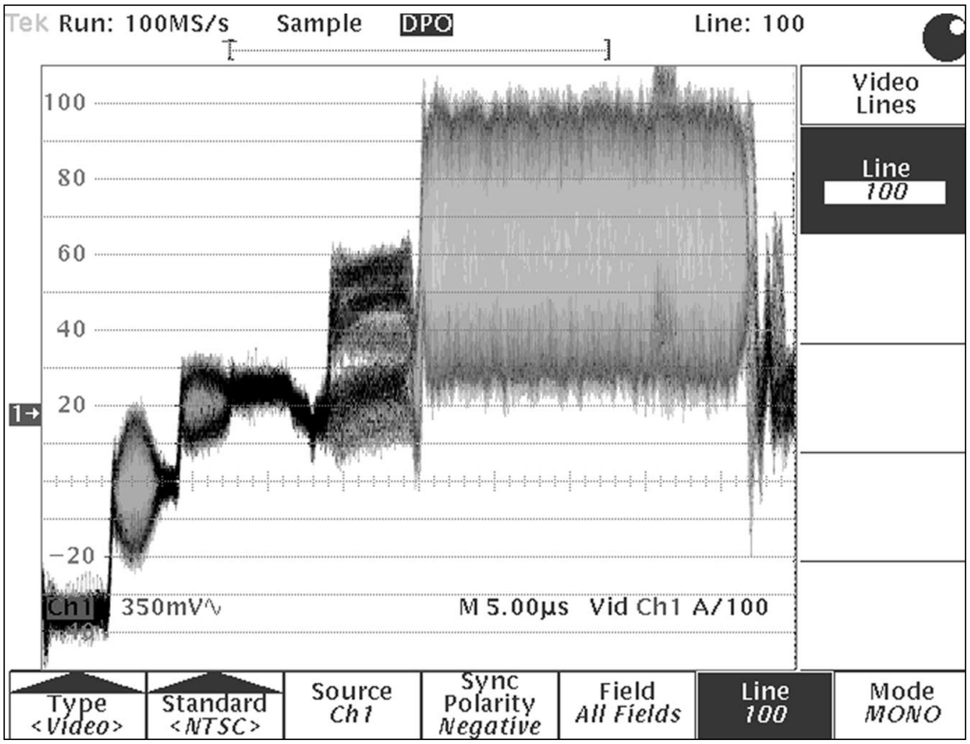
Tektronix

Application Note

Baseband Video Testing With Digital Phosphor Oscilloscopes



Video signals are complex waveforms comprised of signals representing a picture as well as the timing information needed to display the picture. To capture and measure these complex signals, you need powerful instruments tailored for this application. But, because of the variety of video standards, you also need a general-purpose instrument that can provide accurate information – quickly and easily. Finally, to display all of the video waveform details, a fast acquisition technology teamed with an intensity-graded display give the confidence and insight needed to detect and diagnose problems with the signal.

This application note demonstrates the use of a Tektronix TDS 700D-series Digital Phosphor Oscilloscope to make a variety of common baseband video measurements and examines some of the critical measurement issues.

Video Basics

Video signals come from a number of sources, including cameras, scanners, and graphics terminals. Typically, the baseband video signal begins as three component analog or digital signals representing the three primary color elements – the Red, Green, and Blue (RGB) component signals. Baseband video signals are the signals that are not modulated on an RF carrier, such as in analog terrestrial or cable transmission systems.

Figure 1 shows a typical video system block diagram. Notice that in the video signal path shown, the signal changes formats between source and destination. To design and debug such systems, test equipment must be able to examine signals in a variety of formats.

Conversion

The next step, conversion, is where the real differences in video standards begin. The RGB signal is converted into three component signals:

- Luminance signal, Y
- Two color-difference signals, often B-Y and R-Y

The color difference signals may be modified, depending on the standard or format used. For example, I and Q for NTSC systems, U and V for PAL systems, PB and PR for SMPTE systems, etc. The three derived component signals can then be distributed for processing.

Processing

In the processing stage, video component signals may be combined to form a single composite video signal (as in NTSC or PAL systems), divided into separate luminance and chrominance signals (as in Y/C systems: S-VHS or Hi-8), or maintained separately as discrete component signals (as in RGB graphics and HDTV systems).

Composite Video Signals. For analog broadcast and cable TV applications, the most common signals are composite signals which contain more than one signal component. In North America and Japan, for example, the NTSC defines the way that luminance (black and white information), chrominance (color information), and synchronization (timing information) are encoded into the composite video signal. In Europe, the PAL standards provide the same function. In the case of the NTSC and PAL standards, the chrominance signals are modulated on a pair of color subcarriers. The modulated chrominance signal is then added to the luminance signal to form the active portion of the video signal. Finally, the synchronization information is added. Although complex, this composite signal is a single signal that can be carried on a single coaxial cable.

Component Video Signals. Component signals have an advantage of simplicity in generation, recording, and processing where many combinations of switching, mixing, special effects, color correction, noise reduction, and other functions may be applied to the signals. Since there is no encoding/decoding process as in composite video, signal integrity is more easily maintained in component video systems and equipment, resulting in a higher quality image. However, the signals are carried on separate cables. In practice, this limits the distances over which the signals can be transmitted and requires careful matching of signal paths.

