Digital Audio Effects

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October 17, 2018

Course website: https://github.com/mathieulagrange/musnu

Outline

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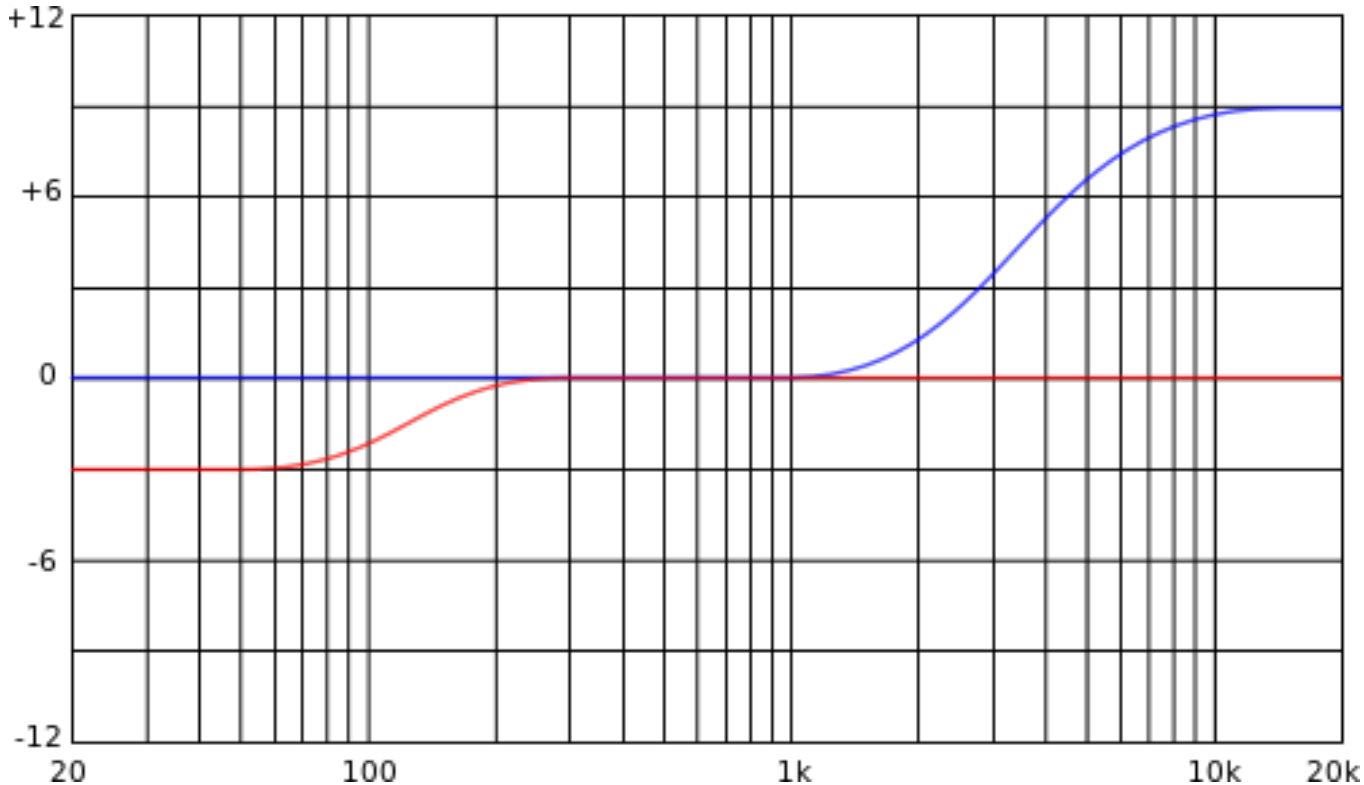
Equalization

