The Lenkurt® Demodulator

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Performance Testing of Television Channels

Part Two

Last month's article in this two-part series discussed some of the more conventional test signals for evaluating video transmission systems. Many of these "steady-state" testing methods share certain disadvantages because they are based on sine waves or other repetitive signals. As transmission requirements have become more severe, particularly with the widespread acceptance of color television, more rigorous testing is in order. So-called "waveform" testing—a means of testing the system's ability to reproduce typical waveforms is generally required. This article discusses the most widely accepted waveform method, the sine-squared or "pulse and bar" test.

The chief disadvantage of sine-wave test signals is that they are not really representative of typical video signals, and thus may not fully reveal how a transmission system actually responds. Television transmission is waveform-dependent, which means that a true representation of the subject cannot be obtained from the magnitudes of the signal spectral components (energy distribution) alone, as in the case of speech or music. A typical television signal is more likely to consist of abrupt "steps" (corresponding to a sudden transition from one value of gray to another), or sharp impulses (light or dark spots against a contrasting background).

An appropriate test signal should include these typical elements in a way that will clearly reveal system performance, but not respond to system characteristics which do not affect the picture. In general, the test signal should:

1. Be representative of the commonly occurring parts of a television signal;
2. Have a spectrum confined to fre-

quencies of interest, so that distortion outside the band of interest is not indicated;
3. Have a simple "mathematical" shape, thus simplifying calculations;
4. Be easy to generate or reproduce accurately;
5. Have a simple shape that permits easy identification of distortion on an oscilloscope presentation;
6. Be sensitive to the kinds of distortion met in actual television picture transmission, thus allowing the detection of very small errors.

These requirements are well satisfied by a test method which employs a *sine-squared pulse*. This type of pulse simulates transient picture elements well. Unlike a pure sine wave, which has an infinitely narrow bandwidth, or a square wave, which ideally has an infinitely extended bandwidth, the sine-squared pulse has a bandwidth or spectral content which is quite restricted and easily controlled. This is important because unwanted frequency components outside the television band of interest would certainly be distorted and cause misleading test results.

The sine-squared pulse is so-named because its amplitude varies as the *square* of the sine of the phase of the signal: $A = \sin^2 \theta$, where θ is the phase angle. This is nearly as simple a waveform as the sine wave itself, which is defined as $A = \sin \theta$. Both waveforms are shown in Figure 1.

An idealized square wave contains a series of harmonics that extend indefinitely. Practical square waves, the type that are obtained in a test instrument, have very extensive harmonics, but they vary unpredictably with variations in circuits and test conditions. The sine-squared pulse, by contrast, has a limited, easy-to-reproduce spectrum controlled by pulse width. A "sharper" and narrower pulse contains higher frequencies than a broader pulse. Hence, the bandwidth of the transmission system to be tested determines the duration or width of the test pulse to be used.

Sine-Squared Spectrum

Normally, the nominal pulse width T is defined as its half-amplitude duration. When the sine-squared pulse has a duration of $\frac{1}{2f}$, energy content of the pulse is 6 db below peak value at

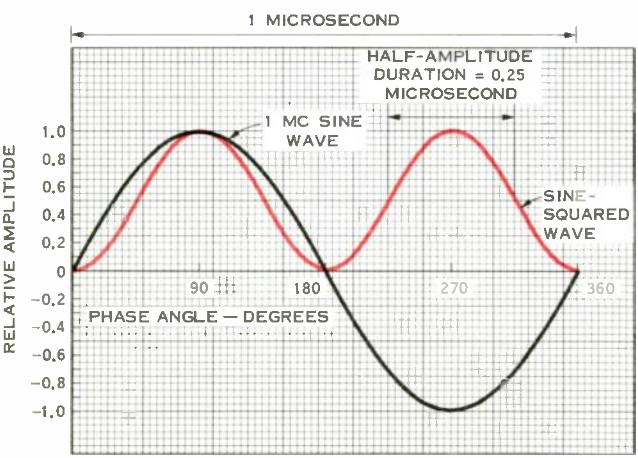

Figure 1. Sine-squared wave can be derived by numerically squaring a sine wave. The sine-squared wave shown contains no significant spectral components above 4 Mc.

