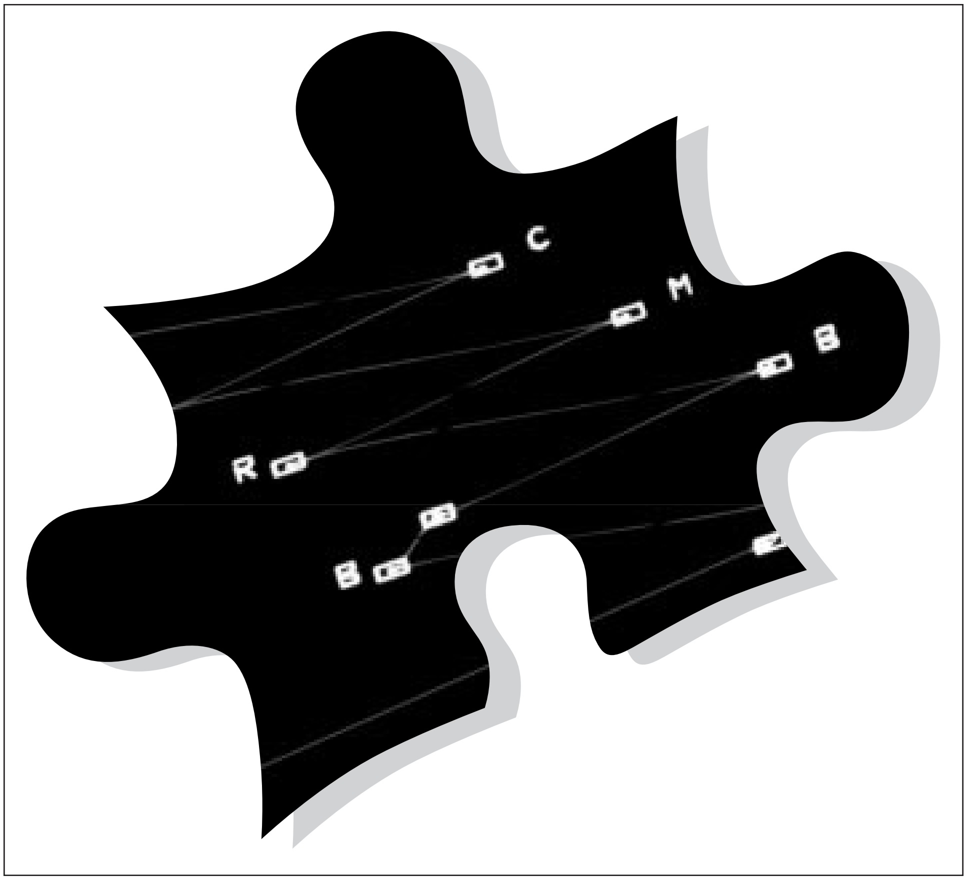
Solving the Component Puzzle



Contents

Preface

Understanding the nature of component video will go a long way toward making you more comfortable and effective in maintaining picture quality in today's complex, often multi-standard, television environment and its multigenerational processes. This booklet will help you become more familiar with the terminology and technical issues of **C**omponent **A**nalog **V**ideo (CAV), especially the test, measurement, and monitoring techniques of these video signals.

You will find information about what the different forms of component video signals should look like and, when the signals are distorted, how to make correct front panel adjustments on component equipment. Engineering and maintenance issues, like comprehensive hardware evaluation or internal calibration adjustments, are beyond the scope of this booklet.

Section I provides generic background information about CAV and compares component video to composite (NTSC or PAL). This material is intended to help you understand the more detailed descriptions of signal distortions and monitoring techniques that are presented in the following sections.

Section II explains practices and techniques required for quality control of a component analog video system. Measuring, monitoring, and viewing methods are outlined using specific Tektronix equipment.

Appendix A describes the various interconnect formats and signal standards currently in use for component video.

Appendix B is a glossary of useful terms.

Red, Green, and Blue Components. Components in some form are a necessary part of any color television system. Color cameras usually analyze the light in the image to develop video signals for three primary colors: Red, Green, and Blue. Since each of these RGB signals carries part of the information in the image, and all are required to recreate a complete image, they are referred to as "components" of the color video. As in the more generic use of the term, each component is a necessary, but not sufficient, part of the whole.

The basic RGB component signals are used again at the output of a television system to display the image on a monitor or TV set. In general, therefore, it makes sense to say that one of the primary tasks of a television plant is to convey these component signals through all the distribution, technical, and artistic processes and deliver them to a display for viewing.

Although some equipment, especially in the past, has distributed RGB signals beyond the camera (or camera control unit), video has almost always been translated or encoded into other formats for recording, interconnection, or long distance transmission, then decoded for display. (See Figure 1.)

Note: In this booklet, "encoding" refers to converting a signal from a component to a composite form, such as from RGB to NTSC or PAL; "decoding" refers to recovering the component signals from a composite signal; and "translating" refers to converting a signal from one CAV standard to another, such as from RGB to (Y, R-Y, B-Y) or (Y, I, Q). (In Europe, "translating" has also been used to describe changing from one color-encoding standard to another without changing the scan standards, such as from 625/50 PAL to 625/50 SECAM.)

Refer to Appendix B for definitions of other useful terms.

Color Difference Components. Starting with the RGB components, the first step of the usual encoding process is to generate a luminance (Y) signal using a weighted sum of R, G, and B. This luminance signal is very much like a monochrome video signal. It carries the information about how much light is in each point of the image.

Further processing, which combines the original R and B components with the new Y signal, yields a set of "color difference" signals (usually R-Y and B-Y). These signals carry information about which color and how much color is in each point. The luminance signal and the two color difference signals contain all the information needed to display any of the broad range of colors possible in the original image. The basic set of three components (R, G, and B) is thus translated to a new set of three components (Y, R-Y, B-Y).

The color difference component form has two advantages over RGB. First, substantially less bandwidth is required to convey the same information: a color difference system needs only one high bandwidth channel because all the fine detail in the image is carried by the luminance signal.[1] An RGB system, on the other hand, requires high bandwidth in all three channels.

Second, gain distortions have less severe effects on a color difference component set than on RGB: a low level on any one channel in a color difference set, for instance, will produce subtle changes in hue or changes in saturation only. A low level in RGB, however, will produce a distinctly wrong-colored image.

The concept of transcoding RGB to one luminance and two color difference signals has proven very useful. Such signals, with relatively minor variations, are the basis for all existing CAV formats and also for composite broadcast standards throughout the world.

What's Different About Component Technology? The composite standards (such as NTSC and PAL) encode the luminance and color difference components into a single signal for recording, interconnection, or transmission. Component technology, on the other hand, keeps the component signals separate through more (or all) of the TV production and distribution processes.

Component recorders use one track of the tape for the luminance signal and another track for the two chrominance (color difference) signals. Although both chrominance signals are recorded on the same track, they are kept separate through time compression and time domain multiplexing: they are time compressed to half their usual duration, then recorded alternately on the chrominance track. During playback, the two signals are "decompressed" to their original duration and resynchronized with the luminance signal.

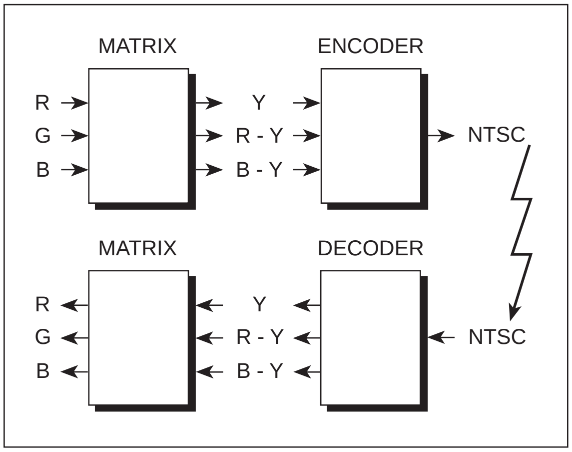


Figure 1. The RGB components from the camera are generally translated to a set of color difference components (such as Y, R-Y, B-Y) before being encoded to NTSC or PAL for transmission. In modern equipment all these operations may take place in the camera. The composite signal must be decoded in the receiver to a color difference format, then translated to RGB for display.

[1] Actually, since Y is derived from nonlinear (gamma corrected) signals, not all the luminance information is carried in Y. The text is correct for neutral color (grays), and the error is small for typical desaturated colors.

There are three ways of connecting a component recorder to other equipment. All three interconnect systems convey essentially the same information but in different forms:

- The one-wire interconnect consists of an encoded composite signal from a built-in encoder.
- The two-wire interconnect consists of one luminance and one compressed, multiplexed chrominance signal. This system allows efficient dubbing between recorders, since the demultiplexing and multiplexing operations don't have to be repeated.
- The three-wire interconnect consists of one luminance and two distinct color difference components. This system is commonly used for connecting equipment in a "component facility'' because it's more compatible with non-VTR video sources, time base correctors, displays, and monitoring equipment.

Why Keep the Components Separate? Keeping the components separate is likely to improve picture quality because encoding a color signal is not a very clean process. Encoding is done by modulating a pair of RF subcarriers with the color difference components, using suppressed carrier AM techniques. The sidebands generated in the modulation process are then combined with the luminance signal.

Although the scanning format and subcarrier frequencies are chosen to minimize problems, the system is not perfect. Whenever video is encoded, some information about the image is lost, and unavoidable artifacts of the modulation and combining processes are generated. These effects are often referred to as the "footprint'' left on the video signal by the encoding and decoding processes.

Encoded video itself is relatively prone to distortion. The chrominance information is carried high in the video frequency spectrum as sidebands above and below the subcarrier frequency (3.58 MHz in NTSC, 4.43 MHz in PAL). These high frequency signals often have high amplitudes as well. Such signals are difficult to handle without distortion in recording and distribution equipment.

Decoding a composite signal can also contribute undesirable artifacts. Chroma crawl, busy edges, loss of detail in colored areas, and cross-color "rainbows'' are encode/decode artifacts that are all too familiar.

These artifacts are especially troublesome when generating a chroma key signal from a composite source. The key signal will often have edge problems related to the "busyness'' of the decoded signal.

Transcoding from RGB to other component formats uses linear processes without the severe bandlimiting and modulation steps needed for encoding. The RGB video developed in the camera (or other source) therefore suffers little distortion in being translated to another component format. A key signal, for example, will be cleaner if it can be derived from component video that has never been encoded.

In fact, the fewer times a signal is encoded and decoded, the better its quality will be. Each pass through the process adds a little more to the footprint, and although the impairments can be improved by using comb filters and other complex techniques, they can never be completely eliminated. By reducing the required number of encode/decode steps, editing in component format generally leads to an improved image.

Do Components Present Unique Problems? Although component signals are quite robust, they are not "bulletproof.'' Two kinds of potential problems exist: those that are inherent to both composite and component systems and those that are peculiar to components.

The advantages of component technology are achieved by maintaining separate, parallel paths for the component signals. Just as for composite video, these paths must be "clean'' in terms of familiar characteristics such as frequency response, transient response, noise, hum, etc. Monitoring the individual components for these attributes employs essentially the same techniques as are used for composite signals.

Most of the quality control issues that are unique to component video are related to differences, primarily in gain or timing, between the three signal paths. The components must be a matched set, and anything that changes the relationships between them will cause a distortion in the image they represent.

Editing and post production bring together signals that may have come from different sources and/or may have taken different paths through the system. This increases the chances for problems in both composite and component facilities, but the risk is greater for component systems in which multiple paths (usually three in parallel) are used for each signal.

How Critical is Timing? The relative timing of two three-wire component signals involves many of the same issues as the relative timing of two composite signals. But small internal timing errors affect signals in component form very differently from those in composite.

Internal timing problems in **composite** signals include differential phase distortion, burst phase error, and chrominance vs. luminance delay. These problems occur when certain parts of the signal are advanced or delayed relative to others. Even small errors of this type — especially timing errors between the reference burst and the chrominance subcarriers — may distort large areas of color in the image.

These large effects in composite signals become evident during decoding. Because the color difference signals are conveyed with suppressed carrier modulation, it's necessary to regenerate the (sub)carrier as part of the demodulation process. But since the color burst conveys the subcarrier phase information, any timing errors between the burst and the modulated chrominance signal will result in serious color distortions.

Internal timing problems in **component** signals result from differences in timing among the three components that form a video signal. (Such problems are sometimes referred to as “inter-channel’’ timing errors.) Small internal timing errors will cause slight horizontal displacements that produce distortions only around vertical lines or edges.

In a single-pass component system (like most ENG facilities) relative timing is usually not an issue. It takes fairly large timing errors — as much as 10 to 30 nanoseconds between channels — to produce noticeable edge artifacts in a component video image. Keep in mind, however, that timing errors can be cumulative if video is passed through the same channels many times in a complex process. In that case, even a few nanoseconds of error might be troublesome.

What About Amplitude? Component systems are prone to different kinds of amplitude errors from composite. In **composite** signals, the most likely amplitude imbalance results from frequency response problems. Since the color difference components have been shifted to frequencies high in the video band, their level may not match that of the lower frequency luminance signal. Such chrominance vs. luminance gain errors affect the saturation of colored areas, manifesting themselves as either too much or too little color.

Component signals risk another kind of amplitude error: Because the color difference components travel separate paths, they can be mismatched to each other as well as to the luminance component. Gain ratio errors between the chrominance components cause hue problems in the image. Mixed colors will be wrong. (The effect will look somewhat like small burst phase errors in a composite system.)

In some cases, errors in gain ratio between components will generate an “illegal’’ signal — one that exceeds its specified amplitude range. Even if a signal is within the amplitude limits in one format, it can exceed the limits when translated to a new format. An illegal signal may suffer permanent damage by being clipped or otherwise distorted in subsequent processing and is likely to cause other problems as well. (The concepts of “legal’’ and “valid’’ are discussed at greater length on page 24 and are defined in Appendix B.)

Although the basic monitoring and measuring techniques for component signals are not much different from those for composite signals, additional special methods have been devised that allow certain component measurements to be made with greater ease or accuracy. Both basic and special measurement techniques are discussed in this section, with emphasis on the special component techniques.

While the synchronizing and reference portions of the video signal have known characteristics that can be tested, the active (picture) portion of the waveform is quite arbitrary. We usually don't know precisely what image the video represents, so we can't detect distortions by just looking at the waveform itself. Rather we must replace the picture with a known test signal and deduce from it how well the system will handle actual video signals.

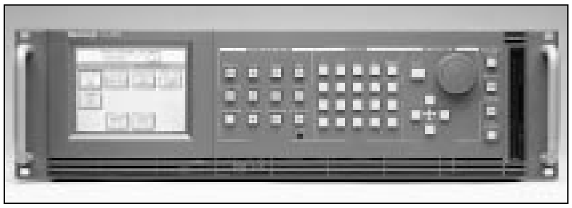


Figure 2a. The Tektronix TG2000 Signal Generation Platform is capable of producing signals in a variety of video formats, including component analog.

Figure 2b. The Tektronix 1760 series of component waveform/vector monitors have facilities for displaying both component and composite video signals.

Many test signals have been designed to enable easy and accurate component video measurements, and specialized test and monitoring instruments are available for evaluating these signals.

Caution: There are essentially three different standards for the CAV color difference format. Make sure you know the signal requirements for your specific equipment before you proceed with measurements. (Refer to Appendix A for descriptions of the various component interconnect formats and standards.)

Equipment Requirements

For testing component equipment and systems you need a component test signal generator and a component waveform monitor. All of the examples in this book were generated using Tektronix component generators, such as the TG2000 (Figure 2a) and component waveform monitors, such as the 1760 series (Figure 2b).

The TG2000 is a programmable signal generator, based on a modular platform architecture. This allows it to be configured for virtually any video format and standard, including analog component. The standard analog generator module (AVG1) comes complete with all of the component test signals described in this book.

The 1760 series is a family of combination waveform/vector monitors, with multiformat capability. They feature eight loop-through video inputs, allowing them to monitor two composite and two component analog signals. This is particularly useful, as most component video facilities must also handle composite signals as well.

Miscellaneous Guidelines

The examples in this section are organized by measurement type: amplitude, timing, or signal validity. If a particular test signal and waveform monitor display present information about more than one characteristic of the signal, they may be discussed in more than one context.

The thoroughness of video measurements can range from simple and perfunctory to complex and meticulous. When considering which equipment and measurement techniques are most appropriate, it's important to consider your objective:

Perhaps you just wish to know if the video is present, along with some very general information about its content or quality. You're only trying to find out whether the video is from a camera or from a test signal feed, whether sync is present, etc.

On the other hand, you may need enough information to quickly determine if your equipment is working well enough to do the job at hand. You want to know if the level is about right, if everything is terminated correctly, if the black level on the camera has been set, etc.

