise unavailable to a layperson. We have provided the ability to know, and subsequently take steps to minimize, one's exposure to noise.

In addition, the ER200D has made possible a set of small- and large-scale assessments of noise exposure. For example, we are currently conducting what is, to my knowledge, the largest study of comprehensive noise exposure that has ever been attempted in an unscreened population. To date, this study has obtained continuous noise dosimetry data over a period of over 3000 person-days. Interim results from this study have shown that the average person hovers near the auditory injury threshold in daily life, and that occupation plays a role in one's overall noise exposure profile – even in those occupations that would not be conventionally considered noisy.

The results also demonstrate that although there is a gender difference in noise exposure, the difference seems to be limited to the upper end of the exposure distribution. That is, the most-exposed men have considerably higher exposures than the most exposed women. However, this gender difference disappears for moderate and low levels of exposure.

The papers in the current issue are only the visible parts of the greater iceberg of Mead's impact in the field. But as with many prominent people in the field, his contributions extend well beyond the visible. Perhaps his greatest influence has been the part he plays in the orchestra of professionals working tirelessly to improve the state of hearing health.



What Is It Worth To You? The Value of Sound Quality, Mentoring, and Friendship

By Catherine V. Palmer, PhD

About the Author

Dr. Palmer is an associate professor in the Department of Communication Science and Disorders at the University of Pittsburgh and serves as the director of audiology and hearing aids at the University of Pittsburgh Medical Center. Dr. Palmer opened the Musicians' Hearing Center at the University of Pittsburgh Medical Center in 2003 and has focused a great deal of energy on community hearing health since that time. This work has included a partnership with the Pittsburgh Public Schools and the Pittsburgh Symphony that promotes hearing protection for young and professional musicians.

In 1989, I found myself in the enviable position of having Mead Killion as a co-advisor in my journey through the PhD program at Northwestern University. We met weekly in order for me to realize that I would never know half of what Dr. Killion knows, but more importantly for Dr. Killion to push me to think in new ways about amplification. The discussion moved to outcome measures. Dr. Killion was already thinking out of the word recognition box. As technology improves, how will we efficiently and accurately measure differences among signal processing and hearing aid features without running into ceiling and floor effects? What type of outcome assessment might be intuitive to listeners; something that has every day meaning to them? Value. Everyone understands value. We assign value to things in our lives every day.

So we designed an experiment to assess the value of sound quality to listeners. Sound quality judgments were obtained on two binaural pairs of laboratory hearing aids. One pair of hearing aids had a low-current-drain "starved Class A" output stage. The other had a new (at the time) "Class D" output stage. Speech and music were rated. Subjects were asked to assign a dollar value to each condition by answering the question "What would you pay for a hearing aid that sounded like that?" Normally-hearing and hearing-impaired groups rated the hearing aids with the class D output stage as having superior sound quality across a variety of input levels and test materials, consistent with objective distortion measurements. On the average, each one-percentage point increase in sound quality rating corresponded to a $6.75 increase in perceived value in these experiments. Subjects had no difficulty understanding the task of assigning a dollar value to sound quality and clinicians had no difficulty relating signal processing and feature choices to perceived value. Of course, class D receivers (or equivalent) are now standard in hearing aids and we have moved on to other signal processing issues.

The real lesson came when we went to publish this work and were told in the first of several rejection letters that value was not an appropriate or acceptable outcome measure in amplification research. The lesson from Mead, of course, was knowing when you are right and refusing to have what you consider work that could positively impact individuals with hearing loss rejected. The editors either finally saw the light through our endless attempts to "educate" them or realized it was easier to publish this paper then continue to interact with us. Either way, financial assignment continues to be an efficient way to assess the value of hearing solutions to listeners and we have seen this metric used in a number of studies since the mid-1990s.[1–6] Just as a note, this method is used extensively in other fields that deal with products and services for which consumers pay.

I continue to learn from Mead (now he is a friend) about all things hearing aids every time we interact. Value continues to be a focus for Mead as he tries to bring technology that has true worth to individuals with hearing loss or individuals trying to protect their hearing at prices that create value for users. These things impact my approach to teaching and research and they encourage me to take a stand when something is important in our field. But the most important thing I ever learned from Mead was to celebrate – often – to celebrate small milestones in life rather than waiting for the big accomplishments, to celebrate friends and family constantly. For this, I am very grateful.

