A Guide to Standard and High-Definition Digital Video Measurements

3G, Dual Link and ANC Data Information

Tektronix

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In The Beginning

It is tempting to think of digital television as something very scientific and even complex. But when we view the end result, we find something very familiar; something television engineers have sought since the very beginning… an experience that just keeps getting better and better… quality video and audio conveying the artist's performance to the viewing audience. The only thing new in digital television is the way the message gets from here to there.

Does it really matter how the message travels? The artist and the viewer (and in many countries, the advertiser) probably don't care what path the signal takes. They can benefit from digital television's improved performance without knowing the details. Ah, but the science…. that's where the fun comes in. Those of us involved in the technical side of television do care; and we do benefit from the significant advances in television science over the past 60+ years… and in particular the advances brought about by digital television over the past 20 years.

Program video, digital audio, and associated ancillary data signals together make up the digital television signal. In the analog world of television, video and audio can exist in totally separate paths from source to the home television receiver. Digital signals may be organized with much more freedom, with video, audio, and other signals working together as a stream of data. All we need to know is how the data is organized to pick out what we want.

Traditional television

We can call analog video and analog audio the elements of traditional television. But it is important to realize we are still trying to accomplish the traditional goals… and maybe more. Digital television builds on analog, and our understanding of digital television builds on what we already know about analog television. Light into the camera lens and sound into the microphone, are still analog. Light from the display and sound to your ears are still analog phenomena.

We already know that analog video is a "sampling" of light values. Values of brightness represented by a voltage. And additional information provides the color of the samples. The samples are synchronized through the transmission system to reproduce an image of the original scene on our display. Analog video travels as a "serial" stream of voltage values containing all of the "data" necessary to make a picture when the receiver knows what to do with the information. So you can see that by just substituting a few words, and by just doing a few things differently to take advantage of what we have learned over the past fifty years, we can understand that digital video is really not very different than analog video.

So if we start with analog light and end with analog light, why use digital video at all? In many cases, the camera sensor is still producing analog video, but it is now common to almost immediately convert the varying analog voltage representing the instantaneous value of video to digital for handling with essentially no degradation. In some cases, such as computer-generated video or graphics, the video will start out in digital format, and with the new digital television systems, it can reach the display never going to analog.

We can still send and receive television signals via analog NTSC, PAL, or SECAM transmissions, but we are already using digital transmissions to convey higher quality, more efficient television signals to the home. Digital television is an available part of everyday life. Some of us will use it and contribute to its improvement. Some of us will take advantage of it without needing to know the details.

The "New" Digital Television

Digital signals have been a part of television for many years, at first buried inside equipment such as test signal and character generators; later throughout entire systems. In this primer, we will deal first with the video portion of the television signal for simplicity. Audio will be digital as well, and will take its place in the digital data stream for recovery at the television receiver. Digital audio will be discussed in later chapters.

Digital video is a simple extension of analog video. Once we understand analog video, it is easy to understand how digital video is created, handled, processed, and converted to and from analog. Analog and digital video have many of the same constraints, and many of the problems that may occur in the digital domain are a result of incorrect analog source video. Therefore, it is important to have standards to reference for the design and operation of both analog and digital video devices.

Numbers describing an analog world

Early digital video was merely a digital description of the analog NTSC or PAL composite analog video signal. Standards were written to describe operating limits and specify the number data describing each voltage level and how each number was generated and recovered. Because of the high speed of the data, it was common to handle digital video data internally on an eight- or ten-bit bus, and initial standards described a multi-wire external connection as well. The standards also described certain ancillary and housekeeping data to synchronize the receiver and the transported data, and to permit additional services such as embedded audio. Later, as higher processing speeds became practical, a single wire composite serial interface standard was developed. In its basic form, digital video is a numeric representation of analog voltage, with number data occurring fast enough to accommodate changing video and necessary ancillary data.

Component digital video

The designers of early analog special effects equipment recognized the advantage of keeping the red, green, and blue video channels separate as much as possible during any processing. The NTSC and PAL encoding/decoding process is not transparent and multiple generations of encoding and decoding progressively degrade the signal. The signal in the camera starts out with independent channels of red, green, and blue information, and it is best to handle these signals through the system with as few format generations as possible before encoding them into NTSC or PAL for transmission to the home. But handling three separate coordinated channels of information through the television plant presents logistic and reliability problems. From a practical standpoint, these three signals should all coexist on one wire, or commonly a single coaxial cable. As it turns out, we can simply matrix these three components, the red, green, and blue video channels, to a more efficient set consisting of luma and two color-difference signals; digitize each of them, and multiplex the data onto a single coaxial cable. We can handle this data signal much as we do traditional NTSC or PAL composite video. Now we are handling a high-speed stream of numeric data. Although this data signal contains energy changing at a much faster rate than the 5 to 6 MHz energy in an NTSC or PAL video signal, it can be handled losslessly and with less maintenance over reasonable distances. Once the video signal is in the digital domain, we can easily extract its components for individual processing and recombine them again in the digital domain without any further loss or interaction among the channels.

Component and digital techniques contribute significant advantages in video quality control, and the speed of digital devices has made the bandwidth of high-definition video practical. Digital also lends itself to processing with various compression algorithms to reduce the total amount of data needed. It is now possible to convey high-definition video and associated multichannel audio in the bandwidth required for high-quality real-time analog video. The subject of video compression is covered in many publications (see Bibliography) and will not be addressed in this primer.
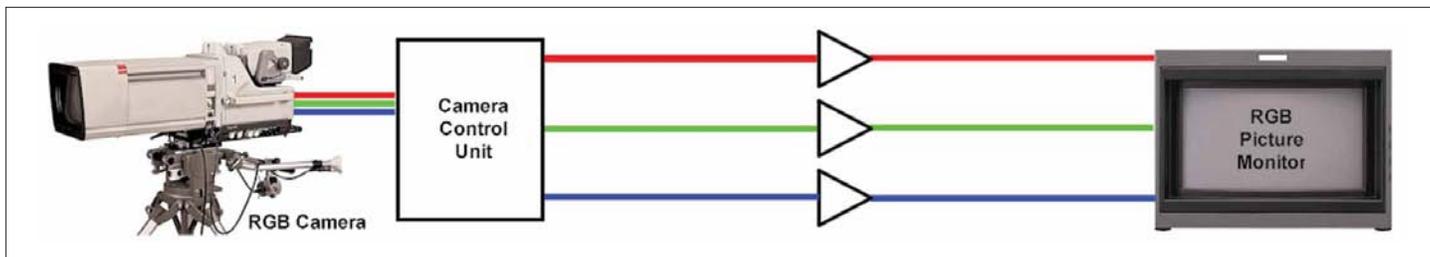
Figure 1. RGB from the camera with direct connections to the monitor.

Moving Forward from Analog to Digital

The digital data stream can be easily broken down into its separate components, often serving the same function as their analog counterparts. We will continue with this analogy as we describe and compare the analog and digital video domains. Once we clearly understand the similarity between analog and digital video we can move to HDTV, which is often a digital representation of the corresponding high-definition analog format.

NTSC and PAL video signals are composites of the three camera channels, the primary color components red, green, and blue, matrixed together to form a luminance channel summed with the modulation products of a suppressed subcarrier containing two channels of color information. A third system of single-channel composite transmission is the SECAM system, which uses a pair of frequency-modulated subcarriers to convey chroma information. In the studio, there is no specific requirement that the signal be NTSC, PAL, or SECAM at any point between the camera RGB pickup devices and the RGB channels of the final display device. While an understanding of NTSC, PAL, or SECAM is useful, we need not invest in any new study of composite video.

The RGB component signal

A video camera splits the light of the image into three primary colors – red, green, and blue. Sensors in the camera convert these individual monochrome images into separate electrical signals. Synchronization information is added to the signals to identify the left edge of the picture and the top of the picture. Information to synchronize the display with the camera may be added to the green channel or occasionally added to all three channels, or routed separately.

The simplest hookup, as shown in Figure 1, is direct R, G, and B, out of the camera, into the picture monitor. The multi-wire transmission system is the same for analog standard or analog high-definition video. A multi-wire connection might be used in small, permanently configured sub-systems.

This method produces a high-quality image from camera to display, but carrying the signals as three separate channels, involves the engineer to ensure each channel processes the signals with the same overall gain, direct curent (dc) offset, time delay, and frequency response. A gain inequality or dc offset error between the channels will produce subtle changes in the color of the final display. The system could also suffer from timing errors, which could be produced from different lengths of cable or different methods of routing each signal from camera to display. This would produce timing offset between the channels producing a softening or blurring in the picture – and in severe cases multiple, separated images. A difference in frequency response between channels would cause transient effects as the channels were recombined. Clearly, there is a need to handle the three channels as one.
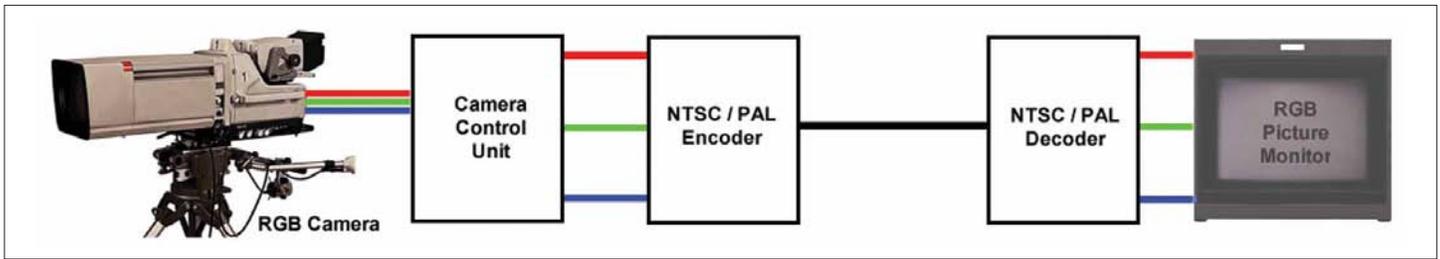
Figure 2. Video encoded to NTSC or PAL for transmission on a single coaxial cable.
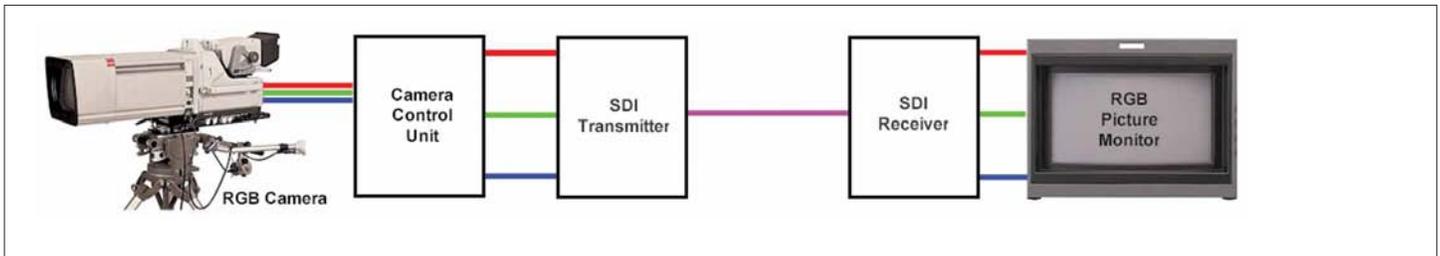
Figure 3. Digital transmission avoids analog signal degradation.