Y/C Video Signals. A compromise solution, implemented in systems such as S-VHS and Betacam, modulates the chrominance signals on a pair of color subcarriers, but keeps the chrominance signal separate from the luminance signal. This minimizes the luminance/chrominance artifacts of composite systems while simplifying the inter-channel timing issues of component systems. This pair of signals can be carried on a single special cable.

Display

After transmission, the objective is to faithfully reproduce the processed image. In composite systems, the signal is decoded to component form and then translated to RGB format for display on the monitor. Component video signals go through less processing, being converted directly to an RGB signal for display.

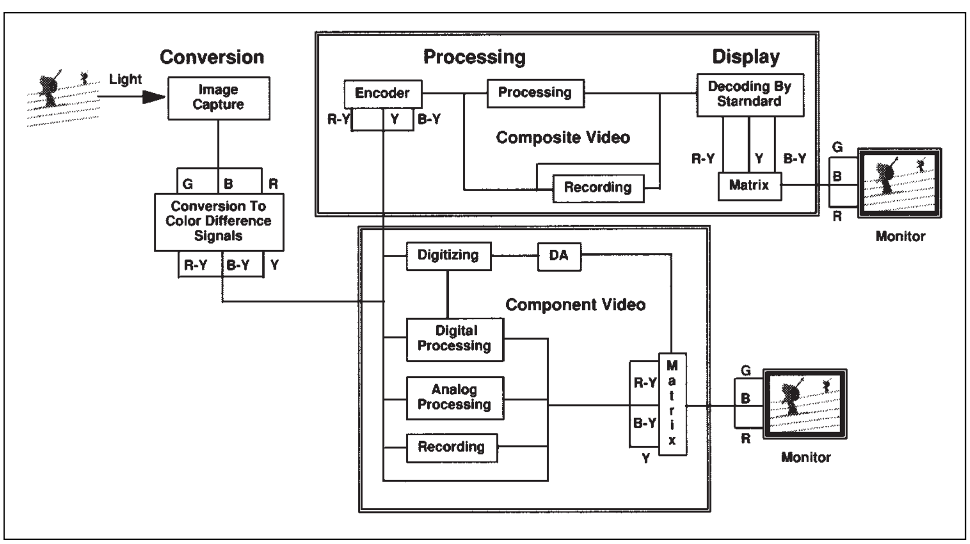


Figure 1. Typical video system block diagram.

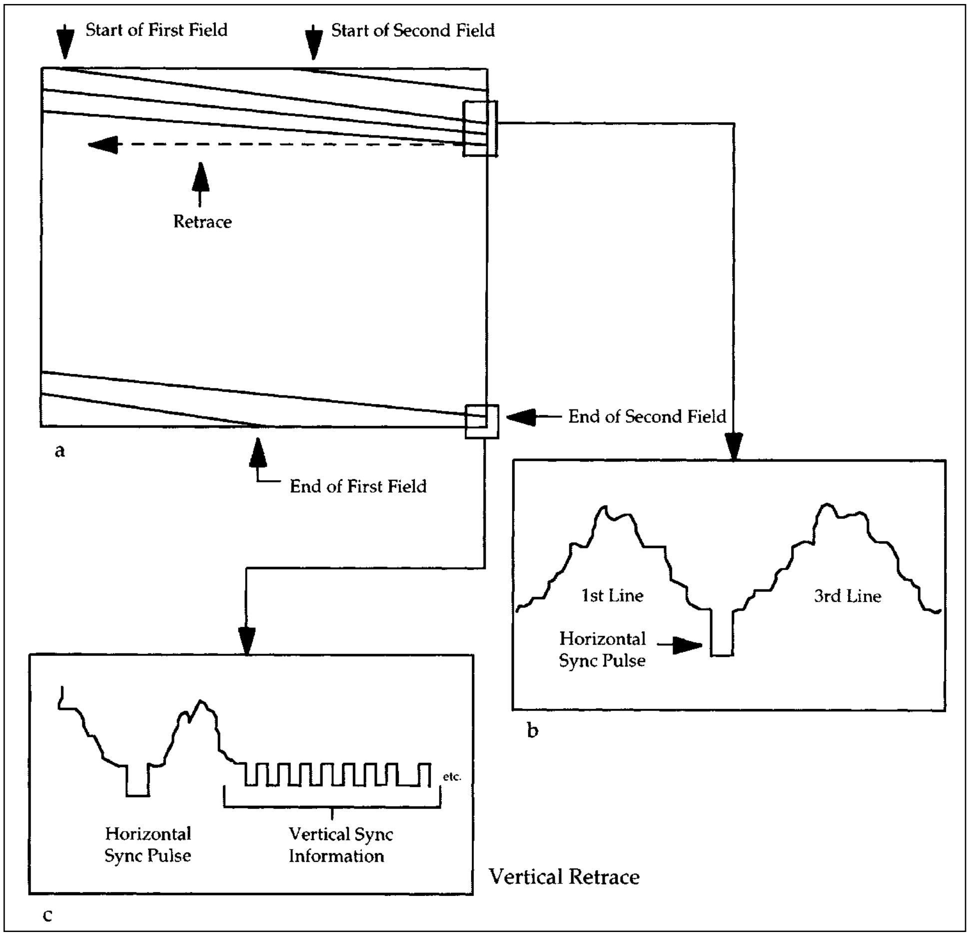


Figure 2. The synchronization signals in an analog composite baseband video signal provide the timing signals necessary to reproduce a video signal on a display.

