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Ezairo® Preconfigured Suite Wide Dynamic Range Compressor

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APPLICATION NOTE

INTRODUCTION

This application note describes the Wide Dynamic Range Compressor (WDRC) included in the Ezairo Preconfigured (Pre) Suite firmware bundles. The WDRC is a highly−configurable multi−channel dynamic range compressor. Channels are groups of one or more frequency bands. Each channel features upper and lower−level compression kneepoints, an expansion kneepoint, and Output−Referred Automatic Gain Control (AGCo) to limit the maximum output level. Three level detectors with independent attack and release times are provided to adjust the dynamic behavior of each channel.

The sections below provide an overview of the algorithm's operation, and a detailed description of available adjustments to the algorithm's behavior. The advanced graphing capabilities available in the Ezairo Sound Designer Software Application that predict the acoustic response of a device are also covered.

DYNAMIC RANGE AND COMPRESSION OVERVIEW

Dynamic range refers to the difference between the softest and loudest possible sounds. A wide dynamic range compressor can be used to map a very wide input dynamic range to a narrower output dynamic range. In general, this involves applying more gain to softer sounds than to louder sounds. This allows the compressor to deliver the appropriate amount of gain to make softer sounds audible without making louder sounds too loud.

The gain applied by the WDRC is specified by an Input/Output (I/O) function that describes the mapping of input sound levels to output sound levels. This function is configured using a series of hard kneepoints with unique thresholds and gains. Kneepoint thresholds specify audio input levels, with the exception of the AGCo Output Limit which specifies a maximum output level.

A multi−channel WDRC maps filterbank bands into independent channels separated by crossover frequencies. This allows for different I/O functions to be applied to different frequency bands. For example, compression could be applied to high frequencies only, while allowing lower frequencies to pass through without any adjustment.

As part of the WDRC operation, the input signal energy in each channel is estimated with a level detector whose output is smoothed with configurable attack and release times. The attack and release times control the dynamics of the algorithm. For example, by using slower attack and/or release times it is possible to slow the rate at which the gain changes. This smoothing also ensures that the algorithm does not adjust the gain too rapidly which might otherwise distort the signal.

The smoothed signal energy is then used to calculate the gain that is applied using the I/O functions that have been defined for each channel. All of these concepts will be covered in greater detail in the next section.

WIDE DYNAMIC RANGE COMPRESSOR TAB

User controls for the WDRC are collected together in a single tab on the Sound Designer Control Panel screen. For example, when starting the Ezairo Sound Designer Software Application for the first time using the Demo Library, the WDRC tab appears as shown in Figure 1. Depending on the product, some (or all) WDRC parameters can be configured differently in each program memory providing customizable behavior for different situations.