Insertion of an NTSC or PAL encoder and decoder (Figure 2) does nothing for simplicity except make the signal easier to handle on one wire within the television plant. System bandwidth is compromised in a friendly way to contain the energy of the three video signals in 4.2 MHz (NTSC) or 5.0 to 5.5 MHz (PAL). The single-wire configuration makes video routing easier, but frequency response and timing must be considered over longer paths. Because both chroma and luma in the NTSC or PAL composite signal share the 4.2 MHz, 5.0 or 5.5 MHz, multiple generations of encoding and decoding must be avoided.

By substituting component digital encoders and decoders, the hookup (Figure 3) is no more complex and is better in perform-ance. Energy in the single coaxial cable is now at a data rate of 270 Mb/s for standard definition signals; 1.485 Gb/s or higher for high-definition signals. Standard definition signals could be converted to analog NTSC or PAL for transmission within traditional broadcast television channels. High-definition signals must be compressed for on-air transmission within the channel bandwidth of existing NTSC or PAL channels.

Gamma correction

An analog factor to be considered in the handling of the video signal is the perception that the video display is accurately reproducing the brightness of each element of the scene. The Cathode Ray Tube (CRT) display is an inherently non-linear device and therefore, the amount of light output is a non-linear function of the voltage applied to the display. This function is called the gamma of the device. In order to produce a linear response, a correction factor must be applied within the TV System. Therefore, the RGB signals in the camera are gamma-corrected with the inverse function of the CRT. Gamma-corrected signals are denoted R', G', and B'; the prime mark (') indicating a correction factor has been applied to compensate for the transfer characteristics of the pickup and display devices. Although the prime mark may appear a bit cumbersome, and is sometimes incorrectly omitted, it will be used throughout this primer for correlation with standards documents.

New LCD and Plasma display technologies are becoming more prevalent today, so one would think that gamma correction would not be needed in the future. However, the human visual response to luminance is also a power function; approximate intensity raised to the 1/3 power. For best contrast representation and signal to noise (S/N), video encoding uses this same power function. This is called conceptual coding.
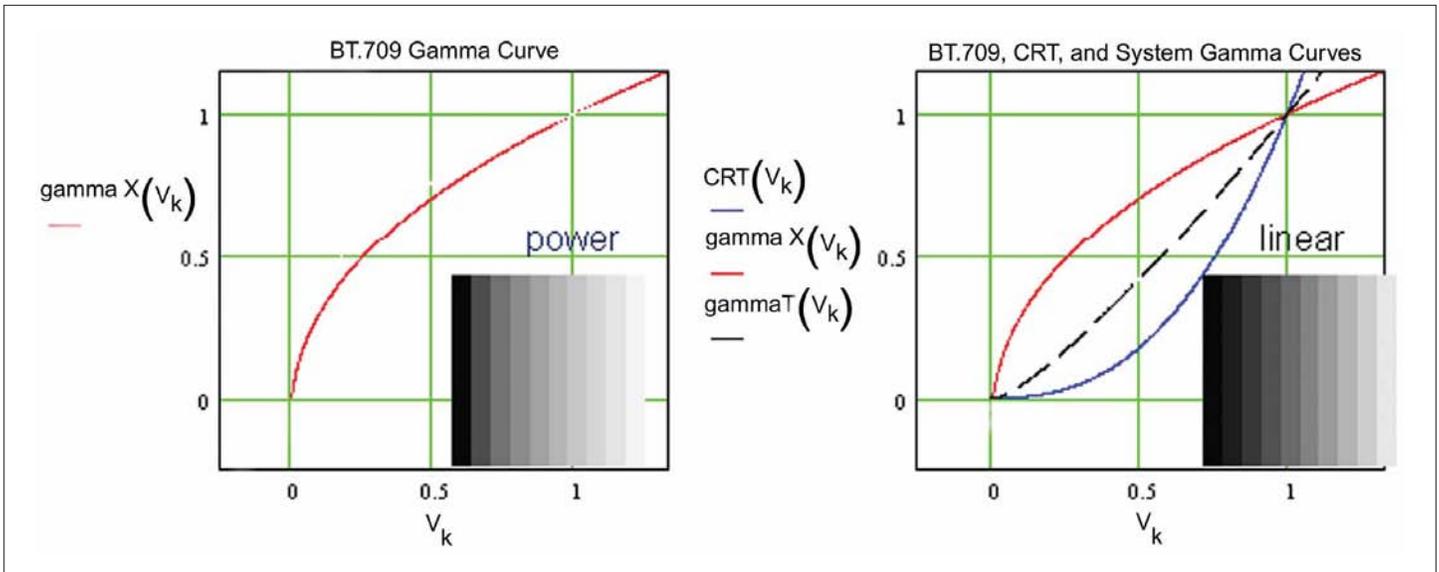
Figure 4. BT.709 gamma correction complements CRT display response.

Gamma correction is more than correction for CRT response

The gamma correction needed for the CRT is almost optimal for conceptual correction. For this reason, care should be taken when evaluating systems where correction factors have been applied within the devices for gamma correction.

Figure 4 shows the gamma correction as a power function of 0.45 as specified in ITU-R BT.709, a predominant standard for digital high-definition video. This gamma correction is applied at the camera to correct for nonlinearities at the CRT and provide conceptual coding. Nonlinearities in the CRT exist as a power function between 2.2 to 2.6, and most CRTs have a value of about 2.5. The resulting total system gamma is about 1.2, which is nearly ideal for typical viewing conditions. This response roughly corrects for human lightness perception, which in turn reduces the number of bits required when the video signal is digitized for transmission.

Conversion of R'G'B' into luma and color-difference

Video components red, green, and blue are native to the camera pickup devices and are almost always used by operators in managing video color. RGB, however, is not the most bandwidth-efficient method of conveying the image during video processing because all three components must be equal bandwidth. Human vision is more sensitive to changes in luminance detail than to changes in color, so we can improve bandwidth efficiency by deriving full bandwidth luma information and allot any remaining available bandwidth to color-difference information.

Processing of the video signal components into luma and color-difference values reduces the amount of information that must be conveyed. By having one full bandwidth luma channel (Y') represent the brightness and detail of the signal, the two color-difference channels (R'-Y' and B'-Y') can be limited to about half the luma channel bandwidth and still provide sufficient color information. This allows for a simple linear matrix to convert between R'G'B' and Y', R'-Y', B'-Y'. Bandwidth limiting of the color-difference channels is done after the matrix. When the channels are restored to R'G'B' for display, brightness detail is

Y', R'-Y', B'-Y' commonly used for analog encoding		
Format	1125/60/2:1, 720/60/1:1	525/59.94/2:1, 625/50/2:1, 1250/50/2:1
Y'	0.2126 R' + 0.7152 G' + 0.0722 B'	0.299 R' + 0.587 G' + 0.114 B'
R'-Y'	0.7874 R' − 0.7152 G' − 0.0722 B'	0.701 R' − 0.587 G' − 0.114 B'
B'-Y'	−0.2126 R' − 0.7152 G' + 0.9278 B'	−0.299R' − 0.587 G' + 0.886 B'

Y', P'b, P'r analog component			
Format	1125/60/2:1 (SMPTE 240M)	1920x1080 (SMPTE 274M) 1280x720 (SMPTE 296M)	525/59.94/2:1, 625/50/2:1, 1250/50/2:1
Y'	0.212R' + 0.701G' + 0.087B'	0.2126R' + 0.7152G' + 0.0722B'	0.299R' + 0.587G' + 0.114B'
P'b	(B'-Y') / 1.826	[0.5 /(1 − 0.0722)] (B'-Y')	0.564 (B'-Y')
P'r	(R'-Y') / 1.576	[0.5 /(1 − 0.2126)] (R'-Y')	0.713 (R'-Y')

Y', C'b, C'r, scaled and offset for digital quantization		
Format	1920x1080 (SMPTE 274M) 1280x720 (SMPTE 296M)	525/59.94/2:1, 625/50/2:1, 1250/50/2:1
Y'	0.2126 R' + 0.7152 G' + 0.0722 B'	0.299 R' + 0.587 G' + 0.114 B'
C'b	0.5389 (B'-Y') + 350 mV	0.564 (B'-Y') + 350 mV
C'r	0.6350 (R'-Y') + 350 mV	0.713 (R'-Y') + 350 mV

Table 1. Luma and Chroma Video Components.

Component	Approximate value (SMPTE 170M and ITU-R BT.470-6)
Y	0.299 R' + 0.587 G' + 0.114 B'
NTSC I	−0.2680 (B' − Y') + 0.7358 (R' − Y')
NTSC Q	+0.4127 (B' − Y') + 0.4778 (R' − Y')
PAL U	0.493 (B' − Y')
PAL V	0.877 (R' − Y')
SECAM Dr	−1.902 (R' − Y')
SECAM Db	1.505 (B' − Y')

Table 2. Luma and Chroma Values for Composite Video Encoding.

R'G'B' for display, brightness detail is restored at full bandwidth and spatial color detail is limited in an acceptable manner. The following paragraphs and tables discuss the conversion process for R'G'B' to Y', R'-Y', B'-Y' that takes place within encoders and decoders.

