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Performance Testing of Television Channels

Part One

Television, having completely conquered home entertainment, is now maturing into a powerful industrial and educational communications tool. Schools, businesses, and utilities are finding in closed circuit TV a valuable means of operating more effectively.

The technical side of relaying television signals from one point to another may provide a few surprises, even to organizations well experienced in other forms of communication. Although television is transmitted over facilities very similar to those used for multi-channel communications, performance requirements and testing procedures are quite unlike those for speech signals. This article is the first of two which review the basic methods of testing and evaluating television transmission channels.

Television, especially color television, imposes new performance requirements on communication circuits. Unlike most other kinds of transmission, television is extremely waveform-sensitive. The ability of a television circuit to transmit an image which faithfully represents the original subject is directly dependent on the ability of the system to reproduce a signal waveform precisely. By contrast, in speech or even data transmission, the accurate reproduction of the signal waveform is relatively unimportant so long as the magnitudes of the various spectral components of the signal are reproduced accurately.

In television, the reproduction of the brightness of individual picture elements is determined by the voltage of the television signal at a given moment. To faithfully reproduce a contrasting edge, say, from black to white or white to black, the television signal must be able to make an abrupt change or "step" voltage without distortion. The shape of the video waveform depends entirely on the content of the picture, possibly consisting of impulses, steps, or level plateaus instead of the sine wave combinations which characterize speech or music waveforms.

This inherent difference between video and audio waveforms naturally leads to differing transmission requirements and capabilities. An effective transmission system for speech must have good amplitude-versus-frequency linearity. That is, amplitude response must not vary appreciably across the frequency band occupied by the audio signal. However, phase irregularities are relatively unimportant in speech transmission.

In a television system, phase characteristics become extremely important. Non-linear phase shifts as a function of

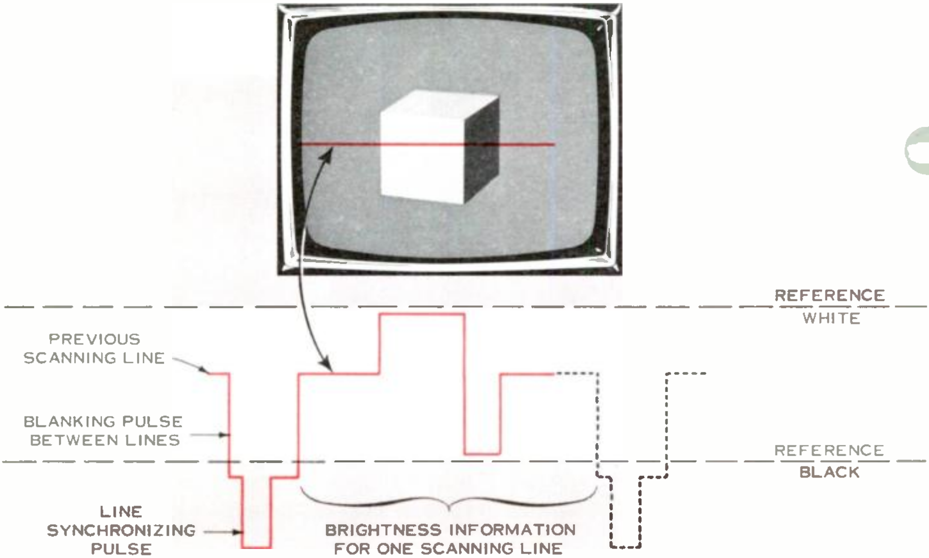

Figure 1. Basic television signal for a single scanning line. The partial scan shown in red in the picture raster produces a waveform like that shown directly below it. At the end of each scan, the blanking pulse darkens the tube while the scanning beam is returned. The scanning sweep is triggered by the synchronizing pulse which occurs during blanking. Ability of transmission system to pass such abrupt waveforms without distortion is vital to good picture reproduction. Clean edges between contrasting colors require excellent ability to transmit square waves and other such transients.