Analog Video Synchronization Signals

Let's take a closer look at an actual analog baseband video signal. To reproduce an image, both the camera and the video display are scanned horizontally and vertically (see Figure 2a). The horizontal lines on the screen might be scanned alternately – odd numbered lines first, then even numbered lines – as in "interlaced" scanning systems, or they might be scanned sequentially, one after another, as in "progressive" scanning systems. Each vertical scan is called a field. Two interlaced fields make up a frame.

Both the camera and receiver must be synchronized to scan the same part of the image at the same time. This synchronization is handled by the horizontal sync pulse, which starts a horizontal trace. During the horizontal blanking interval, the beam returns to the left side of the screen and waits for the horizontal sync pulse before tracing another line. This is called "horizontal retrace" (see Figure 2b).

When the beam reaches the bottom of the screen, it must return to the top to begin the next field. This is called the "vertical retrace" and is signaled by the vertical sync pulse (see Figure 2c). The vertical retrace takes much longer than the horizontal retrace, so a longer synchronizing interval – the "vertical blanking interval" – is employed. No information is written on the video screen during the horizontal or vertical blanking intervals.

Each video standard defines a series of synchronization signals that control how the video signal is displayed. PAL signals display a video frame 25 times a second, where a frame contains 625 video lines. NTSC signals display a video frame 30 times a second, but with only 525 lines. Some high-resolution computer monitors display more than 1000 lines with a frame rate of 72 times a second.

Note that component signals need timing signals too. The synchronization is often combined with one of the components (such as the green channel).

Serial Digital Interface

For digital video applications, the SMPTE and ITU specify the way that the video signal is represented and formed into a serial data stream. For example, the most common serial composite signal is an NTSC signal that is sampled at 14.3 MS/s with 8 to 10 bits of resolution. The resulting bit stream (143 Mb/s) is encoded with Non-Return-to-Zero-Inverted, or NRZI coding and scrambled so it can be sent over 75 Ω coaxial cable. For studios, the most common standard samples component signals (Y, PR, and PB) at 13.5 MS/s with 8 to 10 bits of resolution. This bit stream (270 Mb/s) is also encoded and scrambled and can be sent over 75 Ω coaxial cable.

Test Requirements

Before discussing measurements on video signals, let's review the requirements for the test setup. These requirements include the required oscilloscope specifications and capabilities, signal conditioning, and triggering.

Oscilloscope Requirements

Most oscilloscopes are described by a few basic specifications. The first is usually ***bandwidth***. A good rule of thumb is to use an oscilloscope with an analog bandwidth at least five times the bandwidth of the signal to assure accurate representation of the signal. (A way to estimate the bandwidth of your signal is to divide the number 0.35 by the 10 to 90% risetime of the fastest signal component.)

The ***sample rate*** dictates how fast the signal is sampled. In theory, the sample rate must be at least twice the bandwidth of the signal. In practice, the sample rate on each scope channel should be 4 to 5 times the bandwidth of the signal for accurately capturing signals in a single acquisition and displaying them with sin(x)/x interpolation.

Often you will want to acquire signals repetitively to monitor changes over time. Unfortunately, traditional digital storage oscilloscopes actually capture signals at a much lower repetition rate than analog oscilloscopes. To be sure you have a lively display of the signal, you will want to look at the oscilloscope's waveform capture rate which specifies the rate at which signals are acquired (in waveforms/second). For example, if you're looking at all lines of NTSC or PAL signals, you expect to see more than 15,000 waveforms a second.

The ***record length*** of a digital oscilloscope indicates how many sample points the oscilloscope acquires in a waveform record. The result is a trade-off between detail and record length, or between sample rate and time duration acquired. You can acquire either a detailed picture of a signal for a short period of time (the oscilloscope "fills up" on waveform points quickly) or a less detailed picture for a longer period of time.

Acquisition and Display Modes

The most critical display issue for many video engineers is the ***intensity-graded display***. This display, a familiar characteristic of analog scopes and waveform monitors, shows the signal's statistical behavior by varying the intensities of the displayed samples. (The result is that frequently occurring signals are bright, and relatively infrequent details are proportionately dim.) The TDS 700D-series Digital Phosphor Oscilloscopes provide this intensity-graded display, providing you insight through qualitative intensity information and enabling your eyes to assimilate the subtle details and variations of the signal. Since many digital storage oscilloscopes are not capable of acquiring enough data to accurately represent the video signal, special acquisition and display modes are made available in DSOs to compensate.

The basic acquisition mode of a digitizing oscilloscope is the ***Sample*** mode, where the waveform is sampled in time and the amplitude of each sample is digitized and displayed. With the use of interpolation, these samples can be connected to create a continuous waveform display. However, a scope can also digitally process the signal before it is displayed, enabling complex measurements to be made easily.