Gamma-corrected R'G'B' components are matrixed to create gamma-corrected component luma, designated Y', and two color-difference components. The luma and color-difference components are derived from R', G' and B' to the values shown in Table 1 (the unit of each coefficient is in volts).

Table 1 shows the range of voltages for the conversion of R'G'B' to Y', (R'-Y'), (B'-Y'). The luma signal has a dynamic range of 0 to 700 mv. The color-difference signals, R'-Y' and B'-Y', may have different dynamic ranges dependent on the scaling factors for conversion to various component formats. The analog component format denoted by Y'P'bP'r is scaled so that both color-difference values have a dynamic range of ±350 mv. This allows for simpler processing of the video signals. Analog Y'P'bP'r values are offset to produce Y'C'bC'r values typically used within the digital standards. The resulting video components are a Y' or luma channel similar to a monochrome video signal, and two color-difference channels, C'b and C'r that convey chroma information with no brightness information, all suitably scaled for quantization into digital data.

A number of other color-difference formats are in use for various applications. In particular it is important to know that the coefficients currently in use for composite PAL, SECAM, and NTSC encoding are different, as shown in Table 2.
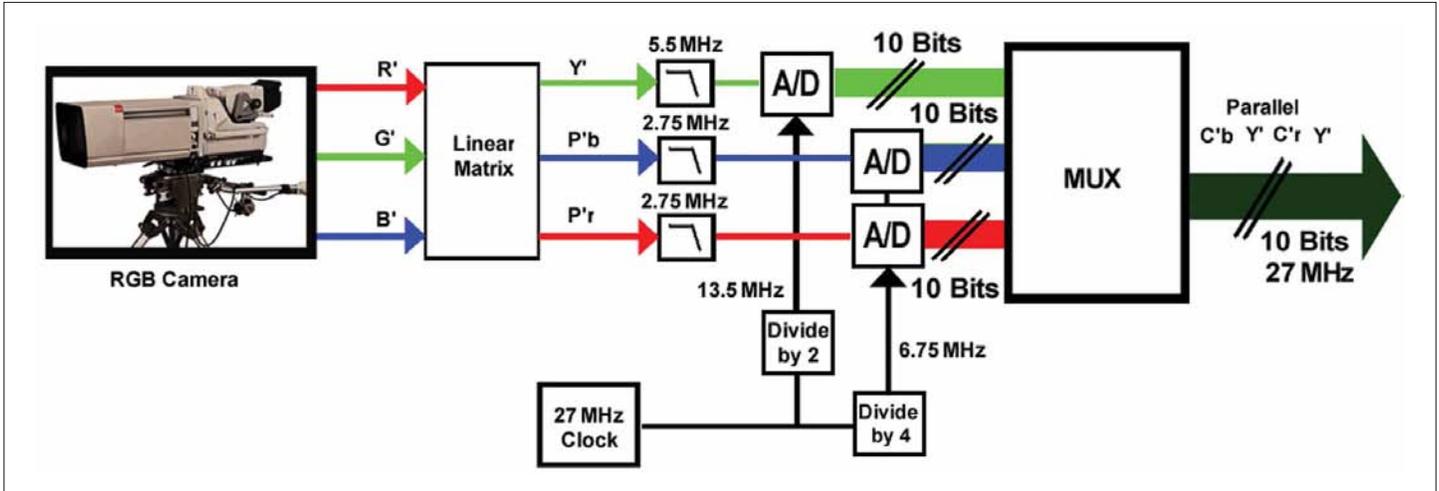
Figure 5. Digitizing RGB camera video.

The Digital Video Interface

A quick overview of the digital interface connecting our analog world of video is appropriate at this point. The block diagrams in Figures 5 through 8 can help you understand how video production equipment handles digital component video signals. Although these block diagrams illustrate a standard definition system, the concept holds for high-definition formats. In high-definition formats, sampling and data rates will be faster and separate 10-bit busses for luma and chroma may be maintained further through the system to minimize the amount of circuitry operating at high data rates.

Gamma-corrected RGB (Figure 5) is converted in a linear matrix to a luma component, Y', and two scaled chroma components, P'b and P'r. Since the eye is more sensitive to changes in brightness (detail) than to changes in hue, the Y' signal will be carried through the system at a higher bandwidth (5.5 MHz in standard definition). The luma and chroma signals are low-pass filtered to eliminate higher video frequencies that might cause aliasing in the sampling (digitizing) process. The filtered luma signal is sampled at a rate of 13.5 MHz in an analog-to-digital converter to produce a 10-bit data stream at 13.5 Mb/s. The two chroma channels are filtered, then sampled at 6.75 MHz in analog-to-digital converters to produce two data streams at 6.75 Mb/s. The three video channels are multiplexed to a single 10-bit parallel data stream at 27 Mb/s.
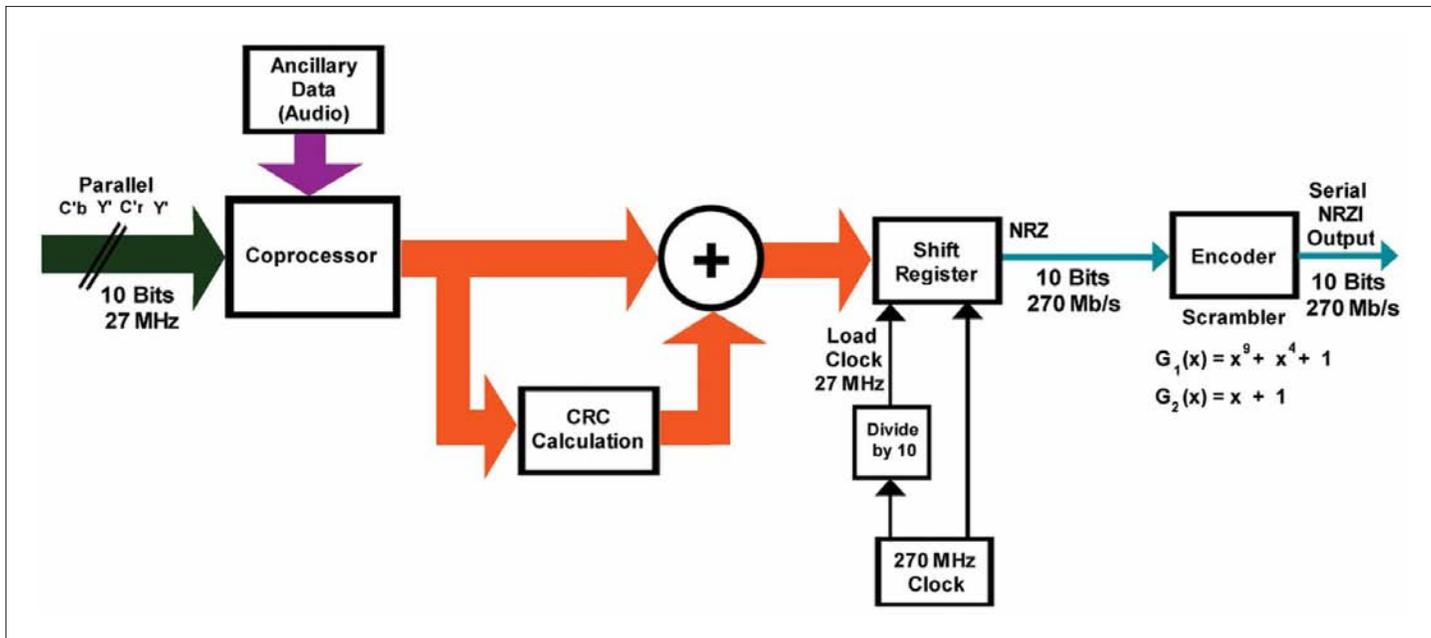
Figure 6. Processing and serializing the parallel data stream.
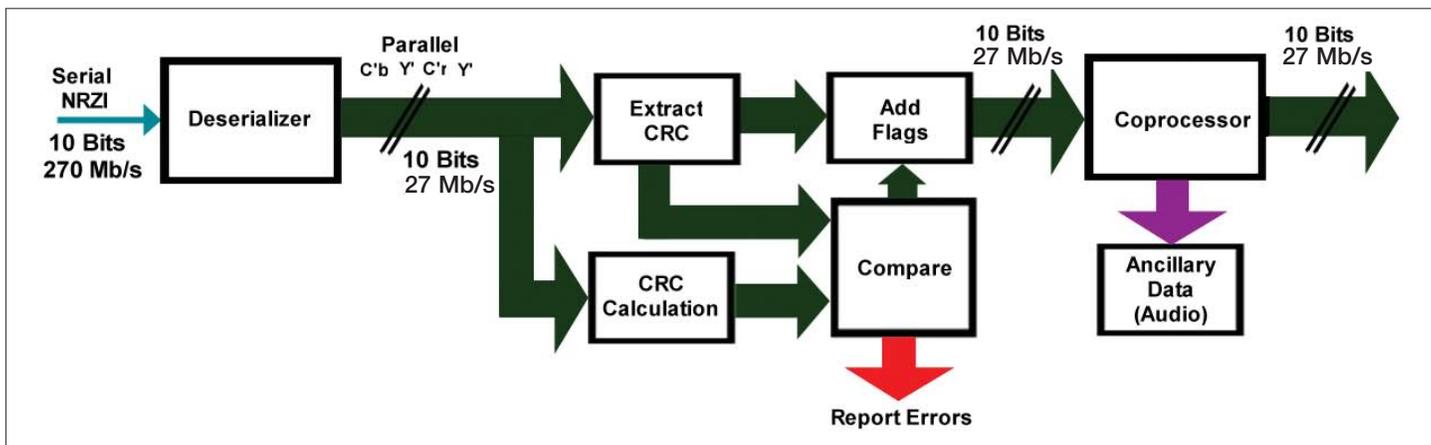
Figure 7. SDI Receiver – deserializes the video data to parallel.

A co-processor (Figure 6) is used to add timing reference signals, AES/EBU formatted digital audio, and other ancillary data. A checksum is calculated for the data and added to the parallel data stream.

The 27 Mb/s, 10-bit parallel data is then loaded into a shift register, or serializer, where it is clocked out at a 270 Mb/s rate and scrambled for efficient transmission compliant with, in this example, standard definition ITU-R.BT-656/SMPTE 259M.