At times, however, you may need to go into much greater depth, using care and even calculations to accurately measure or adjust the characteristics of your equipment.

The examples in the remainder of this section cover a variety of techniques, at differing levels of complexity, for measuring and evaluating component signals. As you gain experience, you'll probably add others to your bag of tricks.

Monitor Calibration

Before making measurements with a waveform monitor, it's a good idea to check the monitor's amplitude calibration. Modern equipment isn't likely to drift, even over quite long periods, but the monitor may have been readjusted by someone else or it may not be set up as you expect.

Most component waveform monitors have a built-in calibrator signal. Setting the unit to its CAL mode applies either a 700 mV or 1.00 V calibrator square wave to the vertical axis. Either two horizontal lines (Figure 3a) or a square wave (Figure 3b) will be displayed on screen.

Using the waveform monitor's vertical position control, check that the calibrator signal matches the graticule markings. This will either be from the "0" graticule line to the ".7" graticule line (700 mV calibrator), or from the "-.3" to the ".7" graticule line (1.00 V calibrator). When the calibrator signal aligns with the graticule, the vertical axis is properly calibrated. Consult the waveform monitor manual if adjustments are necessary.

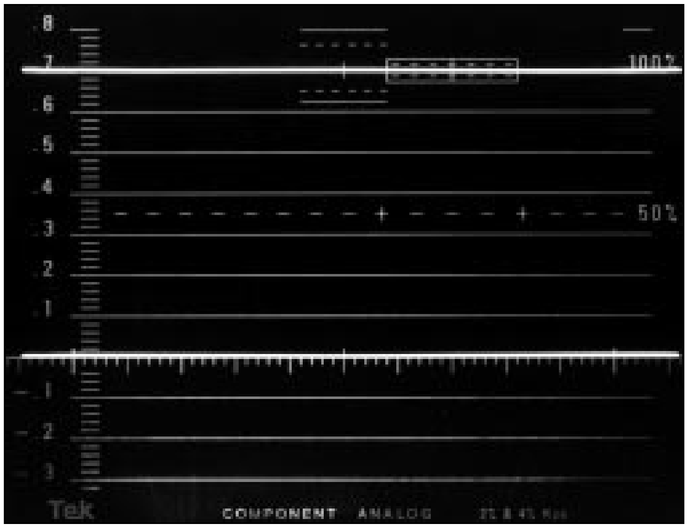


Figure 3a. A calibration signal is internally produced for use in verifying or, if necessary, adjusting the vertical calibration of the waveform monitor.

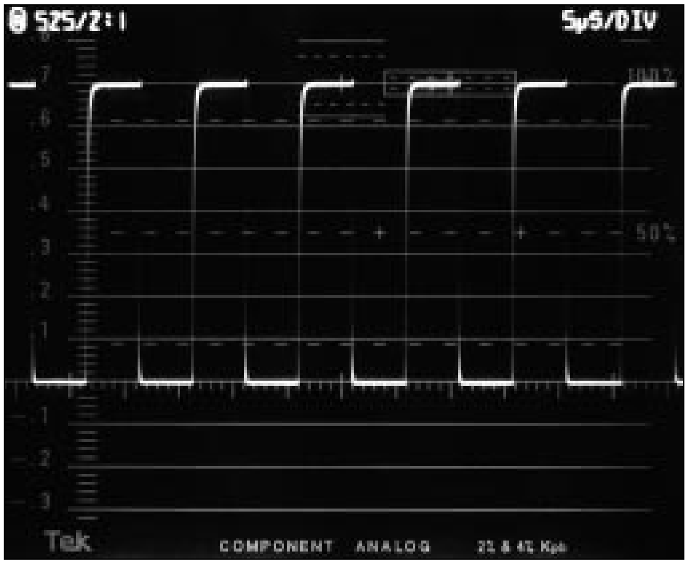


Figure 3b. Example of a square-wave calibration signal.

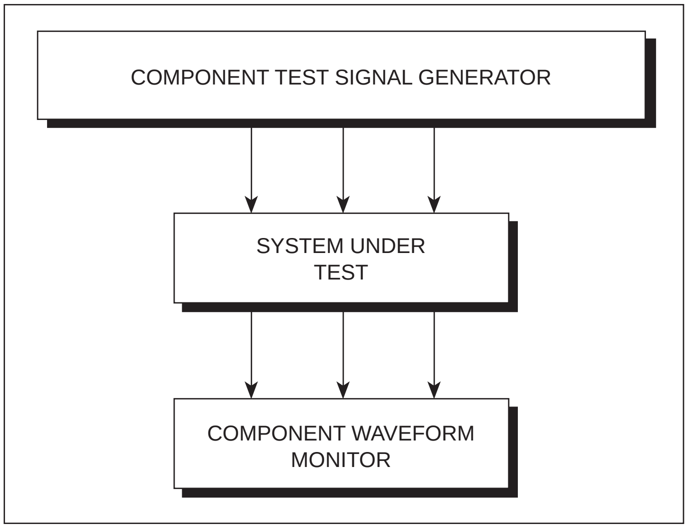


Figure 4. To measure component signal amplitudes, feed the test signal from the component generator through the system under test and into the component waveform monitor.

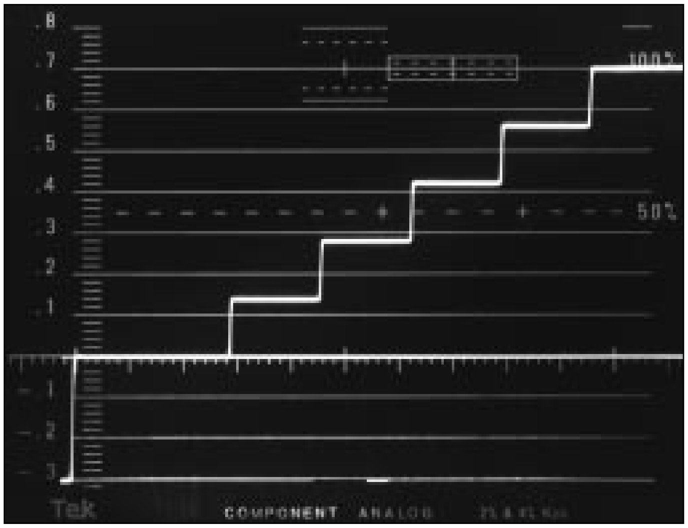


Figure 5. A 5-step staircase can be used to check the luminance channel gain. The top of the staircase should be on the 700 mV line when the blanking level is on the horizontal reference line.

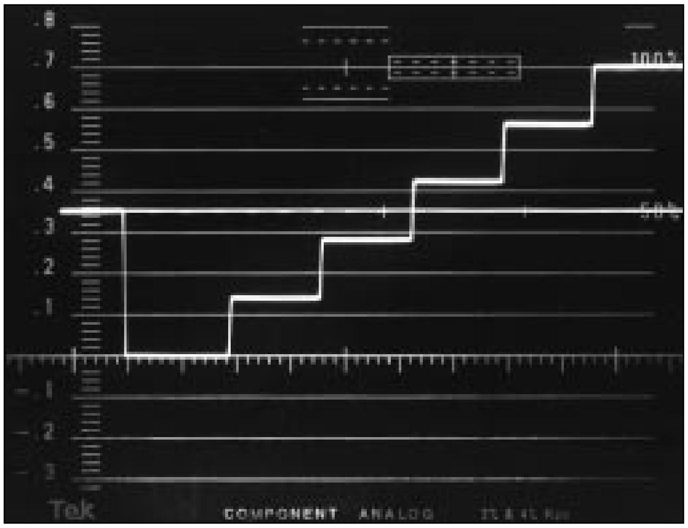


Figure 6. The 5-step staircase in CH 2 must be repositioned vertically so the zero signal level (at the far left of the screen) is on the dotted 350 mV graticule line. The minimum and maximum signal levels should then align with the 0 and 700 mV lines.

Insertion Gain

Insertion gain refers to the overall amplitude of a television signal and is measured as the peak-to-peak voltage of the video waveform (usually including sync on luminance signals). Some pieces of equipment in a component system handle the three signals separately, whereas others process them as a set. The equipment therefore dictates whether you can individually adjust the component insertion gains or not.

You may have access to only one control for adjusting insertion gain, or you may be able to separately adjust the sync and active video levels — changing the range from blanking to peak white with one control and from blanking to sync tip with another. Moreover, equipment that processes the components as a set may have only one overall gain control, or it may have separate controls for adjusting the chrominance and luminance amplitudes.

Waveform Method. The WAVEFORM mode on a component waveform monitor produces a display similar to that of a composite waveform monitor. This display is used for the basic method of measuring insertion gain, in which pertinent waveform features are compared with the graticule markings.

Connect the signal generator to the waveform monitor as shown in Figure 4 and select the test signal. In this example a 5-step staircase is used. The staircase peak should be 700 mV.

Set the monitor to WAVEFORM mode and select the 1 LINE horizontal sweep and the CH 1 (luminance) input. When the blanking level is aligned with the graticule reference line, sync tip should be on the “.3” line and the staircase peak should be on the “.7” line. (See Figure 5.)

You can use this same technique to check levels on the other component channels. Starting with the luminance setup just described, change the waveform monitor input channel selection to CH 2.

The signal in Channel 2 ranges from -350 mV to +350 mV, so it helps to offset the display. Use the vertical position control to align signal zero with the broken graticule line at 350 mV. The displayed peaks should then be at 0 and 700 mV. (See Figure 6.) Repeat this procedure to measure Channel 3.

Note that all three channels, or any combination of two, can be displayed simultaneously.

Mixed Calibrator Method. Some waveform monitors have the capability of mixing the internally generated calibrator signal with the video input signal. This causes the waveform to be written twice, with the two traces separated by the amplitude of the calibrator signal (either 700 mV or 1.00 V). If the applied signal has features that are full amplitude, the top feature of the lower trace will align with the bottom feature of the upper trace. A 700 mV pulse and bar signal in mixed calibrator mode is shown in Figure 7.

You can increase the resolution for measuring any amplitude error between the test signal and the calibrator by activating the vertical gain on the waveform monitor. The waveform in Figure 8 shows correct insertion gain.

If the signal gain is incorrect, the features will not align properly. The example in Figure 9 shows a signal whose gain is 20 mV too low (an error of about 3%).

The mixed calibrator method makes it easy to quickly and accurately set levels in each of the three channels of a component system. What's more, the method works even if the monitor's vertical gain is not precisely calibrated (as you can demonstrate by deliberately misadjusting the waveform monitor vertical calibration while waveforms like those in Figure 7 are displayed). Because the test and calibrator signals both pass through the same circuits in the waveform monitor, they have exactly the same gain to the display.

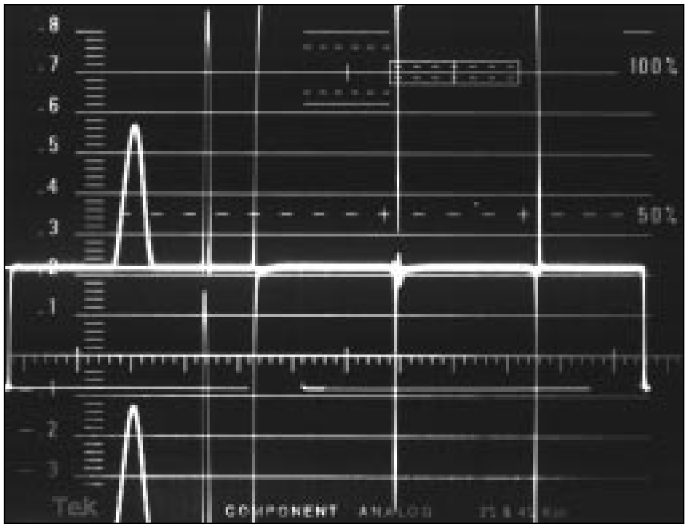


Figure 7. Mixed calibrator mode allows quick verification of channel gain. This pulse and bar test signal shows correct channel gain because the peak of the lower 700 mV bar aligns with the baseline of the upper waveform.

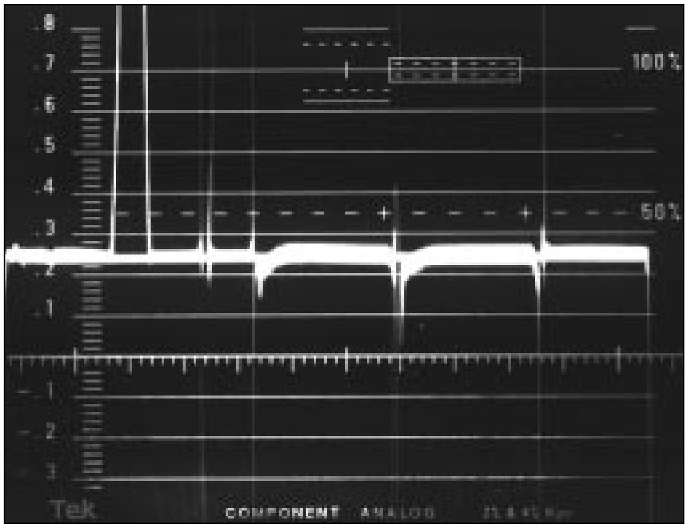


Figure 8. Greater measurement accuracy can be obtained by increasing the vertical resolution of the display. This display was obtained from the one in Figure 7 by pressing the vertical mag front panel button.

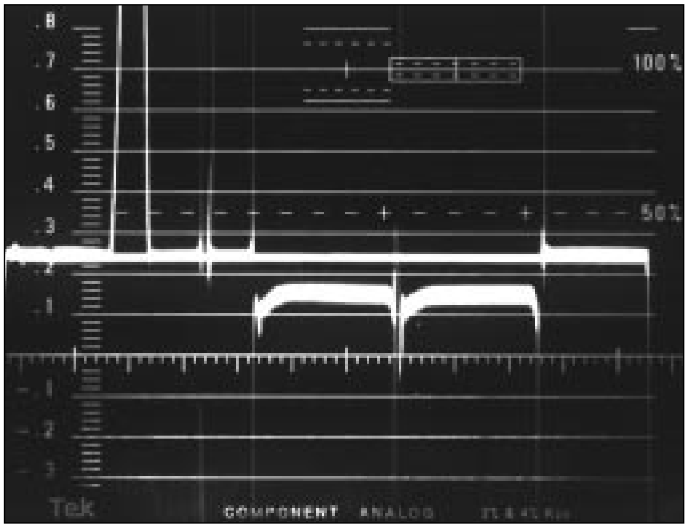


Figure 9. The pulse and bar signal has been passed through a system with reduced gain and displayed using the same setup as in Figure 8. The 100 mV gap between the peak of the lower bar and the baseline of the upper must be divided by 5 to compensate for the X5 display gain. Channel gain error is therefore 20 mV.

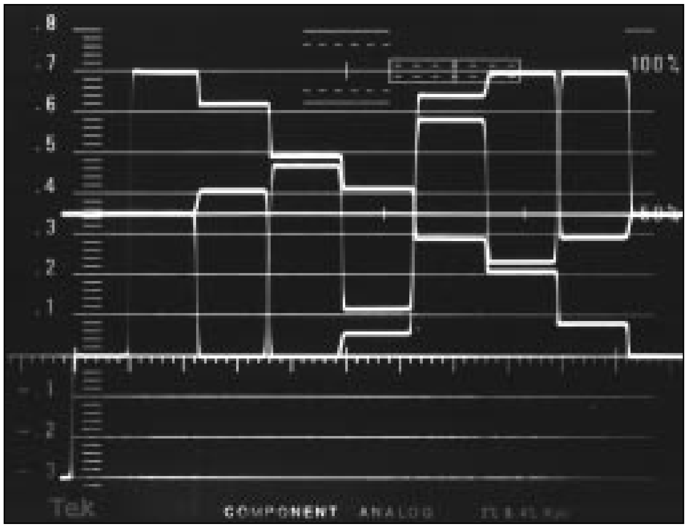


Figure 10. An overlay display of the color bar test signal is good for comparing channel gains.

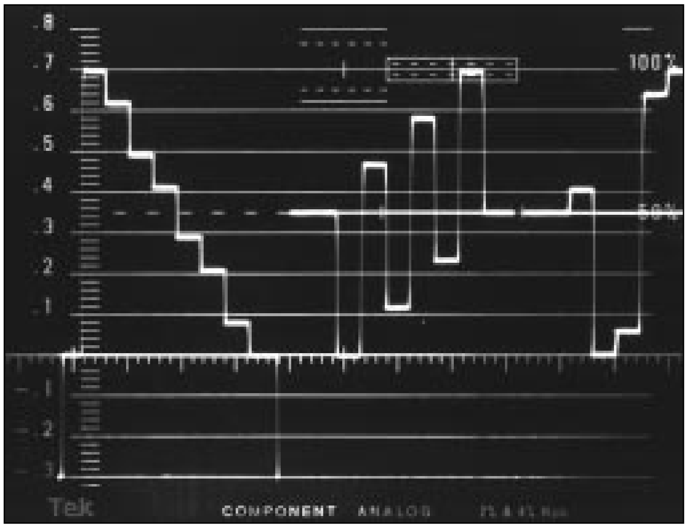


Figure 11. The parade display shows the three component signals side by side — luminance on the left, B-Y in the middle, and R-Y on the right. This display is useful for both relative and absolute gain measurements.

