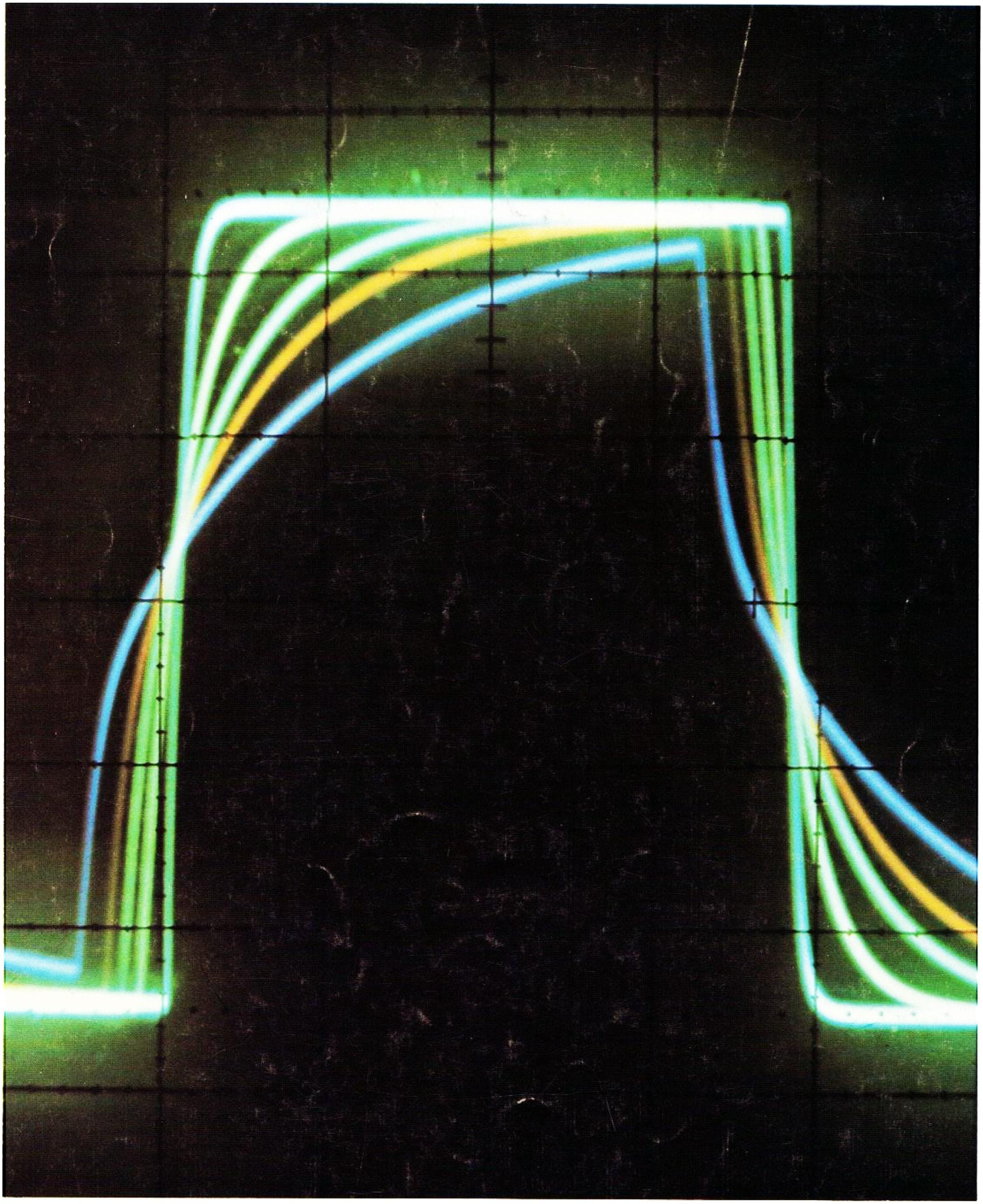
Square Wave Analysis of Audio Amplifier Performance



High fidelity products are evaluated in specific technical language we call "specifications." Yet two competitive amplifiers with the same specifications can sound clearly different. Not necessarily better or worse, but different. This material is an attempt to deal with some reasons for that difference and why it is necessary to perpetually pursue and discover all of the factors that will eliminate distortion and contribute to superior sound quality.

Distortion: Old and New

The search for "perfect" reproduction of sound presents to designers and engineers the same challenge faced by all scientists in every field of endeavor: As we conquer each known impediment to quality, we uncover other problems whose presence was masked by the problem we had solved. At the time inadequate frequency response and noise were the predominant problems in sound equipment, harmonic and intermodulation distortion existed—even before we knew they did. So it is very likely that other distortions lurk beneath the ones we now know.

Total harmonic distortion (THD) and intermodulation distortion (IM) have justifiably occupied a preeminent position in recent years as the principal anomalies in audio amplifier performance. Yet in many modern amplifier designs, these distortions are present in quantities of 0.05% (1 part in 2000) or less. It seems unlikely (to say the least) that these miniscule amounts account for the vast differences in sound quality of the amplifiers we have auditioned.

In this presentation, we shall try to explain why we, at Harman Kardon, make use of square wave response to analyze our products and why we attach great significance to this area of evaluation. It should be clearly understood, however, that our use of square wave analysis is merely representative of our desire to discover *all* of the elements that can continue to advance the state of the art.

Amplifiers and Distortion

An amplifier's fundamental purpose is the change in energy of a signal appearing at its input to the quantity required at its output. The input signal is amplified by the factor we call *gain*. The problem is to process the signal with no change through the operating range of the amplifier. Any change from form, an addition to, a deletion from, or a reorganization of the input signal is distortion.

Understanding this, we can see that THD and IM distortions are additive in nature: the amplifier "creates" them during processing. On the other hand, inadequate frequency response is a subtractive distortion: less than the full complement of frequencies appear at the output than at the input.