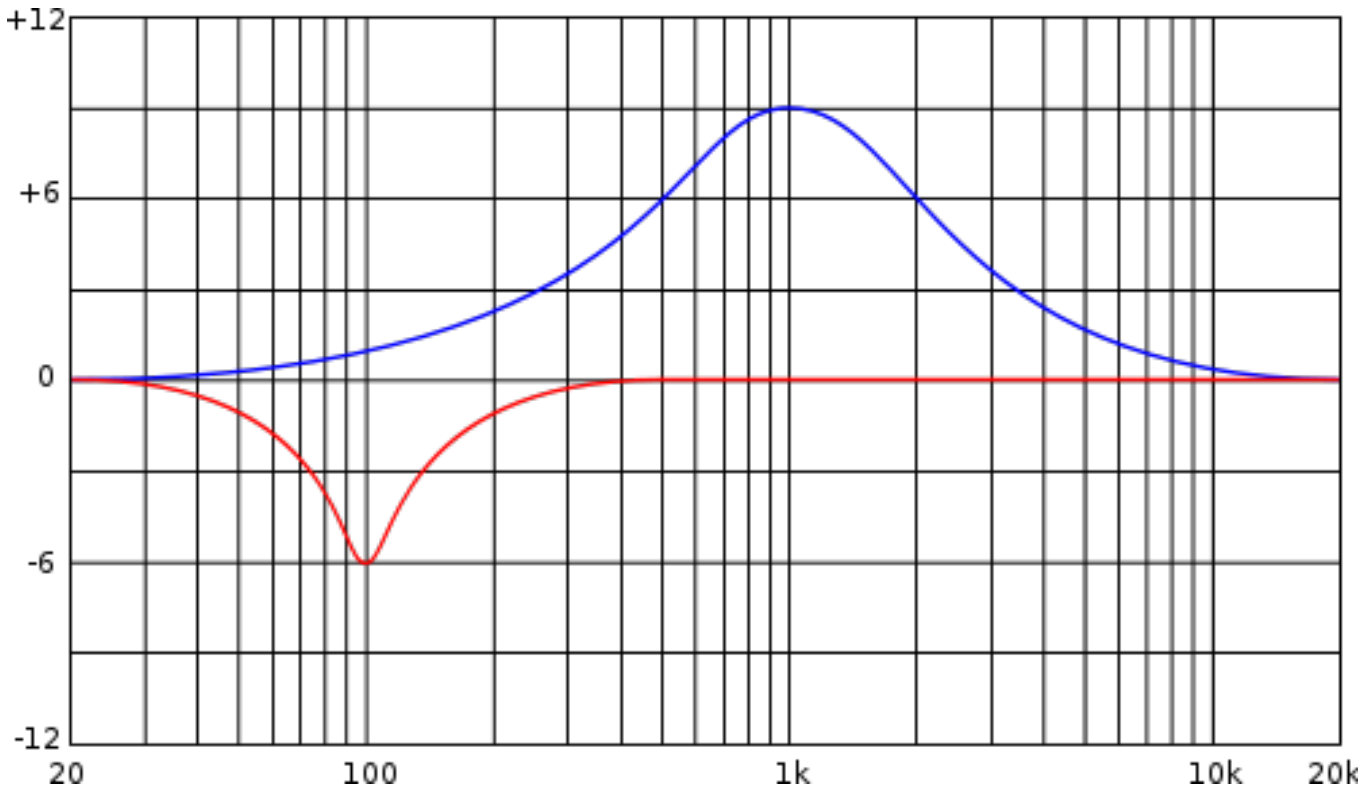
Equalization is the process of adjusting the balance between frequency components within an electronic signal.

- High-pass and low pass filters
- Parametric equalizer : fine control of amplitude, center frequency and bandwidth
- Graphic equalizer : filter bank