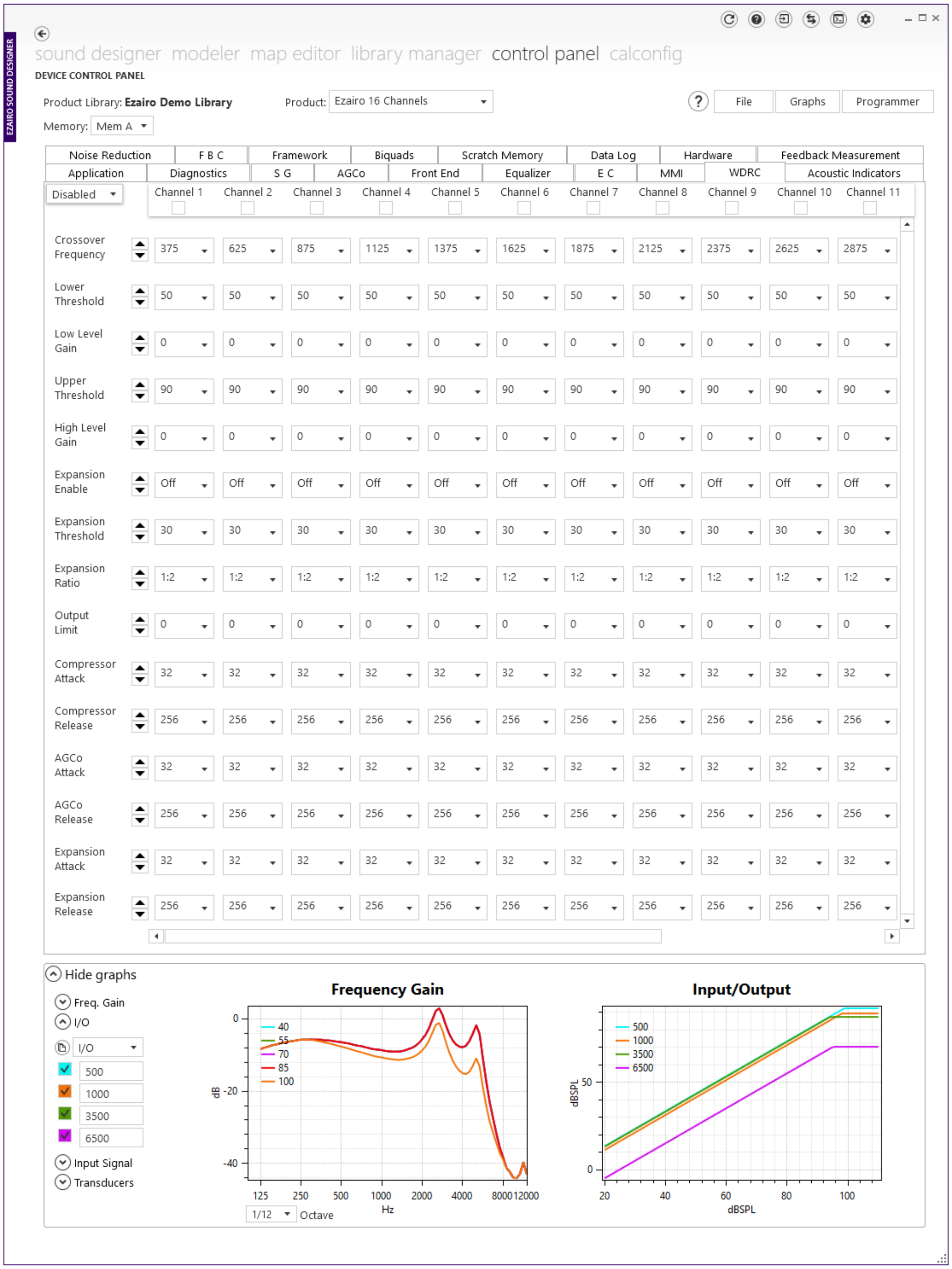

Figure 1. Example Control Panel Tab for the Ezairo Pre Suite WDRC using the Ezairo 7160 SL

The WDRC tab shown in Figure 1 is divided into two areas: user controls and graphs. The user controls section provides adjustments for all available WDRC parameters. The graphs section displays the resulting acoustic response of the device. Each of these is described in more detail below.

GRAPHS

We will introduce the graphs section first because the graphs can be helpful to understand how the user controls work. The graphs section can be revealed by clicking Show graphs at the bottom of the screen.

Any parameter change that affects the acoustic response of the device at steady−state will result in a corresponding change to the graphs. It is important to note that the correct microphone and receiver sensitivities must be modeled, added to the product library, and selected under Transducers to allow the software to accurately model the device.

The graphs include many options for displaying the response of the device using two plots. By default a Frequency Gain plot, and an Input/Output plot are shown. The Frequency Gain plot (also known as a frequency response) displays the gain (dB) as a function of frequency (Hz) for different input levels (dB SPL). It is possible to select up to 5 customizable input levels on the Frequency Gain plot. The Input/Output provides a different picture mapping input levels (dB SPL) to output levels (dB SPL) for different frequencies (Hz). It is possible to select up to 4 customizable frequencies on the Input/Output plot.

Each of these plots features an alternative view that can be selected to provide the same information in a different way. A Frequency Output plot can be selected in place of the Frequency Gain plot. This displays output levels (dB SPL) rather than gain (dB) on the y−axis. An Input/Gain plot can be selected in place of the Input/Output plot. This displays gains (dB) rather than output levels (dB SPL) on the y−axis.

The graphs predict the response of the device under steady−state conditions using pure tones (Hz) by default. This predicted response includes all acoustical, and electrical effects. It is also possible to display the response of the device for a composite flat input signal by selecting this option under Input Signal.

