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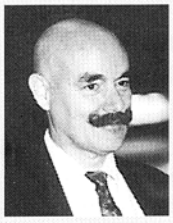
BY H. GUSTAV MUELLER AND MEAD C. KILLION

Yes, folks, Page Ten *is going for a three-peat. Our second year saw this page consistently filled with outstanding articles, thanks to our team of excellent guest writers. My appreciation to all the audiologists who have made* Page Ten *successful. In case you missed it, we held formal commencement exercises for our 1994 and 1995 contributors. Check out* Page Ten *of the November* Journal *for the official graduation photo.*

But, if you thought our past cast of writers was good, how about this list of all-stars you'll be seeing here in 1996: Cindy Compton, Dave Cyr, Dave Fabry, Judy Gravel, Jim Jerger, Nina Kraus, Jerry Northern, Steve Staller, and Pat Stelmachowicz. You know where to find them: Page Ten.

To launch our 1996 season, we're starting with a time-honored Journal *subject—compression amplification. I've asked an internationally recognized expert on the topic to help me answer 20 questions on this often controversial topic. It was back in 1978 that I first heard Cy Libby talk about some engineer in Chicago who could not only design amazing earmolds, but would demonstrate why they work by playing his own set of home-made horns. I knew right away that this Mead Killion guy must be a "different kind of engineer." For those of you who have been to one of Mead's seminars, you know I was right (and we're glad of it, aren't we?). Dr. Killion is president of Etymotic Research in Elk Grove Village, IL and, of course, is best known for his development of the K-AMP™ circuit.*



Mead C. Killion

Gus Mueller

If you're like me, you've probably read more articles on compression hearing aids than you care to remember—many of which left you more confused than when you started. Mead and I hope that we haven't added to the confusion.

Gus Mueller
Editor, Page Ten

1

I can relate to your title. Compression seems to be just about as hot as the World Wide Web. It seems that every time I turn around some hearing aid manufacturer is introducing a new type of compression circuit. Is compression something new? Is it *the* thing of the '90s?

The commercial use of compression in hearing aids is actually a child of the '30s. We're not quite as old as compression, but if you have seen either one of us lately, I doubt that you would consider us "new."

2

If compression really has been around for 60 years, why all the hoopla now?

Compression limiting has been around in hearing aids for several decades. Recent compression-limiting circuits have improved quite a bit: They have lower distortion, many are programmable by one kind of digit or another (i.e., they have one or more adjustable characteristics), and some have variable recovery time to reduce the "pumping" sound that often annoyed users of earlier compression. With the size and cost reduction of integrated circuit designs, compression limiting is rapidly replacing peak clipping as the limiting means of choice. In fact, a survey conducted by David Hawkins, PhD about 5 years ago revealed that the majority of hearing aids sold in the United States (about 80%) were *not* compression instruments but were peak clippers. David has just completed another survey, which revealed that peak clipping is on the wane: down to about 50% usage now.

3

Why did you emphasize compression limiting? Is there another kind?

Yes, indeed. The kind that has rapidly grown from less than 1% of sales in the 1980s to nearly 25% of all hearing aid circuits sold around the world in 1995: wide dynamic range compression or logarithmic compression, which we'll abbreviate as WDR compression. In a way, we've come full circle. The original use at Bell Labs of the term "compression" was to describe what we are calling wide dynamic range compression, but it took a long time to catch on in hearing aids.

4

Hey, I'm starting to lose track here. Why do we need different kinds of compression? Are there significant differences between compression limiting and WDR compression?

Mueller: One way to look at the difference is to consider that with compression limiting, the speech signal is processed in a linear manner until compression occurs at a fairly high level, but average speech is typically not in compression. With WDR compression, the input-output curve becomes nonlinear at a low level and, in fact, speech is always, or nearly always, in compression. I'm guessing that my engineer friend can make it more complicated than this.

Killion: I'll certainly try. A hearing aid with compression limiting will apply the same amount of gain to all incoming speech—soft and loud—until it becomes intense enough to reach the limiting threshold. After that, further increases in input will cause little increase in output. A hearing aid with WDR compression, on the other hand, will increase the gain for softer speech (so that speech soft enough to be inaudible with the limiting hearing aid will be brought into audibility) and decrease the gain for louder speech. Unlike *limiting,* which squashes high-level inputs and does nothing to the normal

range of inputs, WDR compression automatically increases and decreases the gain across the normal range of input levels. (These comments assume that the limiting and WDR-compression hearing aids were both set by the user for conversational-speech-level inputs.) Properly fitted, WDR compression tends to restore normal loudness relationships so that soft sounds *sound* soft (but not inaudible) and loud sounds *sound* loud (but not uncomfortable). Another difference is that compression limiting works over perhaps a 20-dB range of levels above the limiting threshold. WDR compression works over a wide range of levels, typically 50 dB, which is where it gets its name.

