Limiter

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Definition

The output level of an electric guitar can change drastically during music execution, from very low up to highly loud. Sometimes the sound can be distorted unintentionally due amplifier saturation during strong action on the strings. Using a Compressor pedal can overcome this issue, but it also introduces dynamics which may or may not be wanted. The Limiter can be a perfect choice in this situation. It compresses the audio signal without introducing any dynamics like the Compressor, or any distortion, like the Overdrive. It acts directly on the amplitude of the signal instead the output level.

Limiter

The Limiter shall not be confused with any other effect. By definition, a Limiter shall not introduce significant change to the audio signal, although a small distortion is acceptable. The Limiter can be classified within the category of effects that act on the amplitude of the signal, such as Compressor, Sustain, and, similarly, Overdrive. It differs from the Compressor because, unlike the latter, its action is not dynamic. Sustain, on the other hand, applies a dynamic and variable gain, while Overdrive applies a non-linear cut in amplitude. In this way, the Limiter is more similar to Overdrive, but, differently, it does not aim to introduce additional harmonics to the audio signal.

A simple Limiter that cuts the signal when the amplitude exceeds a certain value introduces odd harmonics into the signal, which resembles distortion. To avoid this effect, the limiter must act on the amplitude smoothly, without causing abrupt breaks in the wave shape. Several functions can be used to limit the signal, such as arctangent, hyperbolic tangent, exponentials, etc. All of them, unfortunately, bring together two disadvantages: they require complex calculation using numerical processors, and they have asymptotic behavior, that is, they never reach the limit value, but tend towards it for high amplitude signals. To avoid both problems, segments of linear functions can be used, or, instead, non-linear functions such as quadratic or cubic, for example.

A Limiter can be modeled by

$$y(n) = f[x(n)],$$

where $x(n)$ is the input signal and $y(n)$ is the output. $f(\cdot)$ is a monotonic odd function that maps the argument to the $[-1, 1]$ interval. Good results were obtained on tests by flattening the amplitude with a piecewise quadratic function. Low amplitudes remain unchanged while very high values are clipped down to unity, as can be seen in Figure 1. In the linear range, the output is straightforward: $f[x(n)] = x(n)$. The quadratic function is obtained by imposing continuity of first and second (derivative) orders with the linear function. Moreover, the quadratic function shall reach the upper limit with null derivative. The shape of the quadratic function can be adjusted by the smoothness factor w which establishes half the width interval, centered at $x(n) = 1$. In other words, given a smooth factor w, the quadratic function f is such that

$$f[1-w] = 1-w,$$
$$f[1+w] = 1,$$
$$\left.\frac{\mathrm{d}f}{\mathrm{d}x}\right|_{x=1-w} = 1,$$
$$\left.\frac{\mathrm{d}f}{\mathrm{d}x}\right|_{x=1+w} = 0,$$

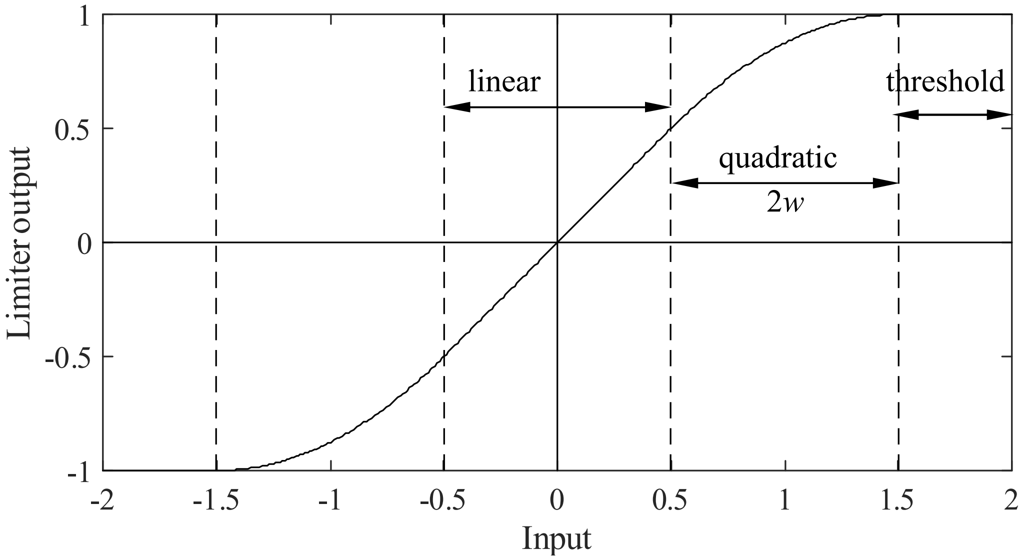

Fig. 1 – Limiter function f(x).

