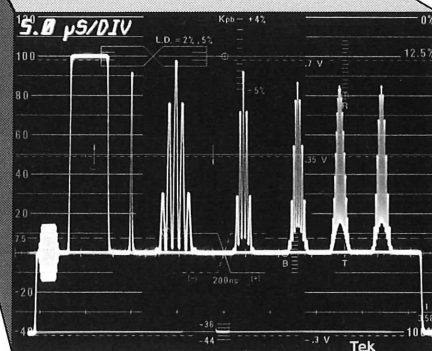
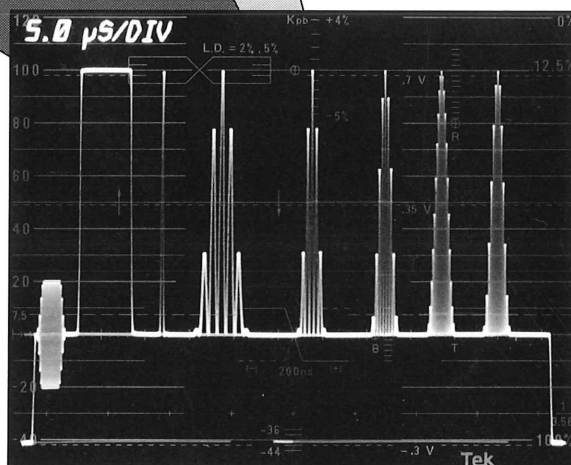
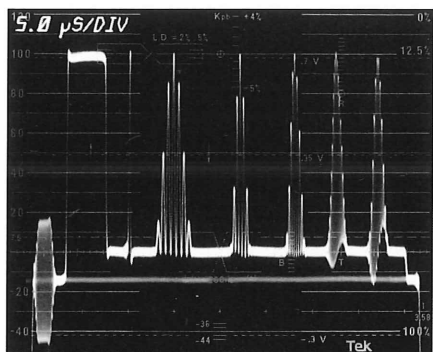


USING THE MULTIPULSE WAVEFORM TO MEASURE GROUP DELAY AND AMPLITUDE ERRORS



Faithful picture reproduction relies on maintaining the relative amplitude and phase relationships of all frequency components in the video signal. If the video system applies different gains to different frequency components of the video signal, a variety of picture aberrations can occur. Similarly, if there are phase shifts (relative delay) between the frequency components, various distortions will be apparent. These problems will affect the luminance signal (ringing, ghosts, soft edges) and/or the chrominance signals (color smearing, wrong saturation, bleeding).

To avoid such problems, the video system must have a flat amplitude-versus-frequency response and a linear phase-versus-frequency response. The phase-versus-frequency response characteristic is often expressed as "group delay" in video system specifications and testing. Mathematically, group delay is defined as the derivative (slope) of phase-versus-frequency. Due to the nature of most video equipment, we are more often concerned with variations in delay between widely separated bands of frequencies than we are with the incremental rate of change of delay-versus-frequency. It is in this context that the term "group delay" is used in this application note.

Verifying video system frequency-response characteristics is done by applying a stimulus signal to the equipment under test and observing the output response (Figure 1). This can be done out-of-service, or it can be done in-service with signals inserted in the vertical blanking interval (VITS). The method of measurement used and amount of information available depends on the type of test signal used.

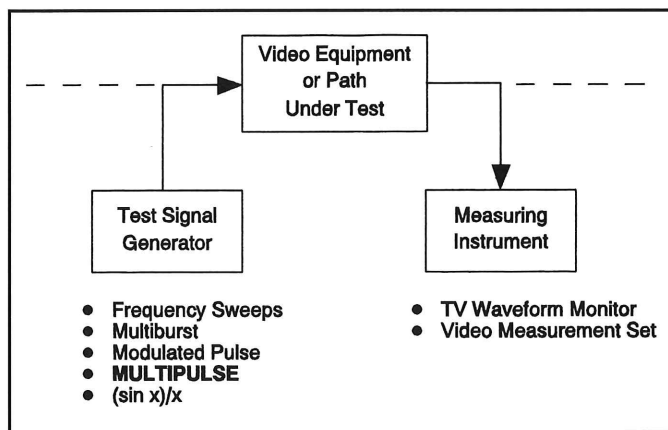


Figure 1. Frequency response evaluation involves applying an appropriate test signal to the video path and observing the response at the output. Typically, the multipulse signal allows the greatest measurement versatility.

The various test signals that can be used include —

- Frequency Sweeps
- Multiburst
- Modulated Pulse
- Multipulse
- $(\sin x)/x$ Pulse

Of these signals, the multipulse shown in Figure 2 is perhaps the most versatile test signal for frequency response measurements. The multipulse is provided by several Tektronix test signal generators. However, the

Tektronix 1910 Digital Generator includes vertical insertion of the multipulse for the added flexibility of in-service testing. (The 1910 also provides all of the other test signals listed above except for frequency sweeps.)