Mueller: I know I already had my say on this question, but that last statement got my attention. It reminds me that I'm often asked to explain the difference between "wide" and "full" dynamic range compression. The difference seems to be directly related to the peculiarities of the people who write the promotional literature; in other words, there probably isn't any difference. I guess that one could argue that a "low kneepoint" would be wide range, whereas a "*really* low knee-point" would be full range, but, for me, that's more nitpicking than necessary.

5

Finally you tell me something that makes my life simpler. What about the "standard" AGC-I hearing aids that I have been fitting in the past. Are these WDR-compression instruments?

We don't think so. Traditional AGC-I hearing aids usually apply compression only above an average-speech-level input (a kneepoint around 65 dB SPL). They don't conveniently fit into either category that we have described; they reduce gain for loud sounds, but typically provide little or no increase of gain for soft sounds. They do help prevent discomfort and distortion for loud sounds since the user can alter the maximum output of the hearing aid by adjusting the volume control.

6

Let's get back to WDR and compression limiting. The fact that you two are writing this article tells me that you agree on the need for both of these signal-processing strategies.

Killion: Not necessarily, but we think our disagreements will help make this column more interesting. For example, I believe that limiting is required for only one type of hearing loss, whereas my friend Dr. Mueller has been known to successfully fit all types of hearing losses with hearing aids that use compression only for limiting.

Mueller: I tend to fit primarily WDR compression, but you're right, I have fit compression limiting to all types of hearing loss, and I'm not ashamed of it. I'm not at the point of reserving compression limiting for a certain type of hearing loss; I don't think it's that simple. It's important to remember that all hearing aids limit somewhere. The question is *how* they limit. The old-fashioned peak-clipping circuits limit with enormous amounts of distortion. Not only does that distortion make it hard to understand speech in high-level noise, but research has suggested that such distortion effectively reduces the patient's aided loudness discomfort level (LDL). Low-distortion compression limiting expands the dynamic range, which provides us more room for packaging the aided speech signal. With minimal distortion, the patient is less likely to turn down the gain, which helps to maintain audibility of soft sounds.

7

So is there a type of hearing loss that is best suited for compression limiting?

Killion: Now we're getting to important stuff. I believe that compression limiting is needed for a hearing loss in which the patient needs a hearing aid to amplify all speech up to just below discomfort in order to carry on a conversation in noise. I call this a Type 3 hearing loss. (I'll figure out a way to work in Type 1 and Type 2 before we're finished with this article.) We typically see this with 70-dB to 85-dB losses, but the controlling element is the need for listening just below discomfort in order to understand speech in difficult situations. Often speech is clearer if that person is willing to be a little uncomfortable.

8

Why do you think that a person with a "Type 3" hearing loss needs compression limiting?

Because he or she cannot understand speech in noise without listening near discomfort level. When the limiting point is adjusted to just below discomfort, the user can turn the volume control up high enough so that all sounds are amplified into the limiting level, which is okay because the limiting keeps all sounds just *below* discomfort.

9

Are you talking about linear circuits with compression limiting? Is that a *linear* circuit or a *compression-limiting* circuit?

The answer to both parts of the second question is "yes." Most compression-limiting circuits provide linear processing below their threshold of compression, so you could accurately call them linear circuits. The distinction here is between low-distortion limiting and peak clipping. You can't hear any difference until you reach the limiting threshold. The point is, linear processing is *not* the opposite of compression; they can coexist (quite happily) in the same hearing aid.

10

You seem to be making the point that no hearing aid should be without compression limiting.

Mueller: Not really, and I'm sure that Dr. Killion would like to expand on this one.

Killion: I would. Except for the type of hearing loss that we discussed earlier, the only reason you would need limiting would be if you had too much gain for high-level sounds. Most of the time, limiting is a fix for a problem created by the hearing aid designer and/or the dispenser. Research suggests that you almost never need limiting if you provide only the amount of gain needed to restore loudness for high-level sounds (0 dB to 12 dB, typically). There is increasing market evidence in support of this view. About 20% of all hearing aids sold in 1995 (perhaps 80% of the WDR-compression circuits) have WDR compression with *no* compression limiting.

Mueller: Mead, you seem to be leading our readers back to using peak-clipping. I put in some effort a few questions ago trying to convince them that this was bad. I thought we were working together on this.

Killion: We are, so hear me through. The limitation in those WDR-compression

circuits indeed is peak clipping, *but* it is virtually never reached because a well-designed WDR-compression hearing aid will almost never reach that limit. It will almost never distort with real-world high-level sounds, even at Rockies baseball games, industry cocktail parties, country and western dances, or full symphony orchestra concerts.