Standard definition ITU-R.BT.656/SMPTE 259M compliant signals can be carried by standard video cables up to about 300 meters (approximately 1,000 feet) with near 100% data integrity. high-definition SMPTE 292M compliant signals at a data rate of 1.485 Gb/s are limited to about 100 meters (approximately 300 feet).

At the receiver (Figure 7), energy at half-clock frequency is sensed to apply an appropriate analog equalization to the incoming 270 Mb/s data signal. A new 270 MHz clock is recovered from the NRZI (Non-Return to Zero Inverse) signal edges, and the equalized signal is sampled to determine its logic state. The
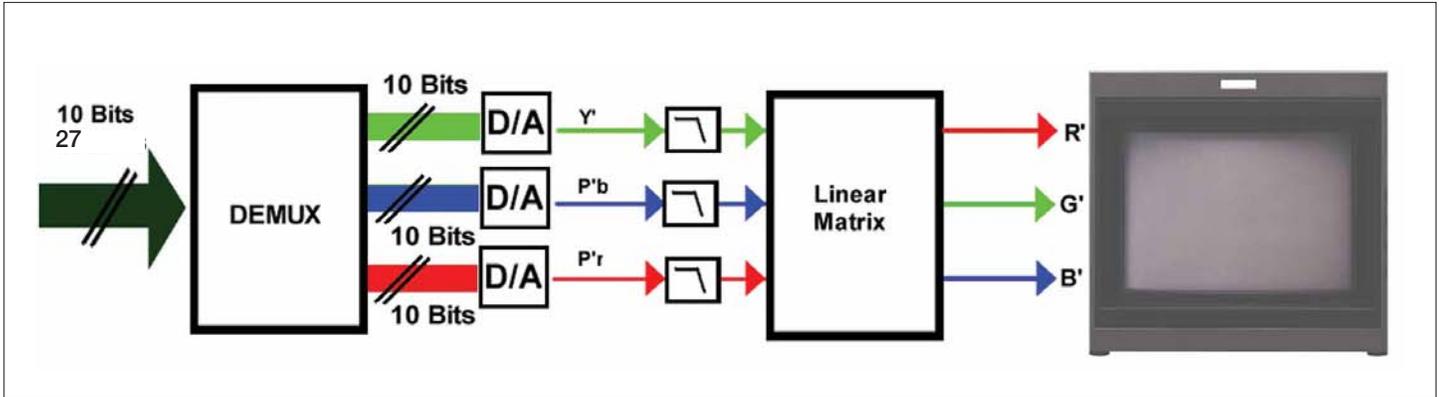
Figure 8. Recovering analog R'G'B' from parallel data.

deserializer unscrambles the data using an algorithm complementary to the encoder's scrambling algorithm and outputs a 10-bit data stream at 27 Mb/s. The embedded checksum is extracted by the receiver and compared with a new checksum produced from the received data and any error is reported and an appropriate flag added to the data stream. A co-processor extracts any audio or other ancillary data.

The 10-bit data is then demultiplexed (Figure 8) into digital luma and chroma data streams, converted to analog by three digital-to-analog converters, filtered to reconstruct the discrete data levels back to smooth analog waveforms, and matrixed back to the original R'G'B' for display.

This quick system overview will help us understand how the system operates. Additional details of the digital interface are provided in the paragraphs to follow.

601 sampling

ITU-R BT.601 is the sampling standard that evolved out of a joint SMPTE/EBU task force to determine the parameters for digital component video for the 625/50 and 525/60 television systems. This work culminated in a series of tests sponsored by SMPTE in 1981, and resulted in the well-known CCIR Recommendation 601 (now known as ITU-R BT.601). This document specifies the sampling mechanism to be used for both 525 and 625 line signals. It specifies orthogonal sampling at 13.5 MHz for analog luminance and 6.75 MHz for the two analog color-difference signals. The sample values are digital luma Y' and digital color-difference C'b and C'r, which are scaled versions of the analog gamma-corrected B'-Y' and R'-Y'. 13.5 MHz was selected as the sampling frequency because the sub-multiple 2.25 MHz is a factor common to both the 525 and 625 line systems (see Appendix B – Television Clock Relationships).
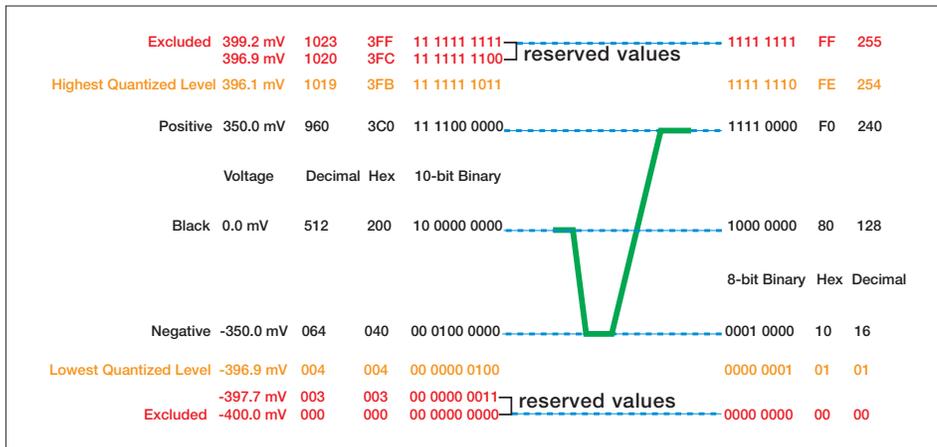
Figure 9. Color-difference quantizing.
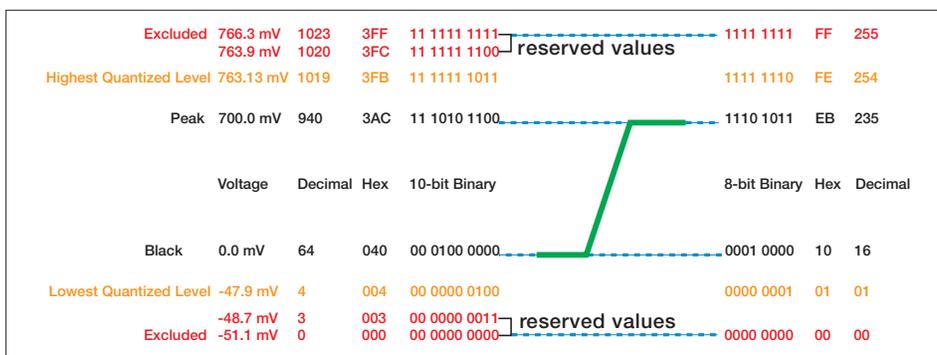
Figure 10. Luminance quantizing.

Although many current implementations of ITU-R BT.601 use 10-bit sampling, ITU-R BT.601 permits either 8-bit samples (corresponding to a range of 256 levels, 00_h through FF_h), or 10-bit samples (corresponding to a range of 1024 levels, 000_h through $3FF_h$). Specified 8-bit word values may be directly converted to 10-bit values, and 10-bit values may be rounded to 8-bit values for interoperability. Color-difference C'b and C'r components values in the range 040_h to $3C0_h$ (Figure 9) correspond to analog signals between ±350 mV. Signal excursions are allowed outside this range and the total available range is nominally ±400 mV. Luma component values, Y' (Figure 10) in the range 040h to $3AC_h$ correspond to analog signals between 0.0 mV and 700 mV. Signal excursions are again allowed outside this range with a total range of nominally –48 mV to +763 mV to allow greater headroom for overload above the white level. A/D converters are configured to never generate 10-bit levels 000_h through 003_h, and $3FC_h$ through $3FF_h$ to permit interoperability with 8-bit systems. Quantizing levels are selected so 8-bit levels with two "0s" added will have the same values as 10-bit levels. In both luminance and color-difference A/Ds, values 000_h to 003h and $3FC_h$ to $3FF_h$ are reserved for synchronizing purposes.

Figure 11 shows the location of samples and digital words with respect to an analog horizontal line and Figure 12 shows the spatial relationship to the picture area. Because the timing information is carried by End of Active Video (EAV) and Start of Active Video (SAV) packets, there is no need for conventional synchronizing signals. The horizontal blanking interval and the entire line periods during the vertical blanking interval can be used to carry audio or other ancillary data. The EAV and SAV timing packets are identified in the data stream by a header starting with the words: $3FF_h$, 000_h, 000_h. The fourth word (xyz) in the EAV and SAV packets contains information about the signal. Ancillary data packets in component digital video are identified by a header starting with the words: 000_h, $3FF_h$, $3FF_h$.

The "xyz" word is a 10-bit word with the two least significant bits set to zero to survive an 8-bit signal path. Contained within the standard definition "xyz" word are functions F, V, and H, which have the following values:

- Bit 8 – (F-bit) 0 for field one and 1 for field two

- Bit 7 – (V-bit) 1 in vertical blanking interval;
  0 during active video lines

- Bit 6 – (H-bit) 1 indicates the EAV sequence;
  0 indicates the SAV sequence

The parallel digital interface

Electrical interfaces for the data produced by Rec.601 sampling were standardized separately by SMPTE as SMPTE standard 125M for 525/59.94 and by EBU Tech. 3267 for 625/50 formats. Both of these were adopted by CCIR (now ITU) and included in Recommendation 656, the document describing the parallel hardware interface. The parallel interface uses eleven twisted pairs and 25-pin "D" connectors. The parallel interface multiplexes data words in the sequence C'b, Y', C'r, Y'… resulting in a data rate of 27 Mb/s. Timing sequences SAV and EAV were added to each line. The digital active video line for both 525 and 625 formats includes 720 luma samples, with remaining data samples during analog blanking available for timing and other data.