Figure 2. Poor frequency response or other irregularities lead to distortion of various sorts in the reproduced picture. Echoes usually result from non-linearities in baseband frequency characteristic, or from multipath transmission. Since transmission errors are rarely as bad as this exaggerated example, sensitive test methods are required to permit accurate evaluation of quality.

frequency serve to distort the all-important waveshape, and these distortions are directly visible on the television screen as some form of picture distortion. Amplitude-versus-frequency linearity is also extremely important because it determines the ability of the equipment to reproduce accurately the brightness values of the subject. Furthermore, it determines the ability of the waveform to make rapid changes from one level to another in response to fine detail in the picture. Thus, good frequency response affects the ability of the television signal to accurately achieve the desired voltage levels and to reach these values at the required time.

When linearity of phase shift or amplitude response is poor, various forms of distortion may be produced. For instance, where low frequency (such as 60 cps) phase and amplitude response is poor the signal is unable to adjust itself to the desired value for a considerable portion of the scanning sweep. This shows up on the picture monitor as "streaking"—errors in the brightness of the image. Response errors at the higher frequencies may result in "ringing," "smearing," or echoes. The magnitude and distribution of frequency and phase errors have an important bearing on the way the picture is affected. The accurate location of picture information on the screen is a function of the ability of the system to respond within a certain time, but not *beyond* the proper time. Frequency and response time are reciprocal functions of each other; one can be transformed into the other, and this transformation determines how the picture is affected by frequency response errors.

For instance, if there is a "narrow" irregularity in the television baseband frequency response—that is, an amplitude variation that is restricted to a rather narrow band of frequencies, the waveform will exhibit a "ringing" of low amplitude but of long duration. This shows up as an echo or "ghost" following important transitions of dark and light in the picture. The greater the bandwidth over which the amplitude response error extends, the smaller the separation between the desired detail and its echo. If the bandwidth occupied by the irregularity becomes smaller, the echo is more widely separated from the main image.

Most of these effects which are of great importance in the transmission of television have only negligible effect on the transmission of single or multiple-channel speech signals. For this reason, conventional methods of testing speech channels are able to reveal little about the suitability of a transmission channel for carrying television signals. Testing methods are required which are sensitive to those characteristics which directly affect picture quality.

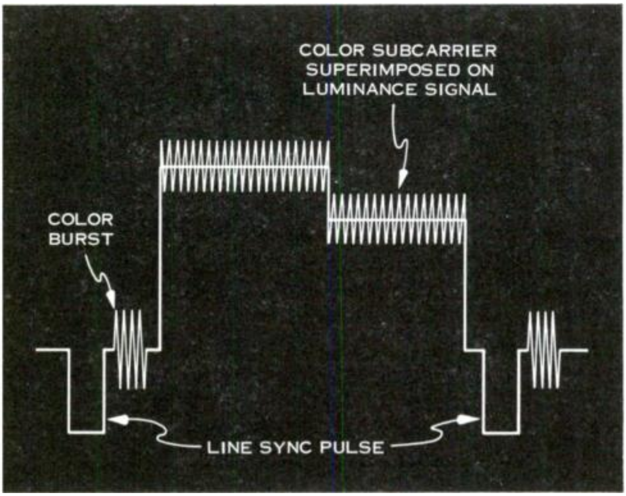

Figure 3. In NTSC color system, "color burst" is transmitted as phase reference for color subcarrier superimposed on luminance signal. Any change in phase or amplitude of subcarrier causes color change in picture. This is called "differential phase" or "differential gain" when caused by changes in luminance signal.

Television Test Signals

A rough idea of transmission quality can be gained simply by observing the transmitted picture, and often a skilled technician can diagnose difficulties directly from the raster. Since such evaluation is entirely subjective, problems arise in defining transmission quality. An impairment barely noticeable to one person may be highly objectionable to another. Under these circumstances what constitutes "acceptable" picture quality, and how should it be expressed?

