Output Compression Limiting (OCL) is a method for limiting the output of a hearing aid by using compression. Without OCL, hearing aid output would be limited by peak clipping – either at the output stage digital-to-analog (D/A) converter, or at the receiver. Both types of output limiting create distortion, but sound quality and clarity with OCL is preferred to peak clipping by most hearing-impaired individuals [1]. OCL is achieved by applying infinite compression to a signal that would otherwise exceed a pre-determined limit, or 'OCL threshold'. Channel-specific OCL thresholds are adjustable via the fitting software and can always be reduced if the patient feels the hearing aid is too loud. But what if the OCL thresholds are set as high as they can go, and the patient feels the hearing aid isn’t loud enough? Is a higher power receiver needed? Not necessarily. Livio® products can access more output than previous product lines without going to a higher power receiver, and without adding more distortion. The additional output is achieved with a new OCL design called 'output-referred OCL' (OROCL).

It is important to note that with the new OROCL, the puretone maximum output (OSPL90) for a given matrix (receiver) will be unchanged. What the patient will notice is the additional output realized for a broadband input. For the purpose of this discussion, a narrowband signal is one that falls completely within one channel of a multi-channel hearing aid. A broadband signal is wider in bandwidth and spans two or more channels. A speech-shaped noise signal, for example, provides input to many channels at the same time, while a puretone provides input to only one channel. Figure 1 shows an arbitrary signal going through a multichannel hearing aid that does not have OROCL. The output of each channel is limited, if necessary, by its own OCL threshold. But after the channels are combined and the signal is once again represented in the time domain, the total output can be too high for the output stage D/A. Like the receiver, the D/A also has an upper limit, above which the signal will be clipped and cause distortion. The question then is ‘how high can the channel OCL thresholds go before clipping occurs at the output stage?’

**Figure 1** - schematic of a multi-channel hearing aid. The input (‘sound in’) is converted to the frequency domain and divided into multiple channels (CH1, CH2, etc). Each channel has gain applied (blue box), and is then limited, if necessary, by its own OCL threshold. The channels are summed and converted back to the time domain (channel summation). The arrow after channel summation indicates the point at which an explicit, time-domain level check is needed before the output stage D/A (red octagon). Clipping can occur if the input to the D/A is too high.
For a narrow band input, the channel OCL threshold can go as high as the output stage threshold without issue. For a broadband input, it’s a different story. Even a signal that spans only two channels, each with an OCL threshold equal to the output stage threshold will sometimes result in clipping. That’s because the combined output of the two channels can be as much as 6 dB higher than the output stage threshold. For every doubling in the number of channels, the summed output potentially increases by another 6 dB. This would happen rarely, but if we wanted to ensure it would never happen, the channel OCL thresholds would have to be set conservatively - well below the output stage limit.

Alternatively, the channel OCL thresholds could be set very close to the output stage limit, and a weighting could be applied to the channel input levels. This was the approach used in products prior to the Livio product. By substituting a weighted, broadband input level for each channel input, effectively overestimating the input, the channel OCL thresholds were reached at lower input levels, resulting in a lower summed output. This was especially true for loud, low-frequency dominated sounds, which are more likely to cause output stage clipping. This method, called ‘Wideband OCL’, was effective in preventing clipping distortion, but did not fully optimize headroom for broadband input, leaving some hearing aid wearers wanting more loudness. With Livio hearing aids, an additional output compressor in the time domain acts as the safeguard against clipping. The threshold of this compressor is set at the clipping level of the D/A. This explicit check of the summed output before the D/A (at the point shown by the arrow after “channel synthesis” in Figure 1), along with the removal of the input level weighting is called ‘output-referred’ OCL. OROCL allows any signal, regardless of bandwidth or spectral shape, to achieve the highest output possible without clipping.

How does OROCL improve sound quality? The hearing aid wearer can expect fuller, more natural, and less harsh sound quality in loud environments. The most dramatic improvement will be noticed by those who are fit near the top of the recommended range for a given receiver. The additional output is there for those who need it without going to a larger, more powerful receiver. Better sound quality can also be expected during streaming for most open fits since a lot of low frequency
gain is needed to compensate for (open) vent loss. In general, the Livio hearing aid will be in output compression less frequently than the comparable Halo device with the same gain and OCL settings, allowing the broadband output spectrum to maintain its prescribed shape at higher input levels - another reason why Livio hearing aids have superior sound quality.

REFERENCES

1. Hawkins, D., Naidoo, S. "Comparison of Sound Quality and Clarity With Asymmetrical Peak Clipping and Output Limiting Compression " J Am Acad Audiol 4: Pages 221-228 [1993]
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The simulated coupler responses for a Livio RIC, and a Halo® RIC are shown in Figure 2. When both are best fit to the same audiogram (flat 60 dB HL), their broadband responses to loud speech (purple lines) look identical. As overall gain is increased (in each plot from left to right), the Halo and Livio broadband responses begin to diverge. Livio output continues to increase after Halo reaches its limit. At full on gain, the broadband output limit for the Livio device is about 10 dB higher than the Halo.

Figure 2 - Livio vs Halo, best fit to a flat 60 dB hearing loss. The maximum output is shown in each panel along with the response to loud speech. Overall gain is shown increasing from left to right (+6 dB, +10 dB, +20 dB, all the way up to full on gain). Note that the maximum output is the same for both products, but the broadband (speech) response is higher for Livio.
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REFERENCES

1. Hawkins, D., Naidoo, S. "Comparison of Sound Quality and Clarity With Asymmetrical Peak Clipping and Output Limiting Compression " J Am Acad Audiol 4: Pages 221-228 (1993)