Understanding Compression
Contents:

- Compression ratios  8
- Input and output controlled compression  18
- Attack and release times  31
- Effective compression & static compression  37
- Troubleshooting, general advice and references  47
The normal ear - a compression amplifier
Cochlear non-linear amplification

Source: Vlaming M., Concave Curvilinear WDRC, Hearing Review, September 2000
Loudness growth curve

Loudness refers to how someone *perceives* a sound
Amplifying (impaired loudness growth)

- 20 dB of linear amplification.
- For a signal level of 60 dB, the hearing aid makes the sound louder than what a normally hearing person would experience.
Linear amplification

Over amplification

Under amplification
Compression ratios

\[ CR = \frac{\Delta Input}{\Delta Output} \]

\[ = \frac{60}{60} = 1 \text{ or linear amplification} \]

30 dB gain

Output level (dB SPL)

Input level (dB SPL)
• 30 dB gain
• Compressive amplification

\[ CR = \frac{\Delta Input}{\Delta Output} \]

\[ = \frac{60}{30} = 2 \]

Or 2:1
Compression ratios (cont...)

- 30 dB gain
- Compressive amplification

\[ CR = \frac{\Delta Input}{\Delta Output} \]

\[ = \frac{90}{30} = 3 \]

or \(3:1\)
Anatomical/physiological basis

Compression Ratio = $\frac{\Delta \text{input}}{\Delta \text{output}}$

- $= 60/60$
- $= 1$ or $1:1$

Compression Ratio = $\frac{\Delta \text{input}}{\Delta \text{output}}$

- $= 60/30$
- $= 2$ or $2:1$
Compression threshold

Output level (dB SPL) vs Input level (dB SPL) graph.

Compression threshold or knee point also known as CT or TK.
A few things to keep in mind about input-output graphs and compression

Input-output graphs look at a “snap shot” in time

- In a real-world situation in a given channel, the loudest sound will trigger the compressor
A few things to keep in mind about input-output graphs and compression

- In any given channel, compression does **not** change the SNR.
- But....noise can be reduced by using compression in the channels where the SNR is worst.
- Overall SNR can be improved, but unless the noise and speech are in different frequencies (not usually the case) intelligibility will not be improved.
- Noise reduction primarily improves comfort.
- Multi-channel compression systems are used.
Linear amplification

Over amplification

Under amplification
Without expansion
With expansion
Input and output controlled compression

**Output controlled**
\( (AGC_o) \)

**Input controlled**
\( (AGC_i) \)

Volume control/amplifier does **not** have an effect on compressor

Volume control/amplifier **does** have an effect on compressor
Limiting maximum output

The maximum output of a hearing aid must be limited to:

- remain below the hearing aid user’s loudness discomfort levels (LDL’s)
- prevent damage to the hearing aid user’s residual hearing

How can we do this?

- Peak clipping
- Compression limiting ($\text{AGC}_o$)
Peak clipping vs \( AGC_o \)

Loud output before being compressed

Compression limiting (\( AGC_o \))

Peak clipping
Peak clipping versus compression limiting

<table>
<thead>
<tr>
<th></th>
<th>Peak clipping</th>
<th>Compression limiting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>Greater output for profound losses</td>
<td>Much less distortion of waveform</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Large distortion of waveform</td>
<td>Reduced output compared to peak clipping</td>
</tr>
</tbody>
</table>
Peak clipping

Driving a car story – peak clipping
Compression limiting - AGC₀

Driving a car story – AGCo
Input and output controlled compression

Output controlled
\((AGC_o)\)

- Input level (dB SPL)
- Output level (dB SPL)
- Compression threshold
- Max vol
- Min vol

Input controlled
\((AGC_i)\)

- Input level (dB SPL)
- Output level (dB SPL)
- Compression threshold
- Max vol
- Min vol

Volume control/amplifier **does** have an effect on compressor

Volume control/amplifier **does not** have an effect on compressor
AGC<sub>i</sub> – why do we use it?

- Selection of compression ratios and compression thresholds is not straightforward….