In the final analysis, of course, a transmission system must provide a picture acceptable to the viewer. Thus, the amounts of tolerable distortion are based on viewing tests by critical viewers. Large amounts of distortion may be tolerated if the effect on subjective picture quality is negligible; but other, more potent types of distortion may be allowed much narrower tolerances. This, of course, suggests the need for standardized test methods which can be readily reproduced under a variety of conditions, but which do not require subjective judgements of quality. Many such tests have been developed by the television industry.

In general, the tests developed for black and white television are concerned with the measurement of three transmission parameters:

1. Amplitude-versus-frequency linearity,

2. Phase-versus-frequency characteristics, and

3. Transient response.

The first of these, amplitude linearity, implies the ability to reproduce signal voltage accurately regardless of the frequency (within the band of interest). The last, transient response, is the ability of the system to "follow" sudden, impulsive changes in the signal waveform. This ability is largely controlled by a combination of the two previous characteristics, amplitude and phase response. In general, good transient response requires excellent amplitude and phase characteristics, but is not necessarily assured, since minor perturbations of one may combine with the

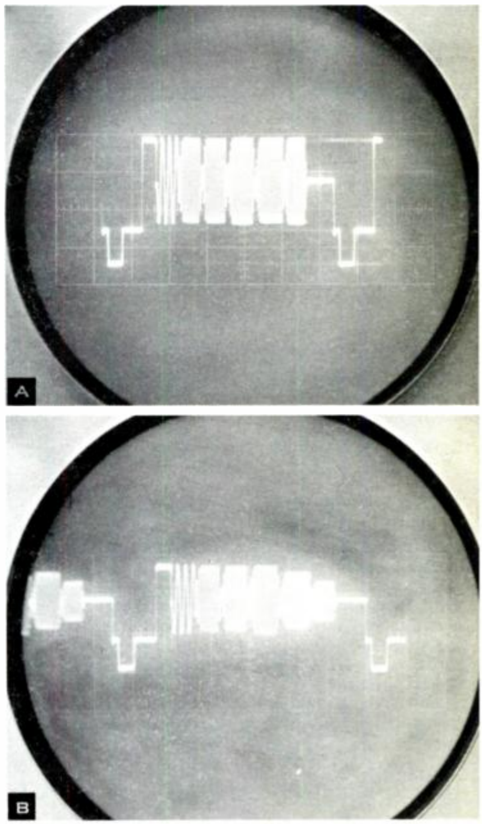

Figure 4. Multiburst signal consists of consecutive "bursts" of ascending frequencies, all transmitted at reference white level (A). Changes in frequency response show up as variations in relative amplitude of different frequencies (B). Note frequency roll-off at upper frequencies.

other in "the wrong way" to cause distortion of transients.

Color television transmission requires the consideration of these three factors, plus two more:

4. Differential gain and
5. Differential phase.

These last two parameters are perhaps the least understood, and yet they are the ones which place the most stringent requirements on the transmission system. *Differential gain* is the variation in the gain of the transmission system as the luminance or brightness signal varies between the values for "black" and "white." Any variation in phase of the color subcarrier as a result of changing luminance level is called *differential phase.* Ideally, variations in the *luminance* signal voltage should produce no changes in either the amplitude or phase of the color subcarrier. Thus, the presence of either one implies distortion—and thus it is redundant to speak of "differential gain distortion" or "differential phase distortion."

Both of these parameters are directly concerned with color information. In the American and Canadian NTSC system, a color subcarrier at a frequency of about 3.58 mc is superimposed on the luminance signal. Different colors or *hues* are indicated by shifting the phase of the color subcarrier. The *saturation* or richness of the color is transmitted by varying the amplitude of the color subcarrier. In an ideal system, which would have no differential gain or differential phase, changing brightness values in the picture would have no effect on the phase or amplitude of the subcarrier. However, when differential phase is present, a change in the brightness of the scene could change the color of a green object to yellow, while differential gain could change the color saturation from, say, a dark green to a pale value.