REFERENCES

1. Abrams H, Chisolm T, McArdle R. A Cost-Utility Analysis of Adult Group Audiologic Rehabilitation: Are the Benefits Worth the Costs? Journal of Rehabilitation Research and Development 2002;39, 549–58.
2. Abrams H, Block M, Chisolm, T. The Effects of Signal Processing and Style on Perceived Value of Hearing Aids. Hearing Review December 2004.
3. Chisolm T, Abrams H. Measuring Hearing Aid Benefit Using a Willingness To Pay Approach. Journal of the American Academy of Audiology 2001;12;383–89.
4. Palmer C, Killion M, Wilber L, Ballad W. Comparison of Two Hearing Aid Receiver-Amplifier Combinations Using Sound Quality Judgments. Ear and Hearing 1995;16(6):587–98.
5. Schweitzer C, Jessee S. The Value Proposition of Open-Fit Hearing Aids. Hearing Review September 2006.
6. Taylor R., Paisley S, Davis A. Systematic Review of the Clinical and Cost Effectiveness of Digital Hearing Aids. British Journal of Audiology 2001;35(5):271–88.

QuickSIN™ Test: It All Began with ABONSO

By Patty Niquette, AuD

About the Author

Patty Niquette has been an audiologist for almost 25 years. She earned a master's degree from the University of Iowa and a doctorate from the Osborne College of Audiology at Salus University. For the past 15 years she has been a research audiologist at Etymotic Research, where she has had the privilege of working with Mead Killion and other talented audiologists, scientists and engineers to develop products to measure, improve and protect hearing.

In the recent *Wired Magazine* article "The Breakthrough Myth," author Clive Thompson noted, "Anything that's going to have an impact over the next decade…has already been around for 10 years." He further stated that "Evolution trumps revolution, and things happen slowly."[1] Interestingly, about 10 years before the introduction of the QuickSIN™ test, Dr. Mead Killion, in discussing the difficulty hearing aid users have hearing in noise, stated that they had lost ABONSO: the Automatic Brain Operated Noise Suppressor Option. He believed so strongly in this concept that he light-heartedly created an alter-ego, Dr. Abonso. Prior to the evolution of the QuickSIN, there was ABONSO. It all started with ABONSO.

Dr. Abonso

The ABONSO concept is simple: the most powerful, exquisite noise suppressor on the planet is the one that each of us is born with: the human brain. The first time I heard the term ABONSO was in Mead's lecture, "The K-AMP™ Hearing Aid: An Attempt to Present High Fidelity for the Hearing Impaired."[2] Mead was discussing what was then, and still is now, the biggest problem reported by hearing aid users: difficulty hearing in noise. In normal hearers, our ABONSO allows us to function in the most difficult listening situation: that in which what we want to hear is speech ("target talker") and what we don't want to hear is *also* speech ("background talkers"). For example, one minute Joe might be the target talker, while Sue, John and Mary are background talkers; when conversation shifts, Mary might be the target talker and Joe, Sue and John the background talkers. We tune in to the target talker and tune out the background talkers, and when the target and background talkers switch, we seamlessly make the necessary shift and carry on. How is this ability affected by hearing loss?

Most sensory hearing loss occurs in the high frequencies and progresses slowly, resulting in a reduction in high frequency speech cues – those that carry the most meaning in our language. In quiet, the person may still be able to function, but when noise covers up a portion of the remaining audible speech cues, the person with hearing loss has difficulty hearing in noise. Historically, hearing aids didn't help much in noise, since they were narrow-band amplifiers that produced too much gain for loud sounds, not enough gain for quiet sounds, and plenty of distortion. Mead contended that by cleaning up hearing aid defects and distortion and providing a clean, audible, wideband signal, the brain could relearn to process the missing speech cues, allowing an individual to reclaim their ABONSO. And Mead's high-fidelity K-AMP hearing aids did just that. Beyond that, Mead contended (and research has since shown), filtering and signal processing don't substantially increase speech intelligibility in noise; that is, no signal processing technology has been shown to be superior to the human brain.[3]

As time went on and millions of K-AMP hearing aids were sold (mere hundreds by me personally), some of us noticed a curious phenomenon: while some patients no longer struggled in noise, others (with the same or better pure tone audiometric thresholds) still had difficulty. Mead concluded that we needed to look beyond what we were measuring on the pure tone audiogram – we needed to actually *measure* the ABONSO.