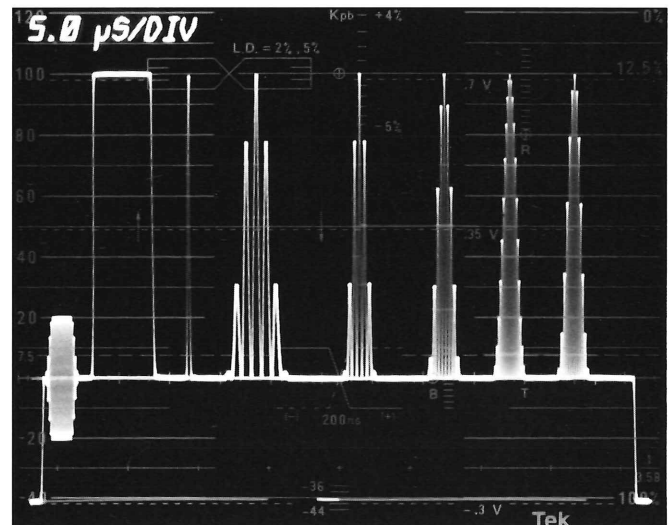


Figure 2. A full-amplitude (100 IRE), undistorted multipulse as viewed directly at the output of a test signal generator. A reduced-amplitude (70 IRE on a 10 IRE pedestal) version is often used for testing transmitters or other devices subject to nonlinear distortions.

The real versatility of the multipulse signal is in the variety of measuring instruments and methods that can be used to obtain frequency response amplitude and group delay results. These methods range from observations on a waveform monitor to semiautomatic or automatic measurement with a Video Measurement Set such as the Tektronix 1780R Series or VM 700A Series.

To fully understand the features and flexibility of the multipulse signal, let's first look at the general definition of the signal and its attributes. Then various methods of multipulse observation and frequency response measurement can be discussed.

What Is the Multipulse?

In the simplest sense, the multipulse is a series of frequency packets. Typically, these packet frequencies are 1, 2, 3, 3.58, and 4.1 MHz. However, the frequencies may vary somewhat for different types of multipulse signals. For example, a Color Multipulse uses the subcarrier frequency for the center pulse with ± 300 kHz frequency increments in the pulses to either side. A 70 IRE multipulse uses the same packet frequencies as the FCC multiburst signal (0.5, 1.25, 2, 3, 3.58, and 4.1 MHz), except that 0.5 MHz is not used in the multipulse.

A major difference between the multiburst and multipulse signals is in the way frequency packets are created. In the multiburst, the various sinusoidal frequencies are simply turned on and then off (in bursts) to cover the packet duration. In the multipulse signal, the sinusoidal signals are modulated by a \sin^2 pulse and then added to the same \sin^2 pulse. This process is illustrated further in Figure 3.

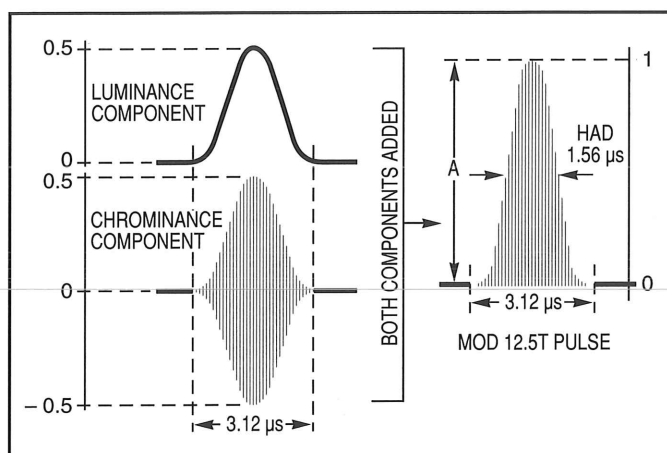


Figure 3. The process of creating a modulated pulse in a multi-pulse signal. HAD stands for half-amplitude duration, and 12.5T refers to time relative to system bandwidth ($T = 1/2f_c$, where f_c is the system bandwidth).

Notice in the multipulse signal of Figure 2, that the first modulated pulse is wider than the other modulated pulses. To include sufficient 1 Mhz cycles, this first modulated pulse has a 25T half-amplitude duration (HAD). The remaining pulses at the higher frequencies are 12.5T pulses.

The other attributes of the multipulse signal include a bar signal and a $2T \sin^2$ pulse following color burst and preceding the series of modulated pulses. The bar provides a useful reference in making amplitude measurements. The $2T$ pulse can be used for making short-time distortion measurements (e.g. pulse-to-bar and K Factor).