Overlay Method. An overlay display of the 700 mV color bar test signal is useful for comparing channel levels. (See Figure 10.) Note that the peak portions of each waveform lie on the 0 or 700 mV graticule lines.

The overlay display of 700 mV color bars is good for evaluating how well the channel gains match in a component system. You can see at a glance if any of the channel gains is different from the others.

Parade Method. Although you can see all three channels at once in the overlay display, you may find it hard to tell which trace relates to which channel. The parade display solves this problem by putting the three waveforms side by side. (See Figure 11.)

Component Gain Balance

Whereas insertion gain refers to the overall level of all three channels in a component signal, gain balance refers to the matching of levels between channels. If any of the components has an amplitude error relative to the others, it will affect the hue and/or saturation in the picture.

Although the overlay and parade displays can be used for evaluating gain balance as well as for insertion gain, the vector and Lightning displays are more accurate and efficient. The following two subsections describe how to use these displays.

Vector Method. The vector display has long been used for monitoring chrominance amplitudes in composite systems. The composite vectorscope display is a Cartesian (x, y) graph of the two decoded color components. (See Figure 12.)

A similar display for component systems can be formed directly from the color components, with no need for decoding. You can get such a display on a component waveform monitor by connecting a component color bar signal and selecting VECTOR. (See Figure 13.)

In a vector display, the R-Y component (which may be called P_R, V, or E'_{CR}, depending on the standard in use) is plotted vertically, and B-Y (P_B, U, or E'_{CB}) is plotted horizontally. If either of these components has the wrong gain, the dots they produce will not fall in the graticule boxes. For example, if the R-Y gain is too high, the dots will fall above the boxes in the top half of the display and below the boxes in the bottom half. (See Figure 14.) Other gain problems will be similarly obvious.

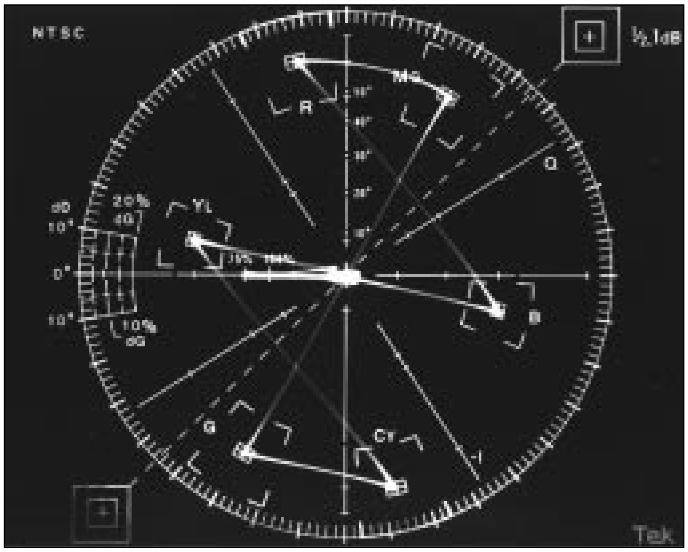


Figure 12. The familiar composite vector display is an X-Y plot of the two decoded reduced-amplitude color difference signals. This display is used with a color bar test signal for checking chrominance amplitudes.

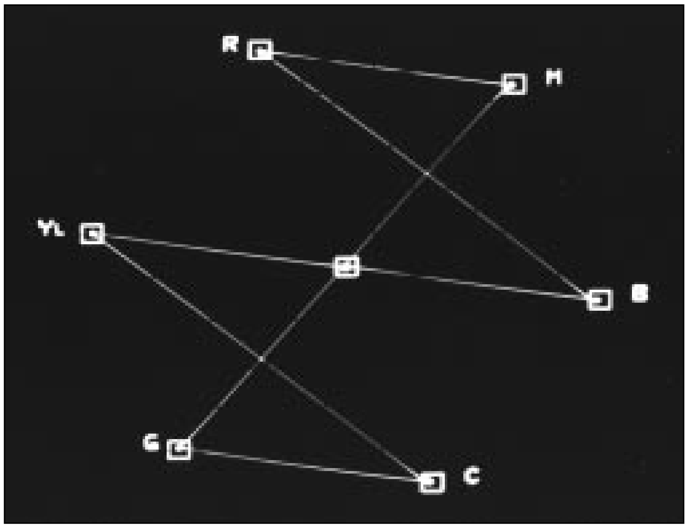


Figure 13. The component vector display is similar to the composite, though it may be proportioned differently if the component amplitudes are not scaled.

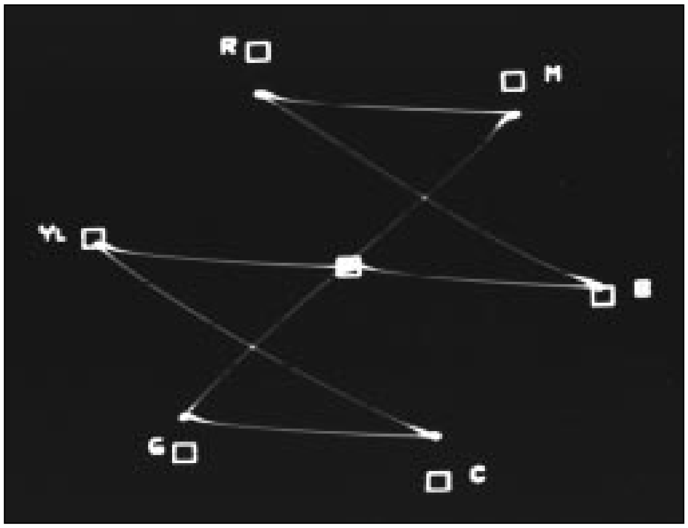


Figure 14. Dots falling outside their graticule boxes indicate that one or both of the color difference components has the wrong amplitude. In this example, the gain of R-Y (which is graphed vertically) is too low.

Lightning Method. The two-axis vector display is convenient for monitoring or adjusting the set of two color difference components, but makes no provision for evaluating luminance gain or for making chrominance/luminance gain comparisons.

Recognizing that a three-dimensional method would be desirable for monitoring the complete set of component signals, Tektronix developed a display that presents all three signals at once, using a standard color bar signal. This display is called “Lightning” because of the zigzag trace it forms on screen. (See Figure 15.)

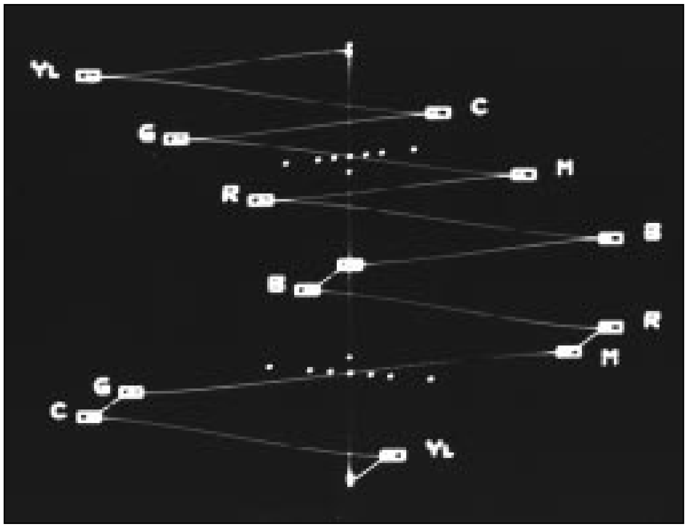


Figure 15. The Lightning display incorporates all three components, allowing for more complete evaluation of channel gains. Like the vector display, Lightning verifies that amplitudes are correct when the dots fall in their boxes (as in this example).

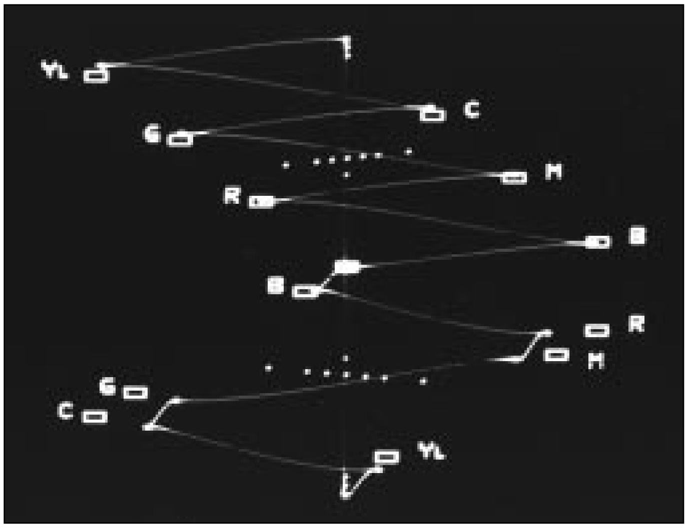


Figure 16. This Lightning display shows that luminance gain is too high and R-Y is too low. (Luminance is plotted vertically; chrominance, horizontally, with B-Y in the top half of the display and R-Y in the bottom.)

The Lightning display is generated by plotting luminance (Channel 1) vs. B-Y (Channel 2) in the upper half of the screen and inverted luminance vs. R-Y (Channel 3) in the lower half — like two vector displays sharing the same screen. The bright dot at center screen is the blanking level (signal zero). Increasing luminance is plotted upward in the upper half of the screen and downward in the lower half.

The example in Figure 16 has luminance set slightly too high and R-Y slightly too low. All the dots have been displaced vertically away from center by the high luminance signal, and the dots in the lower half of the screen have been displaced horizontally toward center by the low R-Y signal. (Remember, if it’s too far away from the center dot, it’s too large; if it’s too close, it’s too small.)

The display can be expanded vertically (as shown in Figure 37) to improve measurement accuracy. Although an expanded display shows only part of the waveform, you can change the vertical position of the display to look at any part you wish.

When using Lightning, you need to set up the waveform monitor to match the system you’re testing. Typical format selections include GBR, SMPTE/EBU N10, MII®, or Betacam®. (Refer to Appendix A for descriptions and specifications of the various formats.) The waveform monitor should also let you choose 75% or 100% for scaling the graticule to the type of color bars in use. Of course you must also be sure to select compatible color bars from the component test signal generator.

Real Signals. The vector and Lightning methods are fast and accurate, but they can only be used when a color bar test signal is available. In the absence of color bars, the black level, setup (if used), white level, and sync pulses can sometimes be measured on "live'' video — as long as the scene contains objects at, or very near, the brightest and darkest that can be reproduced without clipping. (To help set the black level, for example, you could temporarily put a piece of black velvet cloth in the scene.) But even then, it often requires skill to determine which portion of the waveform should be evaluated.

The example in Figure 17 shows a component camera signal in which the black level setup is about 100 mV above blanking, and the peak white level is about 720 mV.

A different scene taken with the same camera setup is shown in Figure 18. This scene contains no peak white and only a small portion of black.

With practice, you can learn to use the Lightning and vector displays on live signals for color-balancing or shading of cameras, correctors, etc. However, these techniques require skill, experience, and examples that are beyond the scope of this booklet.

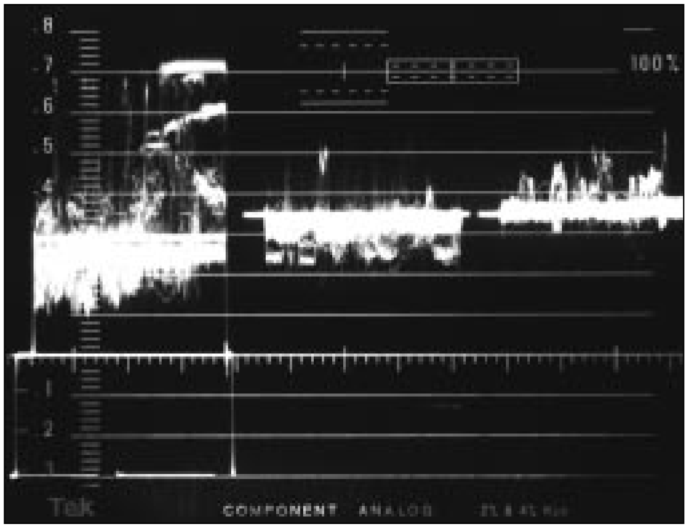


Figure 17. A "real" video signal like this one could be used to set the black and white levels when a color bar test signal is not available because it contains objects that are at or near the extremes of the luminance range. This example shows black level at 100 mV and white at 720 mV.

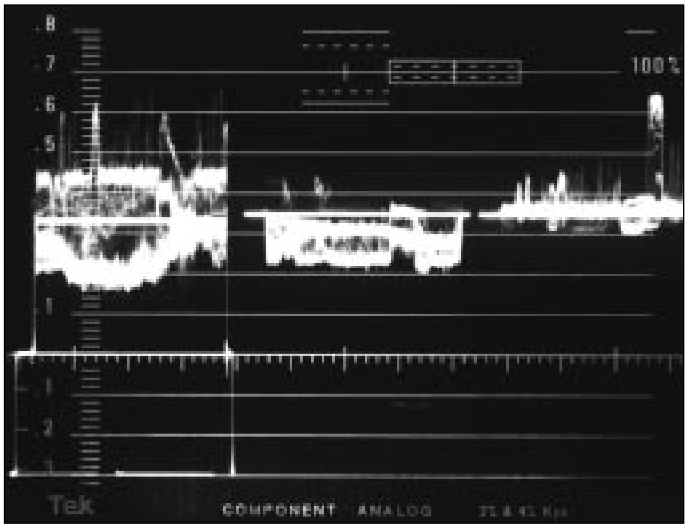


Figure 18. A scene like this one, which contains no peak white and very little black, would not be appropriate for setting levels.

Timing measurements for composite systems fall into three categories:

- Measuring the duration of certain elements in the signal such as sync pulse widths, rise times, etc.
- Synchronizing two video signals by making sure critical events happen simultaneously so the signals can be mixed or switched without problems.
- Finding the chrominance-to-luminance delay by measuring the difference in timing between the lower frequency luminance and the higher frequency encoded chrominance portions of the signal.

Component systems require essentially the same measurements, except that the third category involves timing differences among all three components. The component and composite cases will be compared at the end of this *Timing Measurements* subsection.

(For additional information about making composite signal measurements, please refer to the appropriate booklet: *Television Measurements: NTSC Systems* (25W-7049); or, *Television Measurements: PAL Systems* (25W-7075), available from Tektronix.)

Pulse Widths

Pulse widths are usually specified at 50% amplitude. To measure the width of such a pulse, you must first position the 50% level on the “0” graticule line (which has hash marks for measuring time). To measure the width of a typical -300 mV component sync pulse, for example, you could simply reposition the display 150 mV upward. (If the pulse width were specified at some other level, you would have to modify the measurement technique accordingly.)

You can improve the accuracy of the measurement by vertically expanding the displayed pulse for higher resolution. It helps to select an overall pulse amplitude that makes the 50% level fall on the “0” line when the top of the pulse is aligned with some other graticule line. If, for example, you expand the displayed pulse to 10 divisions, the 50% level will be on the “0” line when the top of the pulse is on the 500 mV line. Other convenient choices are 8 divisions and 7.

To measure a horizontal sync pulse using this technique:

1. Select the vertical X5 magnifier on the waveform monitor.
2. Adjust the pulse height to 10 divisions using the variable gain control. (See Figure 19.)
3. Vertically position the pulse to align blanking with the 500 mV graticule line. (See Figure 20.)
4. Select 1 µs/div sweep speed by selecting the 2 LINE and horizontal mag.
5. Measure the pulse width on the horizontal reference line. The pulse in this example is 4.7 µs wide.

Channel 2 of a 5T 2T Pulse and Bar test signal is shown in Figure 21. Pulse widths in this waveform are specified at the half-amplitude points.