Mead has a remarkable grasp of the scientific literature, and he often points to the wealth of data that already exists in most areas we study. (For example, a quick search of the journal archives of the Acoustical Society of America revealed a citation for speech-in-noise testing dating back to the first issue in 1929.[4]) The only reason to create a new speech-in-noise test would be if an adequate measure didn't already exist. When designing a speech-in-noise test, the choice of speech and background noise materials is a compromise between realism and reproducibility. Monosyllabic words at a uniform intensity level are not representative of real speech, and a constant-level background noise, while easy to control and reproduce, is not typical of the background noise encountered by most people in their everyday lives. Mead thought these factors were essential to incorporate into a speech-in-noise test, and a test of that nature did not already exist.

Etymotic Research's first speech-in-noise test, the SIN Test,[5,6] evolved from the research of Mead's doctoral student, Selda Fikret-Pasa. In her doctoral dissertation, Fikret-Pasa (1993) combined a Massachusetts Institute of Technology recording of IEEE sentences (Institute of Electrical and Electronics Engineers, 1969) with a recording of four-talker babble (Auditec of St. Louis 1971) to study the effects of compression ratio on speech intelligibility and quality. These materials were chosen for their natural speech dynamics and realistic simulation of a social gathering. Based on discussions with Fikret-Pasa and the earlier teachings of Tom Tillman, Mead combined the IEEE sentences and Auditec four-talker babble into test blocks. Each test block had five sentences at each of four pre-recorded signal-to-noise ratios (SNRs of 15, 10, 5 and 0 dB) and two presentation levels (70 and 40 dB HL).

As a clinician I used the SIN Test on a number of my patients. For the first time I could identify before the hearing aid fitting which patients would likely hear well in noise, and which patients would likely have trouble hearing in noise, even after being fit with wideband, low distortion, high-fidelity hearing aids. I was measuring their baseline ability to hear in noise – their ABONSO. And my patients loved it; for the first time, they believed they were being tested for the one issue that gave them the most difficulty: understanding speech in noise. Many times they exclaimed, "This is exactly what it sounds like to be me, listening in noise with a hearing loss!" As constructed, however, the SIN Test was time-consuming and the scoring was cumbersome. This wasn't a problem for Mead, who was known to spend as much as four hours with a single patient in a single visit (and still does, on occasion). However, for the rest of the world, test time and complexity were a deterrent to use of the SIN Test, and it wasn't embraced by the clinical community. Additionally, some subjects couldn't understand enough words, even at the best SNR, to score the test. It was a good tool that needed modification.

Eventually I left clinical work for a position at Etymotic Research, and in the late 1990s we began a series of experiments to develop a clinical speech-in-noise test using the same premise as the SIN Test (realistic speech and background babble, with multiple signal-to-noise ratios) but that was quick and easy to administer and score. The result, the QuickSIN Test[7] was comprised of 12 one-minute lists, each having one sentence at each SNR of 25, 20, 15, 10, 5 and 0 dB. The QuickSIN Test measures SNR loss, which is the increased signal-to-noise ratio needed to understand speech in noise, compared to someone with normal auditory function. The SNR loss cannot be predicted from the pure tone audiogram or any other standard audiometric test.[8] Like hearing loss, we suggested categories of SNR loss (normal, mild, moderate and severe) to aid in describing the degree of hearing-in-noise difficulty and the amount of SNR improvement needed for the person to function in noise. The new test format and simplified scoring method resulted

QuickSIN Test

in a practical test that could be used clinically to quickly and easily quantify a patient's ABONSO and assist professionals in choosing technology (hearing aids, directional microphones, and other signal-to-noise enhancing technologies) and provide information useful for counselling regarding realistic expectations. The QuickSIN™ Test proved so useful, in fact, that informal surveys indicated it is the most widely used speech-in-noise test among audiologists and hearing instrument specialists in the United States.[9,10]

The QuickSIN…it all began with ABONSO. Where will we be 10 years from now? It's difficult to predict, but the process of evolution is exciting. The QuickSIN is showing promise as a tool to assist clinicians in identifying mild traumatic brain injury (TBI) in our soldiers returning from Iraq and Afghanistan, and work is being done to incorporate speech-in-noise protocols as part of a rehabilitative tool. Perhaps 10 years from now, I'll write another article, "It all began with QuickSIN." Stay tuned.