The emphasis here, however, is on how the modulated pulses can be used to observe and measure frequency-response amplitude and group delay errors. To explore this further, let's take a slightly more detailed look at how a modulated pulse is formed. This can be done with the aid of Figure 4.

Basic Measurement Concepts

Looking at Figure 4a first, the top waveform is the \sin^2 pulse used in modulating the sinusoid (middle waveform in Figure 4a.) Often, this \sin^2 pulse is referred to as the luminance component, and the modulated sinusoid is referred to as the chrominance component. When these two components are added directly — with no change in their amplitudes or time relationship — an undistorted modulated pulse is obtained. This is the bottom waveform in Figure 4a.

The modulated pulse in Figure 4a is undistorted because the original amplitude and delay relationships of the pulse and modulated high-frequency sinusoidal component are maintained in the sum. As a result, the negative going peaks of the sinusoidal component are flush with the pulse base line.

Now consider what happens if the sinusoidal component's amplitude is reduced relative to the pulse amplitude. This situation is shown in Figure 4b. Notice that the relatively higher pulse amplitude causes an upward bowing in the sum waveform's base. If the sinusoidal component became increased relative to the pulse component, the sum waveform's base would bow downward.

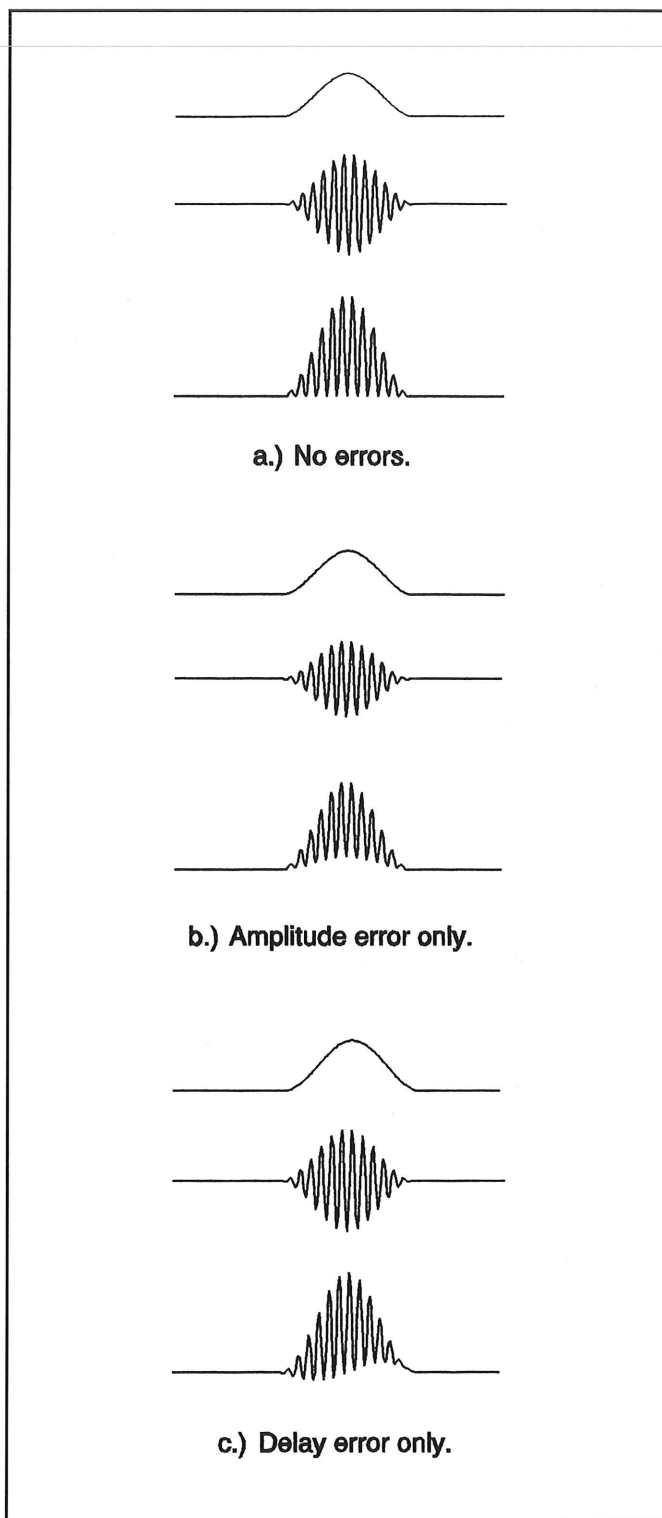


Figure 4. The luminance-chrominance sum exhibits distinctive base-line distortions for amplitude and delay inequalities.

