▶ **TOPICS IN TECHNOLOGY**

Compression: Distinctions

By Mead C. Killion, PhD

Part of the difficulty in fitting compression hearing instruments is that important distinctions in meaning have been obfuscated by words. Some readers may find the distinctions I use here to be useful:

Distinction #1: Compression vs. AGC

Humpty Dumpty said to Alice: "When I use a word, it means just what I choose it to mean." "AGC" means different things because writers have sometimes used this generic term to describe specific applications. The words Automatic Gain Control don't specify what *kind* of AGC is meant, so saying "use AGC" is similar to saying "take transportation" without suggesting whether to fly, drive, or call a cab. All bicycles provide transportation. Not all transportation is by bicycle. All wide-dynamic-range compression is AGC, but not vice versa.

Distinction #2: Compression Limiting vs. Wide-Dynamic Range Compression (WDRC)

It is often useful to look at *compression limiting* as acting to *reduce* gain above some level, while WDRC acts to *increase* gain below some level. That fundamental difference between the two is so important that it is worth saying again in slightly different words. Compression limiting acts *above* its threshold to reduce gain for sounds that are too strong, while WDRC acts *below* its (upper) threshold to *increase* gain for sounds that are too weak. It is possible to have both types of compression in one hearing aid: the ReSound hearing instrument, for example, has compression limiting which acts above 85 dB SPL and WDRC which acts below 85 dB SPL.

Compression limiting is used primarily to prevent loud sounds from causing distortion, pain, discomfort, or—in one reported case of a high-powered body aid whose owner's dog barked into the microphone—a ruptured eardrum. Except in the case of the national debt, limiting means "no more beyond a certain amount." In a hearing instrument, "compression limiting" means that the level of sound is not allowed to increase more than a few decibels above the limiting threshold (e.g., a 20 dB further increase in input may be compressed into only a 2 dB increase in output, for example).

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Wide Dynamic Range Compression is used to restore audibility for weak sounds and simultaneously restore some of the normal loudness perception that is lost with recruitment. The "wide dynamic range" part comes from the fact that the AGC action is spread out over a 40-50 dB range of inputs, with a gradual change in gain spread out over that range. WDRC has nothing to do with recovery time, as has sometimes been suggested.

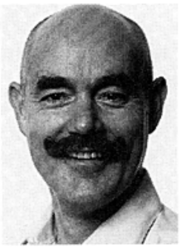
Which one is better? Any AGC action can help squeeze the wide range of normal speech levels into the limited range of hearing of someone with hearing impairment, but WDRC comes closer to restoring the normal loudness experience. What is lost with cochlear hearing loss is the increased gain for weak sounds provided by (the mechanical amplification from) normal outer-hair-cell motion. WDRC acts to provide the gain for weak sounds that the impaired ear can no longer provide for itself.

The problem with compression limiting for most types of hearing loss is that it waits too long to do its job: Only when sounds are *almost* too loud does compression limiting come into play. Once limiting is reached, sounds will be *almost* uncomfortable. Limiting does the squeezing job, but with a heavy hand.

Nevertheless, compression limiting appears to be the compression of choice for individuals with 75 dB or greater loss because they often require real-ear output levels within 10-15 dB of their discomfort levels in order to understand speech in noise. Adjusted to limit just below discomfort level, compression limiting permits the user to turn the volume control up enough so that all speech sounds fall within the 10 or 15 dB range of outputs required for good intelligibility.[1]

Distinction #3: TILL vs. Multichannel Compression

The typical hearing-impaired individual has a high-frequency loss and needs greater high-frequency emphasis for weak sounds than for strong sounds; in other words, he/she needs a TILL or Treble-Increases-at-Low-Levels amplifier. In order to provide this level-dependent frequency response, Villchur[2] and ReSound employed two separate level-detection and amplification channels. With the compression characteristics appropriately adjusted for each channel, a TILL response is readily achieved. In the DynamEQ II, a single level-detection circuit controls gain in two amplification channels to achieve the TILL function. In the K-AMP circuit, a single level-detection circuit controls gain in a single amplification channel, but that channel has two electronic functions (treble



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boost and gain) that can be controlled simultaneously.

In practice, each WDRC circuit can produce a "multichannel" type of level-dependent frequency response. Each can be made to produce similar increases in treble boost for weak sounds.

Distinction #4: Multichannel vs. Multichannel vs. Multichannel

Three distinct "multichannel" operations are possible: Equalization, Detection and Signal Processing or Compression.

Equalization: Several manufacturers provide multichannel (or band) *equalization*, a frequency-response shaping capability similar to that of the multiband *equalizers* found in some hi-fi amplifiers. The most important practical difference between single-channel and multichannel circuits may be in their frequency-response equalization capabilities; multichannel circuits often allow better tailoring of the response for those with unusual audiometric configurations.