REFERENCES

1. Thompson C. 2011. The Breakthrough Myth. Wired, 7/26/11; Retrieved June 26, 2011. http://www.wired.com/magazine/2011/07/st_thompson_breakthrough/.
2. Killion MC. The K-AMP Hearing Aid: An Attempt To Present High Fidelity for the Hearing Impaired. Paper Based On A Presentation at the Mayo Audiology Video Conference. American Journal of Audiology 1993;2(2):52–74.
3. Killion MC, Niquette PA. Principles of High-Fidelity Hearing Aid Amplification. In Sandlin RE (ed), Textbook of Hearing Aid Amplification: Technical and Clinical Considerations, Third Edition. Kentucky, USA: Cengage (In press).
4. Knudsen VO. The Hearing of Speech in Auditoriums. Journal of the Acoustical Society of America 1929;1(30).
5. Killion MC, Villchur E. Kessler Was Right—Partly: But SIN Test Shows Some Aids Improve Hearing In Noise. Hearing Journal 1993;46(9):31–35.
6. Etymotic Research. The SIN Test™ (Compact Disk). Elk Grove Village, IL. 1993.
7. Etymotic Research. The QuickSIN™ Speech-in-Noise Test (Compact Disk). Elk Grove Village, IL. 2001.
8. Killion MC, Niquette PA. What Can the Pure-Tone Audiogram Tell Us about A Patient's SNR Loss? Hearing Journal 2000;53(3): 46–48, 50, 52–53.
9. Mueller HG. In The Words of Shakespeare: Fitting Test Protocols Are "More Honored In The Breach and the Observance." Hearing Journal 2003;56(10):19–20, 22–24, 26.
10. Mueller HG. Three Pre-Tests: What They Do and Why Experts Say You Should Use Them More. Hearing Journal 2010;63(4):17–18, 20, 22–24.

Audibility *is* (almost) Everything!

By Ruth Bentler PhD

About the Author

Ruth Bentler, PhD, is professor and chair in the Department of Communication Sciences and Disorders at the University of Iowa. Her longtime interest in optimizing hearing aid technologies that promote user satisfaction and benefit has driven both her research and her friendships.

It was a dark and stormy night … back in 1996, sitting in the Washington, D.C. airport, awaiting a flight to Chicago. A number of audiologists from around the country had converged on the capital city for a "Hearing on the Hill"; that is, we went to test the hearing of members of Congress in an attempt to bring awareness of both our profession as well as the prevalence of hearing loss in our country. The event was pretty momentous, as we had hoped. At the time, audiology in general, and hearing aids, specifically, were taking pretty hard hits by the FDA and its leader. So, here we sat, two disciples of audiology, Mead Killion and I, rejoicing in our small but positive input to the *cause*. But it really *was* a stormy night in D.C., and flights were delayed. We ran out of accoladic words about our profession and its past and future and began to formulate another plan. What if we did a study (well, I would do the study and Mead would fund it) to show the naysayers just how good hearing aids were; that is, how far we had come in terms of advanced technology in the last 100 years. We almost feverishly plotted how we could start with the ear trumpet era at the turn of the 20th century, include the body aid era of the 30s and 40s, onto those crummy peak clippers of the 50s and 60s, then the first programmable multichannel hearing aids of the 80s, and finish with the newest technology of all: the recently released digital hearing aids of the mid-90s. Because Mead would be funding this venture, we threw in the K-AMP™ as an analog single-channel design, with its TILL processing from the 80s.