USER CONTROLS

The WDRC Enable control turns the WDRC on and off, as desired. If the WDRC is turned off, the audio signal will pass through unmodified (no compression, expansion, or in−channel limiting will be applied).

Crossover Frequencies control the separation between channels and are adjustable in 250 Hz steps. Channel 1 starts at 0 Hz and includes all frequencies up to the first crossover. The last channel starts at the last crossover frequency and includes all frequencies up to half the sampling rate. All other channels include frequencies from the lower crossover frequency to the next highest crossover frequency. Crossover frequencies must be unique and assigned in increasing order.

Each channel also features a number of parameters that specify the I/O and dynamic behavior of that channel. These controls are described in detail below.

Gain Controls

The Input/Output function may contain up to five distinct gain regions shown in Figure 2:

- An expansion region below the Expansion Threshold.
- A lower level linear region between the Expansion Threshold and the Lower Threshold.
- A compression region between the Lower Threshold and Upper Threshold.
- A higher level linear region between the Upper Threshold and the Output Limit.
- An output limiting region.

The Upper, Lower, and Expansion thresholds are all input−referred acoustic thresholds (dB SPL). Because these parameters are acoustic, it is critical that the correct transducers have been modeled and selected.

The Output Limit is a threshold that is specified relative to the full scale or maximum output of the device (dBFS).This is mapped onto an acoustic output limit based on the electroacoustic properties of the reciever. For a given output limit in dBFS, a receiver with a higher sensitivity will result in a higher acoustic output limit than one with a lower sensitivity. The graphs predict the resulting acoustic output limit of the device.

Low Level and High Level Gains (dB) are applied by the WDRC algorithm and are added to other gains in the system including transducers, preamplifiers, and other algorithms. These gains can be positive or even negative to ensure that the desired acoustic response is achieved.

The Expansion Ratio indicates the amount by which the output level will drop for every 1 dB drop in input level below the Expansion Threshold. For example, an expansion ratio of 1:2 means that a signal that is 5 dB below the Expansion Threshold will be attenuated by 10 dB relative to a signal that is at the Expansion Threshold. This can be useful in situations where very low level noise might otherwise be unnecessarily amplified by the Low Level Gain.

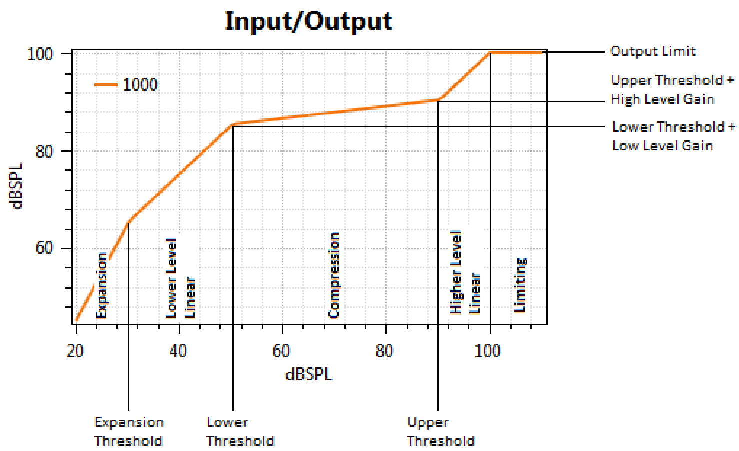

Figure 2. Input/Output Graph Illustrating the Different Gain Regions

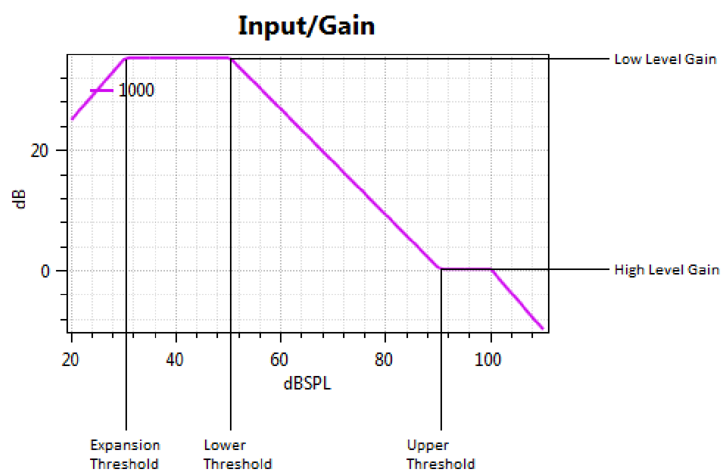

Figure 3. Corresponding Input/Gain Curve to Figure 2

Figure 2 is an example Input/Output graph taken from the Ezairo Sound Designer Software Application, and has been marked−up to illustrate the mapping between WDRC parameters and their effect described above.