Even before color television, there was no simple, easy-to-use test signal

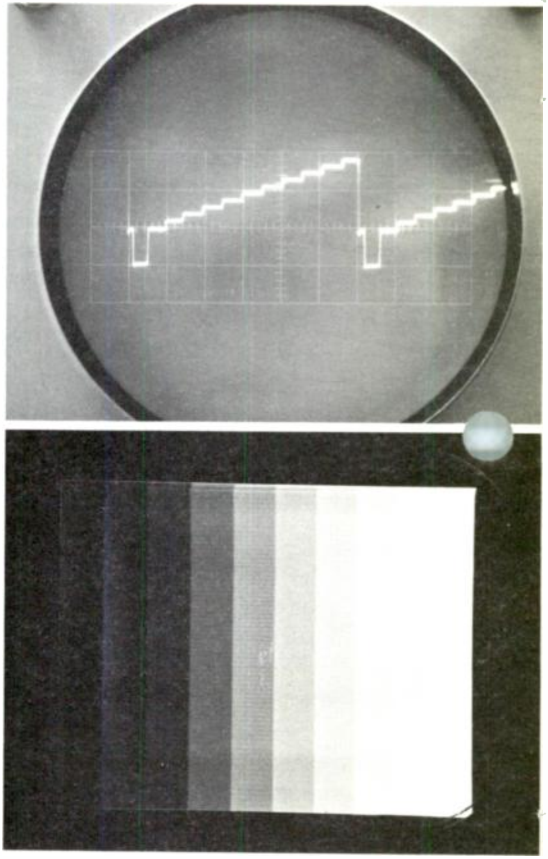

Figure 5. Typical stairstep test signal as shown on the "A-scope," and how it appears on picture monitor. Note that each step represents a shade of light. When applied to system, each step is equal in amplitude. Non-linearities in system are revealed by compression or expansion of individual steps or parts of waveform.

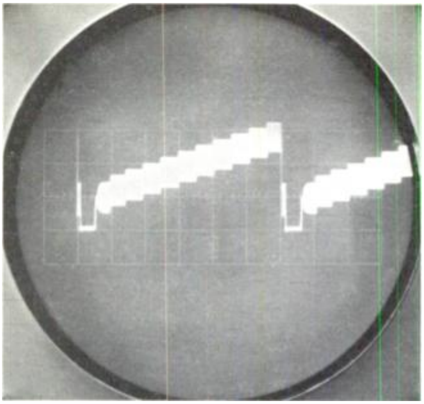

Figure 6. Stairstep test signal with superimposed 3.58-mc color subcarrier can be used to measure differential phase or gain. Differences in amplitude of modulation reveal differential gain. Differential phase measurements require synchronized phase detector.

that would give quantitative as well as qualitative evaluation of *all* transmission impairments. With the addition of differential gain and differential phase to the characteristics to be monitored, the problem of testing became even more difficult. Several test methods, however, have gained wide acceptance for measuring specific impairments, and some can be used for more than one of the parameters listed above.

Multiburst Signal

The *multiburst signal* is used to make a quick check of the amplitude-versus-frequency characteristics across the baseband. The signal consists of a series of "bursts" of equal-amplitude sine waves, each at a different frequency. In addition to the burst frequencies, the test signal includes a horizontal synchronizing pulse and a burst of peak white—the so-called "white flag"—to provide a white reference level. The complete signal is transmitted during one line interval. Typical burst frequencies are 0.5, 1.5, 2.0, 3.0, 3.6, and 4.2 mc. A transmitted multiburst signal appears in Figure 4A, and the received signal is shown in Figure 4B. A quick glance