For example, you can use the scope's ***Average*** mode to remove the effects of random noise to enable you to make precise amplitude measurements. The averaging function, found in the ACQUIRE MENU, smoothes the waveform by averaging multiple waveforms together.

HiRes mode filters the samples taken during an acquisition to create a higher-resolution, lower-bandwidth signal.

On the other hand, you may want to see and measure a relatively small noise riding on a relatively large video signal. For such problems, the TDS ***Zoom Preview*** mode allows detailed signal examination and waveform expansion. You can expand and position the waveform in both the horizontal and vertical direction for precise comparison of fine waveform detail without affecting on-going acquisitions.

Other acquisition functions can make it easy to see noise anywhere in the video waveform. The ***Peak Detect*** mode captures and displays the minimum and maximum values of a waveform, which shows its worst-case amplitude excursions. Choosing the ***envelope*** mode causes the scope to accumulate and display the minimum and maximum values of a series of waveforms over time.

Measurement Features

If you're working with NTSC or PAL signals, the TDS video graticules help display the signal in a familiar format. Graticules for NTSC and PAL signals are available from the DISPLAY menu. When either of these software graticules are selected, the oscilloscope automatically scales the video signal to the graticule you've chosen, allowing you to quickly assess the captured signal.

Manual on-screen measurements can be easily made using the cursors. Controls for the cursors are found in the CURSOR menu. Horizontal cursors allow you to measure signal amplitudes, with the readouts available in units of volts or IRE (for NTSC signals). Vertical cursors allow measurement of signal timing, with readouts in seconds, Hertz, or video line numbers. Paired cursors allow you to simultaneously measure relative amplitude and timing parameters.

The processing power of the Digital Phosphor Oscilloscope can also be used to automatically measure a number of signal parameters. For example, measurements such as peak-to-peak amplitude, sync-pulse width, and inter-channel timing can be easily made. Automated measurements are selected and controlled through the MEASURE menu.

Signal Conditioning

Termination

Most video systems are designed to deliver a known amplitude signal into a specified impedance. Therefore at low frequencies, the measurement accuracy depends on the signal being terminated in a precise resistance, usually 75 Ω. At higher frequencies, the termination must match the impedance of the transmission line (usually coaxial cable). In this case, the termination impedance must have a precise resistance with negligible reactance (also known as maximizing the return loss and minimizing the voltage standing wave ratio). An example of such a terminator is the Tektronix AMT75, which is specified to 1 GHz. Improper termination can result in degraded frequency response.

Video Clamping

A common signal anomaly encountered in analog video measurements is the low-frequency hum produced by AC line voltage. This hum, when not removed from the video signal, causes the signal to drift up and down in the display and can cause the trigger point to vary. The TDS 700D video trigger option includes a video clamp that effectively removes AC hum, as well as any DC offset on the signal. If the signal has been AC-coupled, the clamp also removes low-frequency variations which result as the average picture level changes. The clamp pod attaches to the input BNC connector and serves as a pre-processor of the video signal. It provides "back-porch" clamping on all standard video signals. The video clamp also provides flat frequency response, allowing accurate video measurements.

The first step toward measuring video waveforms is getting a stable waveform. To enable you to capture and analyze the signal, you must first trigger the oscilloscope on the signal. There are a number of advanced trigger modes in the TDS oscilloscopes to make your job easier.

Analog Composite Video Triggering

The TDS video trigger is selected by pressing the TRIGGER button on the front panel and choosing "Video" from the on-screen trigger type menu. By default, this selection automatically sets the scope to trigger on 525-line, 60 Hz NTSC video signals. It also directs the instrument to lock on the interlaced color field 1 using negative sync pulse polarity (see Figure 3).

Use the menus to alter these default settings. Using the "Standard" option, you can also direct the scope to trigger on PAL/SECAM, HDTV, and a variety of custom video signals. Or select "Sync Polarity" and change to positive sync if the portion of the circuit you are debugging has inverted the video signal. Select "Field" in the main menu and choose all, odd, even, or numeric video fields on the side menu.

Since much of the information of interest in a video signal is on specific video lines, you can choose which particular line to display. Select the "Line" option in the side menu and turn the general-purpose knob or use the keypad to specify the line of interest. The line number appears on the screen to help you keep track.

FlexFormat Triggering

There are a variety of high-definition video systems under development around the world. These include the 787.5/60, 1050/60, 1125/60, and 1250/50 formats. However, new formats are still being experimented with. Certain markets have created their own high-definition formats and established their own standards. For example, the medical imaging market and the military have developed HDTV standards to fit their immediate needs. This can add to the confusion when searching for video test and measurement instrumentation.

The TDS video trigger option provides a solution for customized HDTV triggering needs. With the FlexFormat™ triggering mode, you can specify the timing of customized tri-level sync pulses (see Figure 4), select any field rate between 20 and 200 Hz with up to two digit resolution, and define the number of lines and fields in your customized format.