Figure 4c shows a different case. Here, the original relative amplitudes are maintained, but there is a relative time shift between the pulse and sinusoidal components. The time shift, which amounts to about half of the sinusoid's cycle, is barely perceptible in comparing the two components. But look what happens to the base in the sum of the two components. A very distinct and perceptible sinusoidal distortion of the base has occurred in the sum because of the relative shift between components.

From the few simple observations illustrated by Figure 4, it becomes clear that a modulated pulse can indicate amplitude and delay errors in a video system. The modulated pulse is fed into the system. If the system responds to the low-frequency content of the pulse differently than the high-frequency sinusoidal component, the effects will be seen as a distorted base in the output modulated pulse waveform.

In practice, the base distortion will not be a pure and symmetric bowing (amplitude error) or sinusoid (delay error). Instead, there will usually be some combination of the two distortions. The various classes and relationships of these combined distortions are illustrated further by Figure 5.

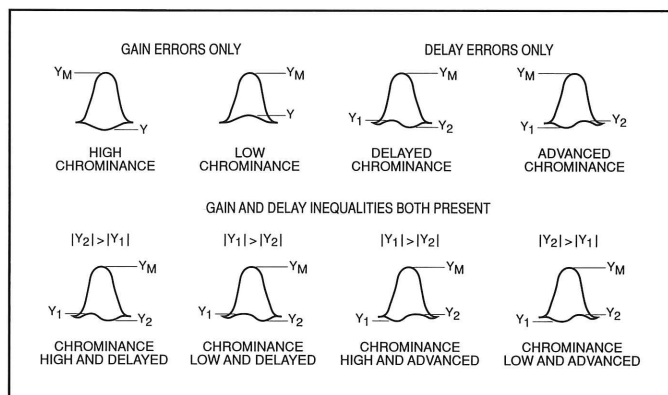


Figure 5. Effects of various gain and delay inequalities on a modulated pulse.

Thus far, the discussion has centered on the effects associated with a general modulated pulse. When the high-frequency sinusoidal component of the modulated pulse is of a specific frequency, the amplitude and delay effects seen in the pulse base line are for that frequency region. In the case of the single modulated pulse, such as provided in a pulse and bar, the modulated frequency is 3.58 MHz. Thus the base line distortions are those for amplitude and group delay errors occurring around 3.58 MHz. (Because the 3.58 MHz sinusoid is modulated, there is a range of frequencies present around 3.58 MHz.)

In the case of the multipulse signal, there are five modulated pulses. Additionally, each pulse has a different modulated frequency. As a result, the multipulse signal is able to indicate frequency-response amplitude and group delay errors for five different points across the video frequency band. This is illustrated in Figure 6, which shows a multipulse signal after it has passed through a video system.

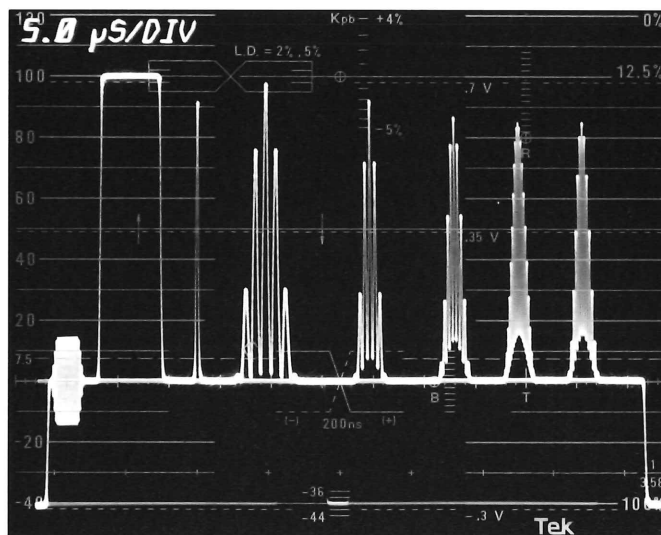


Figure 6. A multipulse signal after passing through a system with gain inequalities. The increasingly pronounced upward bowing in the pulse bases indicates greater attenuation with increasing frequency.

Notice in Figure 6, that the pulse bases have an upward bowing. This indicates an amplitude error. Specifically, the high-frequency components are being attenuated. Also, notice that the bowing becomes more pronounced with each pulse in the multipulse signal. The amplitude error is increasing with frequency.