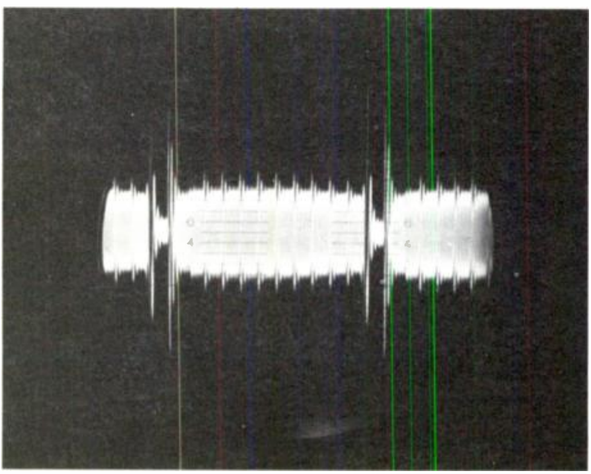

Figure 7. By passing stairstep with subcarrier through a high-pass filter, low-frequency steps are removed, leaving only subcarrier. Variations in amplitude reveal differential gain more clearly than in original unfiltered form (Figure 6).

at the oscilloscope ("A-Scope") waveform presentation of the received signal reveals a substantial decrease in gain with increasing frequency.

Obviously, the multiburst is not a complete check of the amplitude-frequency response. Dips and peaks occurring entirely between the burst frequencies may not show at all. This test is very useful, however, because it provides a spot check of the overall system response which can be evaluated visually in a few seconds.

Stairstep

The *stairstep signal* is so called because the A-Scope presentation resembles a staircase consisting of 10 steps extending from black level to white level. On the picture monitor this signal produces a series of vertical bands. Both presentations are shown in Figure 5. In the undistorted signal these steps are equally spaced. Thus, a visual check of the relative height of the steps after passage through the transmission system provides a quick and easy method for qualitatively evaluating system linearity.

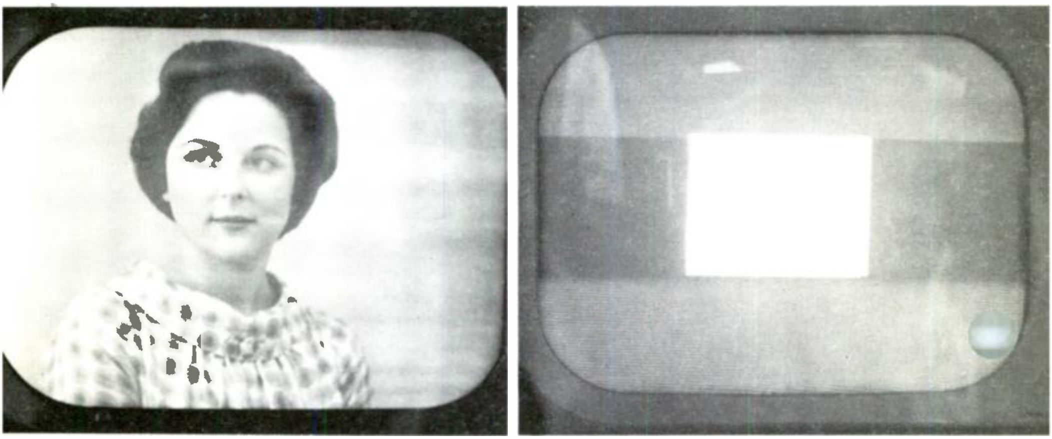

Figure 8. Streaking of picture is caused by poor low-frequency response. Note that relative duration of brightness values determines the amount of visible error in picture at left. At right is a typical window signal as it appears on the picture tube when the same amount of low frequency error is present.

A sine wave of 3.58 mc (the nominal color subcarrier frequency) impressed on the stairstep signal provides a method for measuring differential gain and differential phase. If this composite signal is passed through the transmission system and then through a high-pass filter, the low-frequency step components are eliminated and the 3.58-mc signal remains—distorted by any differential gain or differential phase which may be present in the system. Any differential gain at the 3.58-mc subcarrier frequency shows up as amplitude variations in the horizontal presentation, as shown in Figure 7.

Differential phase can be measured by using a phase detector to compare the phase of the 3.58-mc signal impressed on a stairstep luminance signal with the phase of a reference signal of the same frequency. This reference signal may be provided in several ways. One method is to use a local free-running oscillator synchronized by the horizontal synchronizing pulse transmitted with the stairstep. The phase detector then measures the phase differences between this locally generated signal and the received signal at the various luminance levels. Any difference, measured in degrees, is the differential phase.