Single-Pixel Triggering

With more of the video monitor market moving to flat-panel displays, design and debug applications need single pixel triggering and analysis capabilities. A TDS scope with the video trigger and the "Delay By Events" trigger allows you to define each pulse of the device-under-test's system clock as an event. Each event then corresponds to a pixel, and successive events equate to successive pixels.

First, connect the video signal of interest into Channel 1. Set up Channel 1, main trigger, to trigger on the video signal. Press the TRIGGER MENU button on the front panel and select VIDEO trigger. Select appropriate standard and parameters to trigger on the interesting section of the signal.

Connect the system reference clock to Channel 2. Set the delay trigger to use Channel 2 as its source by pressing the SHIFT and TRIGGER MENU

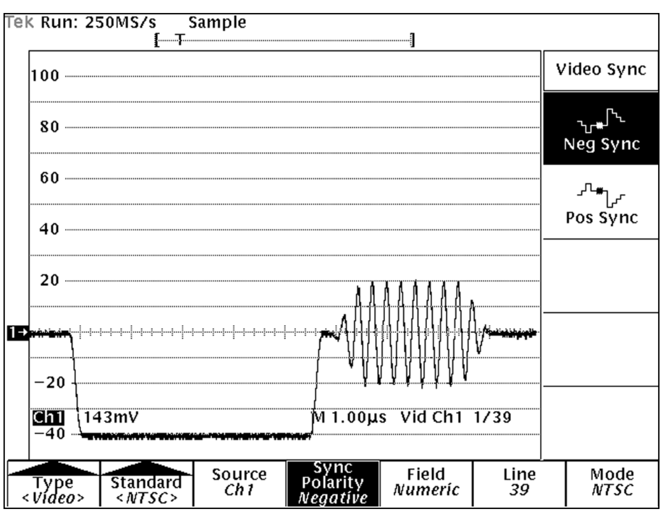


Figure 3. The TDS video trigger allows convenient selection of video standard, channel, sync polarity, and field and line.

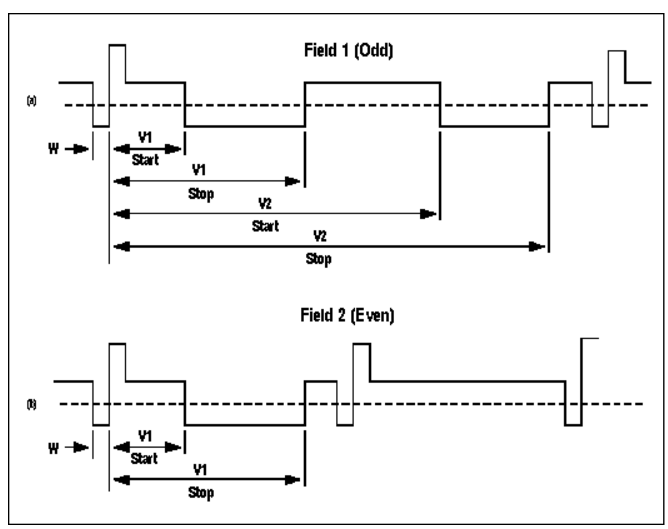


Figure 4. The FlexFormat triggering mode allows you to define the start and stop times of tri-level sync pulses for both odd and even fields.

buttons on the front panel and select Channel 2 as the source of the delay trigger. Now select Delay by Events.

Turn on the Delay Trigger by going to the Horizontal menu and selecting the Delayed Only time base.

Now, you can go back to the Delay Trigger menu and dial in the event you want to see, or enter the appropriate number on the keypad (see Figure 5).

Serial Digital (NRZ) Triggering

The most common way to characterize a serial digital signal is by examining an eye diagram. This display is a composite display of many waveform acquisitions, overlaid upon another, to form a consolidated image of the data pulses which resembles an eye. In general, the larger the opening of the center of the eye, the better the performance of the system under test. A wider vertical opening shows a greater noise tolerance, while a wider horizontal opening indicates more jitter tolerance. In other words, excessive amplitude noise or timing jitter will tend to close the eye.

The oscilloscope may trigger on the rising edge of the serial system clock and capture the data that coincides with the clock edge. This method requires that the clock and the data signals be correlated. Or, the oscilloscope may trigger on the data itself, wait for a few unit intervals, and then acquire enough waveforms to build a display. This can be done with a delayed timebase with delay by time or events.

An easier method is to use an eye diagram trigger. Select the COMM trigger type from the TDS 700D TRIGGER type menu and NRZ from the code menu. Then when you select the serial digital video standard from the list, the oscilloscope is automatically set up to display an eye diagram of the signal (see Figure 6).