Figure 7 shows the display expanded on the highest frequency modulated pulse for more detailed observation. Such detailed observation is necessary both for determining the type of error (amplitude, group delay, or mixed amplitude and group delay) as well as accurately measuring the amount of error. The following guidelines will assist you in making these observations —

Amplitude Only Errors

- 1.) Pulse base bowing that is symmetric to the pulse's center line (Figure 7) indicates amplitude error only.
- 2.) Upward bowing indicates attenuation at the pulse's high-frequency component. Downward bowing indicates gain at that frequency.
- 3.) The maximum shift of the pulse base (bowing peak) from the base line is a measure of the amount of amplitude error. This shift is exactly equal to the displacement of the pulse's peak from top-of-bar when the distortion is purely linear.

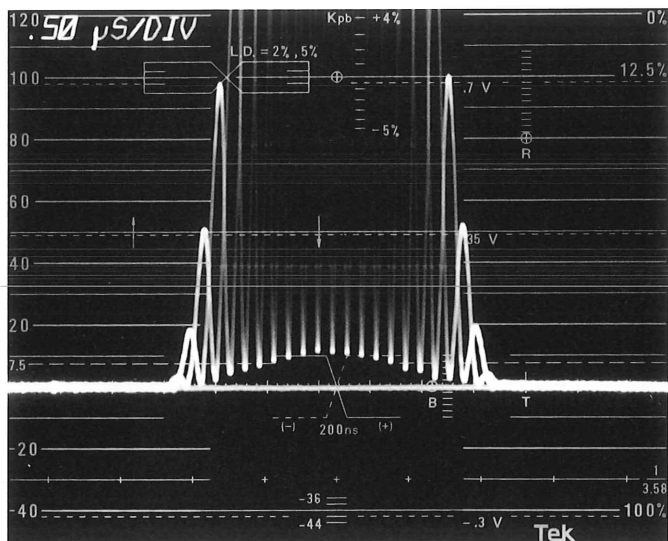


Figure 7. Bowing that is symmetric with the pulse center indicates amplitude only error. Nonsymmetric bowing would indicate some delay error along with the predominating amplitude error.

Delay Only Errors

- 1.) Group delay differences between low video frequencies (luminance) and the pulse modulated frequency (chrominance) cause the pulse base to have the perfectly symmetric shape of a single sinusoidal period (Figure 8).
- 2.) When the positive going lobe of the sinusoid is on the left, the higher frequencies are delayed with respect to the lower frequencies. If the positive going lobe is on the right, the higher frequency is advanced.
- 3.) The amplitudes of the sinusoidal peaks provide a measure of the delay error.
- 4.) The peaks of the modulated pulses appear unchanged when there is delay error only. (This is true only for the smaller delays typically found in practice. Large delay errors will more noticeably affect the pulse peaks.)

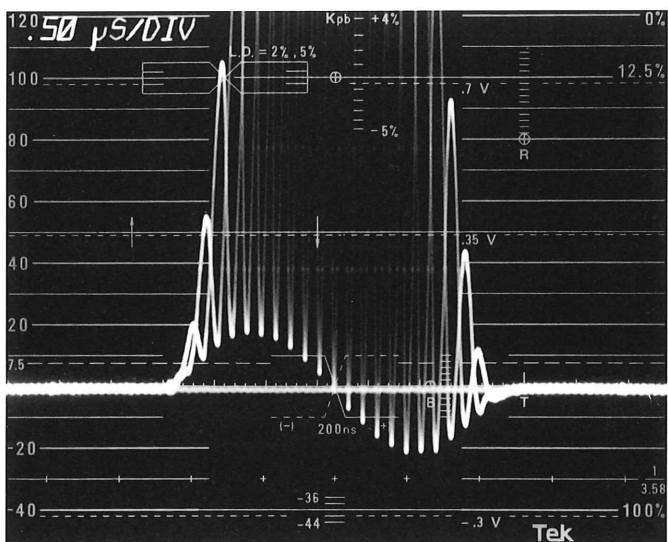


Figure 8. Symmetric sinusoidal distortion of the pulse base indicates a delay only error. The direction and amount of delay is determined from the amplitudes and polarities of the base sinusoid peaks.

Combined Amplitude and Group Delay Errors

- 1.) Combined amplitude and group delay errors cause a nonsymmetric sinusoidal distortion of the pulse base (Figure 9)
- 2.) The individual peak amplitudes and polarities indicate the amounts and direction of group delay and amplitude errors.
- 3.) The peaks of the modulated pulses will be shifted from the top-of-bar reference according to the amount of amplitude error present. (Pulse peaks are also affected by delay, but to a much smaller degree.)