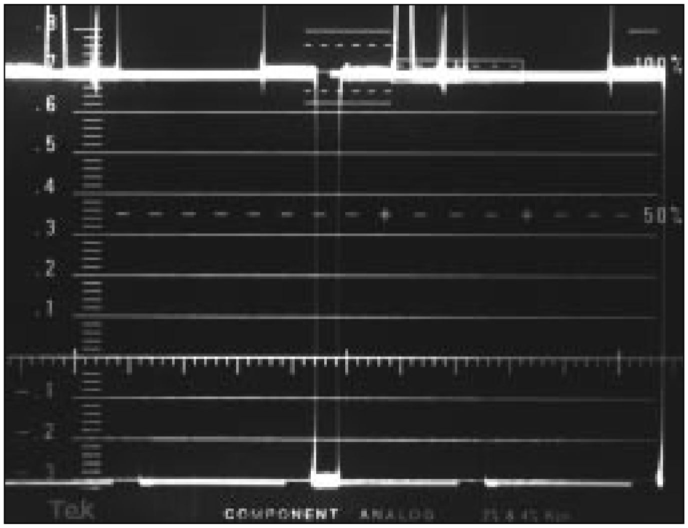


Figure 19. Higher vertical resolution allows for a more accurate pulse width measurement. This horizontal sync pulse has been vertically expanded to 10 divisions, using the X5 and variable gain controls.

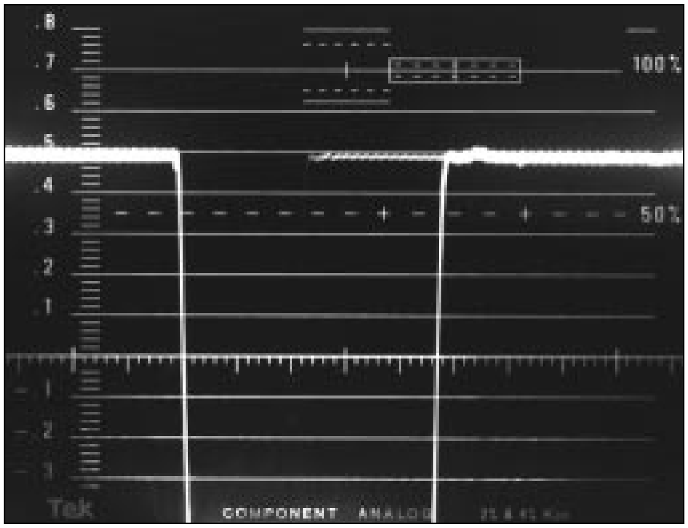


Figure 20. The sync pulse in Figure 19 has been repositioned to align its 50% level with the horizontal reference line and horizontally magnified with a 1µs/div sweep speed.

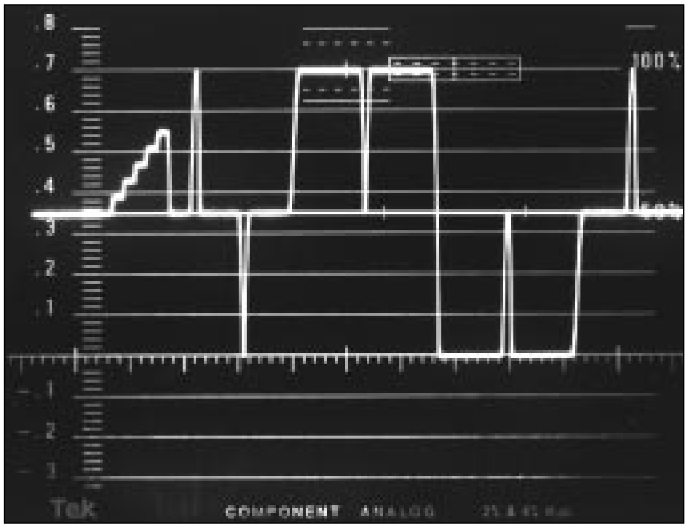


Figure 21. Channel 2 of a 5T Pulse and Bar test signal includes 5T pulses that are both positive and negative going as well as bars at both +350 mV and -350 mV. The display in this example has been offset by 350 mV.

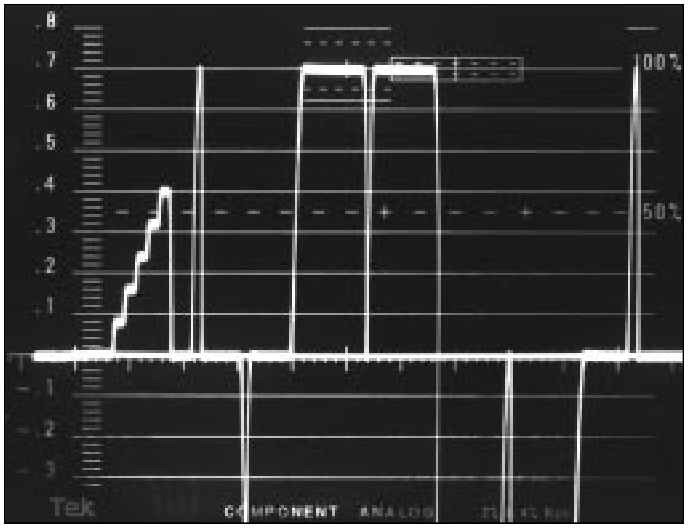


Figure 22. The waveform in Figure 21 has been vertically repositioned and expanded to provide increased resolution for measuring the pulse width. The positive bar now extends from 0 to 700 mV.

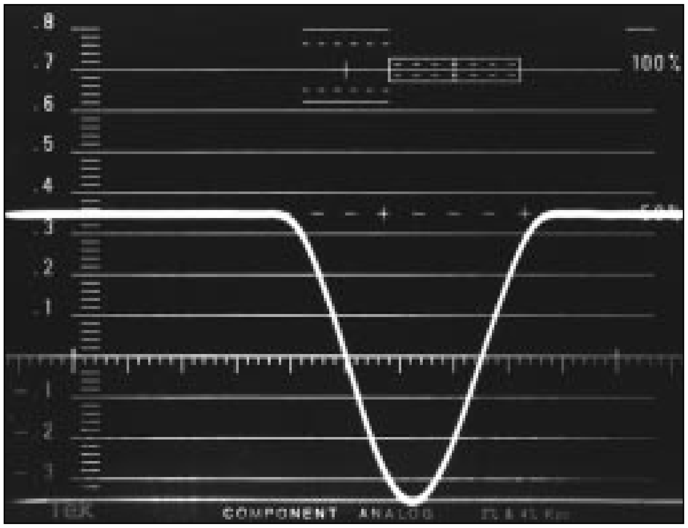


Figure 23. The waveform in Figure 22 has been horizontally magnified with a 200 ns/div sweep speed and vertically repositioned to align the 50% level of the pulse with the horizontal reference line. The horizontal position has also been adjusted so the leading edge of the pulse intersects a major graticule mark on the horizontal reference line.

Suppose you want to measure the width of the pulse that goes negative from the top of the bar:

1. Activate X5 vertical gain.
2. Adjust variable gain for a pulse amplitude of 7 divisions as in Figure 22. (Remember, 7 divisions is one of the convenient alternatives mentioned previously.)
3. Position the trace vertically so the top of the bar is on the 350 mV graticule line (half of 7 divisions). The 50% amplitude is then on the horizontal (0) reference line.
4. Select 1 LINE and horizontal mag, setting the sweep speed to 200 ns/div.
5. Position the trace horizontally, aligning the left side of the pulse with a major division mark on the horizontal reference line. (See Figure 23.)
6. Measure the pulse width along the reference line. (In this case, 2.5 major divisions x 200 ns/div = 500 ns.) This measurement is sometimes called the Half Amplitude Duration (HAD) of the pulse.

Rise and Fall Times

Rise time is usually measured from the 10% to the 90% amplitude points of a positive going transition. Fall time is similarly measured on a negative going transition.

The luminance channel of a Pulse and Bar test signal is shown in Figure 24. The signal is displayed in a 1 LINE horizontal sweep mode.

To measure the rise time of the bar in Figure 24:

1. Adjust variable gain, expanding the transition to occupy 10 major divisions on the display as shown in Figure 25. (Reposition as necessary when changing the gain.) Each division is now 10% of the transition.
2. Activate the waveform monitor horizontal MAG, increasing the sweep speed to 200 ns/div.
3. Position the trace vertically so the bottom of the waveform is one major division below the reference line. (The 10% level of the transition is now on the reference line.)
4. Position the trace horizontally so the rising edge of the trace passes through a major division mark on the reference line.
5. Reposition the trace vertically so the top of the transition is one major division above the reference line. (The 90% level of the transition is now on the reference line.) DO NOT CHANGE THE HORIZONTAL POSITION.
6. Measure the rise time from the 10% starting point located in Step 4 to the 90% point where the rising edge now crosses the reference line. (The photograph in Figure 26 is a double exposure showing the trace in the two positions described.) The rise time in this example is 200 ns.

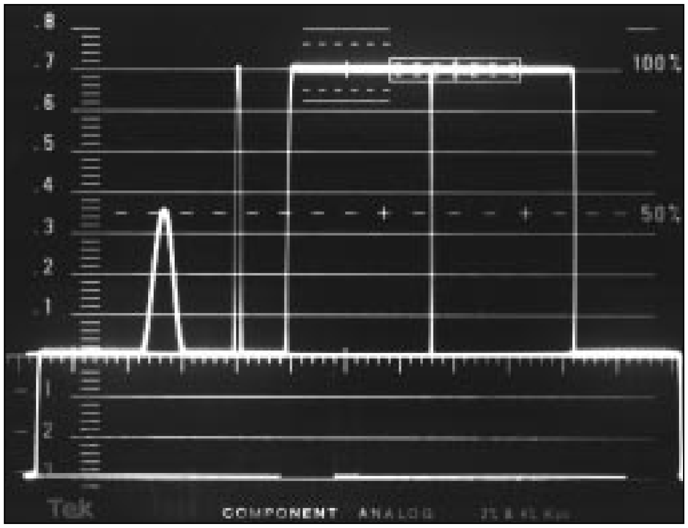


Figure 24. Luminance channel of a Pulse and Bar test signal includes a 350 mV 20T pulse, a positive and a negative going 700 mV 2T pulse, and a 700 mV bar.

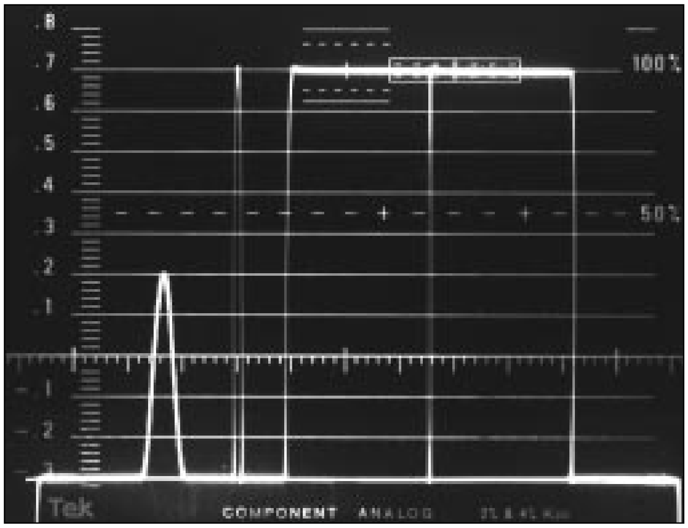


Figure 25. The waveform in Figure 24 has been vertically expanded so the rise time to be measured covers 10 divisions, making each graticule division equal 10% of the transition amplitude.

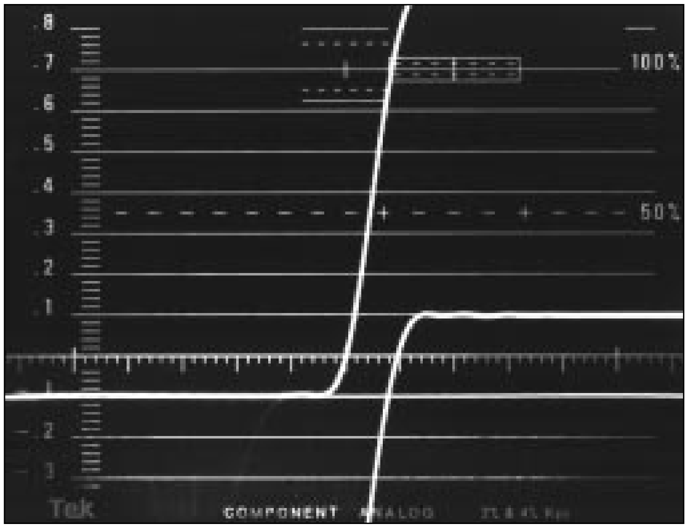


Figure 26. This double exposure shows the two waveform positions used to measure the rise time in Figure 25. Because the 10% and 90% levels are 1 division apart, and the sweep speed is 200 ns/div, the rise time is 200 ns.

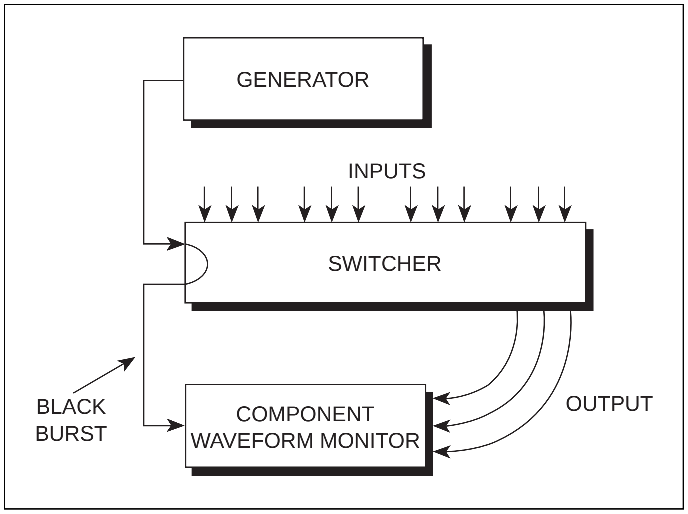


Figure 27. To match the timing of switcher inputs, feed the component outputs into the waveform monitor. Note that an external reference is required. This same method can be used without a switcher by manually connecting the monitor inputs to different sources.

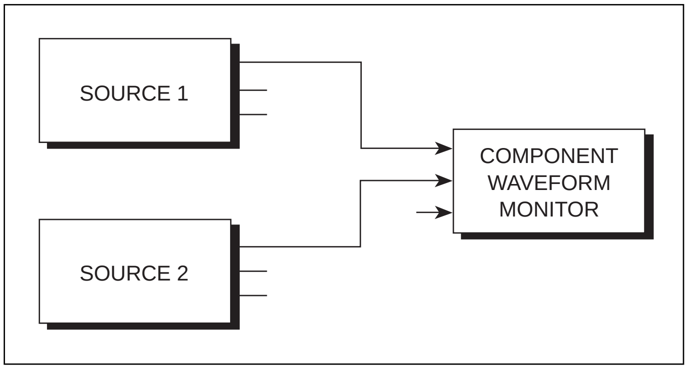


Figure 28. When matching the timing of two signals without a switcher, this setup is more convenient. No external reference is needed, and the two signals can be observed simultaneously. For valid measurement results, the hookup cables must have identical electrical lengths.

If it's not convenient to expand the transition vertically to 10 major units, you can make a good approximation of rise time by estimating the 10% and 90% levels when positioning the top and bottom of the waveform near the reference line. (With a 5-division transition, for example, position the waveform bottom at one-half division below the reference line, which puts the 10% point on the reference line; then position the waveform top at one-half division above the reference line, which puts the 90% point on the reference line.)

Timing Two Feeds

The "timing reference'' mark of a video waveform is the 50% amplitude point on the leading (negative going) edge of sync. In RGB format, timing should be referenced to green even if sync is on all three components. In color difference formats, sync is always on luminance.

To check or adjust the timing of two signals with a waveform monitor, display the signals one at a time with a common sweep sync by activating the external reference function and using the external sync input. (See Figure 27.)

This method is particularly convenient when checking the timing of inputs to a switcher. It can also be used by manually switching the inputs of the waveform monitor from one feed to another.

An alternative method uses the multichannel capability of the waveform monitor and does not need an external timing reference. (See Figure 28.) With this method, both luminance signals are connected to the monitor and compared directly.

To check or adjust timing by the first method, using external sync:

1. Set the waveform monitor for WAVEFORM mode, external reference, and CH 1 input. For greatest accuracy, select 1 LINE horizontal sweep and MAG (200 ns/div).
2. Connect the A feed.
3. Adjust the display, using the gain and position controls, so the midpoint of the sync leading edge passes through a major division mark on the reference line. (See Figure 29, in which sync has been expanded vertically to 6 divisions.) This mark is the reference point for comparing B signal timing to A.
4. Switch to the B signal (either with a switcher or by manually moving the cables). DO NOT CHANGE THE EXTERNAL REFERENCE OR THE HORIZONTAL POSITION.
5. Adjust the vertical position, if necessary, so the 50% amplitude level of the B sync pulse is on the reference line. (If the initial timing error is too great to be seen on screen, use the 2 LINE sweep and make a coarse adjustment first.)
6. Note the point where the trace crosses the reference line. Any discrepancy between this point and the reference point from Step 3 represents a timing error. The photograph in Figure 30 is a double exposure showing both traces. The timing error in this example is about 120 ns.