Sine Waves and Distortion

The method traditionally used to determine the presence and degree of irregularities in audio amplifiers is the "sine wave". It is very useful in a number of ways: (1) musical sound is predominantly comprised of sine waves, so the sine wave somewhat *resembles* musical material; (2) pure sine waves are constant, periodic and repeatable, so they fit into the pattern of methodical scientific investigation; (3) audio oscillators make pure sine waves available in consistent form over a wide range of frequencies, and; (4) sine wave properties are well known.

But although the sine wave is an extremely useful tool, its strength, namely its simplicity, is also its greatest shortcoming. There are properties important to high fidelity sound that are simply not visible through sine wave analysis.

The Square Wave

The square wave is our tool. Like the simpler sine wave, it is constant, periodic, repeatable, measureable over a wide range of frequencies and has well known properties. But unlike the sine wave, it is markedly similar to *musical sound*. Like the sound of a plucked string, the square wave is composed of a *fundamental* frequency *and* its harmonics. The harmonics are arranged in a specific amplitude (loudness) relationship. Not only is this relationship constant from square wave to square wave (regardless of the fundamental frequency), but it plays an important role in maintaining the composite waveform's square shape. The harmonics are also arranged in a specific relationship with respect to time—they are all in *phase*—again contributing to the square wave shape.

The square wave is in such delicate balance that the slightest change in any of its components will change its shape.

Thus—square waves can illustrate:

1. Phase distortion
2. Transient response
3. Frequency response
4. Instability

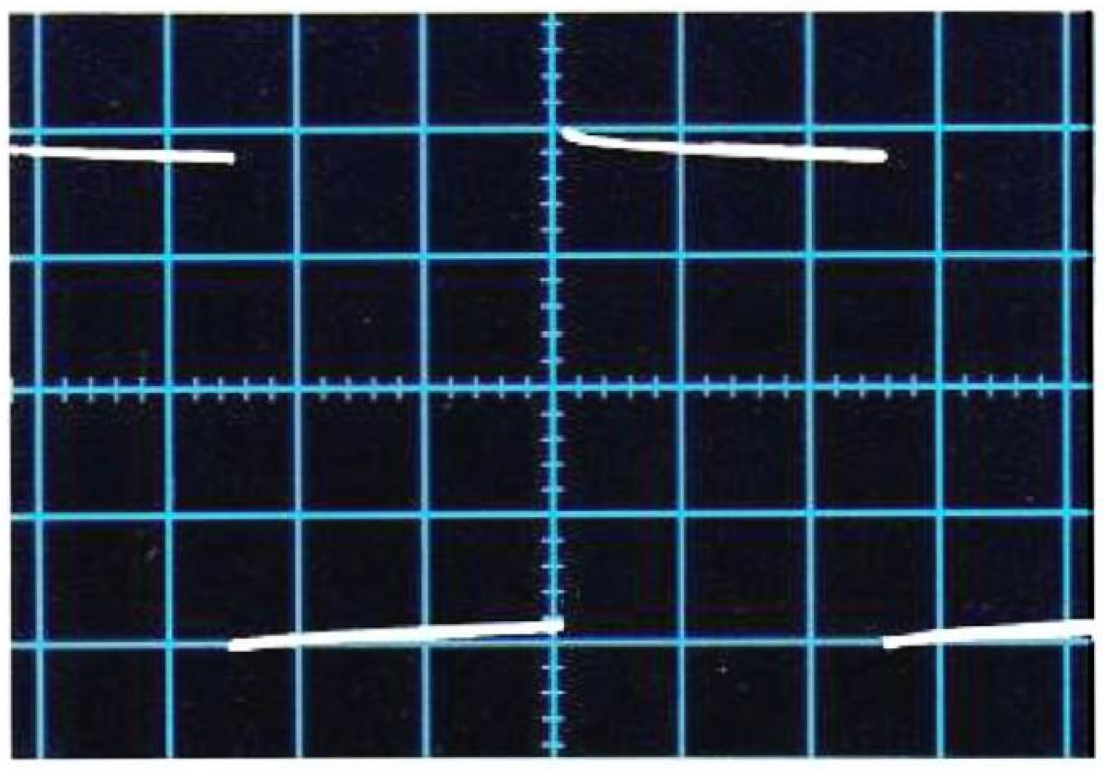
The illustrative photographs we are using were taken by our engineering staff and are unretouched. Because the typical oscilloscope screen is about 10 to 12.5 centimeters in diameter the resolution available has a limit. However, the generator's frequency selector allows us to increase the number of frequencies we can see simply by choosing a new fundamental and set of harmonics. Because audio electronics tend to exhibit smooth and gradual functions, problems that appear in a given square wave and that are a result of a disturbance at a low frequency, reveal that the selection of a still lower frequency will show the problem in greater abundance.