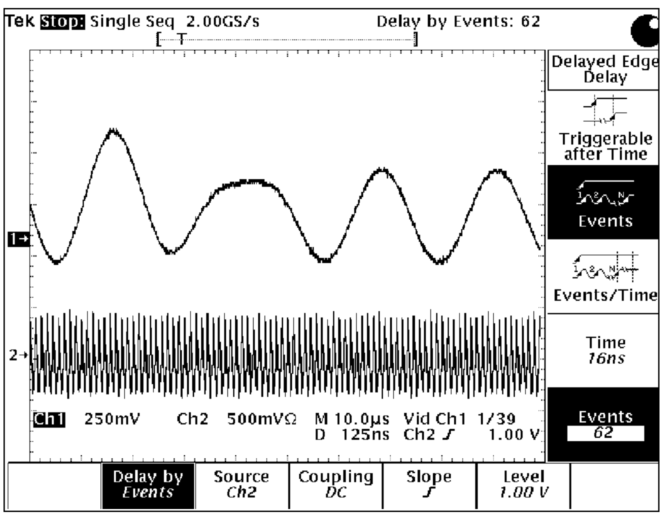


Figure 5. The system clock (bottom waveform) serves as the Delay Trigger for the video signal (top waveform). With Delayed by Events, each event corresponding to a pixel, you can observe the video signal at each pixel.

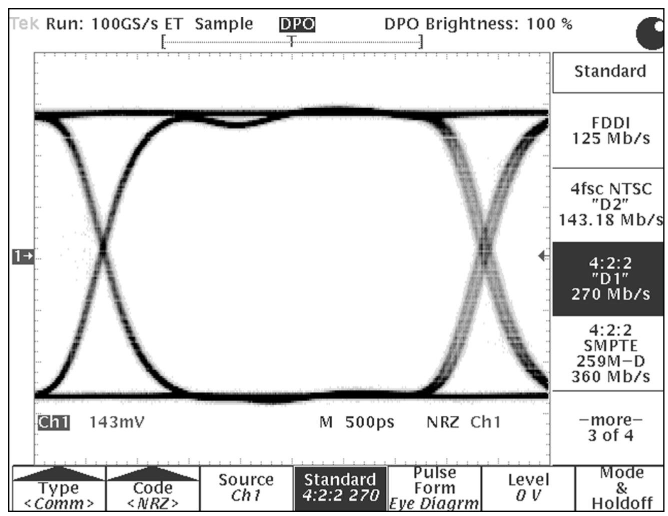


Figure 6. Setting up an eye diagram is easy using the NRZ communication signal trigger.

Video Signal Monitoring

Whether you are monitoring analog or digital video signals, an oscilloscope with an intensity-graded display which is tailored for video applications can be your most valuable debug tool. Subtle variations in the signal, which are not visible on a DSO display, can spell the difference between a video system that works and one that doesn't.

H-rate Intensity-graded Displays of Live Video

The most basic analog video display is the horizontal-rate display of the signal amplitude vs. time. This can be done most easily by edge-triggering on the leading edge of sync. As shown in Figure 7, a Digital Phosphor Oscilloscope with an intensity-graded display (and a waveform capture rate high enough to capture every line) provides the familiar waveform monitor H-rate display.

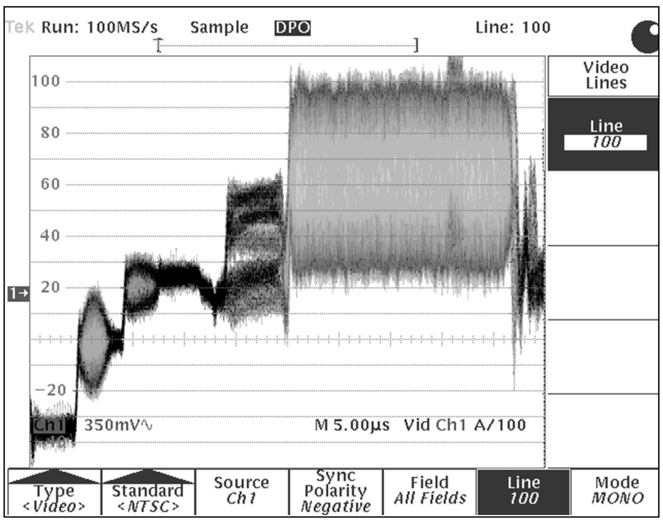


Figure 7. A horizontal-rate waveform monitor display, showing the effect of an intensity-graded display on the oscilloscope.

XY Displays of Chrominance

The Digital Phosphor Oscilloscope's XY display mode allows you to display one signal against another in a manner similar to a vectorscope. Press FORMAT selection in the DISPLAY menu and select the XY mode. If a B-Y signal is connected to Channel 1 and an R-Y signal is connected to Channel 2, the scope will imitate a familiar vectorscope display. Also, the intensity-graded display shows details in the signal which are not visible on ordinary DSOs.

Intensity-graded Displays of Digital Video Eye Diagrams

Intensity-grading is also important for monitoring eye diagram displays, where you want to qualitatively examine the signal variations over time, whether the variations are due to noise or timing jitter. Intensity-graded displays, available with analog oscilloscopes and Digital Phosphor Oscilloscopes, combined with a high waveform capture rate, give you the best method of capturing and identifying infrequent anomalies.

Analog Signal Measurements

Amplitude Measurements

Amplitude measurements can be made a number of ways with an oscilloscope. For example, to measure the peak-to-peak amplitude of the NTSC burst signal, you can simply compare the signal to the TDS 700D's IRE video graticule (see Figure 8.) You can also use the TDS 700D's video cursors to make the same measurement. Finally, if you want to analyze variations over time, the scope can make a number of measurements automatically, and accumulate the measurement statistics.