Flash forward: The study went well. My graduate student, Monica Duve, and I gathered loads of evidence about improvements in bandwidth, distortion, MPO, etc. – all those hearing aid attributes that significantly improved over the 20th century. What we found relative to our speech-in-noise outcomes created plenty of stir in the field, however. The brand new, high technology, digital processors that had just hit the market did no better in noise than some of the earlier models of hearing aids, including the *ear trumpet!* Oh, my. As provocative as that finding was, our intent to impress David Kessler (the current FDA czar) had taken an unintended detour. In fact, by the time our well-intentioned findings were published[1] there were plenty of critics condemning the "ear trumpet" study for reasons such as "no control group" (the unaided ear?), no binaural conditions (we plugged one ear), and failure to fit the hearing aids optimally (all were fit to era or manufacturer specifications), and so on. But Mead was undeterred. In his lifetime he has sought to prove that good high fidelity[2] (class D amplifiers) coupled with cochlear-like nonlinear processing[3] (K-AMP), with a broad-band response[4] were the foundation blocks of hearing aid user acceptance and satisfaction. Our data supported his cause. Most recently, Mead has shown evidence that the success can be further enhanced by easier accessibility and affordability (PSAPs) without compromising the primary tenant of audibility.

While Mead and I might not agree on all things related to hearing aids, we agree on this: Audibility may not be everything, but it is the best place to start. Without audibility, there is no reason to add the bells and whistles of the current market. I would add: Without *verification* steps, we really don't know the status of that audibility. Mead's recognition of the *dead region* impact has led to many papers and presentations devoted to understanding how audibility may be compromised – but not undone – by that unfortunate state.

As a final note, we did another study in my lab a few years later, dubbed the "hype" study.[5] Subjects were fitted with different pairs of hearing aids, deemed to be "conventional" or digital." The reality (for one group) was that the subjects were wearing the same set of hearing aids. Even though we had optimized the audibility for those subjects, many believed that the ones labelled *"digital"* were actually superior. While this non-surprising finding took Mead off into a direction of "making them believers" in their own success, he was still carrying the same thesis: Audibility is the one sure way to begin the success. The rest of the story is convincing the patient they really can succeed. (Flashback to a Jackson Hole Rendezvous where Preacher Killion was convincing Disciple Fabry he *could* walk again if he believed strongly enough).

That dark and stormy night ended pretty well. Our flight took off about midnight, as the rains moved on. Fortuitously for me, my connection from Chicago to Iowa City was cancelled. Mead took me home with him. What a surprise that was for Gail, his wife and my longtime friend. As a result, I got a few more hours of Mead-time, and truly delighted was I to listen, learn, and laugh a little longer, until my flight finally took me home.

REFERENCES

1. Bentler RA Duve M. Comparison of Hearing Aids over The 20th Century. Ear and Hearing 2000; 21:625–39.
2. Killion MC. www.etymotic.com/publications/erl-0008-1985.pdf The Noise Problem, There's Hope. Hearing Instruments 1985;36(11):26.
3. Killion MC. The K-Amp Hearing Aid: An Attempt to Present High Fidelity for Persons with Impaired Hearing. American Journal of Audiology 1993;2:52–74.
4. Killion MC and Villchur E. www.etymotic.com/publications/erl-0024-1993.pdf Kessler Was Right-Partly: But Sin Test Shows Some Aids Improve Hearing In Noise. The Hearing Journal 1993;46(9):31+.
5. Bentler R, Niebuhr D, Johnson T, and Flamme G. Impact of Digital Labeling on Outcome Measures. Ear & Hearing 2003;24:215–24.

ERO•SCAN™

By Laurel A. Christensen, PhD

About the Author

Laurel A. Christensen, PhD, is the chief audiology officer for GN ReSound Group. Prior to joining GN ReSound, she was a researcher and director of sales and marketing at Etymotic Research in Elk Grove Village, IL. While at Etymotic, she was part of the development team for the D-MIC, the Digi-K, and the ERO-SCAN (otoacoustic emissions test system). Christensen received her master's degree in clinical audiology in 1989 and her PhD in audiology in 1992, both from Indiana University.

One of several reasons Mead Killion gives for establishing Etymotic Research was to develop a hand-held infant hearing screener measuring otoacoustic emissions (OAEs). The culmination of years of work on this product development was the introduction of the ERO•SCAN™ in 1998. Figure 1 shows me with the original ERO•SCAN in 1998.