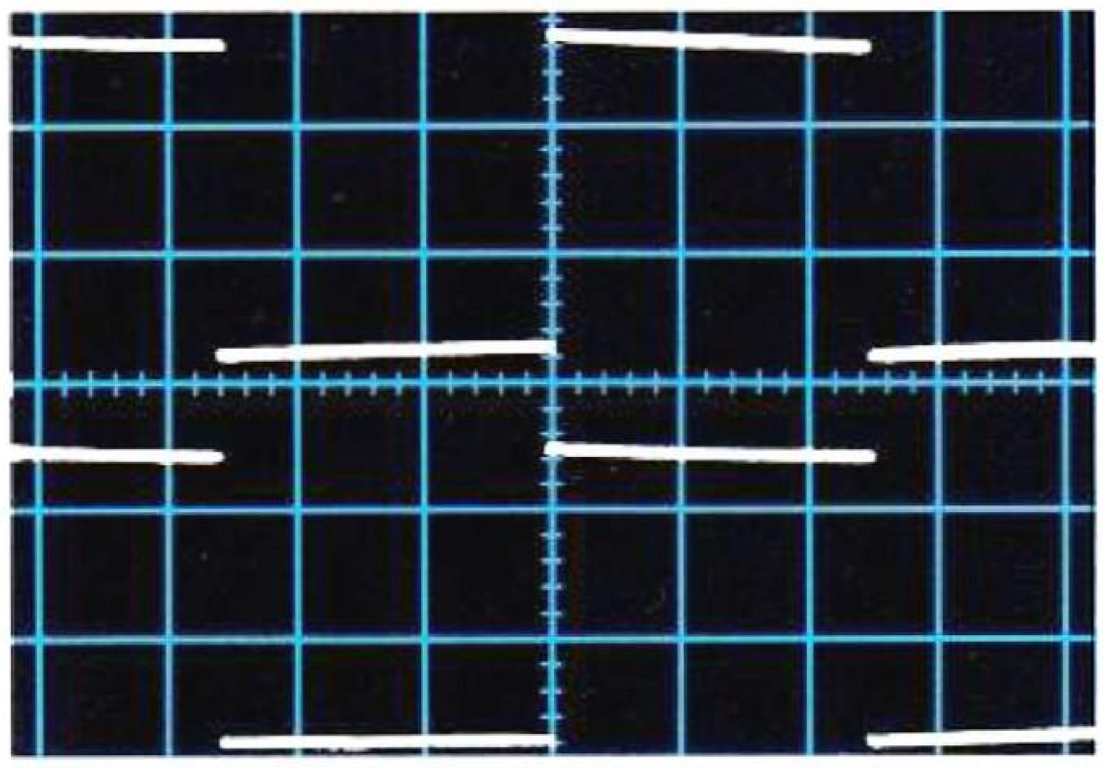
Low Frequency Square Waves

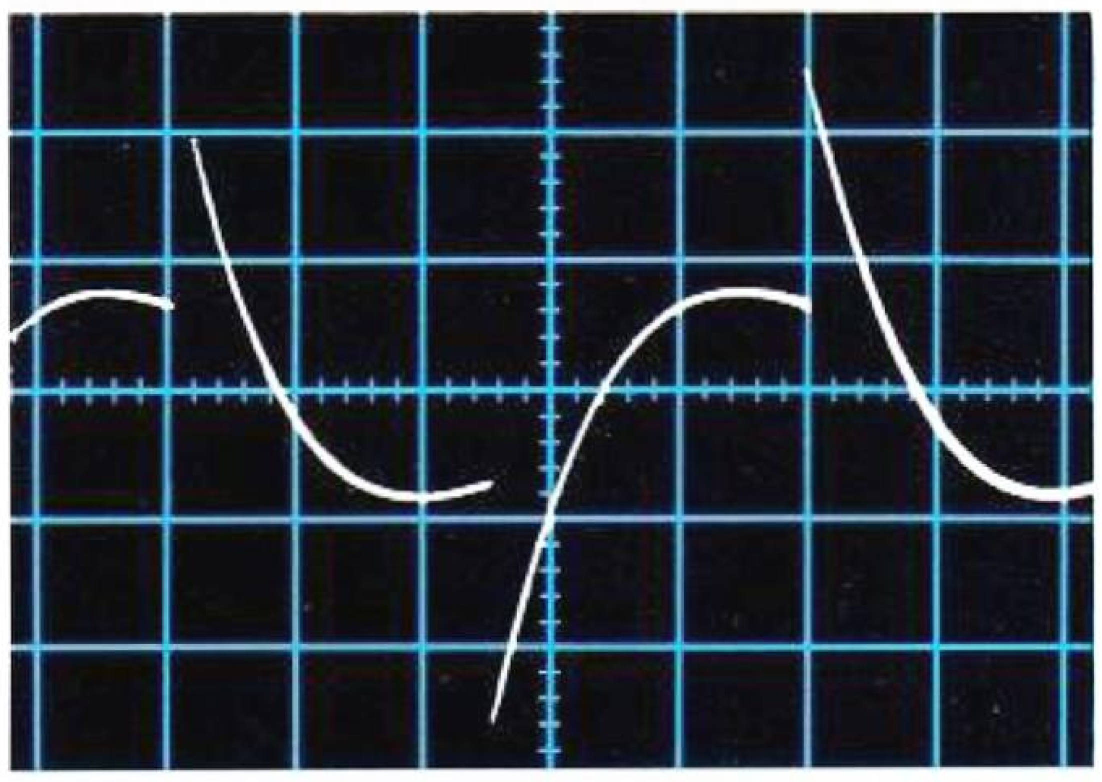
We shall initially examine the 20Hz square wave for three reasons. First, 20Hz is the traditional lower limit of human hearing and it makes sense to determine an amplifier's ability to function at this point. Second, the 20Hz square wave permits us to see out to about 200Hz (covering the entire bass and mid-bass region). Finally, we can see that problems at frequencies lower than 20Hz influence frequencies above that point.