Timing Measurements

Timing measurements are especially critical for component analog systems because they require precise inter-channel timing. The most important use of a multi-channel oscilloscope can be to display the relative timing differences between channels.

Before you can accurately display the multiple channels, you need to match the probe path delays. This can be done with the deskew feature, found in the TDS 700D's VERTICAL menu. Connect both probes to a common signal and adjust the channel deskew with the general-purpose knob until the traces line up on the display.

Now, connect the signals of interest to the scope channels and adjust the channel timing controls to match the signals (see Figure 9).

The oscilloscope can also make timing measurements automatically and accumulate statistics on those measurements. For example, to measure sync width, trigger on the leading edge of sync, turn on HiRes acquisition mode, and adjust the horizontal and vertical controls so the sync pulse fills most of the display. This optimizes the accuracy of the measurement system. Now turn on the negative pulse width measurement in the MEASURE menu. To monitor the mean (μ) and standard deviation (σ) of the pulse width measurement, enable the measurement statistics (see Figure 10).

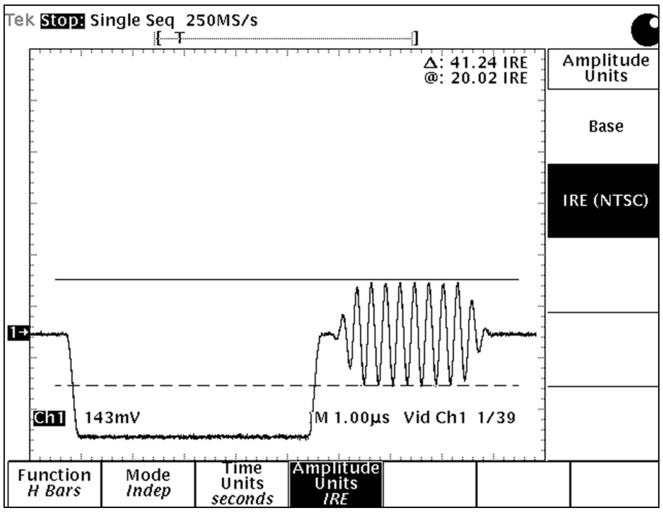


Figure 8. An example of amplitude measurements on an NTSC signal. The peak-to-peak amplitude of the burst packet can either be measured visually with the graticule, or with the video cursors (note cursor readout in upper right corner).

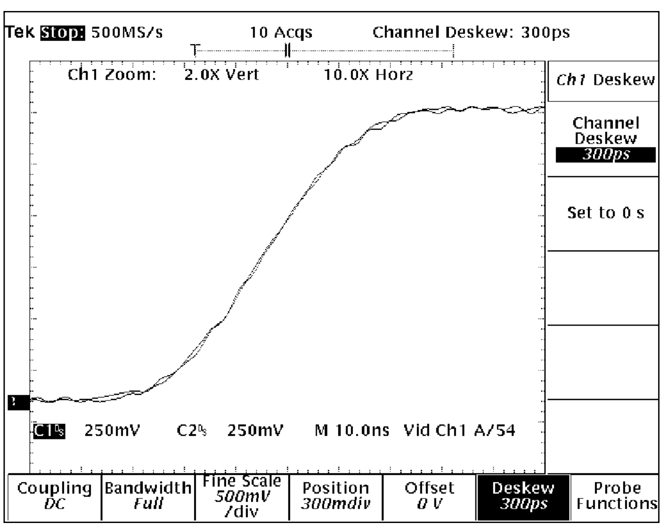


Figure 9. Inter-channel timing is of critical importance in component analog video systems. The display shows the relative timing of the luminance and one of the color-difference signals (after the cable delays were equalized with the channel deskew controls).

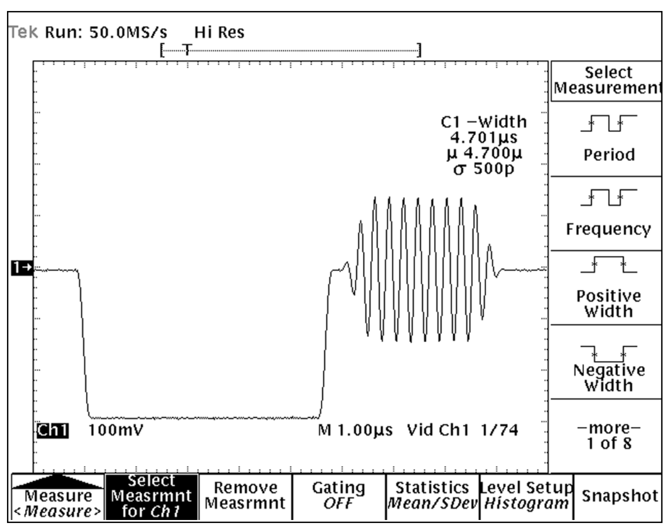


Figure 10. Automatic timing measurements provide an easy and accurate method of repetitively measuring basic signal parameters.

Jitter Measurements

Timing jitter on a signal can affect a receiver's ability to decode a video data stream. The effects are readily seen on an eye diagram because jitter shrinks the opening of the eye. As the jitter increases, the data transition points move closer and closer to the decision point of the receiver, eventually increasing the bit-error rate of the system.