It could be argued that the development of this product started before 1985, when the ER-7 probe microphone was introduced by Etymotic Research for use in auditory research. While not a low-noise microphone, the development of the ER-7 was the precursor to the development of the ER-10 Lo-NoiseTM Microphone introduced in 1986, which was for measuring otoacoustic emissions. After 1986, Etymotic Research introduced the ER-10B Baby Lo-NoiseTM Microphone and the ER-10C Microphone which were both for OAE measurement. Finally, in the 1990s, ER sold a complete OAE system with microphone, earphones and a DSP board for research purposes. Thus,

Figure 1.

Figure 2.

many OAE product developments at ER came before the ERO•SCAN.

The ERO•SCAN had some simple development requirements as outlined by Mead. It had to be hand-held and easy to use, quick, and reliably measure OAEs in environments of up to 70 dB SPL of noise. Although Mead is intimately involved in every product development project at Etymotic Research, the ERO•SCAN development was definitely a team approach with Steve Iseberg, who was among the first employees at Etymotic Research, taking the project lead.

I joined Etymotic Research as the ERO•SCAN prototypes were ready for testing and worked with Mead to set up sites and collect validation data for the new hand-held screener. Through co-operation with Gil Herer, PhD, we started our data collection at Holy Cross Hospital in Silver Springs, MD. On our many trips to Holy Cross, I learned two things. First, never clear airport security with Mead as his pockets contain more than can be unloaded in a reasonable amount of time and doing newborn hearing screening is an acquired skill learned over time. It is not possible to just show up and test babies when you haven't done it before. The staff at Holy Cross was exceedingly patient with our frequent trips bringing engineers, audiologists, and of course Mead himself. The data collected at Holy Cross led to the refinements the system needed and the beginning of the development of a remote probe for infant testing as many prefer this method when testing babies. In an effort to find a test site closer to Chicago, we enlisted the help of Alison Kaye, AuD, who led the Newborn Screening Program at Illinois Masonic Medical Center in Chicago. The ERO•SCAN was used successfully in this setting (without a remote probe) for 15 months for our data collection purposes. After screening over 3,000 babies, the data showed that the ERO•SCAN could accurately screen newborns with a very low refer rate in a large hospital environment.

Although we showed that the ERO•SCAN could be used for newborn testing in the hand-held version, a remote probe was released in 2000 and was a simple plug-and-play solution where the device could be used with or without the probe (see Figure 2).

Work on ERO•SCAN validation took us around the world – babies were screened as already mentioned in Chicago, IL and Washington DC. We also traveled several times to sites in Japan and completed a study in Hildesheim, Germany. In Germany, we compared the ILO292 (Otodynamics) device and the MAICO ERO•SCAN. Maico ultimately became the distributor for the ERO•SCAN and continues in this role today. Results of this German study on 559 newborns showed the ERO•SCAN with remote probe had similar pass rates for both Transient Evoked OAEs (TEOAEs) and Distortion Product OAEs (DPOAEs) when compared to the ILO292, but was able to test an ear in about half the time as the ILO292.

One of the product requirements for the ERO•SCAN was that it could test in higher levels of noise than devices on the market at that time. To do this, a post hoc statistical analysis that successfully rejected noise contaminated samples was used in the device. In an internal study, we compared four TEOAE units in differing levels of speech babble. It was determined that the ERO•SCAN could measure TEOAEs in under 20 seconds in levels up to 70 dB SPL. Other units could either not reliably measure TEOAEs at these levels or increased testing time significantly to do so.

Mead and I took a particular interest in using the ERO•SCAN to screen school-age children and embarked on several projects to explore the use of OAEs for this type of screening. We hired three sites to study the use of the ERO•SCAN for school-age screening. In this study, 1,300 children ranging in age from three to 17 were screened using pure-tone audiometry, tympanometry, and DPOAEs. The three sites included Louisiana State University Medical Center, The University of North Carolina, and the Center for Hearing Speech and Language in Denver, CO. The results of this project showed that OAEs were a promising solution to the cumbersome nature of screening with pure-tones, especially for younger children and children where English was a second language. Using OAEs as the first step in the screening process and then using pure-tones and tympanometry for those who fail this OAE test allows for more efficient overall screening. I know Etymotic Research continues today to push this type of screening for school-age children.

Figure 3.

In 2008, the ERO•SCAN Pro™ (Figure 3) was introduced allowing tympanometry and otoacoustic emissions testing in the same device without changing the probe. While continuing to offer an excellent solution for newborn hearing screening, this device is even more suited for school-age screening with built in tympanometry.