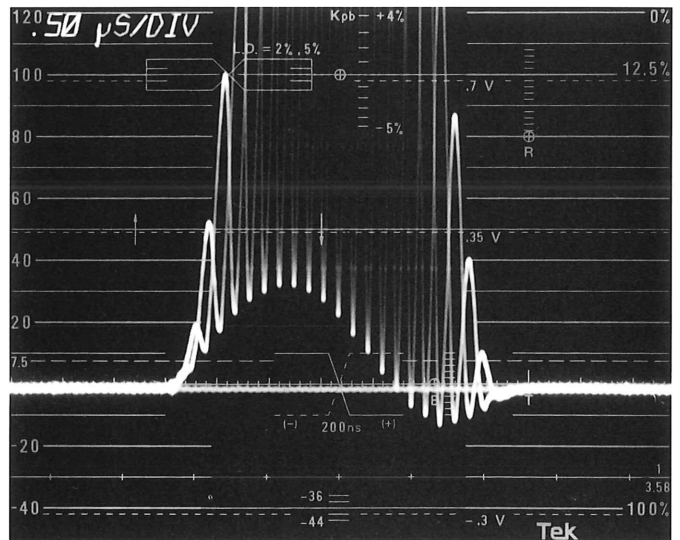


Figure 9. Nonsymmetric sinusoidal distortion of the pulse base indicates combined amplitude and group delay errors. In the extreme, a near zero amplitude for one of the sinusoid peaks could make this appear to be amplitude only bowing.

Making Amplitude and Delay Measurements

Actual measurement of the amount of amplitude or group delay error can be done in several ways. Usually, measurements are made on the modulated pulse having the greatest observed base distortion. This provides the maximum amplitude and group delay error figures for the system. However, the measurements can be repeated for each modulated pulse to obtain amplitude and group delay figures for each modulated frequency.

The typical measurement approach uses an oscilloscope or TV waveform monitor for observing the multipulse waveform. The display is usually expanded on one pulse at a time for greater measurement resolution. The actual items measured are the peak amplitudes, Y1 and Y2, of the pulse base distortion (see Figure 5). The nomograph in Figure 10 can then be used to obtain amplitude and group delay error values from the Y1 and Y2 measurements.

In using the nomograph of Figure 10, the following things must be kept in mind —

- 1.) Measurement of the lobe amplitudes (Y1 and Y2) must be carried out with the pulse height normalized to 100 IRE.
- 2.) The nomograph is directly valid for 12.5T pulses, which comprise all pulses in the multipulse signal except for the 25T pulse used to modulate the 1.0 MHz frequency.

- 3.) For 25T pulses, amplitude error can still be read directly from the nomograph; however, group delay error values taken from the nomograph must be doubled.

When a nomograph is not available, delay error can also be estimated from the 100 IRE normalized pulse measurements using $\text{Delay} = 20(Y1 \cdot Y2)^{1/2}$ nanoseconds. This approximation is quite good for small amounts of delay, but becomes less reliable as delay increases.