When timing is correct, the traces will coincide on the reference line even if the sync rise times are different. (See Figure 31.)

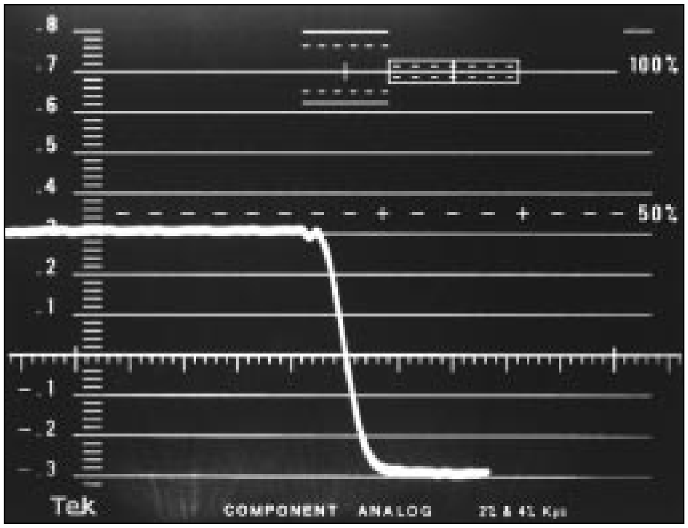


Figure 29. When using a switcher to match signal timing, first identify a timing reference point with one of the sync pulses. This sync pulse, displayed at 200 ns/div, has been vertically expanded to 6 divisions and positioned so its 50% level intersects the horizontal reference line at a major graticule mark.

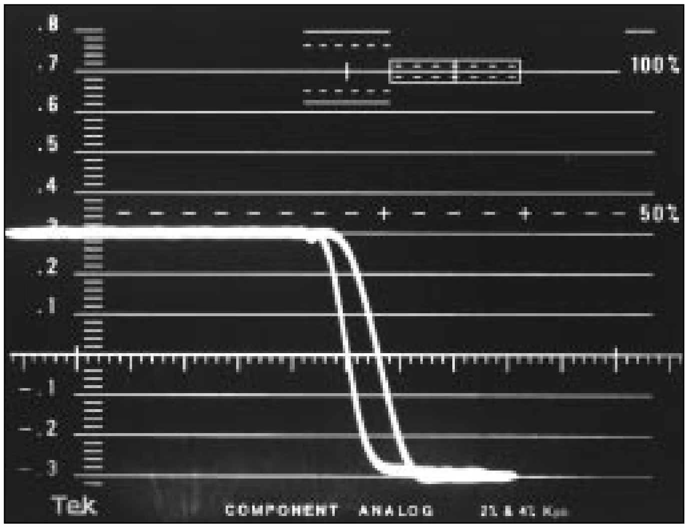


Figure 30. Switch to the second signal and calculate any difference between the timing of its sync pulse and the previously established reference point. Although this double exposure shows both waveforms, they are actually displayed one at a time.

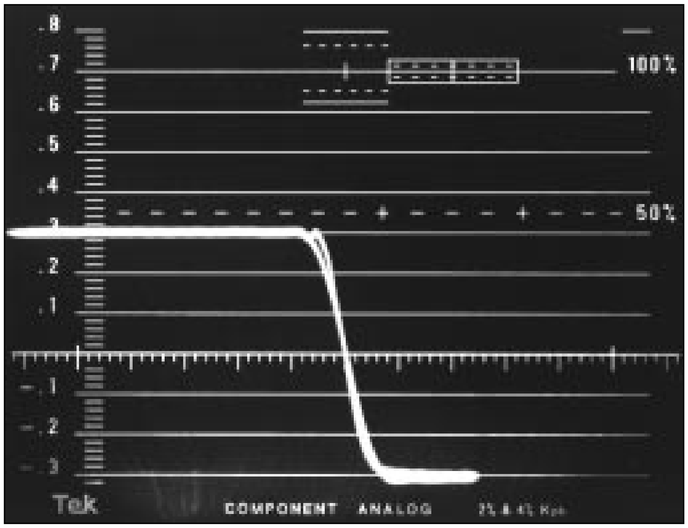


Figure 31. This double exposure shows the two waveforms in Figure 30 with no timing error. The sync pulses can have different rise times, but their 50% levels must coincide on the horizontal reference line.

The alternate method for comparing the timing of two feeds requires simultaneously connecting both luminance (or Green) components to the waveform monitor. No external reference is needed because the internal reference is taken from Channel 1, which is not switched in this method. If you want to use the external reference, however, you can do so with no other change in method.

To ensure that the timing of the two signals at the waveform monitor inputs (as seen on the screen) matches the timing at the point of interest in the system (where the signals are picked up), it's imperative that the hookup cables have the same electrical length. Only if both cables introduce the same amount of signal delay will timing at the monitor directly correspond to timing in the system.

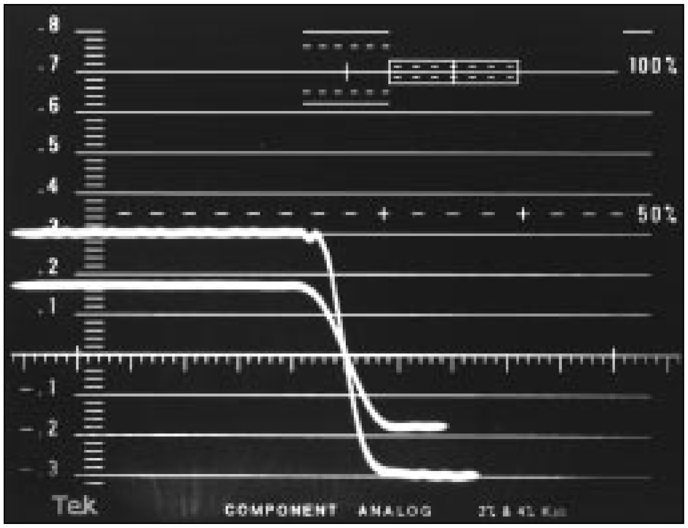


Figure 32. When using the alternate method for matching signal timing, both sync pulses are displayed at the same time. Although the pulse amplitudes need not be exactly equal, it's important that the waveforms be accurately positioned: Both 50% levels must align with the horizontal reference line.

To check signal timing using this alternate method:

1. Connect the luminance (or Green) components of the two feeds to CH 1 and CH 2. BE SURE THE HOOKUP CABLES HAVE THE SAME ELECTRICAL LENGTH.
2. Select both CH 1 and CH 2, displaying the two components at the same time.
3. Adjust the gain and vertical position as in Step 3 of the previous procedure. (There should be a control in the waveform monitor which allows the two displayed signals to be vertically positioned independently.) BE SURE THE 50% LEVELS ARE VERTICALLY ALIGNED.

The resulting display will resemble the double exposures in Figure 30 and Figure 31. (See Figure 32.) Small differences in the sync amplitudes, as in Figure 32, usually won't cause problems. Just be sure to position the traces so their 50% levels are being compared.

Interchannel Timing

Timing differences between the channels of a single video feed will cause problems unless the errors are very small. Since the three components travel through different cables, different amplifiers in a routing switcher, etc., timing errors can occur if the equipment is not carefully installed and adjusted.

There are several methods for checking the interchannel timing of component signals. Although the waveform techniques just described can be used, Tektronix component waveform monitors provide two efficient and accurate alternatives: the Lightning display, using the standard color bar test signal; and the bowtie display, using a special test signal generated by Tektronix component signal generators.

Waveform Method. The waveform technique can be used to verify whether transitions in all three channels are occurring at the same time. For example, a color bar signal has simultaneous transitions in all three channels at the boundary between the green and magenta bars.

Using the waveform method to check whether the green-magenta transitions are properly timed:

1. Route the color bar signal through the system under test and connect it to the waveform monitor.
2. Set the waveform monitor to PARADE mode and 1 LINE sweep.
3. Vertically position the display, if necessary, so the midpoint of the Channel 1 green-magenta transition is on the 350 mV line.
4. Adjust the Channel 2 and Channel 3 position controls so the zero level of the color difference channels is on the 350 mV line. (Because the color difference signals range from -350 mV to +350 mV, their zero level is at vertical center.)
5. Select WAVEFORM mode and horizontal MAG.
6. Position the traces horizontally for viewing the proper set of transitions. All three traces should coincide on the 350 mV line. (See Figure 33.)

An example of mistiming is shown in Figure 34, where Channel 2 (B-Y) is delayed by about 100 ns. You can adjust the timing for minimum error while viewing the display shown in Figure 34. If you wish to measure the timing error, reposition the traces from the 350 mV line to the horizontal reference line and use the timing graticule.

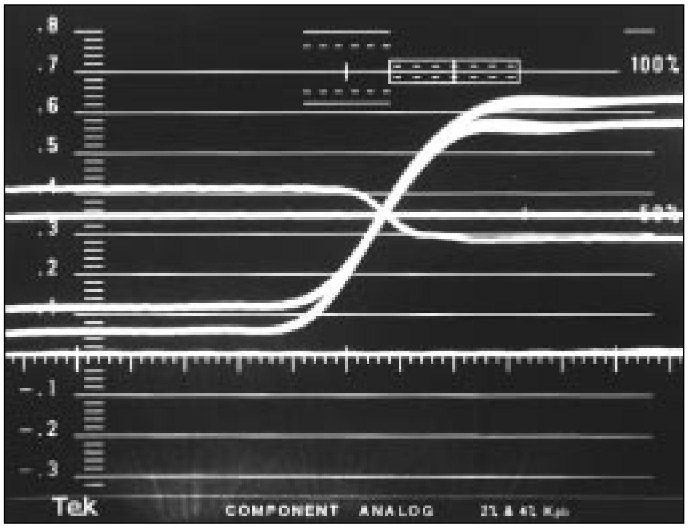


Figure 33. Interchannel timing measurements can be made with an overlay display of a color bar test signal. Position the three green-magenta transitions so their 50% levels align with the 350 mV graticule line. In this example, interchannel timing is correct.

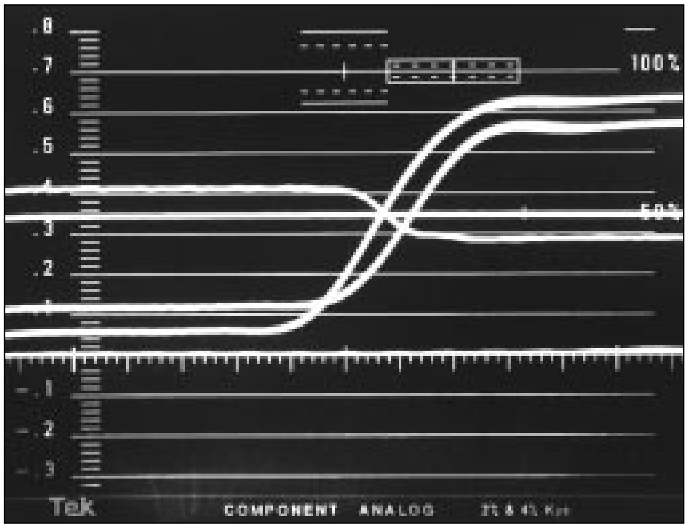


Figure 34. The signal in Figure 33 has been passed through a system with delay in Channel 2 (B-Y). Timing adjustments could be made with the display as is, but for measurements, the display would have to be repositioned to the horizontal reference line.

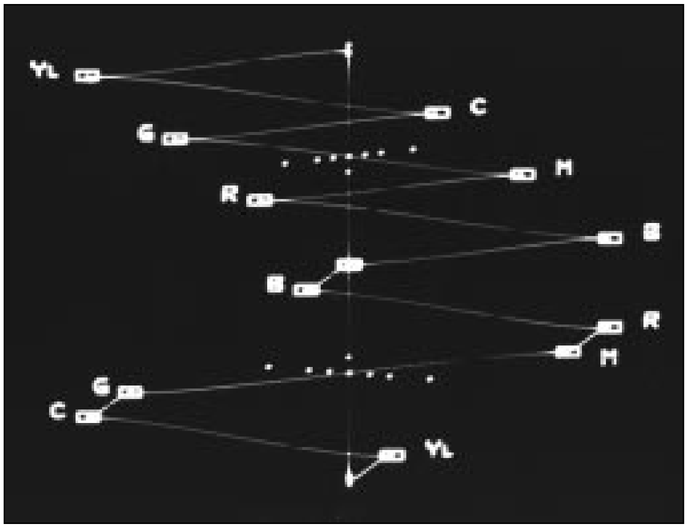


Figure 35. The Lightning display can be used for evaluating interchannel timing as well as for verifying channel gains. Each of the green-magenta transitions should pass through the center dot in the series of seven graticule dots crossing its path. This example shows correct timing.

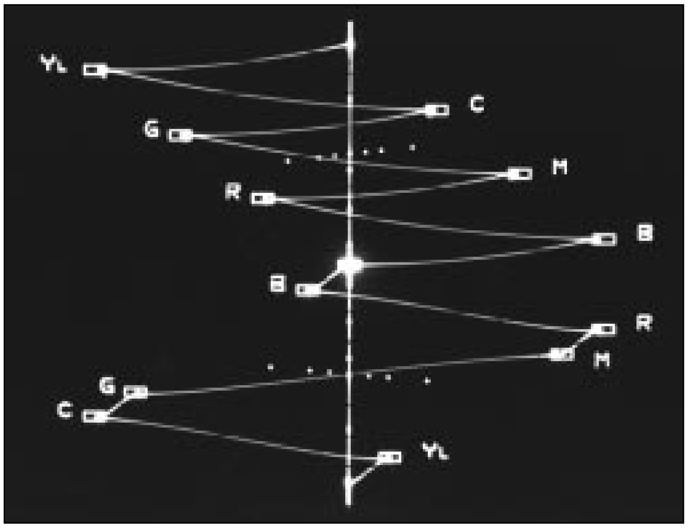


Figure 36. This Lightning display shows the same timing error as Figure 34. The delay in Channel 2 has caused the green-magenta transition in the top half of the display to move toward center screen. Channel 3 timing is correct.

Lightning Method. The Lightning display, discussed earlier under *Amplitude Measurements*, is also useful for evaluating interchannel timing. (Refer to that discussion for cautions about setting up the waveform monitor and selecting the appropriate color bar signal for your system.)

Before checking interchannel timing, it's important to adjust signal amplitudes so the dots are within the Lightning graticule boxes. Timing measurements, which are made at the midpoints of transitions, can only be accurate if the transitions begin and end at the correct points.

Timing is indicated on the Lightning graticule by a row of dots between the green and magenta boxes in both the upper and lower halves of the display. Interchannel timing is correct if the signal trace passes through the center dot of both rows, regardless of whether the transition path is straight or curved. (See Figure 35.)

Timing errors cause the trace to move away from the center timing dot. If the color difference signal is delayed relative to luminance, the trace passes closer to display center (as in the top half of Figure 36). If the color difference signal is advanced, the trace passes farther away from display center.

Remember that Channel 2 is compared to Channel 1 in the upper half of the screen and Channel 3 to Channel 1 in the lower. The example in Figure 36, which is same signal used to illustrate the waveform method in Figure 34, shows B-Y delayed by about 100 ns relative to luminance.

The Lightning display can be expanded vertically by selecting the X5 vertical mag on the waveform monitor. (See Figure 37.) Changing the vertical gain enhances measurement accuracy by providing greater resolution without affecting the calibration of the electronically generated graticule. Although only part of an expanded waveform is visible at a time, you can reposition the display to view any part you wish.

The Lightning display, using a standard color bar signal, shows not only absolute and relative amplitudes but also relative timing for all three components. These capabilities make it a powerful tool for component video monitoring.

Bowtie Method. The bowtie display, which requires a special test signal, makes it possible to evaluate relative amplitudes and relative timing on component waveform monitors which have a bowtie display mode. (See Figure 38) The left side of the display compares Channel 1 and Channel 2; the right side compares Channel 1 and Channel 3.

To use the bowtie display, route the bowtie signal from the component generator through the equipment under test and connect it to the waveform monitor. Activate the BOWTIE display.

If the bowtie patterns have a sharp null, and the null is at the center of each line (as shown in Figure 38), the relative amplitudes and interchannel timing are correct. A relative amplitude error will decrease the depth of the null; an interchannel timing error will move the position of the null. (See Figure 39.) An incomplete null combined with an offset from center indicates both amplitude and timing problems between the channels being compared.

Note: The bowtie signals in Figure 39 have passed through a complex system and are therefore less clean than the signals in Figure 38, which were connected directly from the generator to the waveform monitor.