The ERO•SCAN was one of many product developments that I was able to work on in my five years at Etymotic Research. Like all products at Etymotic Research, the ERO•SCAN evolved to solve a problem in the field of audiology. In this case the need for an easy-to-use, hand-held OAE device for screening hearing in less than ideal environments. The product requirements laid out by Mead were thoroughly tested, and later generations of the product have added even more needed functionality.

Etymotic Man

By Larry Revit, MA

About the Author

A music recording engineer who acquired a severe hearing loss, Larry Revit is now a consultant providing precision sound engineering services, mostly to researchers in hearing aids and cochlear implants (see www.revitronix.com). He is also a professionally active musician.

This brief article relates some highlights of the knowledge, guidance, experience, and friendship that Mead Killion has shared with me throughout the last 28 years. Not too many folks get to coin new words that become part of the language of one's profession, but Mead Killion can be counted among those very few. Importantly, two, somewhat strange-sounding words that he coined, "etymotic" and "CORFIG," have changed our world, for the better.

The first of these, "etymotic" (pronounced "et-im-OH-tik") signifies the philosophy underlying much of what Mead has contributed to the world. The term is said to mean "true to the ear." A pretty good synonym is "high-fidelity sound." Fittingly, Mead entitled his doctoral dissertation, "Design and Evaluation of High-Fidelity Hearing Aids"[1] – which demonstrated that the High-Fidelity K-AMP™ not only sounded great, but was a viable device which changed the world. In Mead's words, "…the important question for hearing aid research [was] no longer "What *can* a hearing aid be designed to do?" but "What *should* a hearing aid be designed to do…?"[2]

To demonstrate to audiologists and hearing aid engineers what a hearing aid "*should* do," in a manner that is "true to the ear," Mead recognized that it was necessary to express what it meant to the wearer to put on a hearing aid, and in language that hearing-aid builders and fitters could easily understand … CORFIG was born.

With his "coupler response for flat insertion gain" (or "CORFIG"),[3] Mead provided a means of transforming real-ear insertion-gain *prescriptions* into 2 cc-coupler test-box responses. By using CORFIG, a hearing-aid builder or clinician could evaluate prescribed hearing aids, in an "etymotic" way, from the get-go – that is, at the factory, or at the fitter's office, before the client put them on the first time. To convert an insertion-gain prescription to a target 2 cc coupler-gain response, one simply must add the CORFIG curve to the prescribed insertion-gain curve. (Of course, your fitting software likely does this automatically – but only for the average ear, unless real-ear measures are included.) Flipping the coin, one could subtract the CORFIG (or add its inverse, the "GIFROC") from the measured coupler-gain response to estimate the real-ear insertion-gain response.[4]

Of course Mead was one of those who saw the obvious: There was a need for measuring actual hearing-aid responses at or near the eardrum – with the hearing aid in place! – leading to the development of the ER-7C probe-tube microphone, whose ultra-flexible, 1-mm outer diameter probe tube set the

Figure 1. Mead ("CORFIG" shirt) and yours truly ("GIFROC" shirt), during a celebration following a Jackson Hole Rendezvous seminar, circa 1994. The Grand Tetons are in the background.

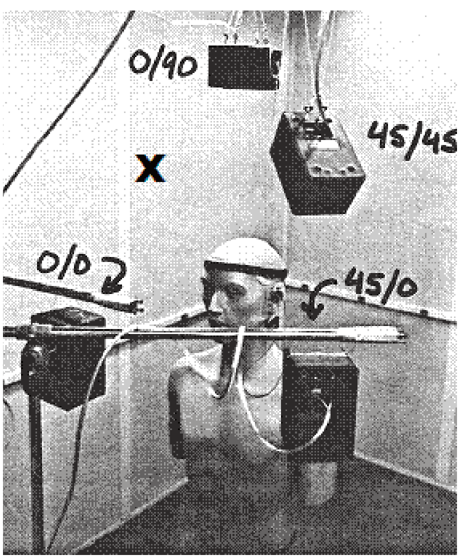


Figure 2. Setup for the author's master's thesis.[5] We should have tried location "X" (0 degrees azimuth / 45 degrees elevation)!

standard for probe-tube microphones in use today.