Figure 3 shows the Input/Gain which provides a complimentary view of the same information found in the Input/Output curve in Figure 2. This shows the gain rather than output level as a function of input level. The Input/Output and Input/Gain curves can be calculated from each other where:

$$\text{Output Level}(X) = X + \text{Gain}(X), \text{ for every input level } X$$

Because the WDRC provides a flexible set of controls, some parameter configurations could result in inappropriate behavior for conventional hearing−aid applications. For example, it would not make sense for the WDRC to apply more gain to louder signals than softer signals above expansion. For convenience, the Ezairo Sound Designer Application Software enforces these restrictions when setting parameters in the WDRC tab.

1. Crossover Frequencies must be unique and selected in ascending order.
2. The Lower Threshold cannot exceed the Upper Threshold within any channel.
3. The Expansion Threshold cannot exceed the Lower Threshold within any channel.
4. The (Lower Threshold + Low Level Gain) cannot exceed the (High Level Threshold + High Level Gain) within any channel.

Dynamics Controls

Each channel features an AGCo, Compressor, and Expansion level detector with independent Attack and Release times. During algorithm operation, only one level detector is used in each channel as the active signal level estimator. This level is then used in all WDRC gain calculations. The active level detector is chosen depending on the operating conditions described below.

1. The AGCo level detector takes priority if it exceeds the Output Limit.
2. The Compressor level detector takes priority if it exceeds the Expansion Threshold and the AGCo level detector has not already taken priority.
3. The Expansion level detector only takes priority if the AGCo level detector has not taken priority, and the Compressor level detector is below the expansion threshold.

As a result, priority is always given to AGCo first, Compression second, and Expansion third. It follows that Expansion will be exited based on the Compressor Attack time at the onset of any signal (including speech) that exceeds the Expansion Threshold.

Attack and Release times are defined based on the *ANSI Specification of Hearing Aid Characteristics (ANSI/ASA S.22−2009)*. The Standard defines a 35 dB level change, and stipulates that the settling time is defined as within 3 dB of the steady−state value for Attack, and within 4 dB of the steady−state value for Release with a tolerance of ±5 ms or 50%, whichever is greater. This test is under maximum compression (the I/O curve is horizontally flat). The following sections provide a more detailed description of how these parameters control the dynamic performance of the WDRC.

There are other ways of defining Attack and Release times, and a common alternative is based on the time it takes to reach 1−1/e (63.5%) of the original signal in response to a unit step function. Time constants that have been derived using this alternative definition result in a slightly faster attack, and much slower release (by approximately a factor of 8) than those defined based on the ANSI Standard. In other words, Attack times that have been used in products using this alternative definition can be used directly in this implementation with little observable difference in behavior. However, Release times that have been used in products using this alternative definition will need to be made approximately 8 times slower in this implementation to result in a similar measured behavior.

In this implementation Attack time controls how quickly the algorithm responds to increasing signal levels and Release time controls how quickly the algorithm responds to decreasing signal levels.

It follows that the Compressor and AGCo Attack determine how quickly gain is reduced, and that Compressor and AGCo Release determine how quickly gain is restored. The inverse holds true for Expansion, because Expansion reduces gain as the signal level decreases; Expansion Release determines how quickly gain is reduced, and Expansion Attack determines how quickly gain is restored. Figures 4 and 5 illustrate the response of different Attack and Release times under ANSI/ASA S.22−2009 conditions.

The fastest supported Attack/Release time is a function of the number of channels used, and can be calculated as max (1, 0.25 * [number of WDRC channels]) in ms. For example, a 16−channel product can support an Attack/Release time that is as fast as 4 ms. A 4−channel product can support an Attack/Release time that is as fast as 1 ms.