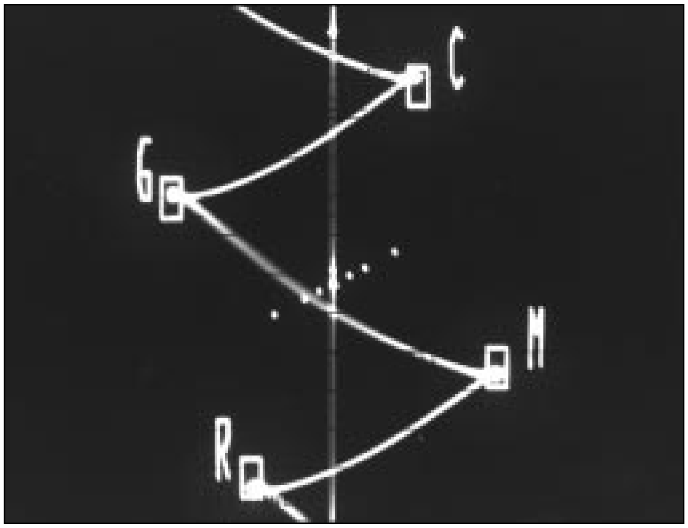


Figure 37. The Lightning display can be expanded vertically to provide higher resolution for evaluating both amplitude and timing accuracy.

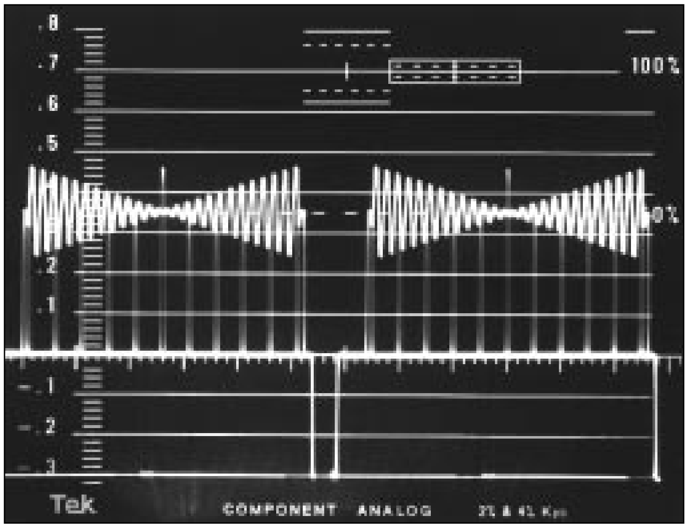


Figure 38. The Bowtie display can be used for evaluating relative channel gain and interchannel timing. In this example, the sharpness of the nulls indicates that all three channels have the same gain, and the centering of the nulls indicates correct interchannel timing.

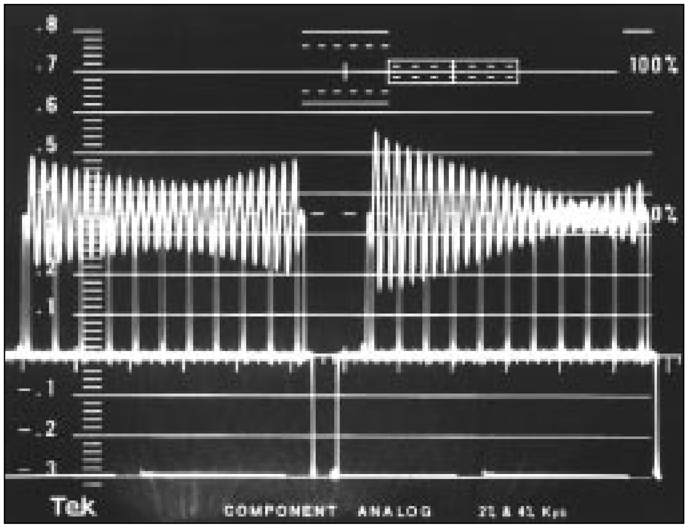


Figure 39. The incomplete null on the left side of this bowtie display indicates a relative amplitude error between Channel 1 and Channel 2. The off-center position of the null on the right side indicates that Channel 3 is delayed relative to Channel 1.

The bowtie test signal consists of a 500 kHz sine-wave packet on Channel 1 and a 502 kHz sine-wave packet of the same amplitude on each of the other two channels. Markers generated on a few lines of Channel 1 serve as an electronic graticule for measuring relative timing errors. (See Figure 40.) The taller center marker indicates zero error, and the others are spaced at 20 ns intervals.

The three sine-wave packets are generated to be precisely in phase at their centers. Because of their 2 kHz offset, the color difference channels become increasingly out of phase with the luminance channel on either side of center.

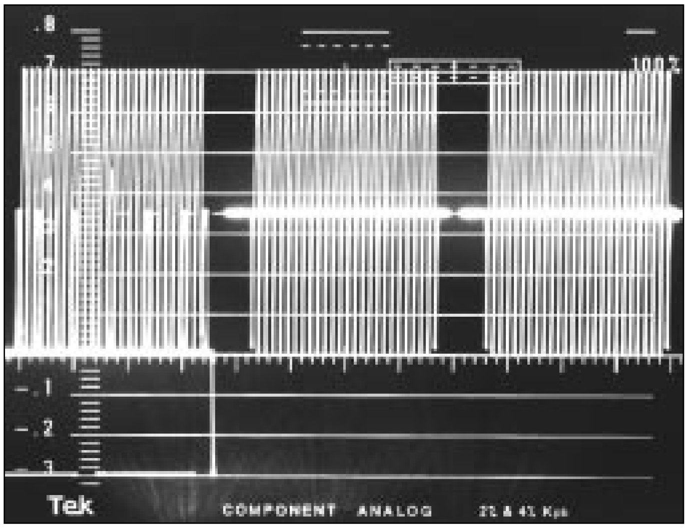


Figure 40. These three sine-wave packets, output by a component generator and displayed in parade mode on a component waveform monitor, are used to create the bowtie display. When switched to BOWTIE mode, the waveform monitor presents a two-line display of (CH 1 – CH 2) followed by (CH 1 – CH 3), as shown in Figure 38.

The waveform monitor subtracts Channel 2 from Channel 1 for the left half of the bowtie display and Channel 3 from Channel 1 for the right half. Each subtraction produces a null at the point where the two components are exactly in phase (ideally, at the center). A relative timing error between Channel 2 and Channel 1, for example, changes the relative phase between the two channels, moving the null off center on the left side of the bowtie display.

The null, regardless of where it’s located, is zero amplitude only if the amplitudes of the two sine-wave packets are equal. A relative amplitude error broadens the null, making it difficult to accurately evaluate timing. If you need a good timing measurement, first adjust the amplitudes on the equipment under test.

The bowtie test signal and display offer two advantages: they provide better timing resolution than the waveform and Lightning methods, and the display is readable at some distance from the monitor screen.

Note: Be careful when deciding where to route a bowtie signal. When translated to RGB, or encoded to composite, the bowtie signal produces an illegal signal with potentially troublesome side effects. (Refer to the next subsection, *Signal Validity*, for a discussion about “legal” and “valid” signals.)

Composite Comparison

Chrominance-to-luminance delay distortion on composite signals is frequently evaluated using the modulated pulse signal. (See Figure 41.) The modulated 20 T pulse in Figure 41 has been optimized for chrominance-to-luminance timing. The pulse for this example was generated by routing one of the pulse and bar signals from a component generator through an encoder and displaying the result on a waveform monitor. (The trace has been raised slightly above the reference line to make the modulation baseline more visible.)

The examples used for illustrating the component timing techniques in this booklet had a color difference timing error of about 100 ns. For comparison, the display in Figure 42 shows the effect of introducing the same amount of chrominance-to-luminance timing error on the modulated 20 T pulse of Figure 41.

Notice that the peak-to-peak distortion at the base of the pulse is about 10 IRE.

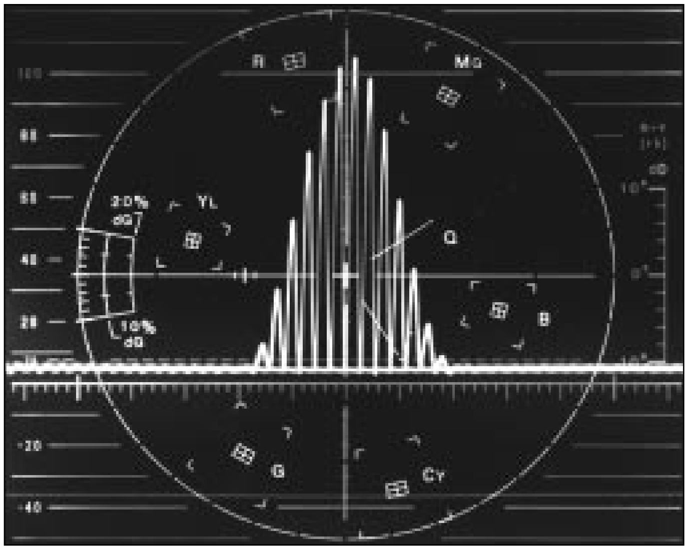


Figure 41. The modulated 20T pulse is used to measure chrominance-to-luminance delay distortion in composite signals. The flat baseline in this example indicates correct chrominance-to-luminance timing.

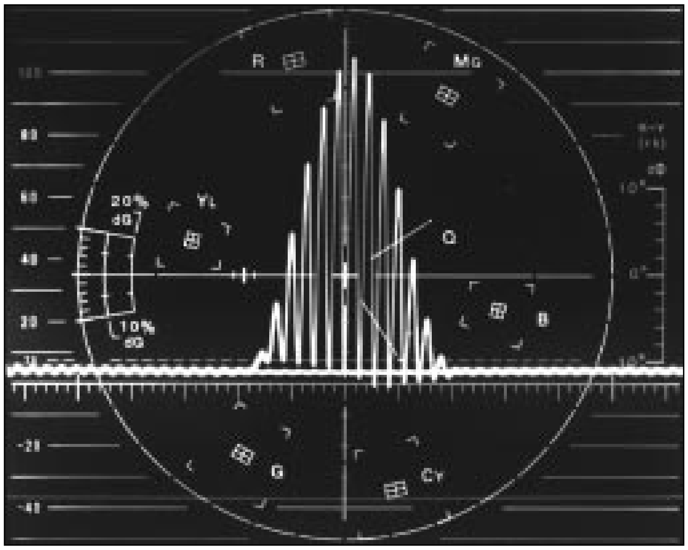


Figure 42. The modulated pulse in Figure 41 has been passed through a system with about 100 ns of chrominance-to-luminance timing error. (Compare with Figures 34, 36, and 39, which illustrate the same amount of interchannel timing error.) The “S” distortion in the baseline is about 10 IRE peak-to-peak.

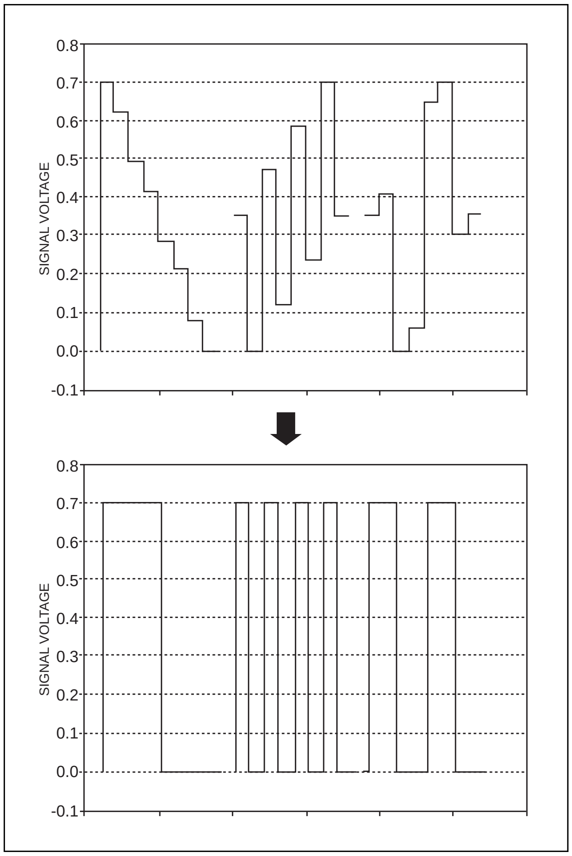


Figure 43a.

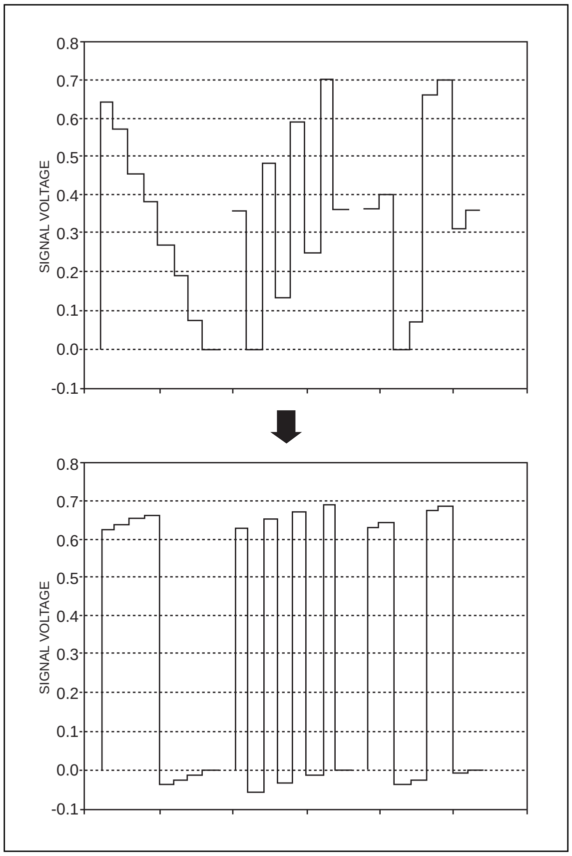


Figure 43b.

With the exception of RGB, all CAV formats include a luminance and two color difference signals. In any of the color difference formats, signals can develop amplitude problems that won't be detected by the usual monitoring methods.

The various CAV interconnect standards specify a voltage range, called the "gamut," for each component channel. (Refer to Appendix A.) If a component signal stays within the limits specified for its channel, it is said to be "legal" (or to have a legal gamut).

In RGB format, each channel voltage may be anywhere within its range without regard for voltage levels in the other channels. Only if a signal is illegal — that is, if it exceeds the fixed limits for its channel — is it likely to be clipped or otherwise distorted, or to cause problems elsewhere in the system.

In a color difference format, however, the limitations are more complex. If a color difference signal produces legal components when translated to RGB format, it is said to be "valid". But if a signal will not translate properly to RGB, the signal is invalid — even if it falls within the legal range in its own standard. An example of how gain distortion in a color difference signal can render the signal invalid, though not illegal, follows.

Note in Figure 43a the color difference signal (top) is both legal and valid — it translates to a legal RGB signal (bottom) with all three components within the specified ranges. Figure 43b (top), however, is distorted; it has a relative luminance channel gain of only 90%. When this signal is translated to RGB format (bottom) the signal is no longer legal — all three components have signal elements below the minimum level. Since the distorted signal cannot be translated to a legal RGB signal it is shown to be not valid. Other forms of distortion can also create non-valid component signals.

Valid signals can be translated, encoded, or input to any part of a video system without causing amplitude-related problems.

The concept of valid video signals is unique to component formats. Camera signals and signals that have been decoded from composite form or translated from RGB are usually valid. Test signals and other generated or modified signals, such as outputs of color correctors, paint boxes, etc., might not be valid. Furthermore, a valid signal can become invalid through distortion.

Tektronix component products provide many valid test signals and special features for monitoring validity. Certain test signals from the Tektronix component generators are designed to test gamut extremes without introducing validity problems.

Gamut Testing

Component Diamond Display. To prevent the undesired impact of color gamut violations, especially when working with color difference signals, Tektronix developed the Diamond display. Figure 44 shows the graticule for the Diamond display, which provides a reliable indication of color gamut violations. Any time the color difference (or RGB) signal violates RGB limits, the waveform trace will lie outside the boundaries of one or both of the diamond-shaped areas of the graticule. If no violations exist, the trace remains on or within the limits of the graticule.

The Diamond display is the most reliable and useful indicator of proper RGB or color gamut. Since the top diamond indicates levels of blue and green signal components and the bottom diamond indicates red and green, it is easy to identify which of the three signal components are in error. Figure 45 shows an example of a signal whose red component is out of gamut.

For a more in-depth description of the Diamond display, refer to the application note *Preventing Illegal Colors with the Diamond Display* (25W-7225).