Jitter comes in two types: deterministic and random. Deterministic, or data-dependent, jitter is caused by the pattern of data bits preceding the current bit in the data stream. By triggering on repetitive data patterns and measuring the variation in edge placement, you can characterize deterministic jitter components. Such an analysis can be time-consuming but useful for detecting problems early in the design process.

Random jitter, on the other hand, is due to random noise in a system and is not correlated to the data. It can be characterized and measured by statistically analyzing the waveform, using the Digital Phosphor Oscilloscope's histogram capability. Display and draw a histogram box around the rising edge, falling edge, or eye crossing where the jitter is to be measured, and then have the oscilloscope draw a histogram of the delay of the edge from the trigger point. If the histogram of the placement of the signal edge is a normally distributed curve, the standard deviation is equal to the RMS jitter of the waveform. You can also turn on the observed RMS jitter (standard deviation) or other histogram measurements to further characterize the jitter (see Figure 11).

Mask Testing

As discussed before, an eye diagram reveals a lot about a serial digital signal, especially about the relative margin available for noise and jitter. It represents the most important time-domain signal characteristics in one display: rise time and fall time, pulse overshoot and undershoot, ringing, duty cycle, jitter, and noise.

To determine if a serial digital video signal complies with the standard, all relevant parameters must be examined to see whether they are within specifications. Measuring the parameters individually would be a tedious business and could easily result in errors. To simplify the verification task, the video standards specify the shape of compliant signals by defining a mask. You simply overlay the mask on the eye diagram and can immediately see if the signal complies by fitting into the allotted areas of the mask (see Figure 12).

Advanced communication oscilloscopes have built-in standard masks, which you can select from a menu. These oscilloscopes also provide calibrated, variable time delay and voltage scales, can automatically adjust the signal to fit the mask, and can even count the number of waveforms acquired and the number of mask violations, or "hits," for faster and more accurate testing.

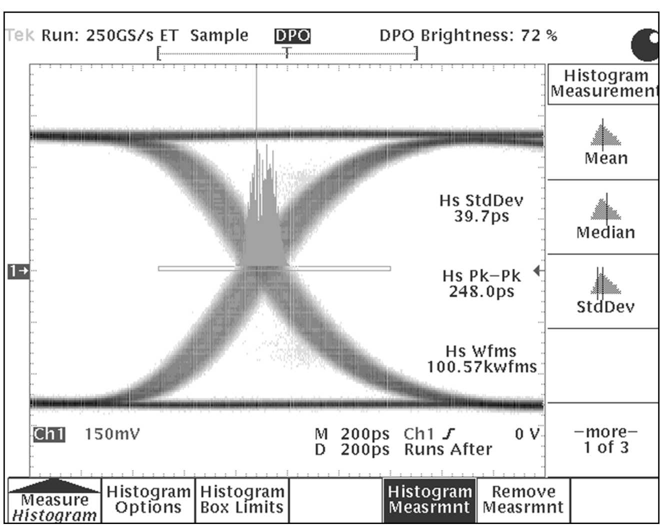


Figure 11. Characterize random jitter on a digital video signal with a histogram. Notice the bi-modal nature of the histogram. Also, measurements on the histogram are shown at the right of the screen, indicating such characteristics as the observed peak-to-peak jitter.

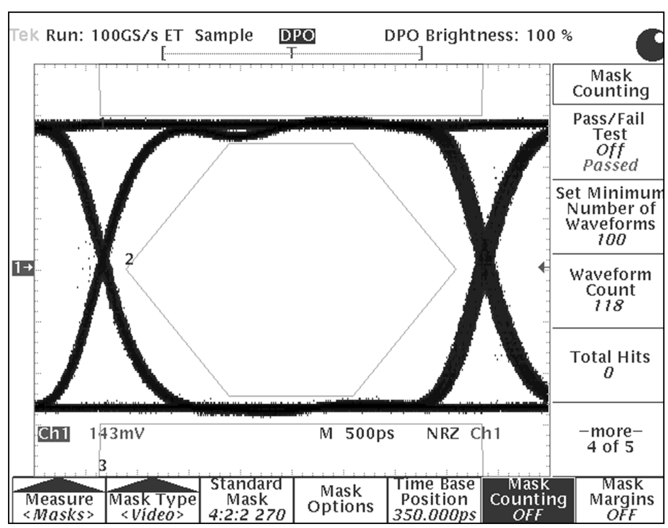


Figure 12. Mask testing provides a convenient and reliable method for verifying the compliance of serial video signals to industry standards. In this example, a minimum of 100 waveforms was compared to the mask, with no errors (0 "hits").

Conclusion

In this application note, we've demonstrated the use of a Tektronix TDS 700D-series Digital Phosphor Oscilloscope to quickly and easily make a variety of common baseband video measurements on a variety of complex video signals. With the power of the intensity-graded display, high waveform capture rate, and abundance of waveform data, this general-purpose instrument is the tool of choice to debug, characterize, and verify your video circuits and systems.

For further information, contact Tektronix:

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