Because of the requirement for multiple conductor cables and patching panels, parallel connection of digital studio equipment is practical only for small, permanently configured installations.
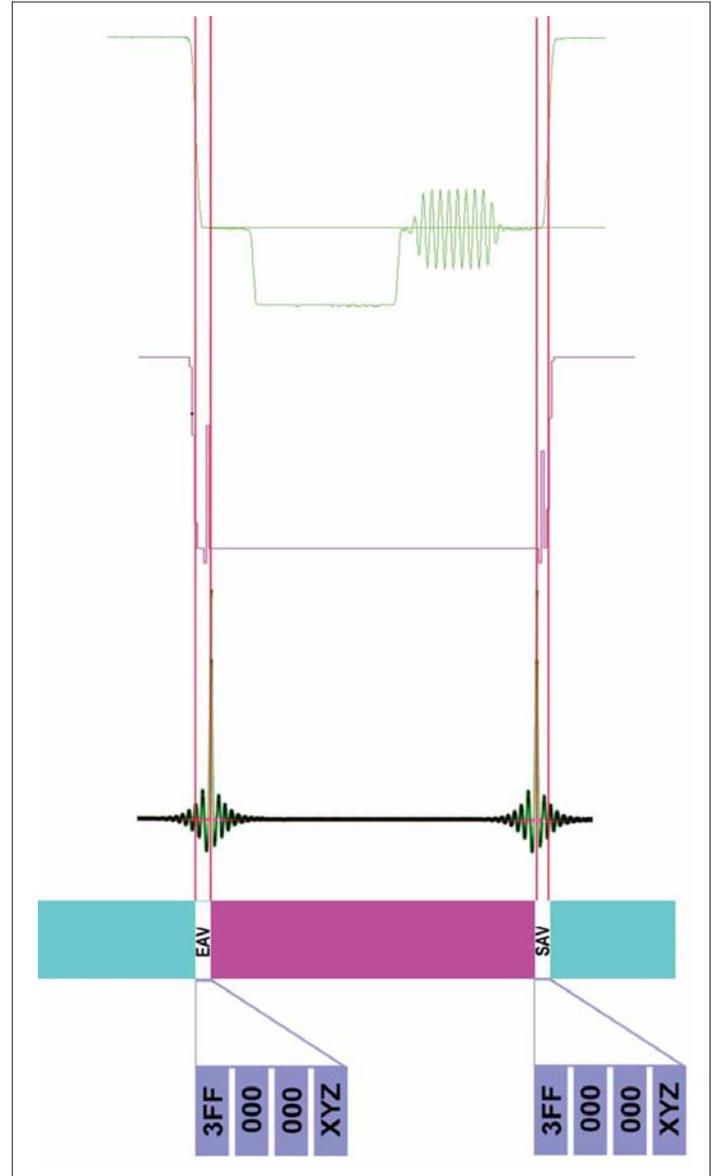
Figure 11. Digital horizontal blanking interval.
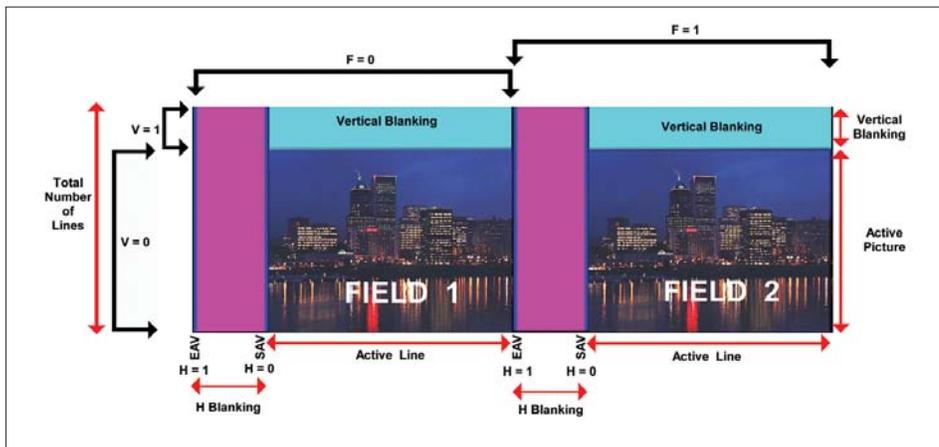
Figure 12. Layout of 2:1 interlaced digital frame.
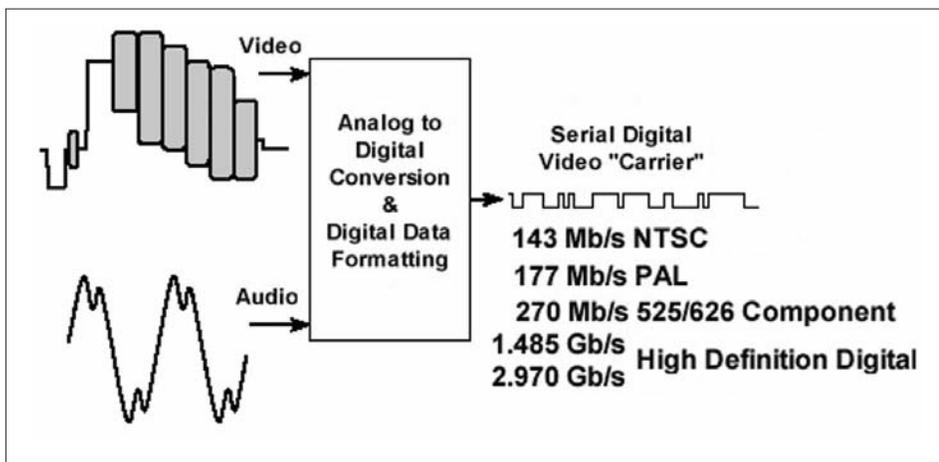
Figure 13. The carrier concept.

The serial digital interface (SDI)

Regardless of format, there is a clear need for data transmission over a single coaxial cable. This is not simply because the data rate is relatively high, but also, if the signal were transmitted without modification, reliable recovery would be difficult. The signal must be modified prior to transmission to ensure that there are sufficient edges for reliable clock recovery, to minimize the low frequency content of the transmitted signal, and to spread the energy spectrum so that RF emission problems are minimized. A serial digital interface that uses scrambling and conversion to NRZI was developed to meet these needs. This serial interface is defined in ANSI/SMPTE 259M, ITU-R BT.656, and EBU Tech. 3267, for both standard definition component and composite signals including embedded digital audio. A scaled version of this serial interface is specified for high-definition transmission.

Conceptually, the serial digital interface is much like a carrier system for studio applications. Baseband video and audio signals are digitized and combined on the serial digital "carrier" as shown in Figure 13. Note, this is not strictly a carrier system in that it is a baseband digital signal and not a signal modulated on a carrier. The bit rate (carrier frequency) is determined by the clock rate of the digital data, 270 Mb/s for standard definition component digital and 1.485 Gb/s (or 2.97 Gb/s) for high-definition formats. (Other rates, including 143 Mb/s and 177 Mb/s for NTSC and PAL composite serial interfaces are also used but will not be covered in detail in this primer.)

Parallel data representing the samples of the analog signal components is processed as shown in Figure 14 to create the serial digital data stream. The parallel clock is used to load sample data into a shift register, and a 10x multiple of the parallel clock shifts the bits out, LSB first, for each 10-bit data word. If only 8 bits of data are available, the serializer places zeros in the two LSBs to complete the 10-bit word. In component formats, the EAV and SAV timing signals on the parallel interface provide unique sequences that can be identified in the serial domain to permit word framing. Coding of EAV and SAV data packets are described in the Digital Studio Synchronization and Timing section of this primer. If other ancillary data such as audio has been inserted into the parallel signal, this data will also be carried by the serial interface.

Following serialization of the parallel information, the data stream is scrambled by a mathematical algorithm, then encoded into NRZI by a concatenation of the following two functions:

$$G1(X) = X\,9 + X\,4 + 1$$

$$G2(X) = X + 1$$

Scrambling the signal makes it statistically likely to have a low dc content for easier handling and have a great number of transitions for easier clock recovery. NRZI formatting makes the signal polarity-insensitive.

At the receiver, the inverse of this algorithm is used in the deserializer to recover the correct data so the end user sees the original, unscrambled components. In the serial digital transmission system, the clock is contained in the data as opposed to the parallel system where there is a separate clock line. By scrambling the data, an abundance of transitions is assured as required for clock recovery. For system stress testing (see Digital System Testing section), specific test signals have been developed that introduce sequences with high dc content and minimum transitions to test the effectiveness of the SDI receiver circuitry. A normally operating serial digital system will not fail even when stressed by these difficult signals.

Figure 14. Parallel-to-serial conversion.

Figure 15. NRZ and NRZI relationship.