Low Pass / High Pass



Pass band



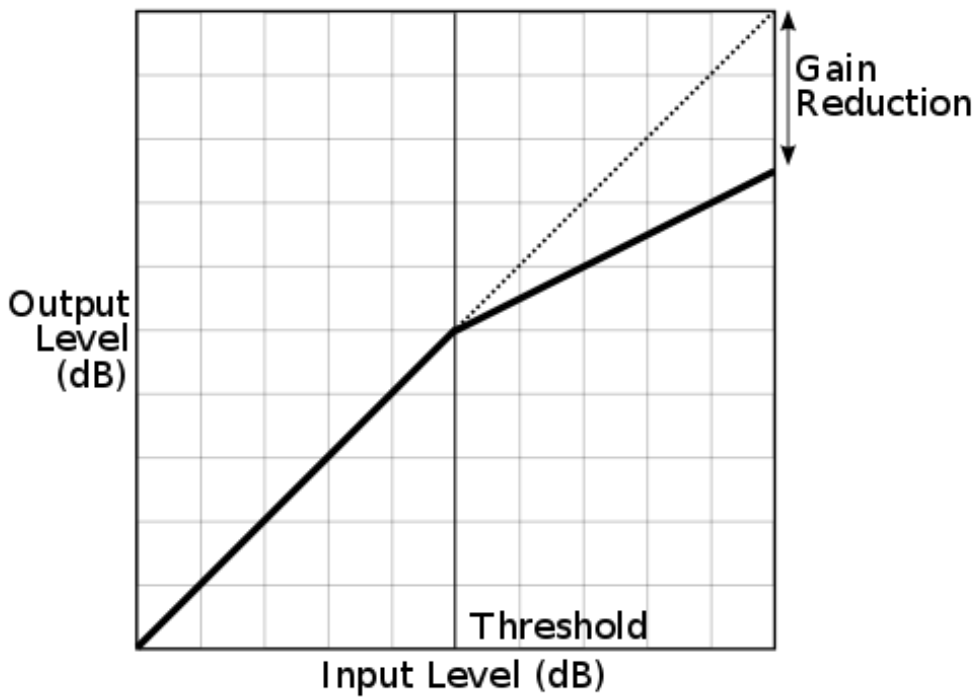
Compression

Dynamic range compression (DRC) or simply compression

- is an audio signal processing operation that reduces the volume of loud sounds or amplifies quiet sounds
- thus reducing or compressing an audio signal's dynamic range.

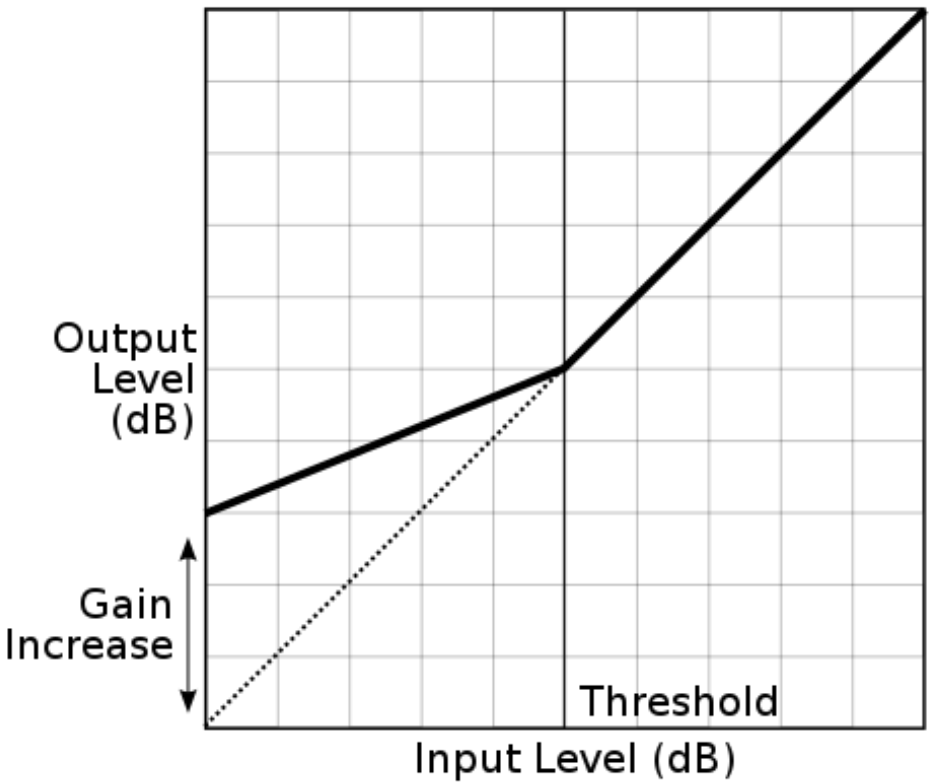
Downward Compression

$$y = \begin{cases} x \text{ if } x < t \\ t + (x - t)/r \text{ otherwise} \end{cases}$$