11

I gather you think that I shouldn't just fit compression limiting to all my patients?

Killion: You've already heard my humble opinion.
Mueller: You could, and many dispensers report success by using only this type of compression. Both types that we have discussed will permit better audibility for quiet sounds, although for different reasons. A recent school of thought, however, is that the processing of the hearing aid should reflect the loudness growth function of the patient, which rarely is linear. To mimic the patient's loudness judgments for soft, average, and loud sounds, it is usually necessary to select a WDR-compression instrument with a relatively low kneepoint (e.g., 40 dB-45 dB). We are not aware of definitive research showing that this type of processing results in superior patient benefit or satisfaction, but it sure seems like a logical approach.

12

You keep talking about "low" kneepoints and "high" kneepoints. That sounds like a strange animal! How many knees does compression have on each leg?

Normally two, sometimes one (sometimes three, but we won't talk about that). With compression limiting there is only one: the upper limiting threshold where compression kicks in. With WDR compression, there may be two: the upper knee and the lower knee. It is the lower knee, often called the threshold knee, that is usually adjustable. In most cases, this adjustment is related to how much gain you want to give the patient for soft sounds. Above the *upper* knee, a WDR-compression circuit can act as a (typically very-low-gain) linear hearing aid, or, as in one popular design, apply compression limiting.

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Is there a certain type of hearing loss that WDR compression is especially good for? Can you please answer this without creating new questions?

Mueller: Ideally, it seems best to look at the loudness-growth function of each patient. (This assumes that you believe in selecting a type of processing that will restore normal loudness.) When I use this approach for mild-to-moderate cochlear hearing losses, I almost always pick some type of WDR compression. I have found that I usually select a kneepoint around 40 dB to 50 dB—some hearing aids have adjustable compression ratios that can make the fine tuning even more precise. Mead has his own classification system which I know he's anxious to explain.
Killion: WDR compression is good for what I'll refer to as Type 1 and Type 2 hearing losses. That is really another topic, but briefly and roughly a Type 1 loss means the inner hair cells are probably still okay; only the outer hair cells are damaged or missing. This shows up as a 40-dB-to-50-dB loss at threshold, but very little hearing loss for intense sounds. A good argument can be made for providing no gain for intense sounds but as much gain as needed to make low-level sounds (say 20 dB HL) audible. WDR compression is perfectly suited to this task. It can also provide approximately the amount of gain required to restore loudness at intermediate points. Type 2 loss usually means there is also some loss of inner hair cell function, so that even loud sounds need some gain (perhaps 4 dB to 12 dB). But, with suitable adjustment, a WDR-compression circuit can restore nearly normal loudness sensation here, too. With today's programmable WDR-compression hearing aids this is pretty easy to accomplish with some minor tweaking of the knee-points and/or ratios.

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Okay, you've given two reasons for using compression: lower distortion and restoration of loudness. All virtuous dispensers can support lowering distortion, but I can't recall any studies showing that my patients will be able to understand speech better if I try to restore normal loudness.

Mueller: I can't recall any either. In fact, at least one study has shown that if you adjust the volume and tone control of a linear hearing aid to meet the test conditions, linear processing will be just as good as WDR compression, as long as the input level stays fixed.
Killion: If you're referring to the study by Richard Lippmann, PhD of MIT, he did find that WDR compression gave slightly better scores when real-world speech with normal level variations was substituted for prerecorded word lists, but I agree with the basic conclusion: If the user is willing to readjust the volume and tone control on a regular basis and can do it quickly enough, there is little argument for compression. No one to my knowledge has shown that compression increases intelligibility *per se* over properly adjusted linear amplification. In fact, Margo Skinner, PhD of Washington University in St. Louis found that her subjects obtained about the same high scores over a 40-dB-to-50-dB range of input levels as long as the "tone control" was readjusted each time to give the best frequency response.

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So really, what is the true value of WDR compression? Will my patients be any happier? I've had fairly good success with this circuitry for new users, but many of my previous hearing aid users complain that average speech just isn't loud enough. Sometimes I send the hearing aid back and have it changed to a linear peak clipper, and then they're happy. How do you explain this?

Killion: Gus, you had a private dispensing practice for several years, how did you handle this?
Mueller: I tried to sound as if I knew what I was talking about, and hoped that the patient stuck with me. Many users have become accustomed to the world of sound that exists just below their LDL; you're probably familiar with the request to "make it sound like my old hearing aid." It takes a while for them to adjust to a different type of speech packaging. Will they adjust in the first week or so after the fitting? Sometimes yes, often not.

Giving them something that sounds like their old hearing aid is a quick fix, but I'm not convinced that patients always know what's best for themselves on the day of the fit, or even during weeks or months after a new hearing aid fitting.