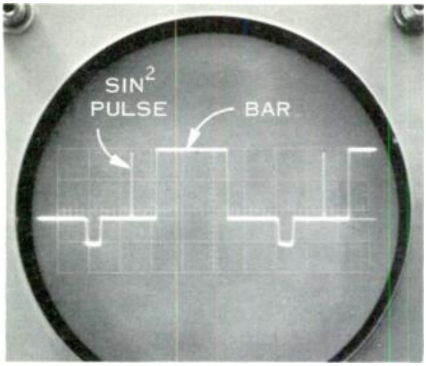

Figure 2. Pulse-and-bar test signal consists of sine-squared pulse and square wave with leading and trailing edges modified to sine-squared shape.

frequency f, zero at $2f$, and has no significant energy at higher frequencies.

Square waves provide the best test of low-frequency distortion, but are still more useful if the spectrum can be limited to the frequencies of interest. The square wave used in a window signal can be modified so that the leading and trailing edges have the same shape as the sides of the sine-squared pulse. If a sine-squared pulse is added to each line of a window signal which has been shaped in this way, a so-called *pulse-and-bar* test signal is obtained. This is illustrated in Figure 2.

The pulse and bar test permits sensitive performance evaluation across the entire frequency band. Because of the large amplitude of its low-frequency components, the bar gives the most sensitive indication of distortion at the lower frequencies—up to several hundred kc — just as does the traditional window signal. Unlike the window signal, however, the modified bar contains no significant out-of-band frequency components to produce spurious distortion indications.

The upper regions of the frequency band are tested by selecting a sine-squared pulse from either of two widths. The narrower pulse has a half-amplitude width of T, where T is the reciprocal of twice the upper frequency limit of the transmission system. For a 4-mc system, T is 0.125 microsecond. An analysis of its power spectrum shows the power to be 6 db below peak value at 4 mc and zero at 8 mc. Therefore, this pulse is particularly valuable for the upper frequencies, especially since considerable phase shift may occur near the upper cutoff frequency.

For frequencies between 0.5 mc and about 2 mc, a $2T$ pulse of 0.25 microsecond half-amplitude duration is often used. It contains no significant energy at frequencies above 4 mc. It is perhaps the most used of the three test signals because it is particularly suitable for use in routine adjustments where a detailed evaluation is not required.

Phase Sensitivity

Because the sine-squared pulse provides a dynamic test covering a broad frequency band, its usefulness is not limited to a particular type of distortion or to one frequency range. For example, the sine-squared pulse is a very good indicator of phase distortion. The sensitivity occurs because the pulse is highly symmetrical about its vertical axis; any transmission phase distortion skews the waveform and makes it unsymmetrical in a way that is immediately evident. If the high-frequency delay is greater than the low-frequency delay a ripple appears following the pulse, while greater low-frequency delay produces a ripple preceding the pulse.

In a low-pass transmission system, the *area* under the pulse remains constant because the area represents the dc component of the pulse. If the amplitude of the pulse is decreased by restricting bandwidth with a slow-cutoff filter, the pulse becomes wider to maintain the same area, thus losing some fine detail. If the bandwidth is restricted by a *sharp*-cutoff filter, overshoot or ringing occurs and is indicated by a damped oscillation following the pulse. Overshoot adds negative area so the pulse height automatically increases to maintain the same area. Pulse height is significant because it represents the brightness of fine details in the picture. In general, because detail is retained, a relatively sharp frequency cutoff is more desirable unless the ringing becomes objectionable.

Although ringing is produced by a sharp-cutoff filter, it may also be caused by a frequency response discontinuity elsewhere in the band. Ringing caused by a dip in the response of the system is evidenced by damped oscillations following sudden transitions in the pulse and the bar. The frequency of this oscillation is the same as the frequency at which the response dip occurs, while the amplitude and damping of the oscillation are controlled by the width of the dip.