And now I can finally get to my master's thesis, which Mead directed. The study used an ER-7C probe-tube microphone to assess the repeatability of real-ear insertion-gain measurements versus loudspeaker location. The study was inspired by one of Mead's notions about prescribing and evaluating the real-ear response of hearing-aids: The real-ear response should be targeted in terms of the random-incidence (diffuse-field) response – which basically means sound coming from all directions at once. (This is a notion I would vigorously defend.[5]) Mead knew (from previous experience) that the diffuse-field response of the ear could be achieved very closely by measuring in the ear from a single sound-source location: directly overhead.

The idea of placing the loudspeaker overhead to achieve a diffuse-field response made sense, because the direction-dependent pinna and concha, are not "seen" from overhead. So if you placed the loudspeaker for real-ear measurements directly overhead, you would not only be measuring the *correct* (diffuse-field) real-ear response, but, because of direction independence, head movements during measurements would likely produce less variability than from other loudspeaker locations. I added an idea from my own listening experience from when I was a music recording engineer: High frequencies are heard best when the sound source is both elevated and toward the side – leading to my hypothesis that the most repeatable measures would come from an "up and over" location (see "45/45" in Figure 2). The 45/45 location combined the reduced direction dependence of elevation with an increase in high-frequency signal-to-noise ratio achieved by moving somewhat to the side.

Well, it turns out that the 45/45 location did give the most repeatable insertion-gain measures. Too bad that that location is impractical for clinical applications! The 45/0 location came in second for repeatability. The 0/90 location did produce the diffuse-field response for KEMAR but it didn't work well for human subjects because, we speculate, reflections from the shoulders created variability in the repeated measures.[6] The worst repeatability came from 0/0, likely because of head-shadow effects with head movements – although it is important to keep in mind that this experiment used no control or reference microphone at the ear, which, when active, helps greatly with achieving consistent measures with head movements.

In any case, I will always remember Mead's gifts of guidance, patience, encouragement, and countless hours with the deepest gratitude and affection."

The reason I have gone into such detail about my master's thesis is to introduce to the reader a new hypothesis: In my thesis study, I believe we should have tried one more loudspeaker location: 0/45. (See the bold "X" in Figure 2.) That is, placing the loudspeaker in front of the subject, but also elevating it (to reduce concha and head-shadow effects), could likely produce a near-diffuse-field response (high validity), with high repeatability (no shoulder bounce), and would not have the inconvenience of having to move the subject (or loudspeaker) for each ear. I hope someone reading this, who may be interested in taking the validity and reliability of real-ear measures up one more small notch, will decide to make a new study out of testing the 0/45 location – perhaps as a capstone project or such!

I will end this article by saying that the first time I, as a music engineer who had acquired a hearing loss, saw the words "high fidelity" and "hearing aids" in the same title,[1,2] I knew that Mead was a very special person. I'm so glad to have become his lifelong student (once a mentor, always a mentor), some-time coworker, and friend.

REFERENCES

1. Killion. MC.. Design and Evaluation of High-Fidelity Hearing Aids. Doctoral dissertation. Northwestern University.1979.
2. Killion MC and Tillman TW. Evaluation of High-Fidelity Hearing Aids.
   Journal of Speech and Hearing Research 1982:25(1):15–25.
3. Killion MC, and Monser EL. CORFIG: Coupler Response for Flat Insertion Gain. Acoustical Factors Affecting Hearing Aid Performance. GA. Studebaker and I Hochberg, eds. Baltimore: University Park Press. 149–68, 1980.
4. Killion MC and Revit LJ. CORFIG and GIFROC: Real Ear to Coupler and Back. Acoustical Factors Affecting Hearing Aid Performance. 2nd ed. GA Studebaker and I Hochberg, eds. Boston: Allyn and Bacon. 65–85. 1993
5. Revit LJ. New Loudspeaker Locations for Improved Reliability in Clinical Measures of the Insertion Gain of Hearing Aids. Master's thesis. Northwestern University. 1987.
6. Killion MC and Revit LJ. Insertion Gain Repeatability Versus Loudspeaker Location: You Want Me To Put My Loudspeaker W H E R E? Ear and Hearing 1987;8(5):68–73.