Upward Compression

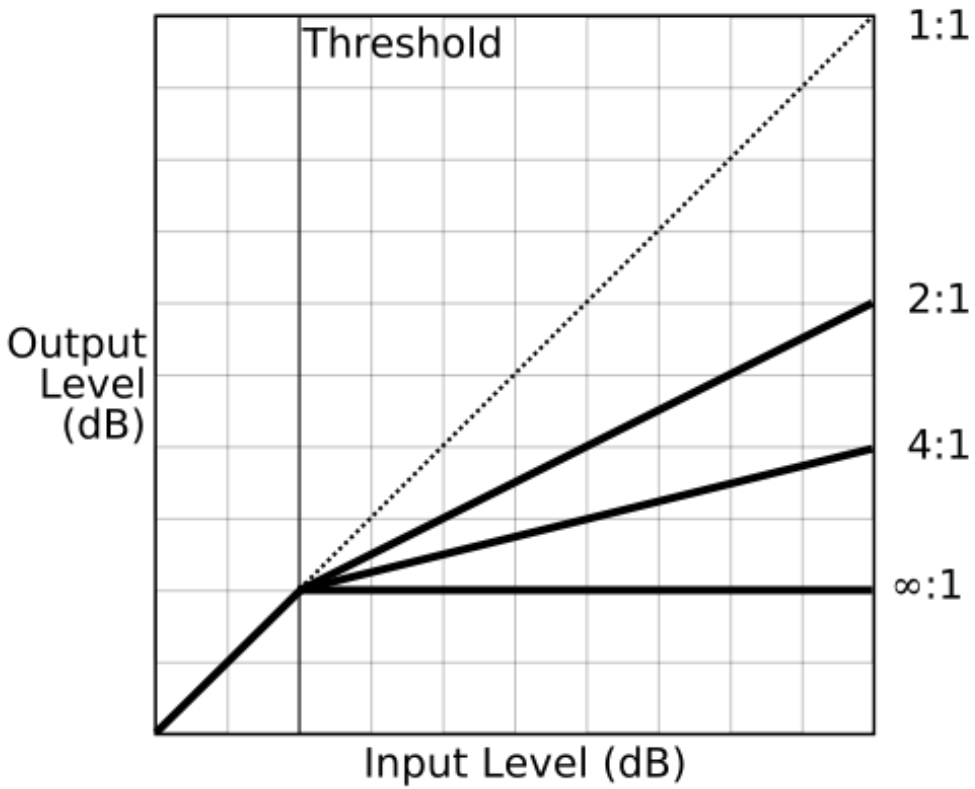
$$y = \begin{cases} x \text{ if } x > t \\ t + (x - t)/r \text{ otherwise} \end{cases}$$