Echoes are perhaps the most easily recognized type of distortion— the "ghosts" they produce on the television screen are familiar to most viewers. An echo occurs when a signal reaches its destination via two paths of different electrical lengths. In broadcast television, this usually happens when the main signal arrives directly and a portion of the signal is received after reflection from a mountain, building, or other object. Echoes may also be caused by electrical discontinuities such as impedance mismatches in the transmission system. It has been shown that all forms of distortion can be represented by characteristic patterns of echoes in

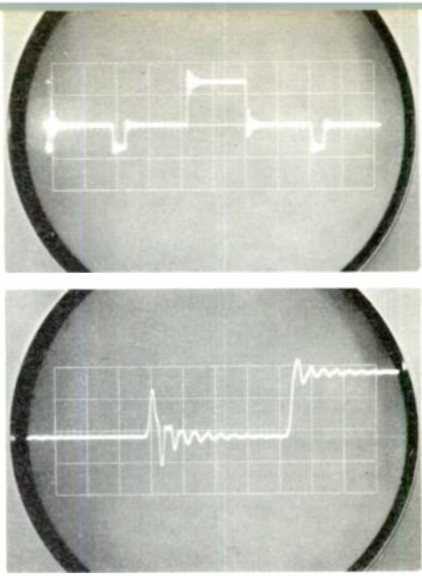

Figure 3. Identical ringing as indicated by square wave (top) and pulse-and-bar signal. Pulse and bar provides a much more sensitive indication of this distortion.

the received signal. Sine-squared test signals show these effects particularly clearly. By correlating the echo effects imposed on a test signal with subjective judgements of the picture degradation caused by the same distortion, it has been possible to create a quantitative rating system for all types of distortion.

Sine-Squared Rating System

Test methods based on waveform distortion were pioneered primarily in Europe, particularly by the British Post Office Department and the BBC. Early European investigators were quick to recognize the shortcomings of steady-state testing. For example, a broad dip of 2 db in the amplitude-versus-frequency response may cause much more waveform (and hence picture) distortion than a "sharp" dip of 6 db;

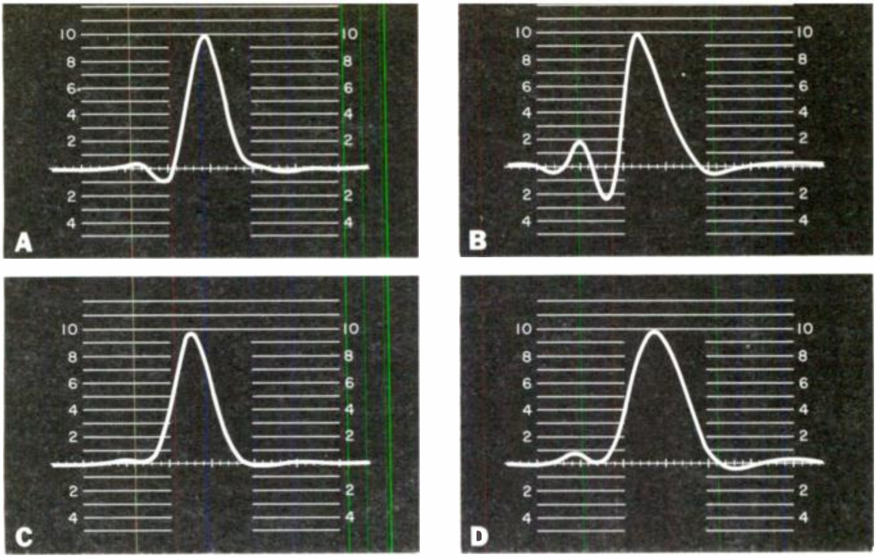

Figure 4. Response of local and long-distance television links to T *and* 2T *sine-squared pulses: (A) local link,* T *pulse; (B) long link,* T *pulse; (C) same local link,* 2T *pulse; (D) same long link,* 2T *pulse. Lack of symmetry about center of pulse indicates phase distortion. Greater effect on* T *pulse indicates distortion at higher frequencies.*

but steady-state tests may indicate that the "slight" 2-db dip is relatively unimportant.