16

This sounds like the old "Me Doctor, You Patient" authoritarian approach. "Wear it a while and you'll get used to it." I had to use that line years ago when I first fitted clients with high-power linear aids with too much gain (I was trained at a university). Now I have to make them go through that again? I'd think we would have made more progress by now.

Killion: If my look-alike companion Dr. Abonso were here he would remind you that brains are constantly changing, rewiring to apply cortical processing to whatever is going on. The rewiring takes weeks or months. Once some hearing-aid users get used to sounds that are too loud, they acquire a preference for them. With newer WDR-compression hearing aids, you can crank up the high-level gain when you first send your patients out and then readjust them to more appropriate settings over time.
Mueller: I'm not as convinced as Dr. Abonso that actual "rewiring" takes place, but I do know that there is at least some type of adjustment or adaptation. This is not only true for the remapping of average and loud sounds, but also is important for getting used to soft sounds, which in many cases are audible for the first time. And you know what, if your preselection process is reasonably thought out and you select quality hearing aids, I happen to think that the "Try it, you'll like it" approach is not all that bad.
Killion: It's important to remember that the older-design linear aids probably give inferior intelligibility because of their narrow bandwidth and high distortion levels. Today we have something better to offer. With good WDR-compression hearing aids, you can obtain a wide bandwidth, low distortion, and the convenience of automatic operation of the volume control so the user doesn't have to adjust the hearing aid all the time.

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I think you've made your point. To change the topic slightly, I've heard about "adaptive" compression. What is it, and is it commonly used?

Adaptive Compression is a trademarked term for "variable release time compression," which provides a combination of a slow recovery time for normal sounds with a fast recovery from sharp transient sounds such as a handclap. It accomplishes two things: It reduces the annoying "pumping" sound you often hear with standard compressors as the gain is changing; and, when used with compression limiting—at least according to one study—it substantially increases intelligibility in very-high-level noise, i.e., when the input SPL is 10 dB to 20 dB above the threshold knee.

18

Hmmm. I'll have to think that over. But, speaking of different compression labels, I've been hearing about curvilinear compression. What's that?

Mueller: Many WDR-compression circuits have a fixed compression ratio, such as 2:1. (A fixed ratio in decibels means linear on a logarithmic scale, so these circuits are sometimes called logarithmic compression.) With curvilinear compression, the ratio varies as a function of the input signal. For example, for a fixed kneepoint of 50 dB SPL, an input of 60 dB SPL might be compressed at a 1.5:1 rate, an input of 70 dB SPL at a 2:1 rate, and an input of 80 dB SPL at a 3:1 rate. As a result, the input-output curve is curvilinear. In theory, at least, this type of signal processing seems like a desirable feature for some patients.
Killion: We know that curvilinear compression reduces distortion, prevents discomfort, and in some cases provides independent adjustment in each of two or three channels. Persons of good will and good moral character can find themselves on opposite sides of the argument about whether the success of these hearing aids has been due to the multichannel flexibility or the curvilinear compression characteristics. One thing is clear: They represent a dramatic improvement over peak-clipping narrowband linear hearing aids!

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Since you're limiting me to 20 questions, it's time to talk about my Monday morning patient. You said earlier that I should adjust compression characteristics for each patient. This sounds like a good idea, but how in the world do I know what compression kneepoint or compression ratio settings are best?

There are no simple answers, but some of the emerging prescriptive fitting methods do help get you in the ballpark. For example, the VIOLA component of the IHAFF protocol allows you to select adjustments that best match the patient's loudness-growth function. (You do have to measure the loudness-growth function first, of course.) The DSL [i/o] will provide you with different ear canal SPL targets for different compression settings. The FIG6 prescriptive method will provide you with three different gain targets based on average loudness-growth functions predicted from the patient's own thresholds. These three methods are relatively new, and have only limited verification, but we recommend that you do your own verification procedures after the fitting. Sound field audiometry should tell you if you've made soft speech audible. If the compression adjustments are set correctly, the patient should rate average level speech (65 dB SPL) as comfortable and high-level speech (85 dB SPL) as loud, but not uncomfortably loud. Keep in mind that this does not assure that you have *maximized* intelligibility, but it's pretty safe to say that you have *improved* intelligibility.

20

So, in closing, I guess I'd better ask, will I be a really bad person if I fit a linear peak clipper tomorrow?

When judged by your colleagues, maybe. When judged by your patients, probably not, as long as they never experience high-quality compression for several months. People can get used to anything. If it has a wide bandwidth and clean Class D peak clipping rather than "crummy peak clipping," two double-blind studies indicate *almost* as many of your patients will be happy as if you had used a better circuit. We just happen to believe that *more* of your patients will be happy when the appropriate compression technology is employed.