Detection: One difference between single-channel and multichannel detector circuits from an academic standpoint is that a single low-frequency tone can control the entire AGC circuit of a single-detector amplifier such as the K-AMP or DynamEQ II circuits, reducing high-frequency gain as well. The high-frequency gain of amplifiers using 2- or 3-channel detector circuits (e.g., ReSound, 3M), on the other hand, may be relatively unaffected by the narrowband signal.

Despite the theoretical arguments, single-channel detection works quite well in the real world. I have encountered problems resulting from single-frequency tones only rarely (in contrast with their frequent appearance in the laboratory!), presumably because most real-world signals and interfering noises have the same general spectral characteristics as speech. The only user complaints I can recall that have been traced to a single-detector channel have involved the 90-100 dB SPL 25-kHz outputs of ultrasonic motion detectors. (The ultrasonic lighting-control system in one well-known multimillion dollar new academic building turns off everyone's hearing aids!)

Signal Processing/Compression: Multichannel WDRC compression permits more flexible adjustment of level-dependent frequency-response characteristics because a slope of 18 dB/octave between channels is often possible. Otherwise, a single-channel device works just fine (see Distinction #3 above), and one can even make an academic argument for its superiority: any multichannel compression device risks distorting the normal loudness relationships internal to phonemic speech elements, relationships which provide cues for phoneme identification. A single-channel-TILL compressor provides only a smooth treble boost to the entire phoneme. Although I enjoy the argument, in all fairness, I know of no evidence to support the hypothesis that single-channel compression is inherently superior to multichannel processing.

Mix and Match: The Audio-D (formerly the "Ensoniq" instrument) provides 13 frequency-response-equalization channels with a single-channel, single-detector K-AMP circuit at the input. The "3-Channel K-AMP" circuit provides fewer equalization channels but much greater slope between channels, again with a single-channel WDRC-TILL K-AMP circuit at the input.

A Historical Note on Compression

WDRC goes back to the 1930's when transatlantic cables were being laid on the ocean floor and talking movies were just starting. Bell Telephone Laboratories' scientists Mathes and Wright[1] (1934) described the use of "companders": *compressors* to increase the signal level of quiet sounds before they began their underwater voyage and *expanders* at the receiving end to restore normal speech levels and loudness variations. Once Steinberg and Gardner[2] (1938) had discovered recruitment and measured the input-output loudness curves of hearing-impaired ears, they commented that the impaired ear acted just as if it had an electronic input expander (like the receiving end of transatlantic telephones), and what was needed to correct for this loss was a compressor in the hearing aid. In their time, "compressor" meant only wide-dynamic-range compressor.

Hy Goldberg in 1965 appears to have been the first to make a high-quality wide-dynamic-range circuit for a BTE hearing aid. Interestingly enough, the problems of proper fitting and counseling with this aid appear to have been one factor in its relatively limited acceptance.

In 1973, Villchur[3] published the results of his own laboratory experiments comparing linear amplification with wide-dynamic-range compression amplification (combined with appropriate post-compression frequency-response tailoring). The dramatic intelligibility improvements he saw, especially in noise, later led Fred Waldhauer of Bell Laboratories and the present author to independently devise high-quality wide-dynamic-range compression amplifiers suitable for hearing aids. The former became the ReSound circuit and the latter became the K-AMP circuit. Other WDRC circuits followed, the most recent probably being the DynamEQ II developed by Steve Armstrong and his colleagues.

References

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2. Steinberg JC and Gardener MB: (1937). The dependence of hearing impairment on sound intensity. *J Acoust Soc Am* 1937; 9: 11-23.
3. Villchur E: Signal processing to improve speech intelligibility in perceptive deafness. *J Acoust Soc Am* 1973; 53: 1646-1657.

Distinction #5: Nonlinear Distortion vs. Nonlinear Amplifiers

The term "nonlinear amplifier" causes a lot of confusion because it has been applied to: a) amplifiers that create nonlinear distortion, and b) compression amplifiers that change gain as a function of input level.

Nonlinear (harmonic and intermodulation) distortion is common in poorly designed or overloaded amplifiers, but it does not occur in any well designed AGC system. As Steve Armstrong has pointed out in lectures, any low-distortion AGC must operate as a *linear* amplifier for *waveforms*; an AGC system that "rides gain" so fast as to affect the waveform is effectively clipping!

The nonlinear part of well-designed AGC systems shows up only over time periods. A linear amplifier implies fixed gain as time passes (assuming no one plays with the volume control), while an AGC system *automatically* adjusts the gain over time as a function of input level: slowly enough so as not to distort the sound waveform but fast enough to adjust to listening situations.