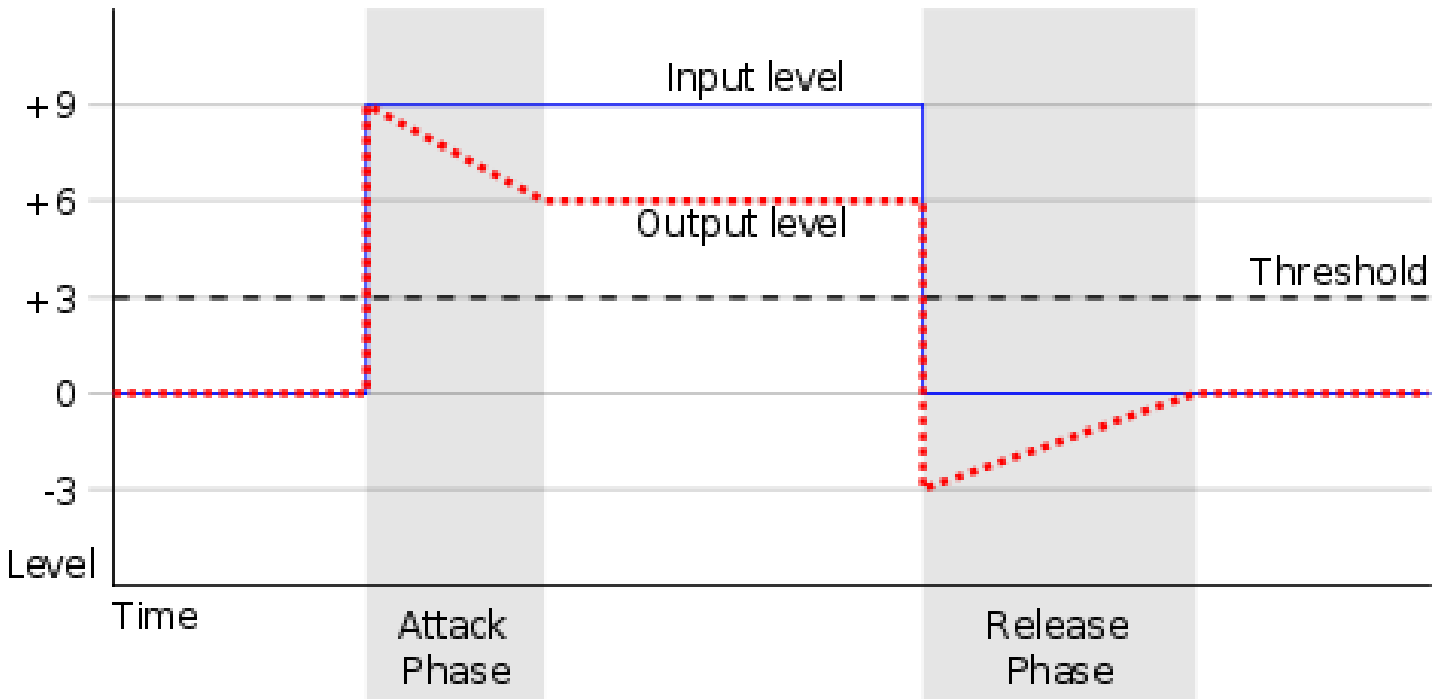
Controls

- Threshold: A compressor reduces the level of an audio signal if its amplitude exceeds a certain threshold
- Ratio : The amount of gain reduction
- Attack and Release: time (in milliseconds) for the compressor to reach full power
- Soft and Hard Knees: this controls whether the bend in the response curve between below threshold and above threshold is abrupt (hard) or gradual (soft).