- Wide Dynamic Range Compression (WDRC) is a type of AGCi
  - WDRC is used to fit useful sounds (such as speech) in to a hearing impaired person’s reduced dynamic range
  - Aims to improve audibility of soft sounds
  - Low compression thresholds are used in WDRC
Main uses of AGCₖ

- To normalise loudness
  - Forms part of the rationale behind some hearing aid prescription methods eg. DSL[i/o]
  - Need to know loudness discomfort values (LDL’s) at different frequencies
    - LDL’s can be measured (although it’s not always straightforward)

- To maximise speech intelligibility
  - Forms part of the rationale for some hearing aid prescription methods Eg. NAL-NL1
    - Target gain is prescribed at various input levels (eg. 40dB, 65dB and 90dB). Compression is used to achieve these targets.
An example of AGCi in action
(hearing impaired: unaided)
An example of AGCi in action
(hearing impaired: linear amplification)
An example of AGCi in action (hearing impaired: WDRC)

- Assumption: it is desirable to apply maximum amplification to soft speech

- CT’s in the range of 40 to 50 dB SPL will usually achieve this goal
# Compression Parameters

## Compression System

<table>
<thead>
<tr>
<th>Curve 1</th>
<th>Curve 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum level in dB SPL</td>
<td></td>
</tr>
<tr>
<td>MPO in dB</td>
<td></td>
</tr>
<tr>
<td>Gain in dB</td>
<td></td>
</tr>
<tr>
<td>CK in dB</td>
<td></td>
</tr>
<tr>
<td>CR</td>
<td></td>
</tr>
</tbody>
</table>

Change values in table see effect of MPO, Gain, CK, and CR settings.

- [ ] Show Dynamics
- [ ] Show
- [ ] Hide

![Graph showing compression parameters](image-url)
Attack and release times

- Compression acts *dynamically* - as input levels change the gain will change – but how quickly?

- How does the gain change over time with different input levels?
  
  ➢ It depends on **attack** and **release** times

**Attack time:** time taken for the compressor to react to an increase in the input level

**Release time:** time taken for the compressor to react to a reduction in the input level
Representation of attack & release time

- Level (dB SPL)
- Time (s)
- Input signal
- Output signal
- Attack time
- Release time
Attack times

- Most hearing aids use fast attack times (around 5 msec or longer)
- Fast attack times are good for sudden loud sounds
- Having fast attack times for very short loud sounds is not really important because very brief sounds are not perceived as being loud
Release times

- There is more debate (than with attack times) about how to set release times in hearing aids

- Short release times are generally 150 msec or less
  - Also known as **syllabic compression**

- Extremely short release times (say about 10 msec) would vary the fundamental voice frequency and cause distortion

- Long release times (say longer than 1 sec) are used in automatic volume control hearing aids
  - Pros: less distortion of waveform
  - Cons: softer parts of speech may be inaudible
Adaptive attack and release times

- Instead of constant attack and release times *adaptive* attack and release times can be used:
  - Usually depends on the duration of the loud sound:
    - short loud sounds trigger a fast attack and release time
    - Longer loud sounds trigger a longer release time
  - Siemens use adaptive compression: choice of “syllabic” or “dual” compression
Effect of time constants on compression:

1. Linear

2. Long attack and release time

3. Short attack and release time

Intensity differences remain fairly untouched

Intensity differences altered
Effective compression & static compression

- The static compression ratio is what is set in the fitting software.
- Effective compression: how changes in the short-term input level affect changes in the short-term output level.
- Effective compression depends on:
  - Attack and release times
  - Number of compression channels
  - Bandwidth of each channel
  - Channel coupling
- The effective CR cannot be larger than the static CR.
- Effective CR usually increases with:
  - shorter time constants
  - increasing number of independent compression channels
Effective compression (cont…)

- Lets look at two extremes for effective compression:
  - Attack and release times much shorter than 120 ms → effective CR similar to static CR
  - Attack and release times much longer than 120 ms → effective CR 1:1, although gain **will** change for long-term level changes
- Most hearing aids fall between these two extremes
Effective compression (cont…)

“Hammering” sound → lots of short term change, big dynamic range

BEFORE COMPRESSION

![Graph showing level (dB SPL) vs frequency (Hz)]
Effective compression (cont…)

“Hammering” sound → lots of short term change, big dynamic range

LONG ATTACK AND LONG RELEASE TIME
Effective compression (cont…)

“Hammering” sound → lots of short term change, big dynamic range

**SHORT ATTACK AND RELEASE TIME**

![Effect of time constants on effective compression](image_url)

- **Output signal:** Short release time
Benefits and disadvantages of multi-channel compression

Advantages

- Multi-channel compression increases audibility
  - People have varying degrees of loss at different frequencies
  - Increased sound comfort
  - Useful way of limiting maximum output for many clients
Benefits and disadvantages of multi-channel compression

Disadvantages

- Decreases some of the essential differences between different phonemes\(^1\) resulting in decreased intelligibility under certain conditions eg. for severe losses where high compression ratios are required

  - Usually recommended not to use compression ratios > 3:1 (has been shown to reduce intelligibility for hearing impaired listeners using multi-channel compression\(^2\))

1. Dillon H., Hearing Aids (2001), pp 185

Spectral flattening – what it means

- Different spectral shapes help us to discriminate one phoneme from another.
- Multi-channel compression reduces peaks and raises the valleys, disrupting the spectral information.
Connexx First Fit: single channel CK & CR

How are the CK and CR calculated?