Since the final test of transmission performance is subjective — the viewer's judgment of picture quality — the investigators used the reactions of a number of critical observers to establish performance limits. The tests revealed that the pulse-and-bar signal was in fact a sensitive indicator of the types of distortion which are most noticeable on the raster. But more important, the degree of distortion of the test signal gave a good indication of the amount of picture degradation. This allows the system performance to be specified in terms of a single factor — often called the *K* factor. The *K* factor is a quantitative measure of the distortion suffered by the pulse and bar.

Two test methods are generally used, one for *routine* testing and one for system *acceptance* testing. Both use the pulse-and-bar test signal and the *K* rating factor; the difference is in the method of interpretation. As the name implies, the routine-test method is used for everyday tests and adjustments where complete accuracy is not as important as speed and simplicity. By contrast, the acceptance-test method is a precision test used mainly to evaluate new systems or systems that have been modified.

Routine Testing

For routine testing, an oscilloscope graticule marked as shown in Figure 6 is used to determine the permissible distortion, usually of the bar and the *2T* pulse. Essentially, the test amounts to a visual inspection to see whether the received test signal fits into the limits engraved on the graticule. These graticules often show two limits. For example, a graticule now being marketed by a United States manufacturer indicates the limits for both $K = 2\%$ and $K = 4\%$. These limits are established by subjectively comparing distorted pictures with a picture impaired by a single undistorted echo delayed by more than $1\frac{1}{3}$ microseconds. (This arbitrary echo delay assures that the echo is not masked by the main signal. Echoes more widely separated tend to increase in annoyance value until a separation of about 10 microseconds is reached). Then, if the echo has an amplitude of 2% of the original pulse, the rating factor K is 2%. Any other type of distortion producing the same amount of picture impairment would also have a rating factor of 2%.

Other rating methods such as the "echo rating technique" use empirical bandwidth and frequency weighting curves to achieve a similar evaluation based on echo simulation. Thus, the use of the echo as the standard of comparison permits the placing of quantitative limits on all types of distortion.

Precision Testing

The acceptance-test method uses the same rating factor, but achieves more precise evaluation by mathematical analysis. A microscope is used to sample photographs of the transmitted T pulse and the received pulse waveforms at short intervals—equivalent to the waveform sampling in a time-division multiplex system. The series of samples forms a "time series" which can be used to describe the waveform mathematically. If the time series for the received pulse is divided by the time series obtained from the original transmitted pulse, the result is a "filtered" time series which is free from the imperfections of the test equipment. In a distortionless system, the mathematical expression for this filtered series would contain only one term. Therefore, any additional terms represent distortion. These distortion terms represent echoes of the undistorted pulse displaced in time. They appear both before and after the main pulse, but not necessarily in matched pairs because they do not represent attenuation or phase distortion separately.

As the name implies, the acceptance-test method provides a means for specifying the required performance of a transmission system and for ensuring that the system meets the specifications. By performing various fairly elaborate computations on the mathematical time

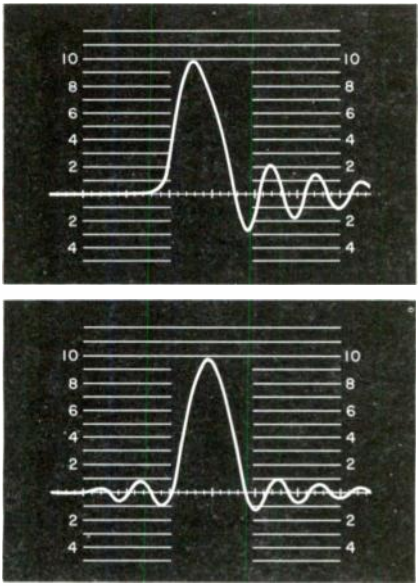

Figure 5. Ringing caused by low-pass filter follows pulse. Phase distortion is indicated by lack of symmetry. Partial phase equalization transfers some of the ringing to the other side of the pulse, improving symmetry.