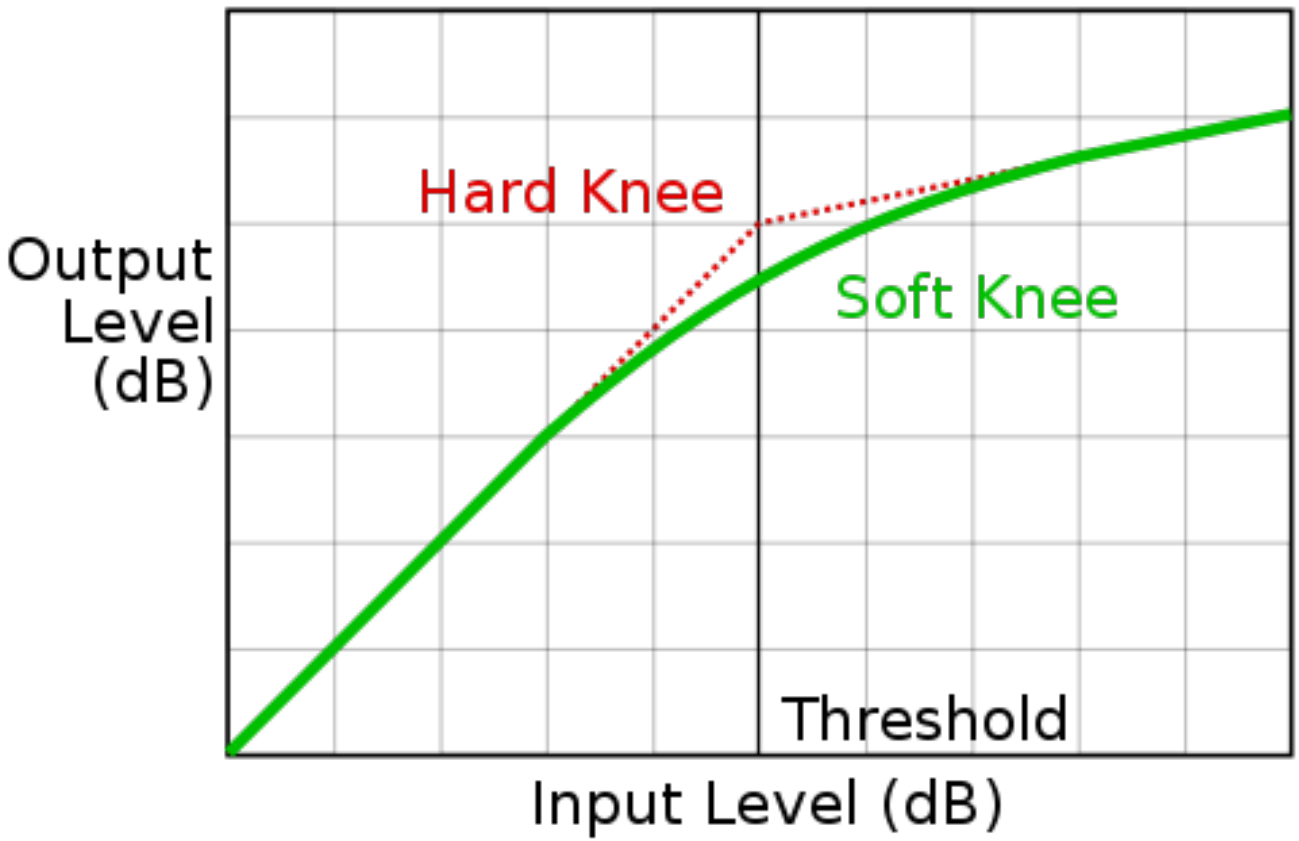
Threshold and Ratio



Attack and Release



Soft and Hard Knees



Examples

Distortion

The most popular effect used in rock music is distortion.

