Distortion of Signals

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Distortion is the result of any non-linear action on the signal. Clipping is a form of distortion due to the finite dynamic range of a system. Transfer distortion is caused by a non-linear transfer function within the dynamic range (i.e. not clipped) of the system and may be significant at considerably lower levels than clipping.

Only significant distortion can be seen on an oscilloscope. The lowest level of distortion on a simple sine wave that a well trained eye can detect on an oscilloscope is about one percent. Normally, the threshold for an untrained observer to observe distortion on an oscilloscope is three percent or more. Ten percent distortion is severe and is readily visible to even the untrained eye. Thus, an oscilloscope can only show when the system is very non-linear. It takes specialized equipment to measure distortion at low levels.

Generally, it is desirable for distortion to be well below 1 percent. Considerable effort is made in high quality audio systems to keep distortion below 0.1 percent. Expensive systems target distortion in the 0.001 to 0.01 percent range. The following is a general guide concerning distortion in audio systems.

Distortion level and associated comments

30% This is very severe distortion with distortion components only 10 dB below the primary signal. This level is typical of a cheap radio played very loud and is characterized by a very raspy sound particularly on bass notes.

10% This is severe distortion with distortion components down from the primary signal by only 20 dB. Everybody can detect this level although it may be tolerated by many people.

3% This is moderate distortion typical of cassette tape recorders. The distortion components are 30 dB below the primary signal and are generally heard more as a wide band noise that whose level is modulated by the signal. It is well tolerated by most people.

1% This level of distortion is barely heard even by trained ears as the distortion components are 40 dB below the primary signal.

0.3% Low distortion. The distortion components are 50 dB below the primary signal and few people have ears trained enough to detect this.

0.1% Very low distortion. The distortion components are 60 dB below the primary signal. This is about the limit that can be detected with a very well trained human ear.

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0.03% Ultra low distortion with distortion components 70 dB below the primary signal.

0.01% Extremely low distortion. Distortion components are 80 dB below the primary signal. Anybody claiming to detect this with their ear is lying.

Measuring Distortion

The classic method of quantifying distortion is to apply an extremely pure sine wave (i.e. a sine wave with harmonic content at least 80 dB below the fundamental and preferably more than 100 dB below the fundamental) to a system and measure the harmonic content relative to the fundamental in the output signal. This is known as Total Harmonic Distortion (THD) and is given as a percent value as follows:

$$THD = \frac{\text{rms value of harmonics}}{\text{rms value of fundamental}} * 100\% \qquad \text{Eq. 1}$$

There are two common methods to measure THD.

The first method involves using a spectrum analyzer (or tuned voltmeter) to measure the amplitude of the fundamental and significant harmonics. This data is entered into the following equation to compute THD.

$$THD = \frac{\text{sqrt}(H2^2 + H3^2 + H4^2 + \dots HN^2)}{H1} * 100\% \qquad \text{Eq. 2}$$

H1 is the amplitude of the fundamental, H2 is the amplitude of the second harmonic, … , and HN is the amplitude of the nth harmonic. The strongest harmonic will dominate the result. Harmonics more than 20 dB below the strongest harmonic (except H1) have little effect on the final outcome and can be ignored for this calculation.

The second method is an approximation to the first method and involves a simpler instrument known as a distortion analyzer which has a notch filter that removes the fundamental but passes everything else. Distortion is determined by measuring the rms value of the notched filtered signal and the rms of the total signal (including distortion) and using the following equation:

$$THD = \frac{\text{rms of notched signal}}{\text{rms of total signal}} * 100\% \qquad \text{Eq. 3}$$

This second method gives accurate results if the distortion is less than about 10 percent. The reason for inaccuracy at high distortion levels is because the denominator term includes distortion components rather than the first method in which the denominator only includes the fundamental. Thus, this method tends to understate the actual distortion when the distortion level is high. The advantage of this method is that it is much simpler to do. At low levels of distortion the two methods give identical results. In less expensive instruments an approximation of the true rms based on the average value of the rectified signal is used. When the distortion is low the error of this method is very small. At high distortion levels the error is larger but a specific number for distortion becomes meaningless when distortion is high.