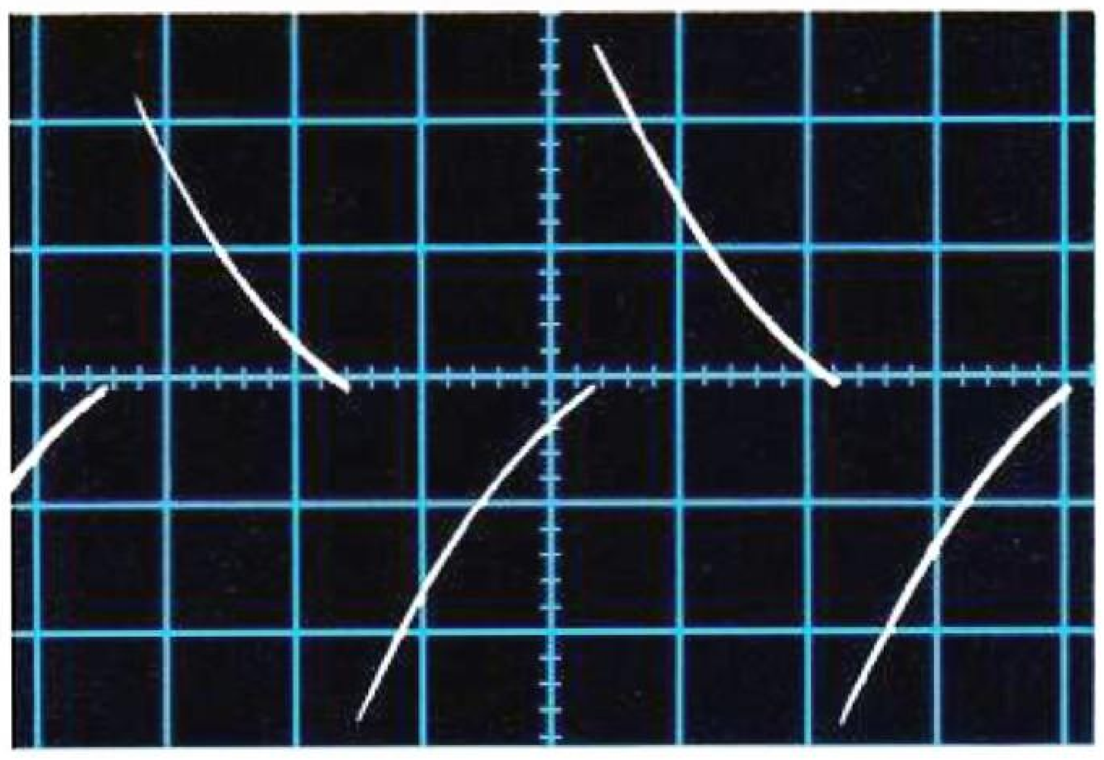
At 20Hz, square wave deformation is in the form of *tilt*. In moderate cases, the tops and bottoms of the waveform will tend to slope toward one another with the tilt increasing with more severe problems. In extreme cases the tilt is precipitous, and in the worst cases the square wave begins to look like an interrupted sine wave.

Excessive tilt reveals low frequency loss, or poor power supply regulation with resultant *phase shift*. The distortion is clearly audible and bass and mid-bass sound becomes dull and boomy.