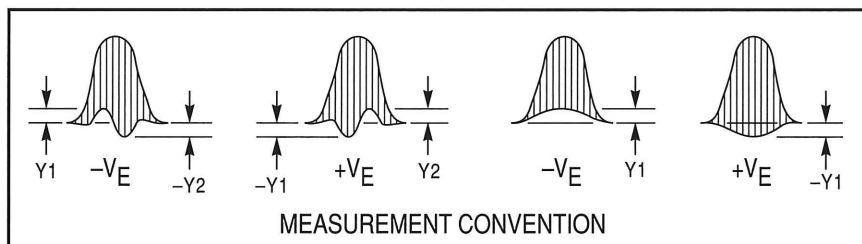
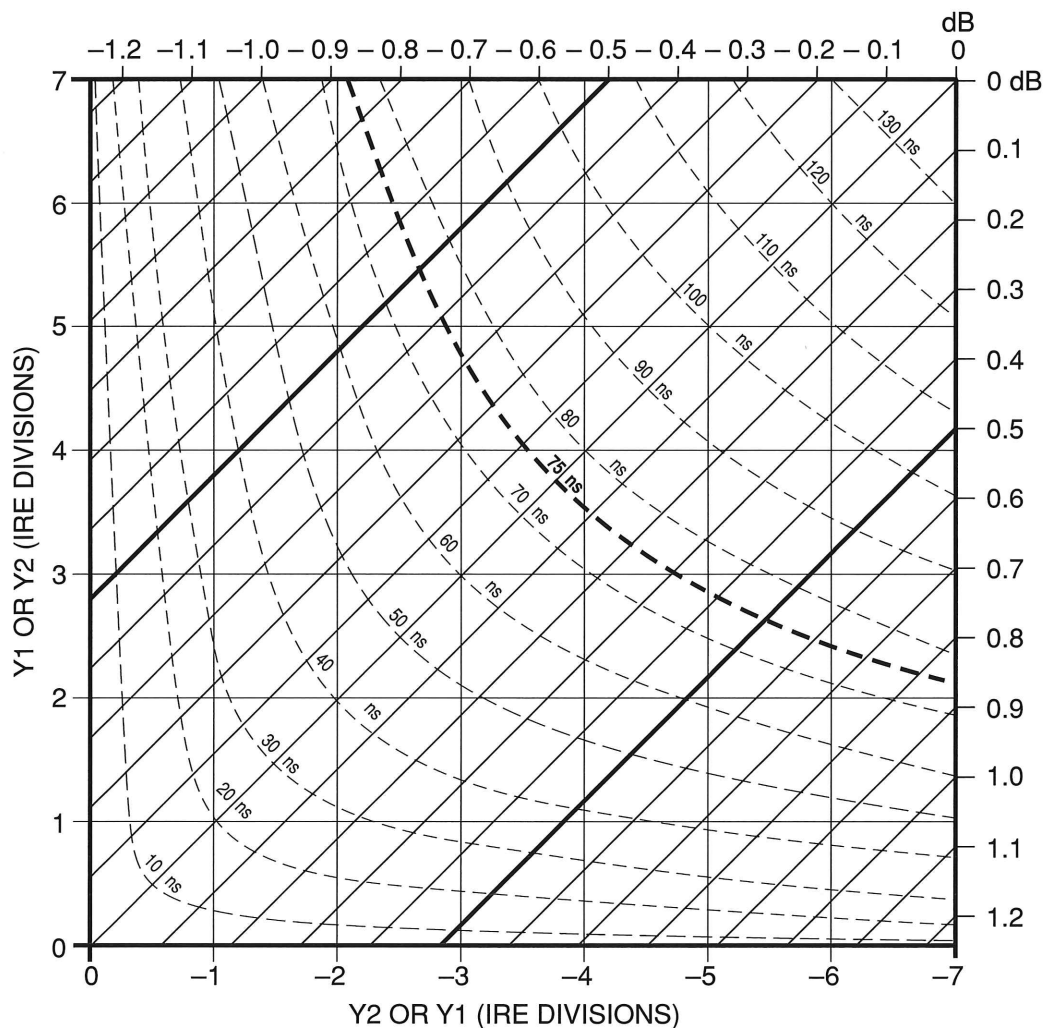


Figure 10. Nomograph for determining amplitude and group delay errors from measured values of Y1 and Y2. Measurements must be made with the pulse peak normalized to 100 IRE. For 25T pulses, double the delay value obtained from this nomograph.

Amplitude error can also be measured directly without using the nomograph. The measurement is made in terms of the pulse height relative to the 100 IRE bar height. This provides amplitude error in terms of IRE. Percent error would be twice the IRE error since amplitude error affects both the top and bottom of the modulation. Percent amplitude error divided by 100% can easily be converted to error in dB. (For example, assume a 7% error: $7\% \div 100\% = 0.07$, $20_{\log}(0.07) = -23 \text{ dB}$.)

When delay errors are small, the above method of determining amplitude error from pulse height should correspond closely to values obtained using the nomograph. When group delay exceeds 200 ns, measurement of pulse height may no longer provide a valid means of estimating amplitude error.

It should also be noted that group delay can be more accurately determined when amplitude error is low. This can be taken advantage of by making measurements while using a variable amplitude equalizer to cancel amplitude error. With the amplitude error cancelled, group delay error can be measured with optimum sensitivity. In fact, the group delay error value can be estimated directly from a simple graticule.

Amplitude error cancellation is a well-known technique used in measurements with the multipulse signal. Naturally, the effectiveness of the technique does rely on using an amplitude equalizer that makes no phase distortion contributions of its own.

Cursors and Measurement Automation

Oscilloscopes or waveform monitors that have built-in measurement cursors are a great convenience in making amplitude and group delay error measurements. The modulated pulse is displayed on the screen in the usual manner. Then the measurement cursors are placed on the peaks of interest and the values read from the cursor readout. With cursors, there's no more squinting at displays and trying to interpolate values between graticule lines.

Of course you still have to apply the cursor readings to the nomograph in Figure 10 and interpolate final results. But even the nomograph can be eliminated when a video measurement set such as the Tektronix 1780R Series is used.

The 1780R series has a built-in CHROMA/LUMA routine that guides cursor placement and automatically computes amplitude and group delay errors. Simply push the MEASURE button and select CHROMA/LUMA from the screen menu. Then adjust the 1780 Series display to show the modulated pulse to be measured. A set of cursors and instructions for placing them are automatically displayed on the screen.

Just follow the step-by-step cursor placement instructions on the 1780R screen. The 1780R keeps track of the measurements. Then, when all of the necessary data is obtained, it automatically extracts the corresponding

amplitude and group delay results from its internally stored nomograph data. These results are automatically displayed in the manner shown by Figure 11.