After the quadratic function reaches it maximum value of 1, $f(x)$ becomes constant and equal to this threshold. The maximum amplitude of the input signal was supposed to be two, or $\max(x) = 2$ for any n. Anyway, this limit can be easily changed if needed.

From the restrictions to the quadratic function it can be achieved that[1]

$$f(x) = x - \frac{[x-(1-w)]^2}{4l\,w},$$

for x ranging in the interval $1 - w$ to $1 + w$. Therefore, the complete set of the Limiter function is given by

$$f(x) = \begin{cases} x, \text{ if } 0 \le x \le (1-w) \\ x - \dfrac{[x-(1-w)]^2}{4w}, \text{ if } (1-w) < x \le (1+w) \\ 1, \text{ if } x > (1+w) \end{cases},$$

for $x \geq 0$. If x is negative, then it holds that

$$
f(x) = \begin{cases} x, \text{ if } \ 0 > x \geq -(1-w) \\ -x + \dfrac{[x-(1-w)]^2}{4w}, \text{ if } \ -(1+w) < x \leq -(1-w) \\ -1, \text{ if } \ x < -(1+w) \end{cases},
$$

Figure 2 shows the Limiter function for x ranging from -2 to 2, and for smoothness factor w going from 0 up to 1 in 0.25 increment: 0, 0.25, 0.5, 0.75 and 1. It is clear that the higher the factor, the smoother the curve.

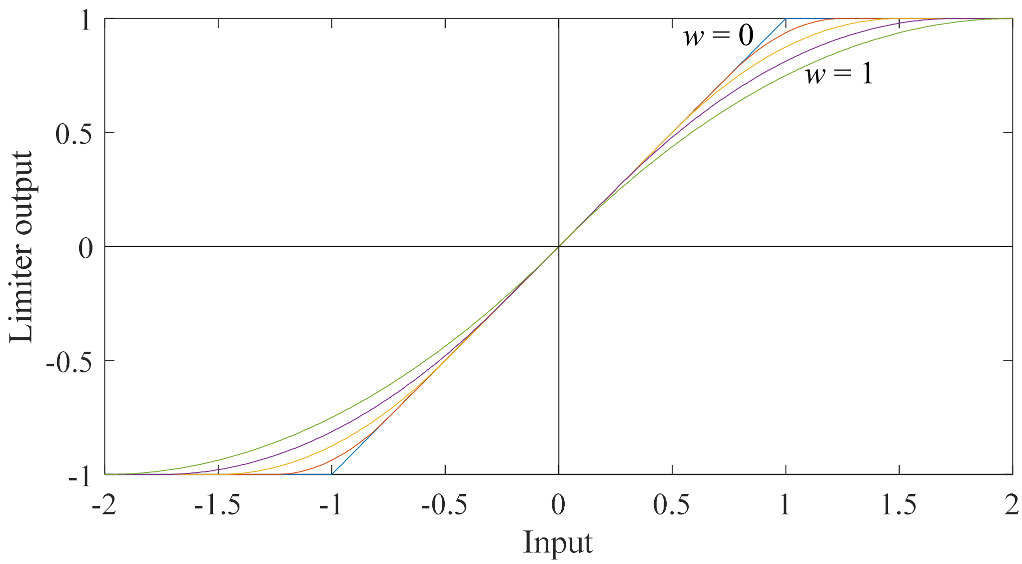

Fig. 2 – Effect of the smoothness factor on the Limiter function.

References

1 Giannoulis, D.; Massberg, M.; Reiss, J. Digital Dynamic Range Compressor Design – A Tutorial and Analysis. Journal Audio Engineering Society, Vol. 60, No. 6, June 2012.