1


2


3

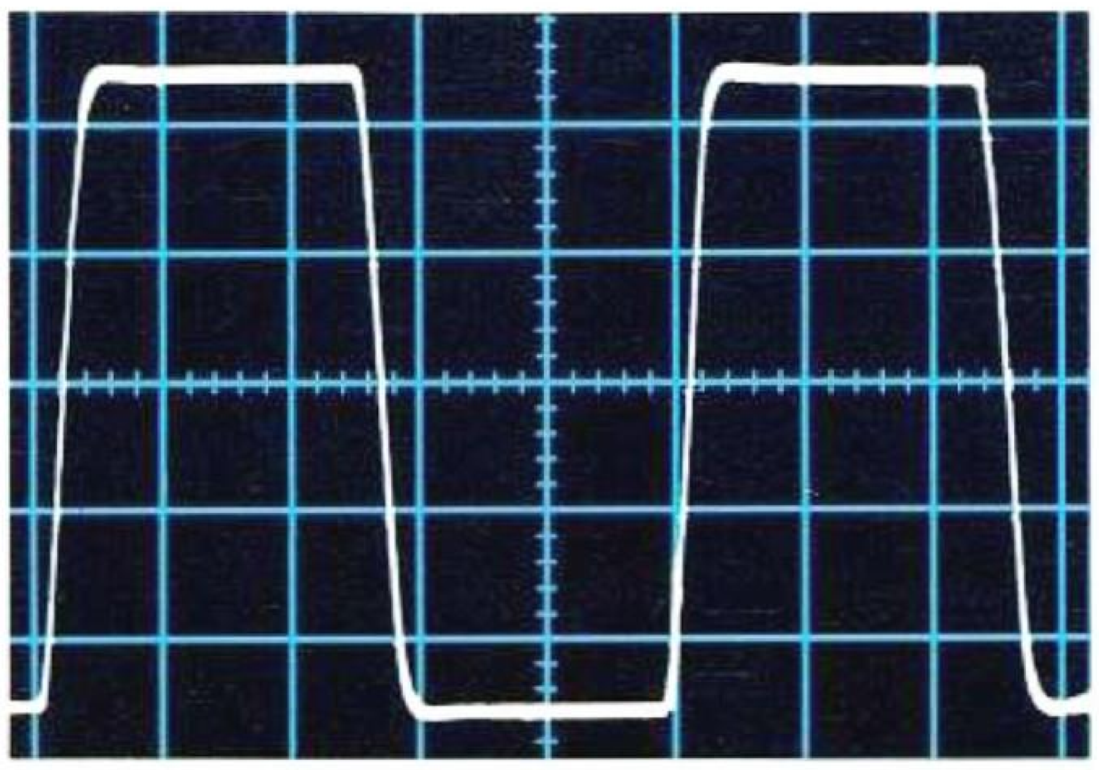

4

1. We can see the shape of the 20Hz square wave of a typical Harman Kardon amplifier. The tilt is less than 3%.

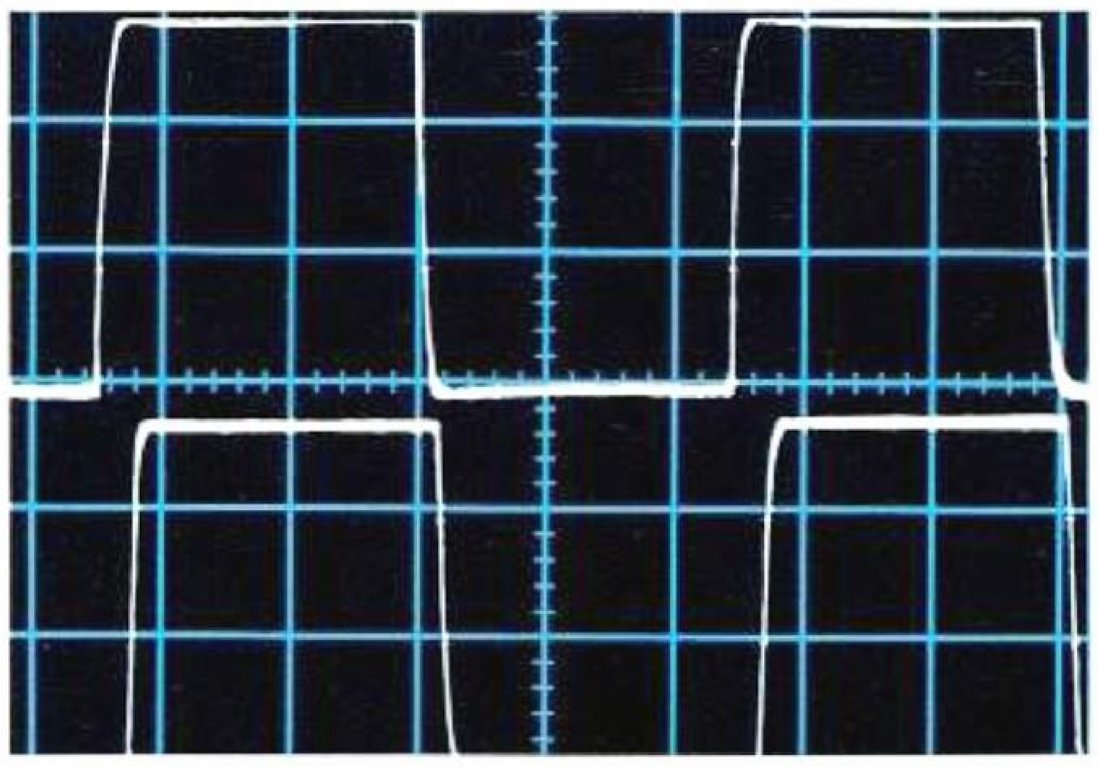
2. It is apparent that there is a remarkable similarity between the square wave of a typical Harman Kardon receiver (lower half) and that of the renowned Citation 16 power amplifier (upper half).

3. This the the 20Hz square wave of an actual unit that we shall call a "typical competitive design." Substantial tilt and bending of the square wave is evident.

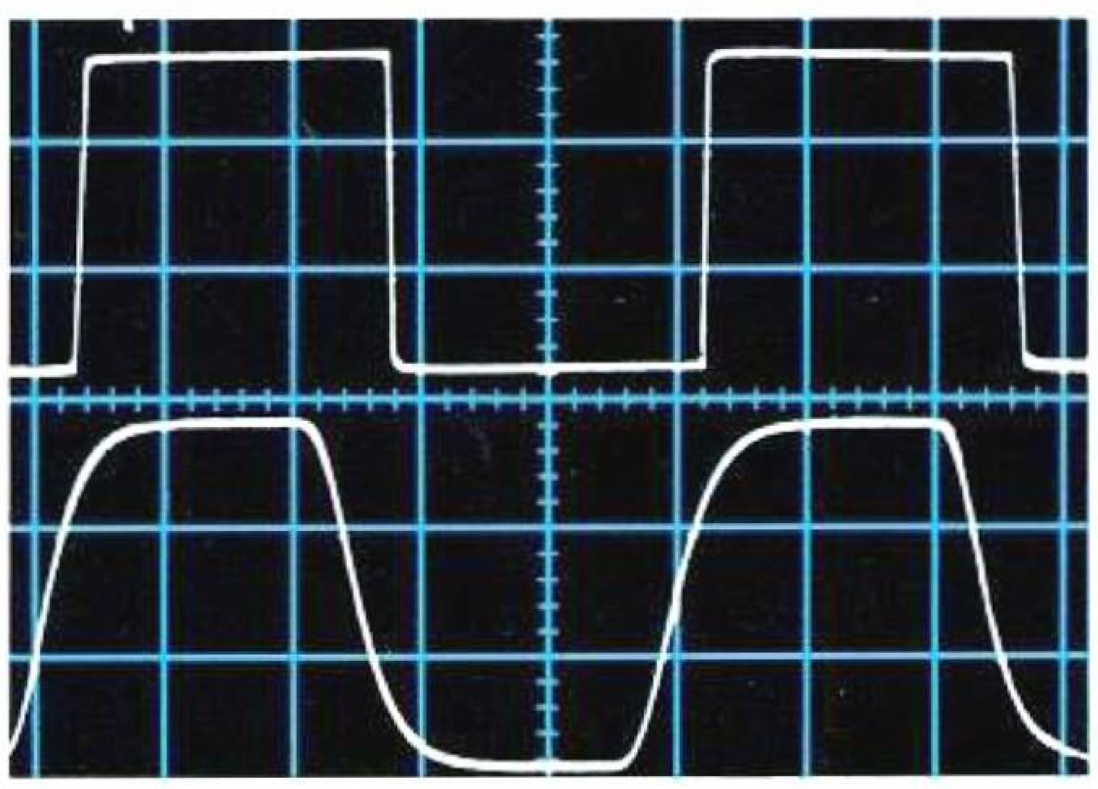
4. Here is the same competitive receiver at 51Hz. Less tilt, less bending. Comparing this with No. 3 illustrates the point that square waves permit us to see problems "around" the chosen frequency.



1



2



3

1. Here is the square wave of a typical Harman Kardon instrument at 20kHz. While it is not perfect, it has steep sides and only slight rounding of the left side corners.

2. The top half of the photo shows the square wave of the Citation 16 amplifier at 20kHz. The bottom half is of a typical Harman Kardon receiver. Note the striking similarity.