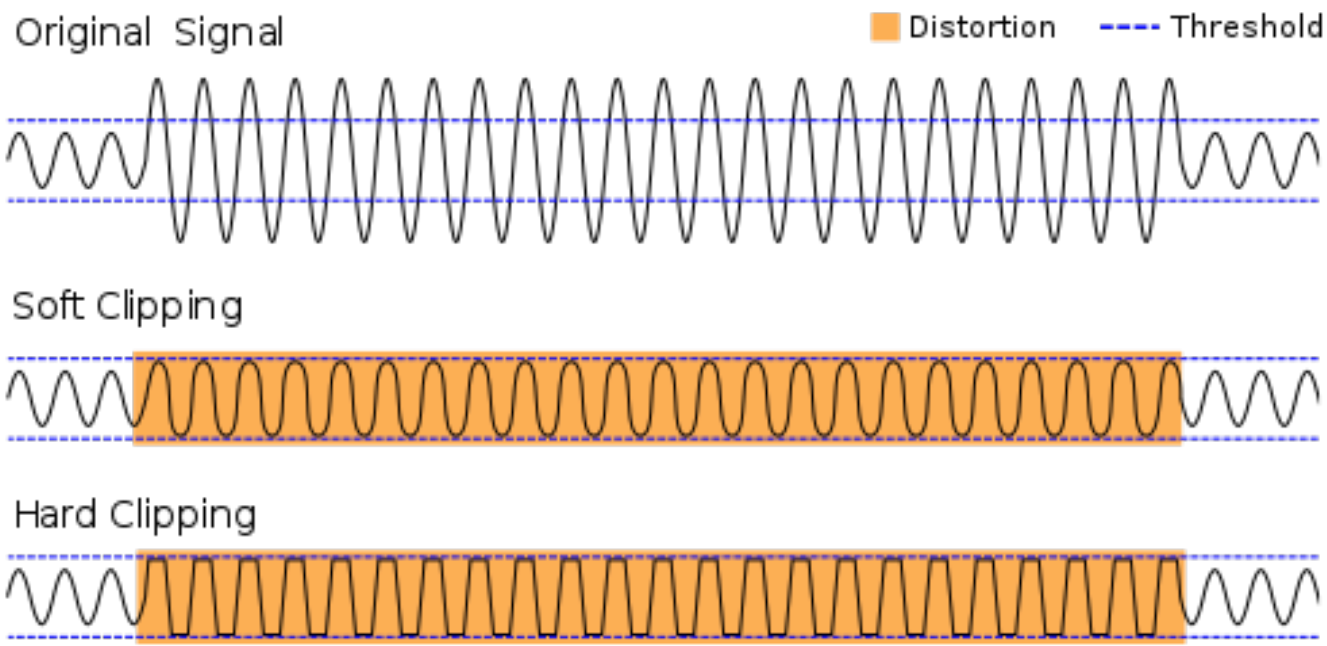
- Distortion is the result of a non-linear characteristic curve, which causes the input signal to be clipped at the output.
- Depending on the non-linearity and extent of clipping, this effect can also be called "Overdrive" or "Fuzz".

Clipping

There are two basic types of clipping:

- Hard Clipping: there is an abrupt transition from the normal part of the Sine Wave to the chopped off peak. Hard Clipping tends to provide a less pleasing to the ear type of distortion.
- Soft Clipping: there is a more gradual or gentle transition from the normal part of the Sine Wave to the cropped off peak. Soft Clipping provides a smoother more pleasing to the ear distortion.

Soft and Hard Clipping



Overdrive

Overdrive is a symmetrical soft clipping of input values. It can be implemented a simple three layer non-linear soft saturation scheme such as:

$$y = \begin{cases} 2x \text{ for } 0 \leq |x| < \frac{1}{3} \\ \text{sign}(x)\frac{3-(2-3x)^2}{3} \text{ for } \frac{1}{3} \leq |x| < \frac{2}{3} \\ \text{sign}(x) \text{ for } \frac{2}{3} < |x| \leq 1 \end{cases}$$

where sign(x) is equal to 1 or -1 if x is respectively positive or negative.

Fuzz

Hard symmetrical clipping, producing a hasher sound.
A non-linear function commonly used to simulate fuzz distortion is given by:

$$y = \frac{x}{|x|}(1 - e^{\frac{ax^2}{|x|}})$$

where a controls level of distortion.

Modulation

Modulation

- is the process where parameters of an audio signal (amplitude or frequency)
- are modified or varied by another audio signal
- usually a sinusoid

Tremolo

The tremolo is a sinusoidal amplitude modulation :

$$y(n) = (1 + am(n))x(n)$$

where

- x(n) is the audio carrier signal
- a is the modulation strength.
- m(n) is a low-frequency oscillator modulator.

In tremolo, the modulation frequency is set below 20Hz.

Delay

The original audio signal is followed closely by a delayed repeat, just like an echo.

$$y(n) = ax(n) + bx(n-m)$$

- The delay time can be as short as a few milliseconds or as long as several seconds.
- A delay effect can include a single echo or multiple echoes, usually reducing quickly in relative level.

Phasing

Phase-shifting, or phasing, is an audio effect

- which takes advantage of the way sound waves interact with each other when they are out of phase.
- By splitting an audio signal into two signals and changing the relative phasing between them, a variety of interesting sweeping effects can be created.

Flanger

Flanging is a type of phase-shifting effect.