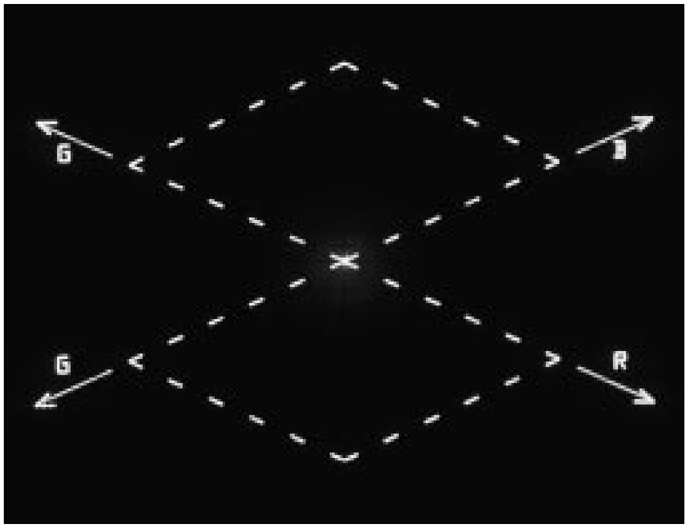


Figure 44. The component Diamond display graticule.

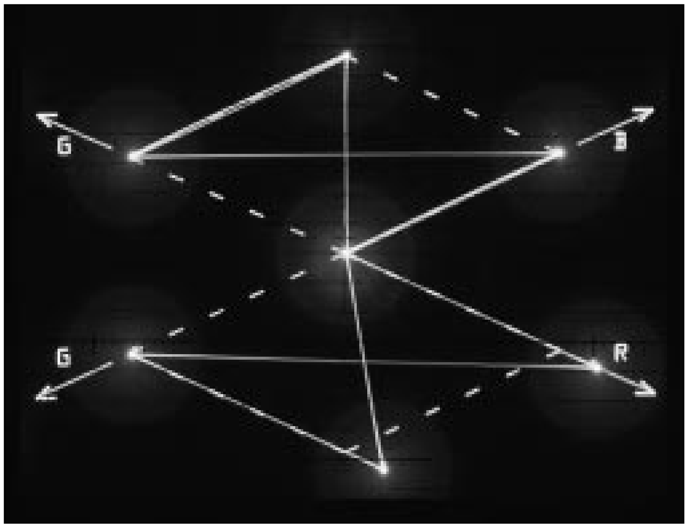


Figure 45. An error in the red channel affects only the lower half of the display, stretching it in the red dimension only.

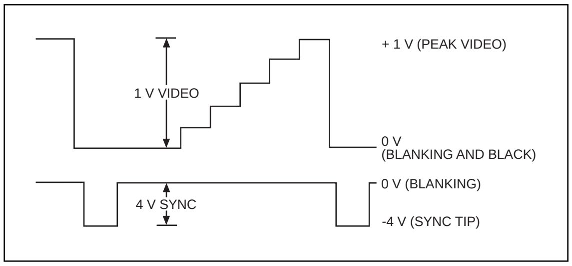


Figure 49. Early non-composite video and sync.

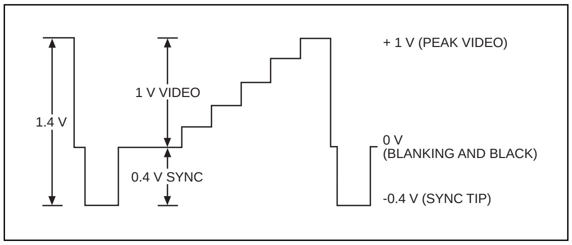


Figure 50. Early composite video.

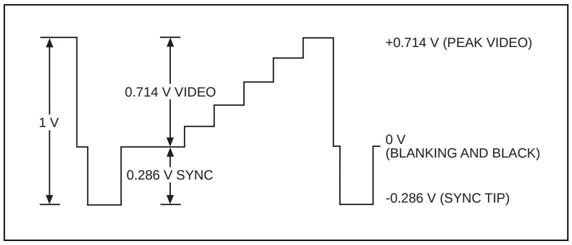


Figure 51. Modern composite video voltage levels (without setup).

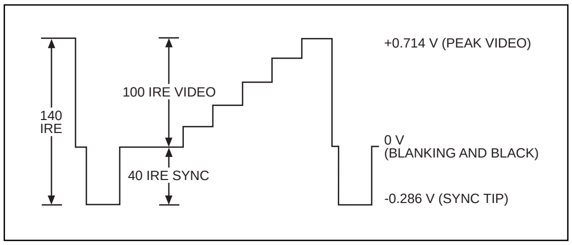


Figure 52. Modern composite video IRE levels (without setup).

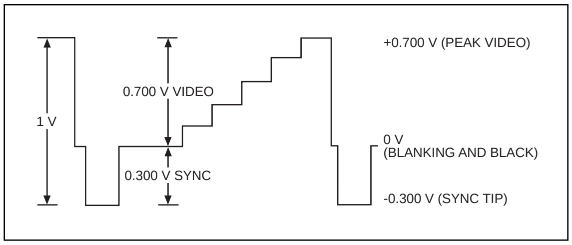


Figure 53. Non-NTSC composite video voltage levels.

Background Information

The discussions in this booklet are limited to CAV interconnect schemes using three parallel wires. Digital component and the various multiplexing methods are outside the present scope.

The SMPTE and EBU have agreed on standards for a CAV color difference format that is based on the +700 mV video and –300 mV sync levels used in non-NTSC regions.

Those of us working in NTSC-related environments, however, are unfortunately faced with a confusing array of component interconnect schemes that have evolved from precedents set in the early days of monochrome and composite color video technology. The following paragraphs provide some background information to show how we got where we are today.

At one time, video and sync were distributed in the studio on separate lines. The video signal, ranging from black to peak white, was scaled to 1.0 V peak-to-peak. The sync signal amplitude was 4.0 V p-p. Usually both of these signals were clamped to establish the black (blanking) level at 0 V, peak white at +1.0 V, and sync tip at –4.0 V. (See Figure 49.)

When sync and video were combined on one line to produce monochrome composite video for transmission, the amplitude of sync was reduced by a factor of 10. The composite signal became 1.4 V p-p, with black at 0 V, white at +1.0 V, and sync tip at –0.4 V. This set the precedent for a 10:4 ratio between video and sync amplitudes. (See Figure 50.)

The specified amplitude for composite video was later reduced to 1.0 V p-p, but the 10:4 video-to-sync ratio was maintained. This established the now familiar NTSC levels: blanking at 0 V, white at +714 mV, and sync tip at –286 mV. (See Figure 51.) These levels were carried over to the NTSC color standard.

Eventually the IRE (later to be the IEEE) established a unit of measure for video signals. This “IRE unit’’ was defined as 1% of the video range from blanking to peak white, without reference to the actual signal voltage. Although defined as a ratio, it became common practice to refer to an IRE unit as “equal to 7.14 mV,’’ because it was usually applied to the standard 1 V composite signal. (See Figure 52.)

Numbers like 714, 286, and 7.14 are not very convenient for measurement and calculation. Europe and elsewhere avoided this difficulty by adopting a 7:3 video-to-sync ratio while maintaining the 1 V p-p amplitude for the composite signal. The resulting levels are: blanking at 0 V, white at +700 mV, and sync tip at –300 mV. (See Figure 53.) With these levels, video measurements can be made in terms of convenient numbers using millivolts as the unit.

So far we’ve described two basic standards: the NTSC-related standard with +714 mV peak video and –286 mV sync; and another (almost universal outside NTSC regions) with +700 mV video and –300 mV sync.

A further distinction is introduced by using ’’black-level setup” in NTSC and NTSC-related signals. By raising video black somewhat above the blanking level, setup provides a transmitted vertical-retrace blanking signal for TV sets. Because television displays are adjusted to produce very little light when the video is black, the blanking level (which is below black) is rendered invisible.

The black-level setup or “pedestal’’ was originally anywhere from +5 to +10 IRE, but eventually the EIA RS-170A specified it at +7.5 IRE. (See Figure 54.) Consequently, since the peak white voltage is not increased with setup, the black-to-white amplitude range is reduced by 7.5%. Also, since the video is usually clamped at the blanking level, the video signal with setup does not include a reference black.

Modern component interconnect standards show the influence of many of the precedents described in the foregoing paragraphs. Some of these standards were initiated by professional groups (SMPTE), some by government related organizations (EBU), and some by manufacturers of hardware (Panasonic, Sony, etc.).

In this appendix, seven component standards will be described: four RGB and three color difference. Strictly speaking, these interconnect schemes are not compatible, but they have enough in common that familiarity with one method gives a sound basis for understanding the others.

With the exception of RGB, all use the idea of one luminance and two color difference signals carrying all the information for a color image.

At the present state of development, many facilities use more than one component standard and may also use component and composite signals in the same facility. A knowledge of the levels associated with the various standards is needed to ensure that each signal input is appropriate for the particular equipment involved.

Color Bar Basics

The signal levels in each standard will be described using the color bar signal. This signal is often used because it exercises the extreme range of signal values allowed in each channel by any of the interconnect schemes.

In NTSC regions, it has been common practice to use a 75% amplitude color bar signal as a test stimulus and reference. In non-NTSC regions, the 100% amplitude color bar is preferred. But in both cases, the saturation of the color bars is kept at 100%.

Note: Sometimes the white bar of a 75% signal is raised to full amplitude as an aid in setting levels. It’s important to keep in mind that a 75% color bar signal with a full-amplitude white is different from a 100% color bar signal. It has become fairly common, although incorrect and confusing, to refer to a 75% color bar signal with full-amplitude white as a “100% color bar.’’

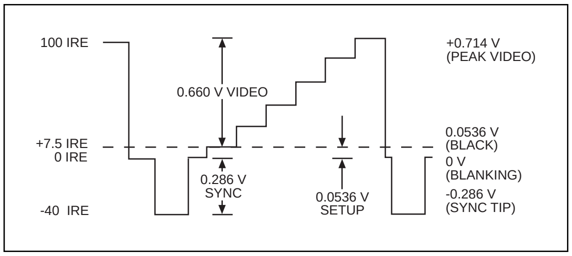


Figure 54. NTSC video voltage levels (with setup).

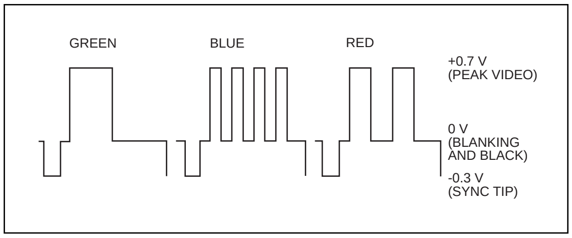


Figure 55. SMPTE/EBU N10 100% amplitude GBR color bar signal.

The RGB Standards

An RGB component signal consists of three monochrome video signals, each representing the image for one of the primary colors. Combining these three monochrome images in a display results in a full color image. Possible sources of RGB video include cameras, telecine machines, composite decoders, character generators, graphics systems, color correctors, and others.

In general, RGB signals use the same peak-to-peak amplitude as the luminance signal in the local composite standard. This explains why there are several RGB standards in use today and why it's important to determine the characteristics of your equipment and calibrate for the appropriate levels (including setup, if required).

The following paragraphs describe the four RGB interconnect standards you might encounter:

- 700 mV RGB (SMPTE/EBU N10)
- 714 mV RGB (NTSC-related)
- 714 mV RGB with setup (NTSC-related)
- 700 mV RGB with setup (MII)

SMPTE/EBU N10

Since the non-NTSC regions have standardized on +700 mV video and -300 mV sync, this is the component interconnect standard in use in most non-NTSC regions. (See Figure 55.)

The SMPTE/EBU component standard specifies that the Y (luminance) signal is on channel one, the blue color difference signal is on channel two, and the red color difference signal is on channel three. Since luminance carries the sync information in color difference formats, and green carries the sync information in RGB, hardware compatibility is achieved by putting the green signal on channel one. Sync will thus always be on the same channel. (Although SMPTE RGB has sync on all channels, this is not always the case in other RGB formats.)

For similar reasons, the blue signal is put on channel two like the blue color difference signal, and the red signal is put on channel three like the red color difference signal. It therefore seems appropriate to call the SMPTE format “GBR’’ rather than “RGB.’’ In the rest of this appendix, we will use the term GBR. Time will tell which term remains in common usage.

NTSC-RELATED

The NTSC system has two characteristics that may lead to differences in the related GBR interconnect: the 10:4 video-to-sync ratio and black-level setup. Setup is usually added as part of the encoding process, so GBR signals coming directly from a camera generally do not have setup. In this case, the non-composite GBR is at 714 mV peak. If sync is added in this system, it will be at –286 mV. (Sync is usually taken from the green channel, although it may be added to all three.) Prior to the advent of component video, this was the common GBR interconnect in NTSC regions. (See Figure 56.)

If an NTSC signal is decoded, and the resulting GBR is normalized to 714 mV peak, setup is included on GBR. Setup may also be added on non-decoded feeds to gain compatibility among various GBR sources. In this case, each of the GBR signals will have the same levels as luminance in NTSC. Another source of 714 mV GBR with setup is translated Betacam® format component signals. (See Figure 57.)

MII

Simple transcoding of an MII format signal that has setup will yield GBR with 700 mV peak and 52.5 mV setup. This is essentially the SMPTE/EBU N10 component signal with setup added. (See Figure 58.)

The specifications for these four GBR standards are summarized in Table I.

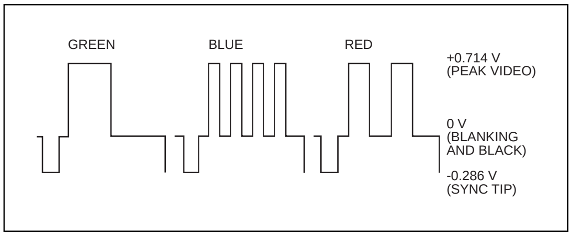


Figure 56. NTSC-related 100% amplitude GBR color bar signal (without setup).

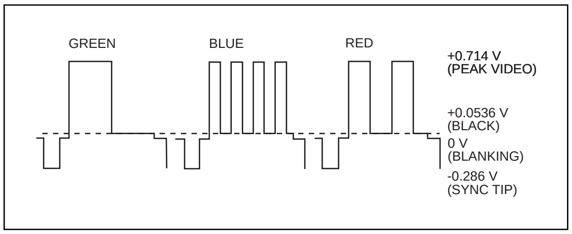


Figure 57. NTSC-related 100% amplitude GBR color bar signal (with setup).

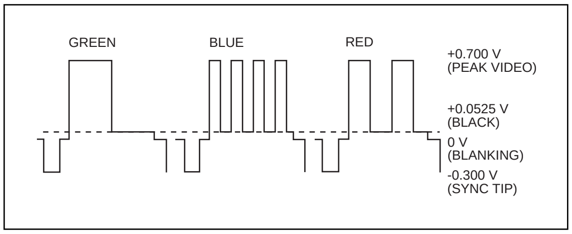


Figure 58. MII 100% amplitude color bar signal (with setup), simply translated to GBR.

	SMPTE/EBU N10	NTSC (no setup)	NTSC (setup)	MII
Max	700 mV	714 mV	714 mV	700 mV
Min	0 mV	0 mV	54 mV	53 mV
Range	700 mV	714 mV	660 mV	647 mV
Sync	–300 mV	–286 mV	–286 mV	–300 mV
P-P	1 V	1 V	1 V	1 V

Table I. Specifications for the Four GBR Standards.

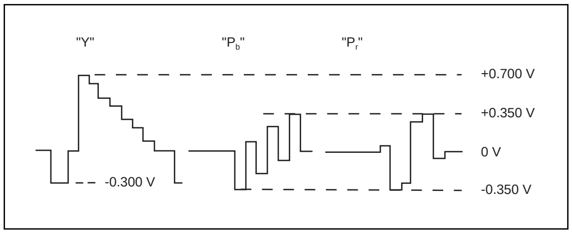


Figure 59. SMPTE/EBU N10 100% amplitude component color bar signal.

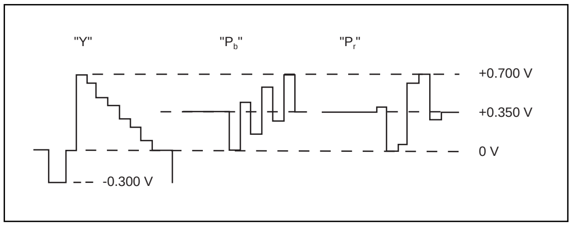


Figure 60. The SMPTE/EBU N10 color bar signal in Figure 59 with the color difference signals offset by +350 mV to match the luminance range.