3. The top half of the photo again shows the square wave of a typical Harman Kardon receiver at 20kHz. The bottom half is of a "typical competitive receiver" at 20kHz. Note the severe loss of harmonics in the competitive receiver.

High Frequency Square Waves

As we move into higher frequencies, other problems deform the square wave. At 10kHz or 20kHz the square wave will exhibit a rounding of the extreme top or bottom of the left or leading edge. The leading edge is used to measure *rise time*. Rise time is simply the time it takes for the amplifier to move its output from maximum negative to maximum positive. This is of critical importance.

The sounds created by virtually all musical instruments possess some *transient* character. This is particularly the case with percussion instruments, bells, chimes, triangle and xylophone. Much of the sound of the harpsichord and piano is transient. Any sound that develops in an extremely small segment of time is strongly transient in character.

If an amplifier is incapable of delivering these transients *at the same speed of the original*, distortion will occur.

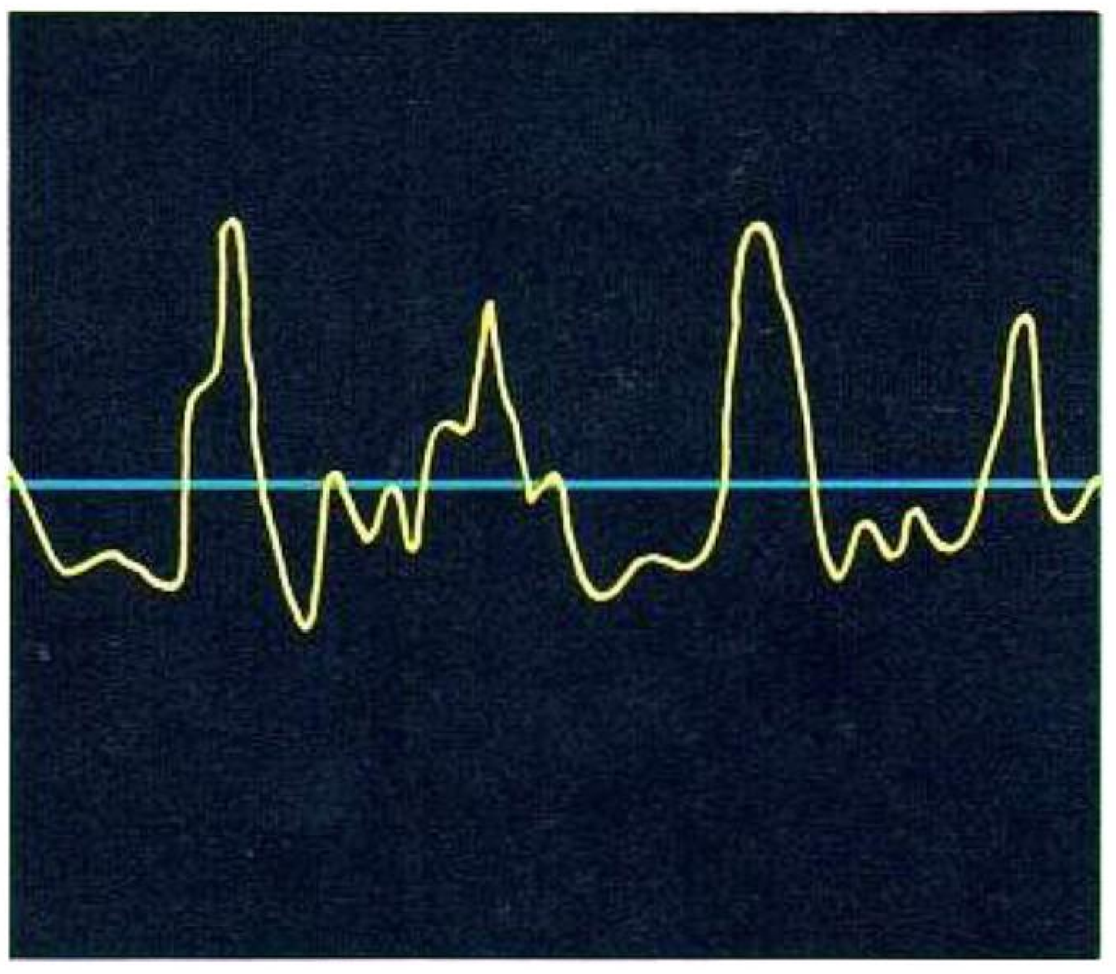
Further, transient capability, reflected in measured rise time, is related to frequency response. After all, an amplifier "measures" time in terms of the highest number of cycles per second it can pass. Thus if an amplifier has a fast rise time, its ability to reproduce the high frequency harmonic components (reflected in the square wave) is enhanced.