Encoding into NRZI makes the serial data stream polarity insensitive. NRZ (Non-Return to Zero) is the familiar logic level, high = "1", low = "0". For a transmission system it is conven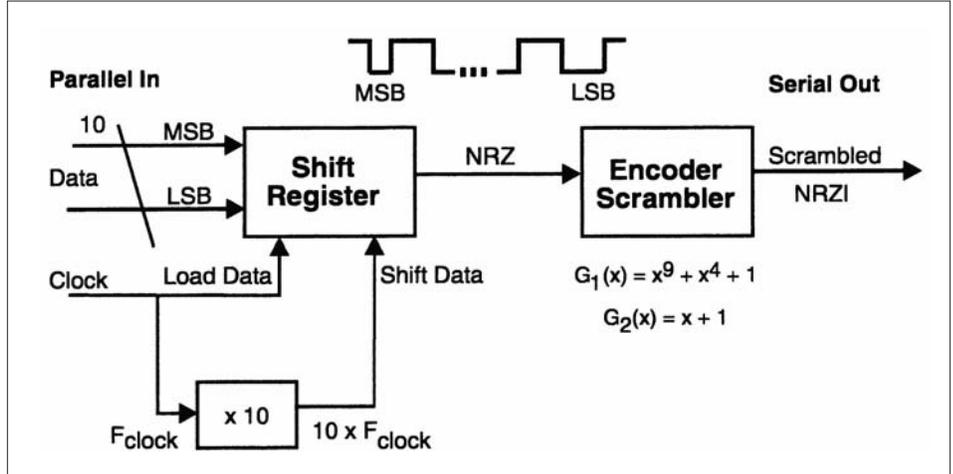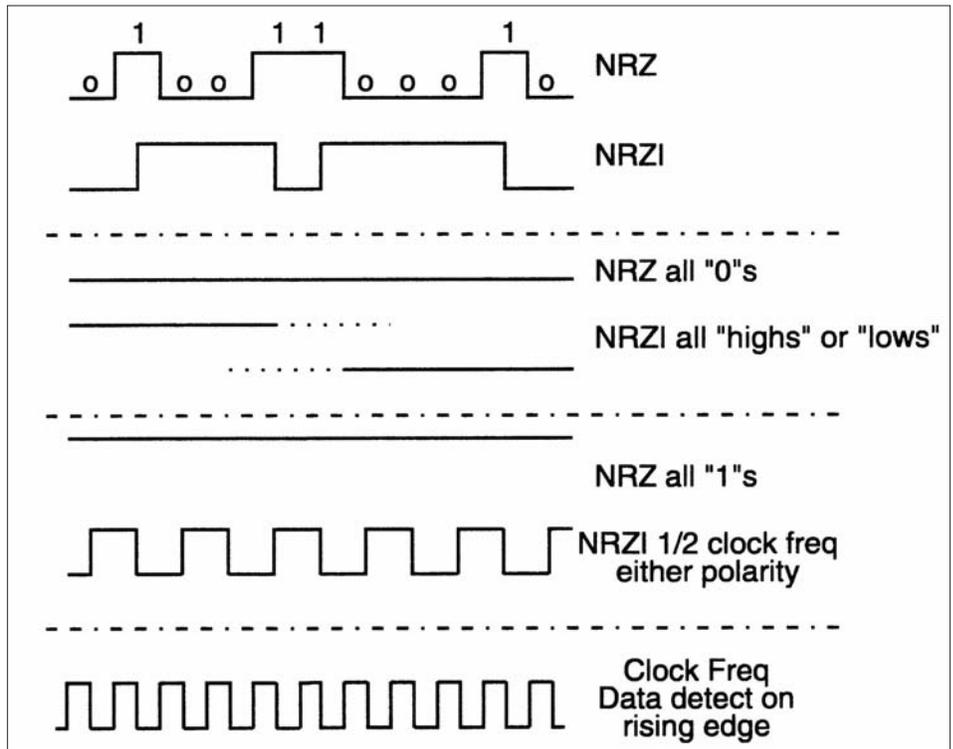ient not to require a certain polarity of signal at the receiver. As shown in Figure 15, a data transition is used to represent each data "1" and there is no transition for a data "0". The result is that it is only necessary to detect transitions; either polarity of the signal may be used. Another result of NRZI encoding is that a signal of all "1"s now produces a transition every clock interval and results in a square wave at one-half the clock frequency. However, "0"s produce no transition, which leads to the need for scrambling. At the receiver, the rising edge of a square wave at the clock frequency would be used for data detection.

The serial digital interface may be used over moderate distances in a well-designed system with normal 75-ohm video cables, connectors, and patch panels. As an example, the effects of an unterminated cable, such as may be found on a T-connector, may be unnoticeable with analog video but will cause substantial reflections and potential program loss with serial digital video.

This discussion of component video in the parallel and serial domain is generally applicable to both standard definition and high-definition scanning formats. Sampling and quantization levels are generally the same, as is the formatting of synchronizing information. Sampling rates are higher, and there are generally more samples available for ancillary data in high-definition formats. Line numbering and error-check words are present in high-definition formats, and there are more samples available for multi-channel audio. The principles, however, are the same for standard and high-definition formats. Understanding one component digital format puts us well on our way to understanding all of the others. This primer will point out differences as the discussion continues. Digital standard and high-definition video scanning formats are discussed and compared in the Timing and Synchronization section of this primer.

High-definition video builds on standard definition principles

In transitioning to digital high-definition we can use the basic principles learned for standard definition and apply them to the specific requirements of HDTV. The way we sample the analog signal is the same in principle; we just use higher channel bandwidths and sample rates. The way we process the digital signal is the same in principle; we just handle higher data rates, and take greater care with system design. Everything along the line operates at faster data rates and higher bandwidths, but almost every principle is familiar.

There are a wide variety of formats within high-definition television. This gives the broadcast engineer a wide range of flexibility, but it seemingly increases the complexity of the broadcast system.

Standards define the scanning format, analog interface, parallel digital interface, and the serial digital interface for creating and handling high-definition video. Key standards of interest include:

- **ANSI/SMPTE 240M, Television – Signal Parameters – 1125-Line High-Definition Production Systems.** Defines the basic characteristics of analog video signals associated with origination equipment operating in 1125 (1035 active) production systems at 60 Hz and 59.94 Hz field rates.

- **SMPTE 260M, Television – Digital Representation and Bit-Parallel Interface – 1125/60 High-Definition Production System.** Defines the digital representation of 1125/60 high-definition signal parameters defined in analog form by ANSI/SMPTE 240M.

- **ANSI/SMPTE 274M, Television – 1920 x 1080 Scanning and Analog and Parallel Digital Interfaces for Multiple Picture Rates.** Defines a family of scanning systems having an active picture area of 1920 pixels by 1080 lines and an aspect ratio of 16:9.

- **ANSI/SMPTE 292M, Television – Bit-Serial Digital Interface for High-Definition Television Systems.** Defines the bit-serial digital coaxial and fiber-optic interface for high-definition component signals operating at 1.485 Gb/s and 1.485/1.001 Gb/s.

- **ANSI/SMPTE 296M, Television – 1280 x 720 Scanning, Analog and Digital Representation and Analog Interface.** Defines a family of progressive scan formats having an active picture area of 1280 pixels by 720 lines and an aspect ratio of 16:9.

- **ANSI/SMPTE 372M, Television – Dual Link 292.** Defines a method for carrying 1080i/p YCbCr formats and RGBA 1080i/p formats in either 10- or 12-bit formats via two HD-SDI links.

- **ANSI/SMPTE 424M, Television – 3 Gb/s Signal/Data Serial Interface.** Defines a method for transporting 3 Gb/s serial digital signal over a coaxial interface.

- **ANSI/SMPTE 425M, Television – 3 Gb/s Signal/Data Serial Interface – Source Image Format Mapping.** Defines the method of transporting 1920x1080 and 2048x1080 picture formats over a single transport interface of 3 Gb/s.
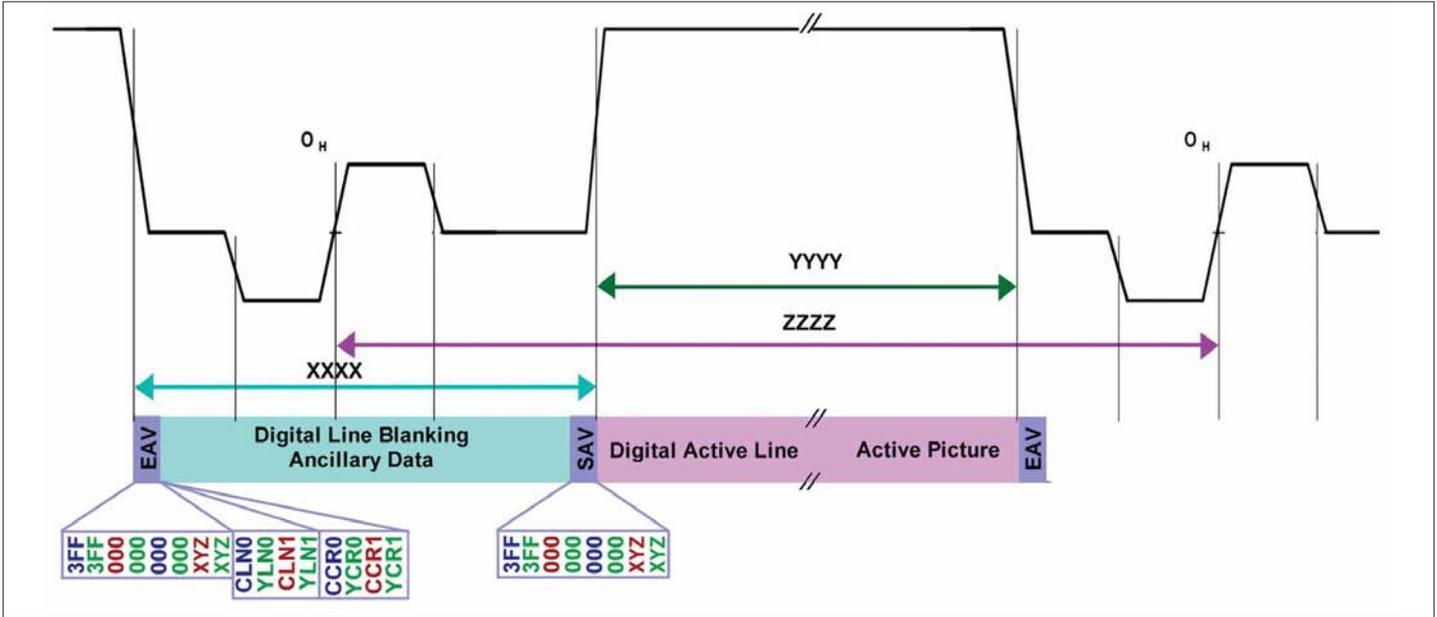
Figure 16. Ancillary data in the digital line vs. analog representation.

Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
LN0	Not B8	L6	L5	L4	L3	L2	L1	L0	R (0)	R (0)
LN1	Not B8	R (0)	R (0	R (0)	L10	L9	L8	L7	R (0)	R (0)

Table 3. Bit Distribution of Line Number Word.

Typical analog video bandwidth of high-definition video red, green, and blue components is 30 MHz for 1080 formats (interlaced and progressive [30, 29.97,25, 24, 23.98]) and 720 progressive scan formats and 60 MHz for a 1080p (50,59.94,60) progressive formats. Therefore, a high sample rate is required to digitize the matrixed luma and color-difference signals. The sample rate for the 30 MHz luma Y channel is 74.25 MHz and half that rate, 37.125 MHz, is used to sample each of the 15 MHz color-difference signals C'b and C'r. The signals are sampled with 10 bits of resolution. C'b and C'r are matrixed into a single stream of 10-bit parallel data at 74.25 Mb/s, then matrixed with the 74.25 Mb/s luma data creating a 10-bit parallel data stream at 148.5 Mb/s in word order C'b, Y', C'r, Y', the same as standard definition. Just as in standard definition, the parallel data is then serialized, in this case, to a scrambled, NRZI, 1.485 Gb/s data stream for transmission within the studio plant. Please note that for non-even frame rates of 59.94Hz, 29.97Hz, 23.98Hz the clock rate should be divided by 1.001.

