FX Basics: Distortion Effects

Distortion effects are some of the better known and most popular effects associated with electric guitar since the 1960s.

They emerged as a result of accidental damage to amplifier vacuum tubes. Recordings were carried out by using damaged units or units working under stress.

Damage or over stress in amplifier circuitry or speaker systems often results into a severe degradation of the signal waveform. Distortion stompboxes often simulate such degradation by dedicated circuitry.

Ex: overdrive, distortion, fuzz
Distortion Principles

The principle of distortion resides on drastically altering the wave shape (morphology) of a signal in a way not possible to achieve by conventional linear filtering.

The basic phenomenon behind early days accidental distortion is called saturation.

Basically, saturation may result from driving an electrical (e.g. amplifier) or mechanical (e.g. speaker spider) device beyond its nominal, linear operation.

Much of digital modeling of distortion effects deals with a computational representation of the nonlinearities introduced saturation-like phenomena.
Distortion Principles (ii)

In general, nonlinearities of the type used in distortion-dedicated circuits cause the bandwidth of the original signal to expand through an enrichment of the spectral content in the form of additional overtones.

EXTREME EXAMPLE | From sinusoidal to square wave:
Generally, distortion-dedicated schemas present a saturating nonlinearity surrounded by tone stages (filters).

**GAIN** | **CONDITIONING STAGE (FILTER)** | **SATURATING NONLINEARITY** | **TONE STAGE (FILTER)** | **GAIN**
---|---|---|---|---

**AMOUNT OF DISTORTION**
Controls how much the input signal goes into saturation region of nonlinear element.

**SHAPE SPECTRAL CONTENT**
Normally fixed by design, it determines the tone of what goes into nonlinearity: defines character.

**INTRODUCE OVERTONES EXPAND BANDWIDTH**
Normally fixed by design, nonlinearity characteristics contribute to character.

**RE-SHAPE SPECTRAL CONTENT**
Adjustable by the user, remains as a ‘taste-driven’ control.

**OVERALL OUTPUT LEVEL**
May compensate for low input gains in low-distortion contexts.
Saturating Nonlinearities

In digital modeling of distortion, some of the most common models for saturating nonlinearities are:

**HARD CLIP**

\[ f(x) = \begin{cases} 
  x, & |x| \leq a \\
  a, & \text{otherwise} 
\end{cases} \]
Saturating Nonlinearities (ii)

In digital modeling of distortion, some of the most common models for saturating nonlinearities are:

**CUBIC SOFT CLIPPER**

\[ f(x) = \begin{cases} 
  -\frac{2}{3}, & x \leq -1 \\ 
  x - \frac{x^3}{3}, & -1 \leq x \leq 1 \\ 
  \frac{2}{3}, & x \geq 1 
\end{cases} \]
Saturating Nonlinearities (iii)

In digital modeling of distortion, some of the most common models for saturating nonlinearities are:

SIGMOID

\[ f(x) = \tanh(x) \]
Saturating Nonlinearities (iv)

In digital modeling of distortion, some of the most common models for saturating nonlinearities are:

Abel SIGMOID

\[ f(x) = \frac{x}{(1 + |x|^n)^{1/n}} \]

\[ n = 2.5 \]
In digital modeling of distortion, some of the most common models for saturating nonlinearities are:

**ARCTANGENT**

\[ f(x) = \tan^{-1}(x) \]
Saturating Nonlinearities (vi)

In general, the sharper the saturation corners, the more bandwidth expansion happens.

- **SIGMOID**
- **SOFT CLIPPER**
- **HARD CLIPPER**

AMOUNT OF BANDWIDTH EXPANSION
Aliasing: oversampling

Due to bandwidth expansion, aliasing may appear:

To avoid aliasing, it is preferred to work at a higher sample rate:

**FX Basics: Distortion Effects**
Aliasing: oversampling (ii)

UPSAMPLING

A very effective method for upsampling (increasing the sample rate of) a signal is by zero-stuffing and low-pass filtering.

\[ \text{ZERO INSERTION} \times N \rightarrow \text{LPF} \]

High-order (sharp cut)
Cut-off not above \( f_s/2 \)
Pass-band gain of \( N \)

\[ \frac{1}{f_s} \quad \frac{1}{3f_s} \quad \frac{1}{3f_s} \]
DOWNSAampling

In order to carry out *downsampling* (decreasing the sample rate) and return to the original sample rate, one can **low-pass filter** and **discard samples**: 

- **High-order (sharp cut)**
- **Cut-off not above** $f_s/2$

\[ LPF \xrightarrow{\text{Sample Discriminant}} xN \]

1. **High-order (sharp cut)**
2. **Cut-off not above** $f_s/2$
3. **Sample Discriminant**
4. **Discard** samples

\[ LPF \xrightarrow{\frac{1}{3} f_s} xN \]

\[ LPF \xrightarrow{\frac{1}{f_s}} x3 \]
Overdrive/Distortion/Fuzz

The basic ‘operational’ difference between different distortion effects is the **amount of distortion** they produce. → By increasing order: **overdrive**, **distortion**, and finally **fuzz**.

The line between overdrive and distortion is thinner:
- **OVERDRIVE**: can be seen as only introducing distortion above certain input amplitude (as a simulation of overdrive).
- **DISTORTION**: by design, distortion may be introduced equally at all input amplitude levels; also, a harder nonlinearity may be used.

For the case of **FUZZ** effects, hard-clipping the input signal even at low amplitudes produces a **square-like wave** which, once tone-shaped, may then be further processed (ex: ring modulator) before being sent out.