AUDIO UPDATE

A Distortion Primer—Part 1

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In any compilation of the real (and imaginary) problems troubling audio reproduction, distortion would rank right up there near the top of the list. Almost everyone agrees that distortion is *not* a good thing. But beyond that basic point, arguments start. Exactly what's the problem? Simply this: Electronic audio distortion, while easy to measure in its various manifestations, is devilishly difficult to correlate with the perceptions of the human ear/brain apparatus. The situation is further complicated by some manufacturers of expensive audio equipment, accessories, and connecting wires, who are pleased to invent wonderfully esoteric distortion problems (with accompanying voodoo solutions) to satisfy the needs of the devout tweaks and techno-crazies.

Terminological confusion

My *Illustrated Encyclopedia of Electronics* tells me that "Distortion is any change in a signal that alters its basic waveform or the relationship between its various frequency components." Some of the misunderstanding about standard distortions and their audibility arises from ambiguities in terminology. For example, sometimes the technical name for a distortion describes the way the afflicted waveform looks on a scope (e.g., clipping distortion when the tops and/or bottoms of a waveform are decapitated); other times the name refers to the electronic flaw in the amplifier that produces the problem (e.g., crossover distortion).

The terms *harmonic distortion* (HD) and *intermodulation distortion* (IMD) in effect describe kinds of test procedures rather than specific flaws in the equipment under test. If an amplifier has a problem, the same condition should show up on both HD and IMD distortion tests—and provide entirely different measurement numbers. Keep in mind that the numbers provided by distortion-testing instruments are somewhat arbitrary; they depend as much on the type of test and the specifics of the test signal used as on the magnitude of the flaw in the amplifier. And for perhaps the same reason, none of the distortion-measurement numbers correlate directly with audible unpleasantness—or with each other. In other words, 2% distortion does not necessarily sound twice as bad as 1%, or even necessarily worse than 0.5%.

Harmonic distortion

In any discussion of harmonic distortion, keep in mind the distinction between the natural harmonics that are a part of all tones produced by musical instruments and the undesired spurious harmonics that result from flawed amplification. It is the natural harmonic content that causes the same musical note played on a clarinet, a piano, and a flute to sound different—and to look different on an oscilloscope. Any complex waveform can be "discussed" by a mathematical process known as a Fourier analysis and shown to be composed of a large number of odd and even harmonics. Figure 1 shows a violin note and its second, third, fourth, fifth, sixth, and eighth harmonic components. With the proper instrumentation, it is possible to detect harmonics as high as the twentieth.

HD comes about *not* through distortion of the harmonics of a signal, nor does it result from spurious harmonic frequencies generated by an oscillating amplifier. What happens is that the amplifier, because of some technical inadequacy, changes (distorts) the original shape of the signal waveform. That change can be quantified by analyzing it in terms of the spurious harmonics added to the fundamental test signal—which is, in general, the way the ear hears it.

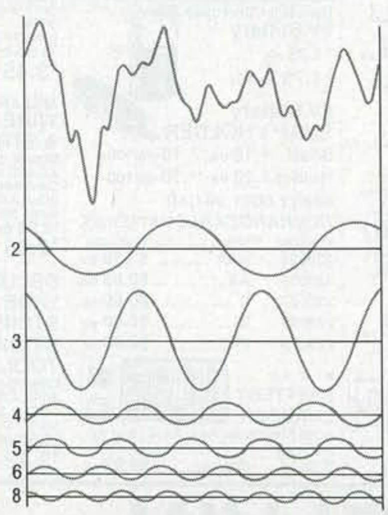

FIG. 1—FOURIER ANALYSIS of a violin note showing the relative strengths of the strongest natural harmonics.

When testing an amplifier's HD performance, you feed in as distortionless a sine wave as can be generated. The HD analyzer, which is connected across the amplifier's output test load, operates by nulling out the input test signal and reading (as a percentage of it) whatever harmonics and noise are introduced by the amplifier. If, say, a 3-kHz test signal was used, amplifier nonlinearity might produce spurious harmonics at 6 kHz, 9 kHz, and so forth. The term *THD* indicates that the lumped *total* of all the harmonic components is included in the measurement. A more sophisticated instrument, called a spectrum analyzer, is capable of indicating the relative strengths of *each* of the spurious harmonics. It is recommended by the EIA Amplifier standard (RS-490) and is used by many test labs.