Chroma and luma quantization (refer back to Figures 9 and 10) is the same for standard definition and high-definition signals and decimal 10-bit codewords 0, 1, 2, 3 and 1020, 1021, 1022, and 1023 are still excluded values. The codewords for EAV and SAV have the same functionality for standard and high-definition. Additional words follow EAV in high-definition formats to number individual lines and provide line-by-line error checking of luma and the two color-difference channels.

Formatting of data in the video line is shown in Figure 16, which also illustrates the timing relationship with analog high-definition video.

In high-definition formats, the four-word EAV sequence is immediately followed by a two-word line number (LN0 and LN1): followed by a two-word CRC (YCR0 and YCR1). The first of these is a line counter which is an 11-bit binary value distributed in two data words, LN0 and LN1, as shown in Table 3. For example, for line 1125, the two data words would have the value LN0 = 394_h and LN1 = 220_h, for a binary data word 10001100101.
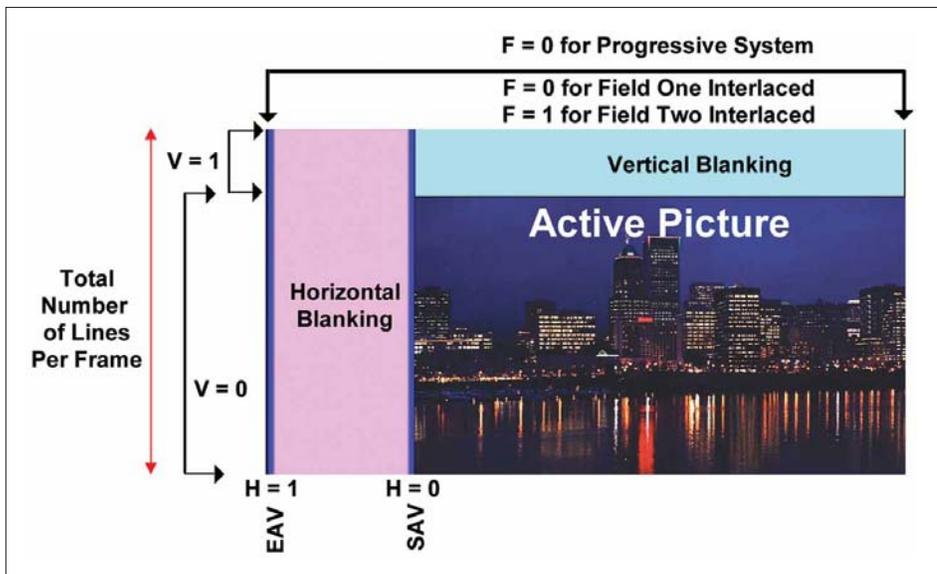
Figure 17. Spatial layout of the digital frame with V, F, and H-bit values.

Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
YCR0	Not B8	CRC8	CRC7	CRC6	CRC5	CRC4	CRC3	CRC2	CRC1	CRC0
YCR1	Not B8	CRC17	CRC16	CRC15	CRC14	CRC13	CRC12	CRC11	CRC10	CRC9
CCR0	Not B8	CRC8	CRC7	CRC6	CRC5	CRC4	CRC3	CRC2	CRC1	CRC0
CCR1	Not B8	CRC17	CRC16	CRC15	CRC14	CRC13	CRC12	CRC11	CRC10	CRC9

Table 4. Bit Distribution of Words Making Up Luma and Chroma CRCs in High-Definition Formats.

CRC checking, in high-definition, is done separately for luma and chroma on each line. A CRC value is used to detect errors in the digital active line by means of the calculation $CRC(X) = X18 + X5 + X4 + 1$ with an initial value of zero at the start of the first active line word and ends at the final word of the line number. The value is then distributed as shown in Table 4. A value is calculated for luma YCR0 and YCR1, and another value, CCR0 and CCR1, is calculated for color-difference data.

Luma and chroma CRC values can be displayed on the measurement instrument and used for determination of any errors accumulating within the signal as it travels from point to point.

In standard definition formats, EAV ends with the xyz word; there is no line numbering. A CRC for active picture, and a CRC for the complete field (excluding the time set aside for vertical interval signal switching), is optionally done once per field in the vertical blanking interval as described in SMPTE RP-165.

All words in the digital line horizontal blanking area between EAV and SAV (Figure 17) are set to black (Y' = 040$_h$, C'b and C'r = 200$_h$) if not used for ancillary data.

Timing and Synchronization

Standards provide information that allows interchange and interoperability among the various devices in the end-to-end video chain. Good standards allow economical utilization of resources and technologies. Standards promote cooperation among users and encourage innovation. Standards are necessary if the video professional and the home viewer are to produce and view the same program.

The American National Standards Institute, Society of Motion Picture and Television Engineers, Audio Engineering Society, and International Telecommunications Union publish the reference standards and recommendations for video and audio. Representative standards and recommendations, listed in Appendix D – Reference Standards for Television, define signal parameters that allow compatibility and regulatory compliance. Standards issued by these bodies are developed with great care, and are very helpful in describing the precise characteristics of each system. The following discussion is an interpretation of those standards to provide a broad understanding of many different individually standardized formats.

Successful creation, transmission, and recovery of a video picture depend on each device in the system operating in synchronization with every other device. As the television camera detects the value of a picture element at a certain position in the scene, it must somehow identify where that value is to finally be reproduced on the television display. Synchronizing elements tell the camera how to produce a picture in concert with other cameras and sources and tell the receiver how and where to place the picture on the screen when the picture is finally displayed.

The camera, and finally, the display know how to scan the detector or screen. They just need to know where to start, and how to keep in step. The synchronizing information is refreshed once each horizontal line and once each vertical sweep of the display (two sweeps for each full picture in a 2:1 interlaced format). Inside a large studio plant, synchronizing information is provided by an external master synchronizing generator. In a small system, one camera may provide synchronizing information for itself and other video sources as well.

Analog video timing

There are six standard definition composite analog video formats in common use: PAL, PAL-M, PAL-N, NTSC with setup, NTSC without setup, and SECAM. Additionally, some countries permit a wider on-air transmission bandwidth, leaving room for higher video bandwidth. Studio production in SECAM countries is often done in component or PAL, then formatted into SECAM for transmission. SECAM and PAL video formats are similar with the difference primarily in the way the chroma information is modulated onto the luma video.

Studio video is a continuous stream of information that may be used as it occurs, delayed to match other sources, or recorded for playback later. Whenever it moves, it moves in real time, and it must carry along all of the information necessary to create a picture at the destination. Video contains picture information and timing information to properly reproduce the picture. Timing information includes a pattern of regularly occurring horizontal sync pulses or reserved data words that identify each line of video, interrupted by less frequently occurring vertical sync information that instructs the display to start writing the picture at the top of the screen.

In NTSC or PAL composite video formats, video and timing information can be easily observed. A video waveform monitor is equipped with preset sweep rate selections to display video horizontal lines, the horizontal blanking interval, a sweep of all picture lines (vertical rate), or just the lines in the vertical blanking interval. It is important to recognize these displays are all of the same video signal, the difference being when the signal is displayed and for how long each time. In modern terms, composite analog video is a time-division multiplex of luminance video and synchronizing information. The chrominance information is a frequency-division multiplex of the two color-difference channels. Just look for what you want when it occurs.
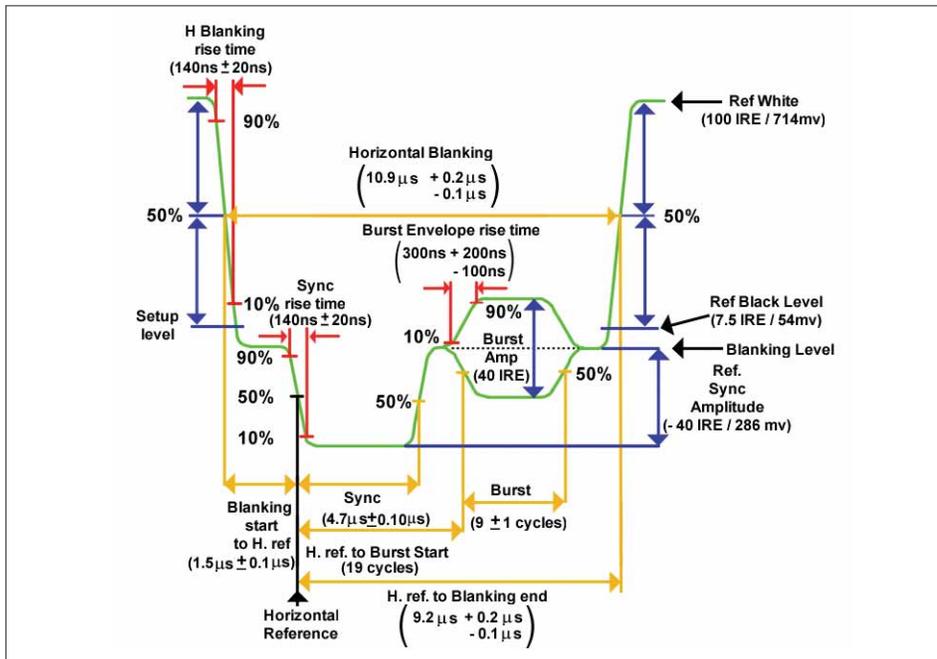
Figure 18. NTSC horizontal blanking interval.
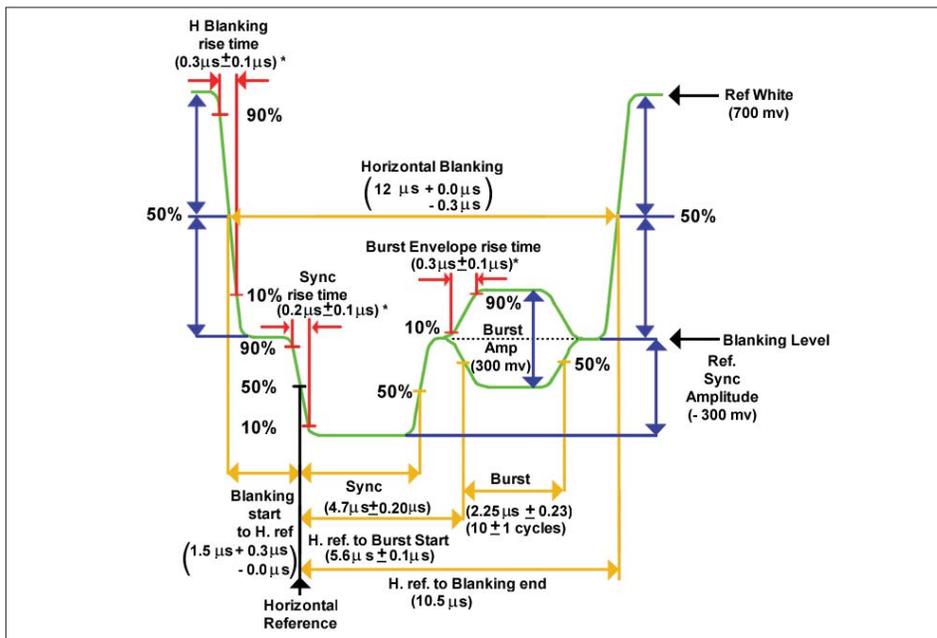
Figure 19. PAL horizontal blanking interval.