Even if waveform distortion is avoided, Fikret-Pasa's[3] experiments suggest that it is possible to automatically adjust the gain so quickly (using what is called a "short recovery time AGC") that intelligibility in noise is reduced. In her tests with limiting circuits, the industry-standard 50 mS recovery time gave poor intelligibility scores, suggesting that we may have focused too much on not recovering quickly *enough*, without realizing that our resultant AGC designs muddy up whole sentences with a recovery that is *too* fast. (The K-AMP design uses a variable-recovery-time circuit that appears to be free of this problem, scoring as well as properly-adjusted linear amplifiers in Fikret-Pasa's experiments.)

Linear aids aren't so bad? Since linear aids still constitute 50% of sales, perhaps the important question is still "why should anyone switch to compression?" The strongest answer is to point out that well-designed compression can relieve the user of the task of constantly adjusting the volume control.

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The user with a facile finger can prevent most overload distortion by simply turning down the volume control and make most weak sounds audible by turning it up. I don't think any substantial research has shown any advantage for compression over a properly-adjusted-for-the-circumstances linear amplifier. In hearing instrument research, this has meant a linear hearing instrument with its gain and tone controls set for optimum reception for the test material (usually constant-presentation-level words or sentences)—*but don't stop reading now!*

The problem is that in real life most users don't know how to adjust the gain and tone controls with the skill that research audiologists use during "linear vs. compression" studies. Even users who *can* soon get tired of making constant adjustments. Either way, most users don't bother to "ride gain." *Then* the many disadvantages of linear circuits that are not constantly readjusted (lack of audibility for weak sounds, discomfort and/or distortion for strong sounds) come to the fore. The non-gain-riding user often turns down the gain once to avoid discomfort and then can't hear well in quiet *or* noise. WDRC compression permits the user to attend to other things without any *disadvantage* over an optimally set volume control.

Distinction #6: Compression Ratio vs. Low Level Gain Increase

I see no point in worrying about compression ratios for fitting hearing aids. Compression ratios *matter*, but they are the hard way of looking at things. Although fitting programs such as FIG6 show compression ratios, they also give targets for low-level gain, speech-level gain and high-level gain. Those *gains* can be most easily set using a multi-curve option on a test box (which will *not* display compression ratios). When those targets are hit correctly, the circuit will have been automatically set to the needed compression ratio. (The compression ratio can be checked, of course, by running an I/O curve and getting out a slide rule.)

When I have a client in front of me, what the client and I are concerned with is nothing more or less than our old friend *gain*. Will there be enough gain for weak sounds to make them audible? Will there be too much gain for strong sounds so they hurt? Will normally loud sounds be loud but not uncomfortable?

Those of us who carry pencils in our pockets and loudness-growth curves (with hearing loss as parameter) in our heads find compression ratios useful because they help us design circuits. We know that a 40 dB cochlear loss typically shows about a 2:1 increase in slope over the normal loudness-growth curve, so that an amplifier with approximately a 2:1 compression ratio will restore the aided loudness-growth curves to normal (and is consistent with Ruggero and Rich's[4] physiological data for loss of outer-hair-cell-amplifier function). A 60 dB loss typically shows a 3:1 slope in loudness growth.[1] In practice, somewhat lower compression ratios than these theoretical values are prescribed by existing fitting targets (and chosen subjectively).

Distinction #7: Input vs. Output Compression

Don't worry about this one: If you freeze the volume control with tape, you can't tell which is which anyway.

OK, my editors say I should mention that, when limiting is used, there is a theoretical advantage for properly-set *output compression* (the control circuit is introduced *after* the volume control), because it gives the user the freedom to choose gain for weak sounds, by adjusting the volume control, without worrying about discomfort.

Most WDRC circuits use *input compression*, permitting the user to choose the desired gain for *strong* sounds by adjusting the volume control; weaker sounds are automatically given greater gain by the WDRC action.

One other combination has been popular since the 1970s: compression-limiting circuits with input compression, typically adjusted for action above 65-70 dB SPL (i.e., for a limiting threshold of 65-70 dB SPL at the input, above which the output would increase very little). The term "input compression aid" has traditionally meant such a compression-limiting input-compression circuit.

Distinction #8: WDRC+Linear vs. WDRC+Limiting

One final distinction may be useful. In commercial WDRC hearing instruments, there are three different types of I/O behavior observed once the input SPL rises above approximately 85 dB:

1. Change to linear (K-AMP);
2. Continuation of the same WDRC Compression (e.g., Dyn-Aura, Omni, many more-recent 2:1 circuits); and
3. Change to compression limiting (e.g., ReSound).

Where restoration of normal loudness is desired, #1 (high-level linear operation) is indicated, since most impaired loudness-growth curves exhibit complete or partial recruitment (return to normal or near-normal loudness) at about 85 dB SPL. Where protection of someone with moderate-severe hearing loss from discomfort is indicated, #3 (high-level compression limiting) is indicated. Characteristic #2 is a reasonable compromise between the two. ◆

References

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