Window Signal

The *window signal* takes its name from its appearance on the picture monitor — a rectangular white area on a black background. The signal is generated as a line frequency (15.75 kc) square wave having a peak value equal to reference white. Since only half of each cycle is at reference white, the other half cycle being near reference black, only half the width of the screen is white. If the line frequency square wave is modulated by a 60-cycle square wave, the window signal will occupy only half the height of the picture raster. Most commercial window signal generators permit the resulting window to be adjustable in size and position.

The window signal is particularly useful in testing for low-frequency distortion. Phase distortion in the frequency range below about 200 kc produces "streaking"—one of the more objectionable forms of picture impairment. Streaking is the appearance of an incorrect luminance in the picture because of the waveform's inability to reach the correct value promptly. It usually spreads to the right from a point of sharp transition between light and dark or vice versa, as shown in Figure 8. In addition to being visible on the raster

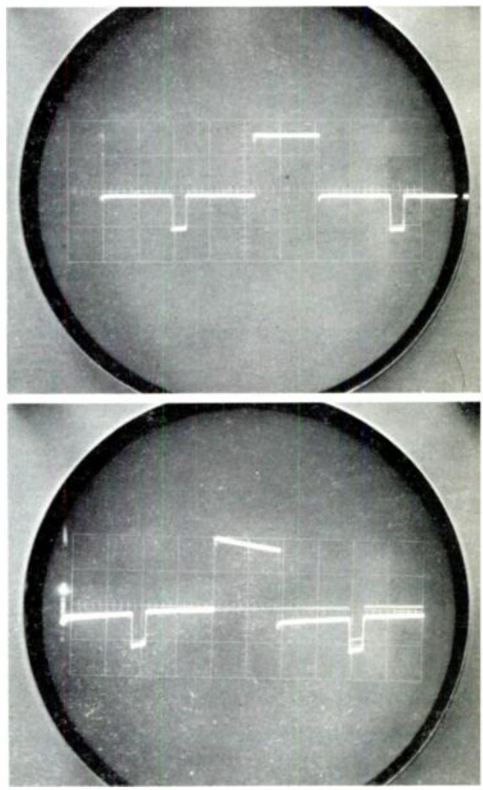

Figure 9. Oscilloscope presentation of square wave response in system with poor low-frequency response. Upper waveform is reasonably good (note tilt of sync pulse). Bottom picture illustrates very bad low-frequency response. Streaking would be severe.

presentation of the window, low frequency phase distortion can also be seen on the A-Scope, where it is indicated by a tilting of the square wave from the horizontal. As little as 2% tilt may be detectable in the picture, and 5% tilt indicates distortion which is readily noticeable. Figure 9B shows an extreme amount of "square-wave tilt."

The window signal is also used to test for "ringing"—a waveform "overshoot" or damped oscillation. Ringing is usually produced by sudden voltage transitions in a system with a sharp upper frequency cutoff, or by a transmission discontinuity below the cutoff frequency. The frequency of oscillation approximates the cutoff frequency or the frequency of the discontinuity. The "sharpness" of the discontinuity determines the duration of the ringing. As shown in Figure 10 each oscillation due to ringing shows as a light or dark band following the tonal transition which induced the ringing. By measuring the overshoot of square-wave transitions, it is possible to estimate the effect on picture quality and to determine the degree of correction required. Figure 11A shows the A-Scope presentation of the same degree of ringing shown in Figure 10, and Figure 11B shows the same effect on a sine-squared test pulse.

Figure 10. "Ringing" shows in picture as echoes displaced to the right of transitions between dark and light.

Transient Response Tests

Most of the tests described above are essentially "steady state" tests—that is, tests which employ sine wave signals or other signals which are inherently repetitive. Although these tests have significant value in evaluating the overall response of a television transmission system, they have definite limitations.