To illustrate the mechanisms involved, an exaggerated example of distortion is shown in Fig. 2. Let us say that a malfunction of the amplifier causes third-harmonic distortion of waveform (*a*), a 1000-Hz sine-wave input signal. The distorted output signal (*c*) would look as though a 3000-Hz tone (*b*) were combined with the 1000-Hz tone. Keep in mind that a distorting amplifier does not actually generate spurious harmonic waveforms and mix them with the original wave; what it does is distort the original waveform in such a way that the output waveform looks as it would if specific spurious harmonics were added. Of course, in real life we would have not only third-harmonic distortion but also an assortment of various odd and even harmonics of various strengths.

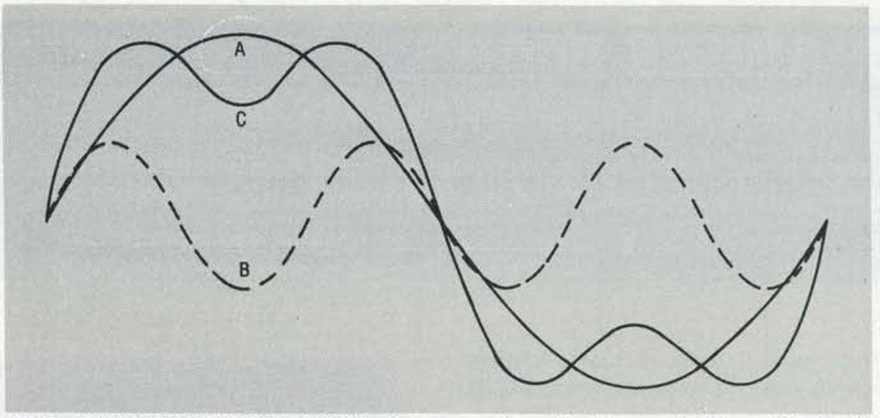

FIG. 2—SIMPLIFIED ILLUSTRATIONS of how a spurious third harmonic (*b*) combined with the input signal (*a*) produces a distorted signal (*c*).

There's some evidence that the specific HD content of a distorted signal (meaning the relative strengths of the distortion components extending up to the tenth harmonic or higher) is more audibly significant than the absolute THD figure. In other words, depending upon the ways that two amplifiers are distorting a piece of music, a measured 3% THD from one might sound a lot worse than 3% from the other.

Intermodulation distortion

The same amplifier nonlinearities that produce THD also produce intermodulation distortion (IMD), but through a somewhat different mechanism. When two (or more) signals are fed through a nonlinear amplifier, the signals tend to *intermodulate*, meaning that they interact in a specific and undesirable way. If, for example, a low-frequency signal of 40 Hz was traveling through a nonlinear amplifier along with a higher frequency of, say, 2 kHz, spurious sum and difference frequencies that are known as IM products would be produced at 1920, 1960, 2040, 2080 Hz, and so on and so forth.

There are two different IMD test techniques in current use, both employing a pair of test tones applied simultaneously. The older SMPTE (Society of Motion Picture and Television Engineers) IMD test uses a composite 60- and 7000-Hz test signal in a 4:1 ratio, while the IHF-IM test uses two equal-amplitude high-frequency tones. The description of the IHF test incorporated in the current EIA Standard (formerly IHF-A-201 1966) reads as follows: "The percentage of IHF intermodulation distortion (IHF-IM) of a composite signal composed primarily of two relatively high-frequency sinusoidal signals, one having a frequency of f_1 and the other having a frequency of f_2, of equal amplitude, is numerically equal to 100 times the square root of the sum of the squares of the second- through fifth-order distortion components divided by the square root of the sums of the squares of the amplitudes of the sums of the components at frequencies f_1 and f_2." All of which, I think, helps explain the relative popularity of the SMPTE method over the IHF-IM method.

Unlike THD, IMD distortion components do not have a harmonic relationship with the music and, therefore, can't be heard as part of the music. For that reason, IMD is generally thought of as more audibly unpleasant. However, I would say that, given the very low distortion figures of *all* of today's better standard-brand audio amplifiers, neither THD nor IMD are likely to be audible, *assuming* that the amplifier is working properly and is never driven into overload. And, even under overload clipping conditions, with complex program material such as a loud symphonic work, it is well documented that distortion (of any flavor) has to reach approximately 6% before it becomes audible. That is true because the spurious distortion frequencies are overwhelmed (technically, "psychoacoustically masked") by music occurring at the same frequencies. However, when the test signal is a pure tone, distortion as low as 0.15% can be heard. Probably for all of the above reasons, it seems that few professional testers will bother with IM measurements.

In next month's wrap up on our distortion discussion, we will look at some of the popular "new" distortions and try to place the entire topic in a real-world context. **R-E**