- It is an effect which mixes the original signal with a varying, slightly delayed version of the signal.
- The original and delayed signals are mixed more or less equally.

$$y(n) = ax(n) + bx(n - m(n))$$

where $m(n)$ is a sinusoidal signal with a frequency of about 1Hz

Reverb

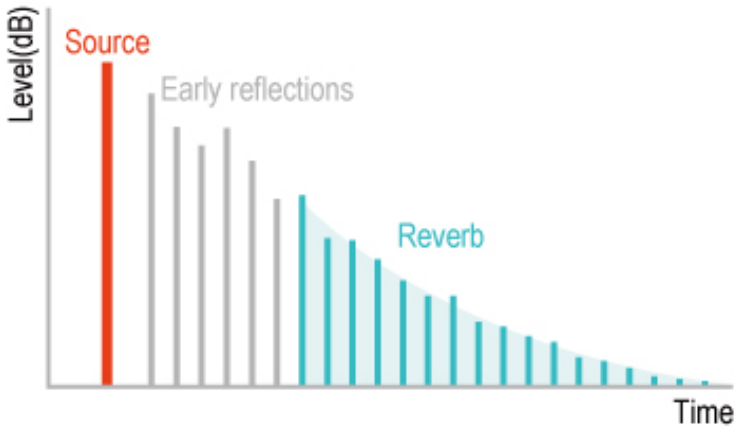
Reverberation, or reverb for short, refers to the way sound waves reflect off various surfaces before reaching the listener's ear.

Reverberation

When sound waves reflect off walls, two things happen:

- They take longer to reach the listener. They lose energy (get quieter) with every bounce. The listener hears the initial sound directly from the source followed by the reflected waves. The reflections are essentially a series of very fast echoes, although to be accurate, the term "echo" usually means a distinct and separate delayed sound. The echoes in reverberation are merged together so that the listener interprets reverb as a single effect.
- In most rooms the reflected waves will scatter and be absorbed very quickly.

Impulse responses



Vibrato

The term vibrato refers to small, quasi-periodic variations in the pitch of a tone.

- On a violin, vibrato is produced by wiggling the finger stopping the string on the fingerboard; A typical vibrato depth is on the order of 1 percent (a semitone is $2^{1/12} \approx 6$ percent).
- In the singing voice, vibrato is produced by modulating the tension of the vocal folds at ≈ 6Hz. Vibrato is typically accompanied by tremolo, which is amplitude modulation at the same frequency as the vibrato which causes it.

Vibrato

To implement a vibrato effect

- it is necessary to apply a quasi-periodic frequency shift.
- This can be accomplish using a modulated delay line.
- This works because a time-varying delay line induces a simulated Doppler shift.

Chorus

The chorus effect (or "choralizer") is any signal processor which makes one sound source (such as a voice) sound like many such sources singing (or playing) in unison. Since performance in unison is never exact, chorus effects simulate this by making independently modified copies of the input signal. Modifications may include

- delay,
- frequency shift
- amplitude modulation.

Wah

A wah-wah pedal (or simply wah pedal)

- is a type of effect that alters the tone and frequencies of the signal to create a distinctive sound, mimicking the human voice saying the onomatopoeic name "wah-wah".
- The pedal sweeps the peak response of a frequency filter up and down in frequency to create the sound, a spectral glide, also known as "the wah effect".
- it can be implemented as a band pass filter whose center frequency is controlled.

Auto-Tune

Auto-Tune is an audio processor that

- measure and alter pitch in vocal and instrumental music recording and performances.
- It was originally intended to disguise or correct off-key inaccuracies
- allowing vocal tracks to be perfectly tuned despite originally being slightly off-pitch.

The phenomena

- While working with Cher on the song "Believe" in 1998, producers Mark Taylor and Brian Rawling discovered that if they set Auto-Tune on its most aggressive setting, so that it corrected the pitch at the exact moment it received the signal, the result was an unsettlingly robotic tone.
- According to Chris Lee of the Los Angeles Times, Cher's 1998 song "Believe" is "widely credited with injecting Auto-Tune's mechanical modulations into pop consciousness".