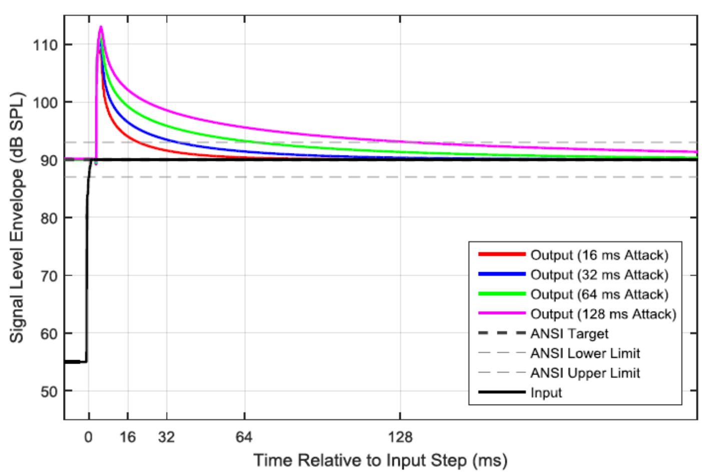

Figure 4. Compression Signal Levels for Various Attack Times for a 1 kHz Tone

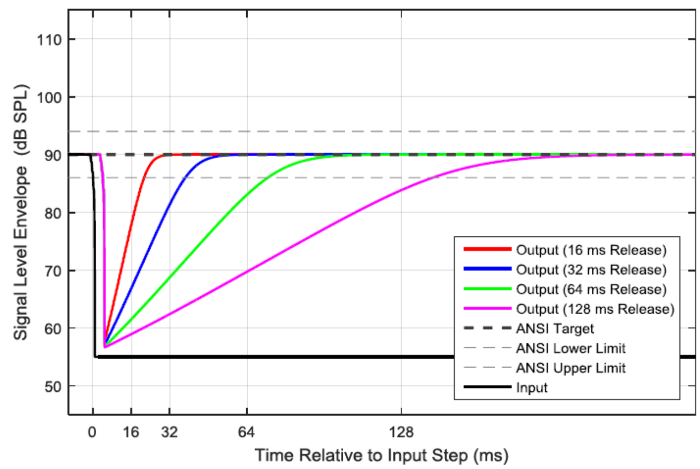

Figure 5. Compression Signal Levels for Various Release Times for a 1 kHz Tone

There are many different ways to configure Attack and Release times, and so the following serve only as very general recommendations that may be useful.

In general, consider configuring the AGCo level detector with the fastest Attack time of the three level detectors. A fast Attack time will apply harder limiting, whereas a slow Attack time will provide softer limiting but runs the risk of clipping/saturation under transient conditions.

Some configurations have tradeoffs. For example, by selecting a faster Release time, expansion will tend to engage and track the noise floor more quickly any time the Compressor level detector drops below the Expansion Threshold. This could be desirable because it will rapidly suppress noise. However, this may also result in more noticeable breathing (modulation) to the noise floor especially under quiet conditions with interruptions like speech where you may be entering and exiting expansion too rapidly. By selecting a slower Release time, expansion will tend to engage more slowly every time it engages and the transition may be less noticeable.

Changes to WDRC dynamics parameters will not be reflected in the graphs because they do not change the response of the device at steady−state.

WIDE DYNAMIC RANGE COMPRESSION EXAMPLE

The following section illustrates an example of wide dynamic range compression by taking a closer look at the Input/Output behavior over time. In this example, we have configured the WDRC with a Lower Threshold of 50 dB SPL, a Low Level Gain of 30 dB, an Upper Threshold of 90 dB SPL, and a High Level Gain of 0 dB. This results in significant compression for inputs between 50 and 90 dB SPL, which will be mapped to 80 and 90 dB SPL at steady−state (a compression ratio of 4:1). See Figure 6 and Figure 7.

To examine what happens over time, we have configured a Compressor Release time of 128 ms, and applied a 1 kHz pure tone to the input which drops abruptly from 90 to 50 dB SPL at time 0 ms. The Input and Output levels are shown in Figure 8.