While the different standards described in this section are quite similar, they are not strictly compatible. The differences in peak level (700 mV vs. 714 mV) will not, in themselves, make very noticeable errors in displayed light levels, but incompatibility in setup will make quite noticeable differences in the displayed images. (An error of 7.5% at black will be very apparent.) In addition, the change in peak-to-peak video amplitude (voltage range from black to peak white) required to accommodate setup is noticeable in peak white areas of the image.

For example: a picture monitor calibrated for a no-setup signal will display peak whites at about 83% relative light output if driven with a 7.5% setup signal. The opposite case (monitor calibrated for a setup signal, but used with a no-setup signal) will have display highlights about 21% higher than normal. (These numbers apply if the displayed black level has been appropriately readjusted, but the monitor gain has not been recalibrated.)

Until such time as GBR interconnect levels are really standardized, it’s important to make certain that each GBR feed is appropriate for the input specifications of the equipment it drives.

The Color Difference Standards

The three color difference CAV interconnect standards you're likely to encounter are:

- SMPTE/EBU N10
- Betacam®
- MII

SMPTE/EBU. The SMPTE/EBU standards for color difference format component analog video is much like its GBR counterpart. Each of the signal wires carries a 700 mV video signal, there is no black-level setup, and sync tip is at –300 mV.

Sync is only on the Y (luminance) channel, which is channel one. The blue color difference signal, P_B, is on channel two, and the red color difference signal, P_R, is on channel three. (See Figure 59.)

It's often convenient to display the P_B and P_R signals with the reference level offset to +350 mV on the display so all signals occupy the same range on the waveform display. (See Figure 60.)

The color difference signals are the familiar B-Y and R-Y, normalized for 700 mV peak-to-peak on a 100% amplitude color bar signal. Except for gain differences, these signals are identical to the U and V signals in PAL.

Betacam®. The NTSC-related Betacam® format uses 714.3 mV peak video and includes 7.5% setup in the luminance channel. To maintain the 1 V p-p amplitude of the composite format, sync tip on luminance is –286 mV. The color difference channels, however, have a range of 933.3 mV (4/3 times the 700 mV range of SMPTE/EBU N10). (See Figure 61.)

In some cases, Betacam® equipment must be calibrated using 75% amplitude color bars. In the 75% luminance signal, the black-to-white video range is reduced from 660 mV to 495 mV. (The 54 mV setup brings peak white to 549 mV.) The color difference signals are reduced from 933 mV to 700 mV. (See Figure 62.) Please refer to the manufacturer's documentation to determine proper calibration levels and test signals.

The Betacam® SP format is compatible with Betacam® and has extended capabilities. The 12-pin "dub" cable three-wire inter-connect is compatible with standard Betacam®. In addition, BNC connectors provide a three-wire component output that is compatible with the SMPTE CAV standard.

MII. The three signals in MII are luminance, scaled B-Y, and scaled R-Y. In 50 Hz regions, MII three-wire interconnect complies with SMPTE/EBU N10 standards (700 mV p-p in each channel for a 100% color bar signal).

In 60 Hz (NTSC) markets, black-level setup will be recorded and played back if it exists on the input signals. In this NTSC-related component standard, the luminance peak is limited to 700 mV (not 714 mV). When setup is included on luminance, the black-to-white range is restricted to 647.5 mV (700 mV minus the setup), and the color difference signals are also rescaled to 647.5 mV, giving them the same range as the active luminance channel. (See Figure 63.)

The alignment tape for MII uses a 75% amplitude color bar with a 100% white reference level. (See Figure 64.)

The recorded MII signal includes 2.25 MHz timing bursts. Because these timing bursts are generated in the CTCM (Chrominance Time Compressed Multiplex) circuitry, they are included in the two-wire dub interconnect but are not part of the three-wire input or output signals.

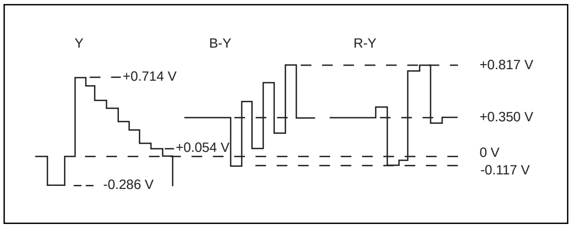


Figure 61. NTSC-related (60 Hz) Betacam® 100% amplitude component color bar signal.

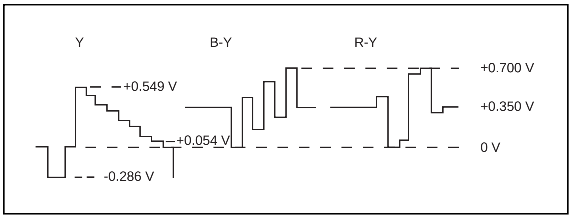


Figure 62. NTSC-related (60 Hz) Betacam® 75% amplitude component color bar signal.

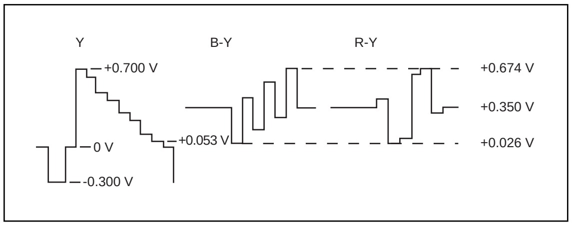


Figure 63. MII 100% amplitude component color bar signal (with setup).

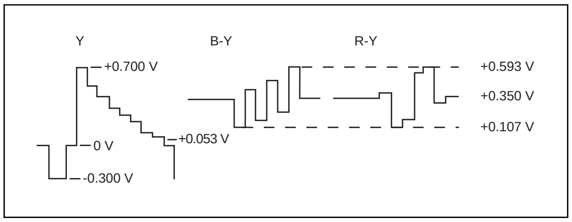


Figure 64. MII 75% amplitude, 100% white bar component color bar signal (with setup).

The specifications for these three CAV standards are summarized in Tables II and III.

	SMPTE/EBU N10	**Betacam®**	**MII®**
Luminance			
100%	700 mV	714 mV	700 mV
Max	700 mV	714 mV	700 mV
Min	0 mV	54 mV	53 mV
Range	700 mV	660 mV	648 mV
Chrominance			
Max	350 mV	467 mV	324 mV
Min	– 350 mV	– 467 mV	– 324 mV
Range	700 mV	934 mV	648 mV
Sync	– 300 mV	– 286 mV	– 300 mV
P-P	1 V	1 V	1 V

Table II. Specifications for 100% Color Bars in the Three CAV Standards.

	SMPTE/EBU N10	**Betacam®**	**MII®**
Luminance			
100%	700 mV	714 mV	700 mV
Max	525 mV	549 mV	539 mV[a]
Min	0 mV	54 mV	53 mV
Range	525 mV	495 mV	486 mV
Chrominance			
Max	262.5 mV	350 mV	243 mV
Min	– 262.5 mV	– 350 mV	– 243 mV
Range	525 mV	700 mV	486 mV
Sync	– 300 mV	– 286 mV	– 300 mV
P-P	1 V	1 V	1 V
[a] As shown in Figure 64, the 75% color bars include a 100% (700 mV) white level.			

Table III. Specifications for 75% Color Bars in the Three CAV Standards.

Note: Terms used in definitions that are defined elsewhere in this glossary are printed in italics.

A-to-D CONVERTER, ADC — A device used to convert *analog* signals to *digital* signals.

ANALOG, ANALOG COMPONENTS — Video signals in which a continuously variable voltage or current (rather than a set of numbers) represents the value of a *pixel*. (The same as CAV.)

BETACAM®, BETACAM® FORMAT — A camera/ recorder system and related equipment originally developed by Sony, the name may also be used for just the recorder or for the *interconnect format*. Betacam® uses a version of the (Y, R-Y, B-Y) component set.

BETACAM® SP — A Superior Performance version of *Betacam®* that uses metal particle tape and a wider bandwidth recording system. The *interconnect standards* are the same as Betacam®, and there is also limited tape interchangeability with standard Betacam®.

BRIGHTNESS SIGNAL — Same as the *luminance* signal (Y). This signal carries information about the **amount** of light at each point in the image.

CAV — Component Analog Video. *Component* video signals in which an analog voltage or current represents the value of a pixel. (The same as *Analog Components*.)

CHROMA KEY — The process of controlling the replacement of part of a video image with a second image. The control signal is developed from characteristics of the *chrominance* of a video signal.

CHROMINANCE SIGNAL, CHROMA — The modulated subcarrier sidebands in a composite video signal. Also used to describe the *color difference signals* in a *component* system — that is, those carrying information about the hue (which color) and saturation (how much color) in a *pixel*.

COLOR CORRECTION — A process by which the coloring in a television image is altered or corrected electronically. Care must be taken to insure that the modified video does not exceed the limits of subsequent processing or transmission systems.

COLOR DIFFERENCE SIGNALS — Video signals which convey only color information: For example, unmodulated R-Y and B-Y, I and Q, U and V, P_R and P_B, etc.

COMPONENT VIDEO SIGNALS — A set of signals, each of which represents a portion of the information needed to generate a full color image: For example: R, G, and B; Y, I, and Q; or Y, R-Y, and B-Y.

COMPOSITE COLOR SIGNAL — A signal consisting of combined *luminance* and *chrominance* information using frequency domain multiplexing. For example, *NTSC* or *PAL* video signals.

CROSS COLOR — Spurious signals resulting from high frequency *luminance* information being interpreted as color information in decoding a *composite* signal. Typical examples are “rainbows” on venetian blinds, striped shirts, etc.

CROSS LUMINANCE — Spurious signals occurring in the Y channel as a result of *composite chroma* signals being interpreted as *luminance*, such as “dot crawl” or “busy edges” on colored areas.

D-to-A CONVERTER, DAC — A device used to convert *digital* signals to *analog* signals.

DECODER — A device used to recover the *component* signals from a *composite* (encoded) source. Decoders are used in displays and in various processing hardware where component signals are required from a composite source, such as composite *chroma keying* or *color correction* equipment.

DIGITAL COMPONENTS — *Component* signals in which the values for each *pixel* are represented by a set of numbers.

EBU — European Broadcasting Union.

ENCODER — A device used to form a single (*composite*) color signal from a set of *component* signals. An encoder is used whenever a composite output is required from a source (or recording) which is in component *format*.

FORMAT, INTERCONNECT FORMAT — The configuration of signals used for interconnection of equipment in a specified system. Different formats may use different signal composition, reference pulses, etc.

GBR, GBR FORMAT — The same signals as *RGB*. The sequence is rearranged to indicate the mechanical sequence of the connectors in the *SMPTE standard*.

GAMUT — The range of voltages allowed for a video signal, or a *component* of a video signal. Signal voltages outside of the range (that is, exceeding the gamut) may lead to clipping, crosstalk, or other distortions.

INTERCONNECT FORMAT — See FORMAT.

INTERCONNECT STANDARD — See STANDARD.

KEYING — The process of replacing part of one television image with video from another image; that is, *chroma keying* and insert keying.

LEGAL SIGNAL — A video signal in which each *component* remains within the limits specified for the video signal *format*; that is, it doesn’t exceed the specified *gamut* for the current format.

LUMINANCE SIGNAL (Y) — The video signal that describes the amount of light in each *pixel*; equivalent to the signal provided by a *monochrome* camera, Y is often generated as a weighted sum of the R, G, and B signals.

MII (M2), MII FORMAT — Second generation camera/recorder system developed by Panasonic; also used for just the recorder or the *interconnect format*. MII uses a version of the (*Y, R-Y, B-Y*) component set.

MAC (MULTIPLEXED ANALOG COMPONENTS) — A system in which the *components* are time multiplexed into one channel using time domain techniques; that is, the components are kept separate by being sent at different times through the same channel. There are many different MAC *formats* and *standards*.

MONOCHROME SIGNAL — A "single color'' video signal — usually a black and white signal but sometimes the *luminance* portion of a *composite* or *component* color signal.

NEUTRAL COLORS — The range of gray levels, from black to white, but without color. For neutral areas in the image, the RGB signals will all be equal; in color difference formats, the *color difference signals* will be zero.

NTSC (NATIONAL TELEVISION SYSTEM COMMITTEE) — The organization that formulated the "NTSC'' system. Usually taken to mean the NTSC color television system itself, or its *interconnect standards*.

PAL (PHASE ALTERNATE LINE) — A *composite* color *standard* used in many parts of the world. The phase alternation makes the signal relatively immune to certain distortions (compared to NTSC).

PIXEL — Picture element, or PIX ELement. Related to a particular image address in *digital component* systems or to the smallest reproducible element in *analog* systems.

PRIMARY COLORS — Colors, usually three, that are combined to produce the full range of other colors within the limits of a system. All non-primary colors are mixtures of two or more of the primary colors. In television, the primary colors are specific sets of red, green, and blue.

RGB, RGB FORMAT, RGB SYSTEM — The basic parallel *component* set (Red, Green, and Blue) in which a signal is used for each primary color. Also used to refer to the related equipment, *interconnect format*, or *standards*. The same signals may also be called "GBR'' as a reminder of the mechanical sequence of connections in the *SMPTE* interconnect standard.

RISE TIME — The time taken for a signal to make a transition from one state to another — usually measured between the 10% and 90% completion points on the transition. Shorter or "faster'' rise times require more bandwidth in a transmission channel.

S-MAC — A *MAC* standard proposed for studio intraconnection by the *SMPTE* working group on Component Analog Video (*CAV*) Standards. The S-MAC system uses time compression and time domain multiplexing techniques to convey (Y, C_R, C_B) video signals — a version of (*Y, R-Y, B-Y*).

SMPTE — Society of Motion Picture and Television Engineers.

SMPTE FORMAT, SMPTE STANDARD — In *component* television, these terms refer to the SMPTE standards for parallel component *analog* video interconnection. The SMPTE has standardized both an RGB system and a (Y, P_R, P_B) color difference system — a version of (*Y, R-Y, B-Y*).

STANDARD, INTERCONNECT STANDARD — The specific signal configuration, reference pulses, voltage levels, etc., that describe the input/output requirements for a particular type of equipment. Some standards have been established by professional groups or government bodies (such as *SMPTE* or *EBU*). Others are determined by equipment vendors and/or users.

VALID SIGNAL — A video signal that will remain legal when translated to any other *format*. A valid signal is always legal, but a legal signal is not necessarily valid. Signals that are not valid will be processed without problems in their current format, but problems may be encountered if the signal is translated to a new format.

Y, C1, C2 — A generalized set of *CAV* signals: Y is the *luminance* signal, C1 is the 1st *color difference signal*, and C2 is the 2nd color difference signal.

Y, I, Q — The set of *CAV* signals specified for the *NTSC* system: Y is the *luminance* signal, I is the 1st *color difference signal*, and Q is the 2nd color difference signal.

Y, P_B, P_R — A version of (*Y, R-Y, B-Y*) specified for the *SMPTE analog component* standard.

Y, R-Y, B-Y — The general set of *CAV* signals used in the *PAL* system as well as for some encoder and most decoder applications in *NTSC* systems. Y is the *luminance* signal, R-Y is the 1st *color difference signal*, and B-Y is the 2nd color difference signal.

Y, U, V — *Luminance* and color difference components for *PAL* systems. Y, U, and V are simply new names for *Y, R-Y*, and *B-Y*; the derivation from *RGB* is identical.

For further information, contact Tektronix:

World Wide Web: http://www.tek.com; **ASEAN Countries** (65) 356-3900; **Australia & New Zealand** 61 (2) 888-7066; **Austria, Eastern Europe, & Middle East** 43 (1) 7 0177-261; **Belgium** 32 (2) 725-96-10;
Brazil and South America 55 (11) 3741 8360; **Canada** 1 (800) 661-5625; **Denmark** 445 (44) 850700; **Finland** 358 (9) 4783 400; **France & North Africa** 33 (1) 69 86 81 08; **Germany** 49 (221) 94 77-400;
Hong Kong (852) 2585-6688; **India** 91 (80) 2275577; **Italy** 39 (2) 250861; **Japan** (Sony/Tektronix Corporation) 81 (3) 3448-4611; **Mexico, Central America, & Caribbean** 52 (5) 666-6333;
The Netherlands 31 23 56 95555; **Norway** 47 (22) 070700; **People's Republic of China (**86) 10-62351230; **Republic of Korea** 82 (2) 528-5299; **Spain & Portugal** 34 (1) 372 6000; **Sweden** 46 (8) 629 6500;
Switzerland 41 (41) 7119192; **Taiwan** 886 (2) 765-6362; **United Kingdom & Eire** 44 (1628) 403300; **USA** 1 (800) 426-2200

From other areas, contact: Tektronix, Inc. Export Sales, P.O. Box 500, M/S 50-255, Beaverton, Oregon 97077-0001, USA (503) 627-1916

ISO 9001

6/97 FL2901/XBS 25W–7009–2