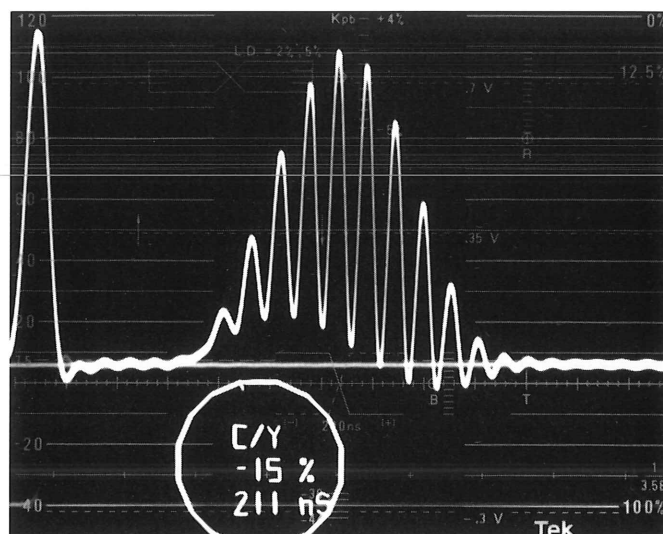


Figure 11. Amplitude and group delay error results obtained with the CHROMA/LUMA selection in the 1780R Series MEASURE mode. The 1780R displays on-screen messages to guide cursor placement and automatically extracts results from its stored nomograph data.

An even higher level of automation can be obtained by using the ChromLum GainDelay menu selection provided by the Tektronix VM700A Series of Video Measurement Sets. A Special Position submenu allows selection of the specific pulse for analysis from the multipulse display. The selected pulse is then automatically analyzed by the VM700A. The results are displayed graphically as shown in Figure 12.

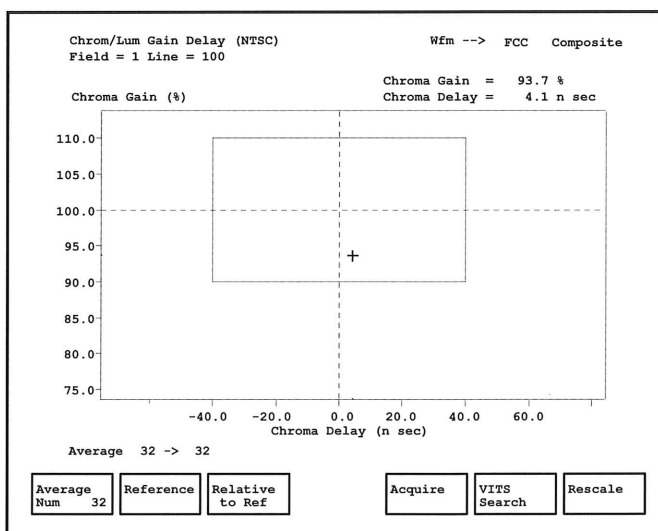


Figure 12. Display of VM700A Series chrominance-to-luminance gain and group delay results. The results are obtained automatically by digital signal processing (DSP) methods.

The VM 700A Series results shown in Figure 12 are obtained by automatic digital signal processing (DSP) techniques. Basically, the processing method involves separating the pulse into two parts — the \sin^2 pulse used for modulation and the \sin^2 modulated sinusoid prior to addition of the \sin^2 pulse. These are the two modulated pulse components discussed in Figures 3 and 4. The VM 700A then digitally analyzes these two components to determine their relative amplitude differences (amplitude error) and time shifts (advance or delay).

The VM 700A can also compute amplitude and group delay versus frequency using frequency-domain methods. This has the advantage of providing amplitude and delay data across the entire video bandwidth rather than at just the individual frequencies of the modulated pulses. However, the frequency-domain method does require use of a $(\sin x)/x$ test signal.

When a $(\sin x)/x$ test signal is not available, a multipulse signal and the ChromLum GainDelay approach provides a perfectly valid and comprehensive alternative. Also, the Function Key feature of VM 700A can be used to create a single-key procedure for automatically positioning on each pulse and measuring that pulse's amplitude and group delay error.

All of this serves to re-emphasize the flexibility of the multipulse signal for measuring amplitude and group delay errors. The construction of the signal is such that amplitude and delay errors are manifested in several manners. This allows various measurement methods to be applied, depending on the instrumentation available.

The errors can be observed on a simple waveform monitor screen as base line distortions. The distortion amplitudes can then be measured from the screen and converted to final results via a simple nomograph. Or, as just described, the multipulse signal can be automatically analyzed with DSP techniques. All of the information is available in the multipulse signal. It's just a matter of how you want to extract it.

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