The most typical television signal is not necessarily repetitive at all, but may consist of a number of transients or instantaneous changes in amplitude. Such signals impose performance requirements on a transmission system which cannot be adequately simulated by sine wave substitutes. A television subject may consist of "optical transients" in which a small bright object may appear against a contrasting dark background. For perfect reproduction, the signal waveform should rise instantly to the value representing the

Correction: In the August, 1963 issue on "HF Radio Transmission," a statement was inadvertently reversed from its original meaning. On page 3, column 1, the statement following the equation $F^2 = 81N$ should read, "Thus, the higher the electron density, the *higher* the critical frequency."

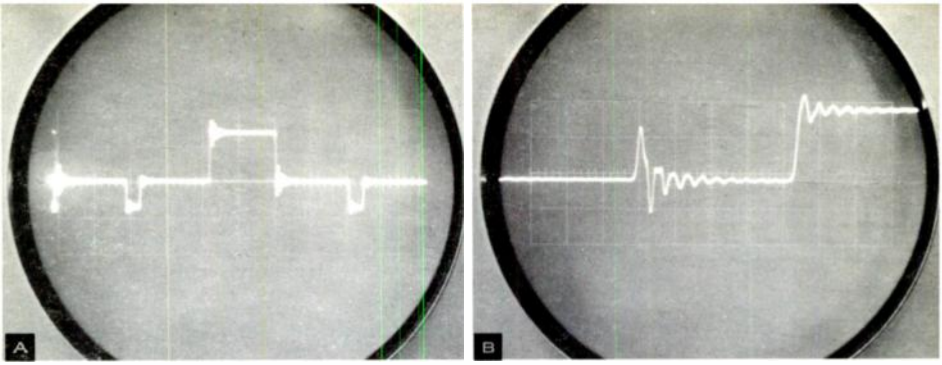

Figure 11. Same amount of ringing as in Figure 10 produces severe distortion of window signal (A) and sine-squared test pulse (B). Note severe oscillations at beginning and end of square wave. Sine-squared test is the more sensitive of the two, but is harder to evaluate qualitatively. Next month's article discusses this test in detail.

brightness of the small object, then just as quickly return to its former value as the scanning beam moves on.

In steady-state types of testing, the low-frequency components of the waveform that are necessarily present as a result of the long duration of the test signal may obscure or modify the response of the system to transients. Since steady state signals are not necessarily typical of those which the system may be called upon to transmit faithfully, they are not fully adequate in evaluating performance of the system. Furthermore, steady-state tests are less suitable for establishing *tolerances* on the distortion which may be allowed in a television system.

Because of these more or less inherent disadvantages of the "traditional" steady-state test methods, waveform or transient response tests have been developed, and these are becoming more widely accepted, particularly in England and other European countries. The most widely used transient response test is a combination of a "sine-squared" pulse and a modified square wave which together form the so-called *pulse and bar* test signal. This test method offers many advantages under some circumstances and has been recommended, along with some other tests, by the CCIR (International Consultative Committee for Radio). The sine-squared pulse and bar test will be discussed in the second article of this series, which will appear in next month's DEMODULATOR. •

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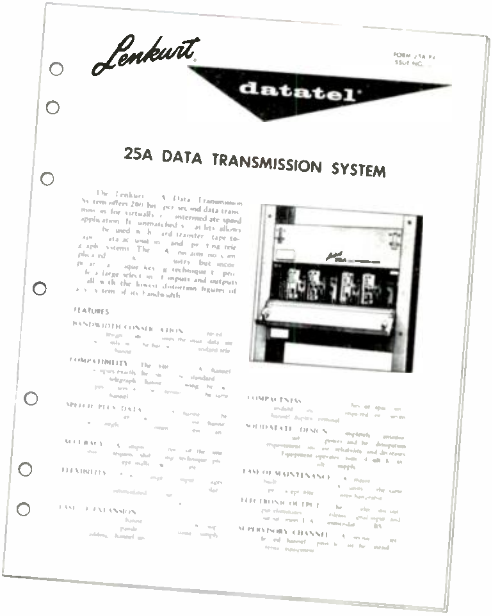
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