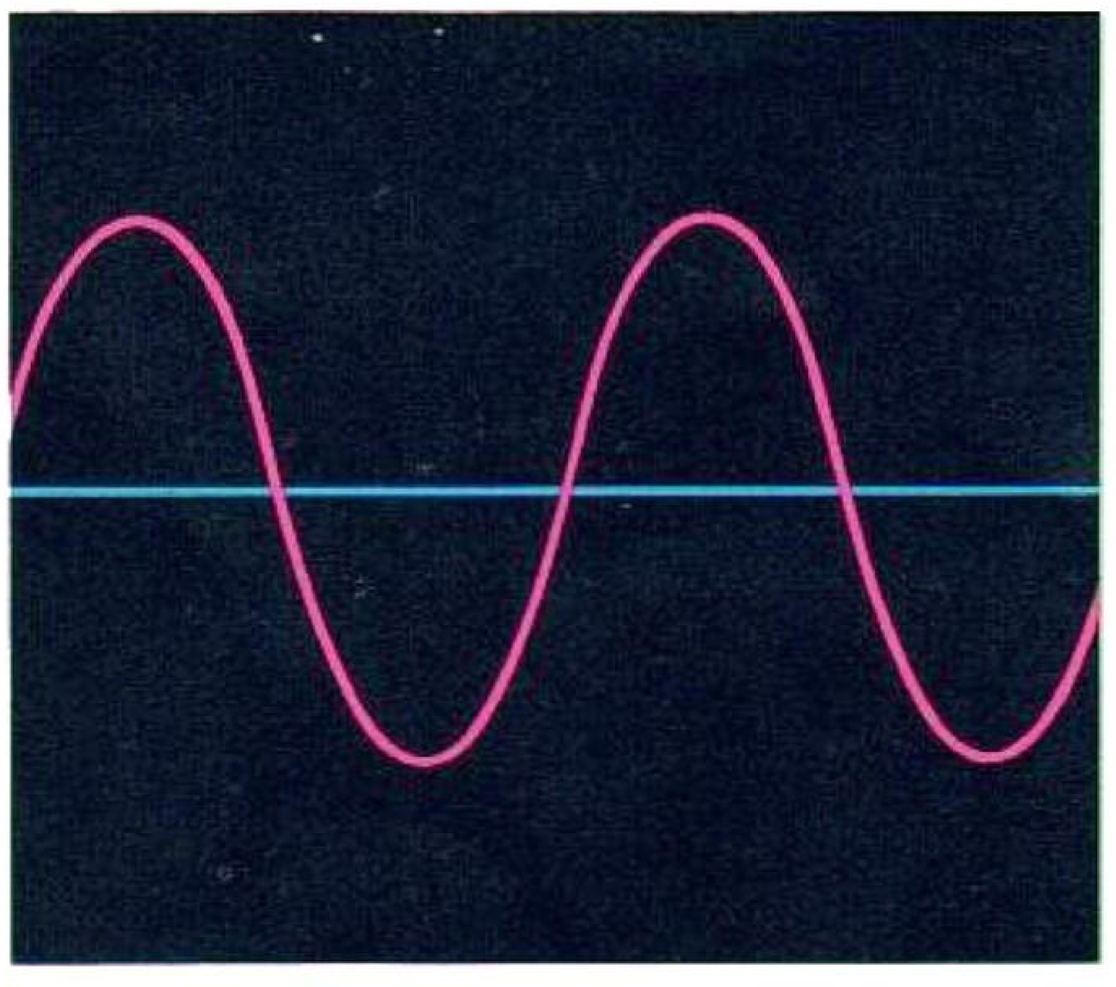
While the precise requisite speed is not known, we do know that the faster the amplifier, the better its reproduction of music. Definition, detail, articulation, imaging and the sense of space in reproduced music are all enhanced by greater speed.