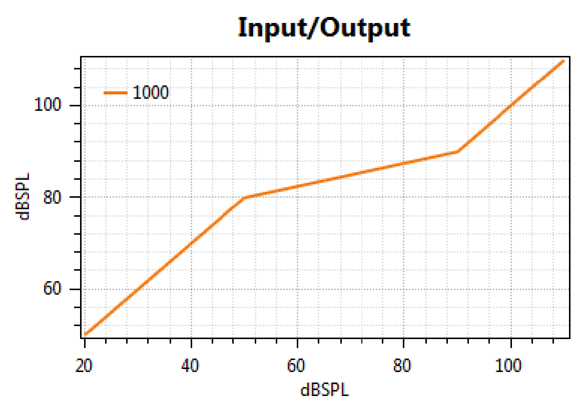

Figure 6. Input/Output Curve with a Linear Gain and Compression

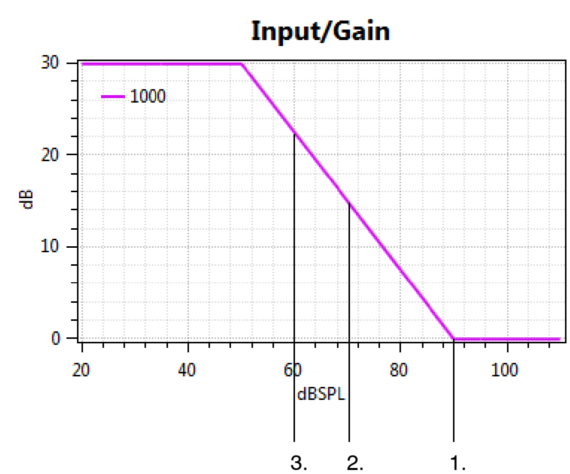

Figure 7. Corresponding Input/Gain Curve to Figure 6

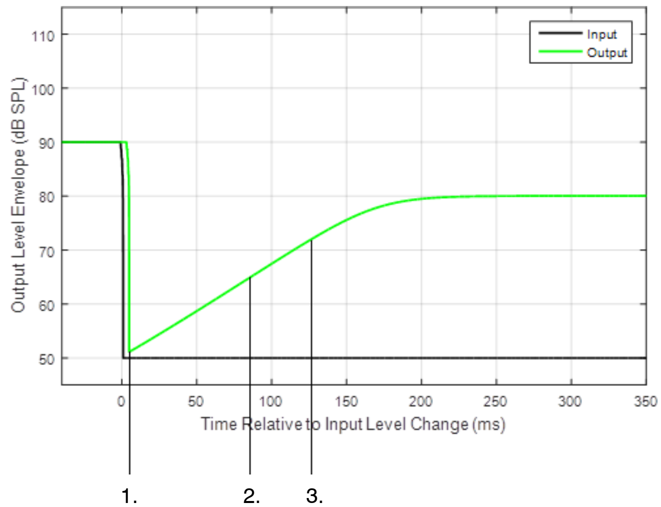

Figure 8. Input/Output Responses over Time for a Step Input

Referring to Figures 7 and 8, we can see that before time 0 ms, both the input and output levels are 90 dB SPL. After time 0 ms we can observe the behavior of the algorithm at snapshots in time as indicated by the numbers in those figures.

1. At precisely 0 ms the input level drops down to 50 dB SPL and is held there. We can see that just after this time, the output level drops to nearly 50 dB SPL as well. This is because the WDRC continues to apply the same 0 dB High Level Gain, and it takes time before the Compressor Release provides the full 30 dB of gain to the now lower level input.
2. At approximately 85 ms, the Compressor Release has allowed 15 dB of gain to be applied of the total 30 dB at steady−state, resulting in an output level of approximately 65 dB SPL.
3. At approximately 128 ms, the Compressor Release has allowed 22 dB of gain to be applied, resulting in an output level of approximately 72 dB SPL.

After approximately 22 ms longer, we can see that the compressor has released most of the gain to be within 4 dB of the steady−state value, and at 200 ms released the full amount of gain to reach steady−state.

In this way, we can see that a wide input dynamic range has been mapped to a much narrower output dynamic range by applying significant gain to lower input levels, and progressively less all the way to 0 dB gain to higher input levels. The amount of time it takes to restore gain when under compression depends on the Compressor Release.

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