CR: determined by target at 65 and 90 dB
CK: intersection of gain @40 dB and CR
Target completely determines CR and CK
**Connexx First Fit: differences between single channel and multi channel CT and CR**

**Key differences:**

- *Connexx First fit operates so that all channels enter compression simultaneously* (requirement based on NAL research)
  - This means different compression thresholds for different channels (lower CT for high frequency channels)

- Multiple channels means that the power level in each channel is less (which means lower compression thresholds needed in each channel)

- The underlying principle for calculating CR and CT is still the same as a single-channel hearing aid
### Troubleshooting compression settings

<table>
<thead>
<tr>
<th>Client reports</th>
<th>Suggested action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing aid whistles</td>
<td>Increase CT (and reprogram medium level gain)</td>
</tr>
<tr>
<td>Can’t hear soft speech</td>
<td>Decrease CT (and reprogram medium level gain)</td>
</tr>
<tr>
<td>Too much noise even in quiet places</td>
<td>Increase CT (and reprogram medium level gain)</td>
</tr>
<tr>
<td>Hearing aid doesn’t sound clear</td>
<td>Decrease the high frequency CR</td>
</tr>
<tr>
<td>Distant sounds heard better than close sounds</td>
<td>Decrease the CR</td>
</tr>
<tr>
<td>Hearing aid sounds weak</td>
<td>Decrease the CR</td>
</tr>
<tr>
<td>Client is annoyed by “swishing” sound (pumping)</td>
<td>Increase release time or use adaptive release times (if available)</td>
</tr>
</tbody>
</table>

Some information adapted from: Jenstad et al. (2003)
## Troubleshooting common environmental sounds

<table>
<thead>
<tr>
<th>Loudness (with normal hearing)</th>
<th>Low Freq</th>
<th>High Freq</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>loud</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dog barking sounds too loud</td>
<td>Increase low channel CR</td>
<td>Cutlery and crockery sounds are too loud</td>
</tr>
<tr>
<td>Increase high channel CR</td>
<td></td>
<td>• Check MPO</td>
</tr>
<tr>
<td>Increase low channel CR</td>
<td></td>
<td>• Increase high channel CR</td>
</tr>
<tr>
<td><strong>soft</strong></td>
<td>Increase CT for low channel(s)</td>
<td>Increase CT for high channel(s)</td>
</tr>
<tr>
<td>• Fridge sounds too loud</td>
<td>• Birds sounds are too loud</td>
<td></td>
</tr>
<tr>
<td>• Dripping tap too loud</td>
<td>• Rustling paper too loud</td>
<td></td>
</tr>
<tr>
<td>• Traffic noise too loud</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>medium</strong></td>
<td>Decrease low freq gain</td>
<td>Voices sound too sharp</td>
</tr>
<tr>
<td>Air-conditioning too loud</td>
<td></td>
<td>Decrease high freq gain</td>
</tr>
</tbody>
</table>
General advice for the clinic

- Multi-channel compression is preferable
  - Intelligibility is likely to be increased for steeply sloping losses\(^1\)
- Generally use the lowest compression ratios and thresholds possible
  - Use of lower compression ratios leads to less disruption of spectral cues\(^2\) and less disruption of intensity differences
- Need to balance low compression ratios with audibility requirements for different degrees of loss
- Need to balance low compression ratios with comfort for louder sounds
- Generally don’t use compression ratios greater than 3:1
General advice for the clinic (cont....)

- Longer release times are generally preferred by clients
  - There is some evidence people with poorer cognitive performance (often older people) do better with longer release times\(^1\)

- The first fit approach used by fitting software gives a good starting point
  - compression settings are based on the underlying prescription used (e.g., NAL-NL1, DSLi/o, etc.)

- Remember, if you manually change compression thresholds rematch the target gain for medium sounds (65dB)

---

2. Patterns of candidature
References

Dillon H., Hearing Aids (2001), Boomerang Press

Vlaming M., Concave Curvilinear WDRC: Optimizing the Shape of Compression, The Hearing Review, September 2000


DeGennaro et. al. (1986), Multi-channel syllabic compression for severely impaired listeners, J Rehab Res Dev, 23(1):pp.17-24

Jenstad et al. (2003). Hearing aid troubleshooting based on patients’ descriptions. JAAA, 14, 347-360