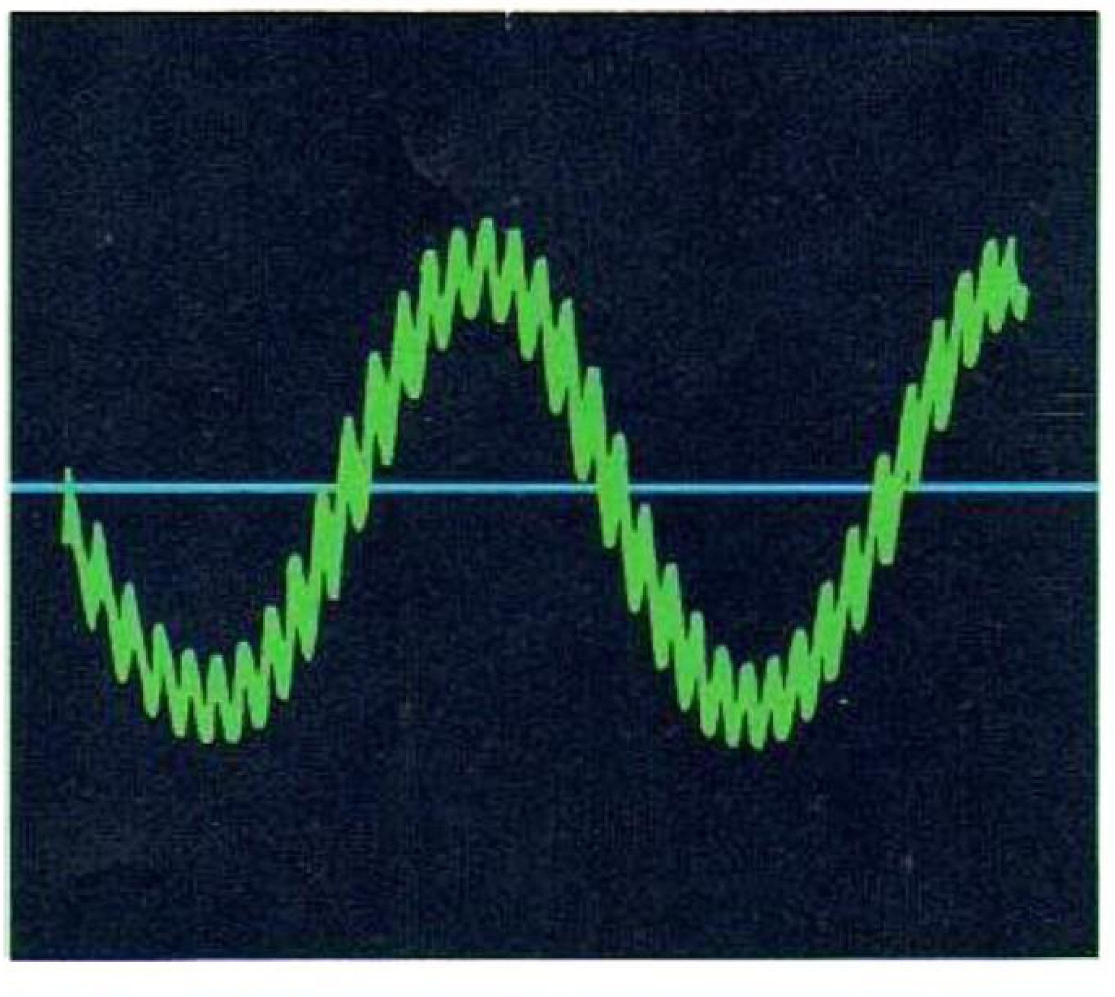
Conclusion

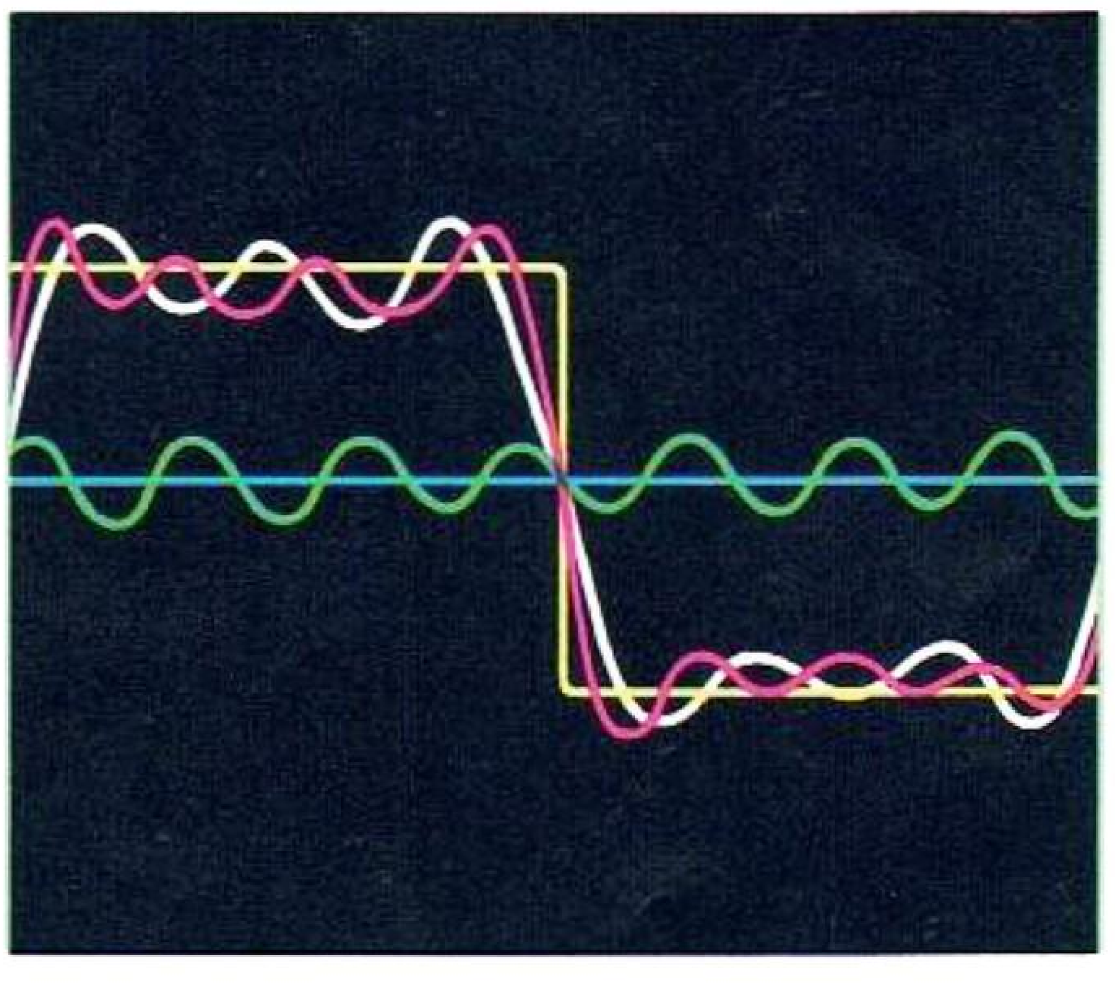
Potential sources of distortion are probably infinite, but all of them have an impact on the quality of sound. It is in this context that we, at Harman Kardon, pursue technical advances—not for their own sake, but as a means of improving *performance*. Square wave response and rise time are clearly identifiable today as elements that *must* be added to conventional specifications in order to enable us to predict *musical* authenticity.

Elements of Musical Sound


1


2


3


4

Music is composed predominantly of sine waves. But the sound produced by a musical instrument (even when a single string is plucked) is a *combination* of sine waves at different frequencies. The pitch of the sound is called the *fundamental* and occurring along with it is a series of sine waves called *harmonics*.

When we set a single string into motion, it will vibrate along its full length at a certain frequency. This frequency is the fundamental. But the string will exhibit secondary vibrations along divisions of its length, i.e., one-half its length, one-third, one-fourth, etc. Each of these secondary vibrations produces a frequency *related* to the fundamental frequency. The half-length vibration produces two times the fundamental and is called the second harmonic, the one-third length vibration produces three times the fundamental, and so on, theoretically to infinity. All the harmonics, taken *together* with the fundamental, produce the musical sound we hear.

When we add the number of vibrating strings, resonant air columns in horns or organs, and the vibrations set up by instruments that use membranes, in a musical ensemble, we see that the complexity of musical sound is staggering.

Clearly, the sine wave, with its simple elegance, is not adequate to the task of predicting musical authenticity. It becomes necessary to find another tool to aid us in evaluating an amplifier's ability to handle the complex tasks we assign to it. A pure tone is virtually non-existent in nature. One note (figure 1), played on one musical instrument, is far more complex than a simple tone used in conventional sine wave testing (figure 2). That same note is far more complex than the two tones used in testing I.M. distortion (figure 3). At Harman Kardon, square wave testing (figure 4) is done with standard sine wave tests.

harman/kardon 55 Ames Court, Plainview, N.Y. 11803

Printed in U.S.A. All specifications and features are subject to change without notice.

243-633-D-0153

90731099