Horizontal timing

Horizontal timing diagrams for 525/59.94 NTSC (Figure 18) and 625/50 PAL (Figure 19) scanning formats are similar in concept, and were developed with the constraints of camera and display devices available in the mid 1900s. The horizontal blanking interval occurs once per line of video information and is modified to provide the vertical blanking interval.

The horizontal FRONT PORCH defines a time for the video in each line to end as the beam approaches the right of the screen. The 50% point on the falling edge of the sync pulse, the system timing reference, can then trigger retrace of the picture tube beam. The SYNC TO BLANKING END assures that video won't start illuminating the screen while the beam is still retracing. The REFERENCE WHITE and REFERENCE BLACK levels are specified to assure every program will appear on the display at the same maximum and minimum brightness for a constant contrast without viewer adjustment. The 7.5 IRE difference in setup (the difference in blanking and black levels) in the NTSC format has been the subject of some discussion over the years and some countries operate with no setup. The color subcarrier burst provides a periodic stable reference for synchronizing the receiver color oscillator for stable demodulation of chroma information. Although the subcarrier burst is an eight- to ten-cycle sample of a constant frequency, the waveform monitor will be locked to the horizontal sync pulse timing reference and the NTSC burst will appear to alternate in phase from line to line and, because of a 25 Hz frequency offset, the PAL burst will appear to be constantly changing. Sync edge timing reference and the color subcarrier burst are individually their own constant phase; they will appear to alternate or be changing because they come into step with each other only periodically.
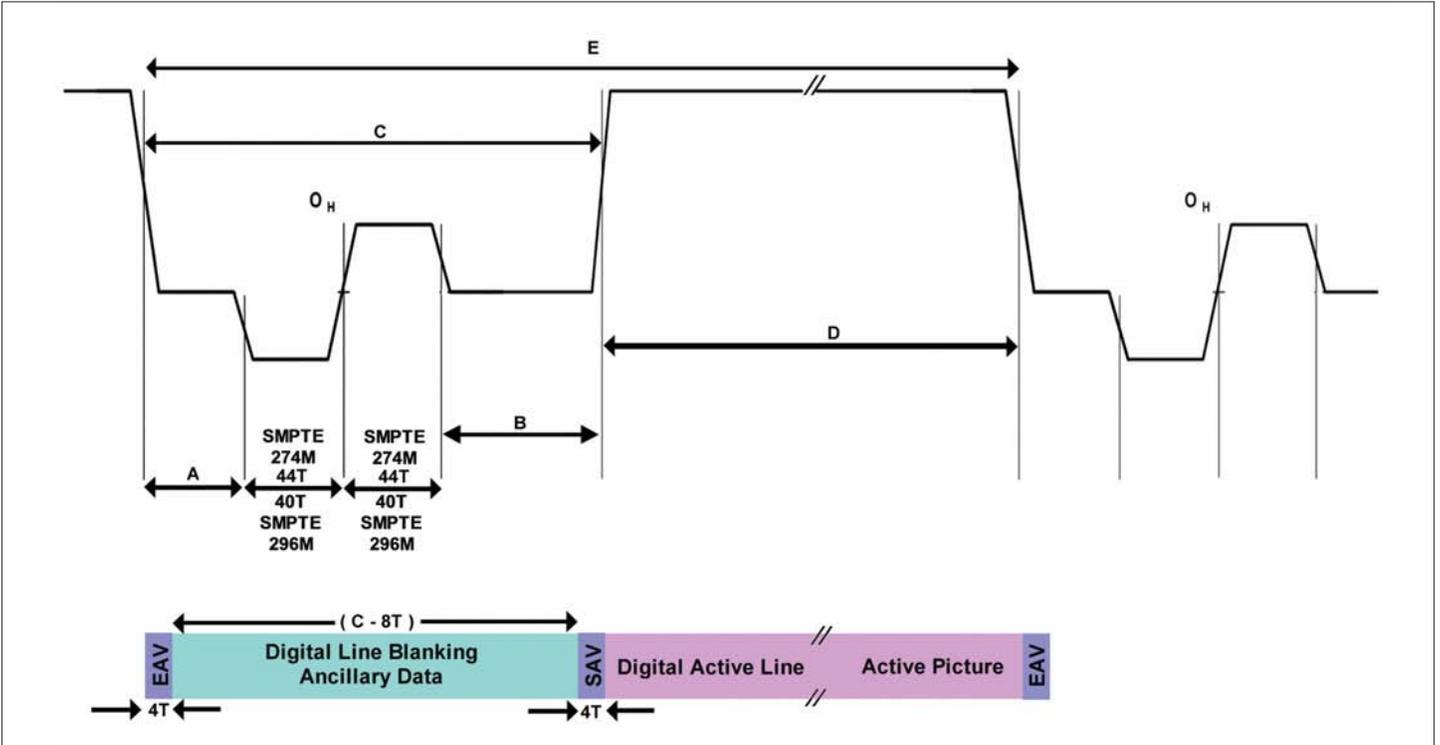
Figure 20. High-definition line timing.

A line of analog video starts at the 50% point of the falling edge of the bi-level sync pulse and ends at the same point in the next horizontal video line. High-definition analog production formats may use a tri-level sync timing pulse extending first below, then above blanking level. Timing reference, 0_H, for analog tri-level sync is the positive-going transition of the sync waveform through blanking level (Figure 20 and Table 5).

The spatial relationship of the timing signals to the picture time of the video signal is illustrated in Figure 21. For a progressive 1:1 format, the complete picture (the frame) is scanned from top to bottom, including every picture line in one pass. In interlaced 2:1 formats, the first pass from top to bottom will write half the lines with each line spaced vertically, and the second pass will be offset to fill in a new field (and complete the frame) between the lines of the previous pass.
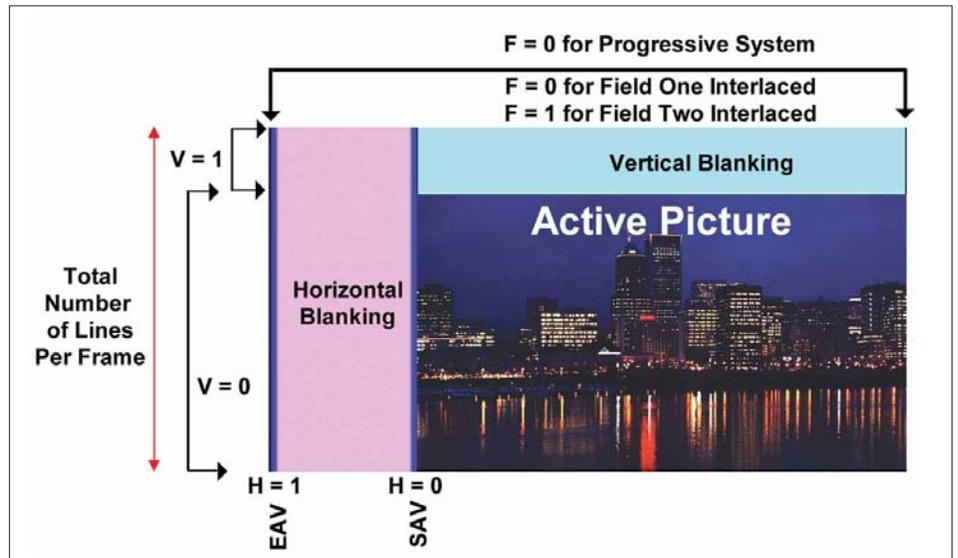
Figure 21. Spatial layout of the video frame.

Format	Sampling Frequency (MHz) (1/T)	A	B	C	D	E
1920x1080 60 1:1	148.5	44T	148T	280T	1920T	2200T
1920x1080 59.94 1:1	148.5/1.001	44T	148T	280T	1920T	2200T
1920x1080 60 2:1	74.25	44T	148T	280T	1920T	2200T
1920x1080 59.94 2:1	74.25/1.001	44T	148T	280T	1920T	2200T
1920x1080 30 1:1	74.25	44T	148T	280T	1920T	2200T
1920x1080 29.97 1:1	74.25/1.001	44T	148T	280T	1920T	2200T
1920x1080 50 1:1	148.5	484T	148T	720T	1920T	2640T
1920x1080 50 2:1	74.25	484T	148T	720T	1920T	2640T
1920x1080 25 1:1	74.25	484T	148T	720T	1920T	2640T
1920x1080 24 1:1	74.25	594T	148T	830T	1920T	2750T
1920x1080 23.98 1:1	74.25/1.001	594T	148T	830T	1920T	2750T
1280x720 60 1:1	74.25	70T	220T	370T	1280T	1650T
1280x720 59.94 1:1	74.25/1.001	70T	220T	370T	1280T	1650T
1280x720 50 1:1	74.25	400T	220T	700T	1280T	1980T
1280x720 30 1:1	74.25	1720T	220T	2020T	1280T	3300T
1280x720 29.97 1:1	74.25/1.001	1720T	220T	2020T	1280T	3300T
1280x720 25 1:1	74.25	2380T	220T	2680T	1280T	3960T
1280x720 24 1:1	74.25	2545T	220T	2845T	1280T	4125T
1280x720 23.98	74.25/1.001	2545T	220T	2845T	1280T	4125T

Table 5. High-Definition Line Timing in Sampling Clock Cycles (T).

Vertical timing

Vertical timing information is a change in the shape of regularly occurring horizontal synchronizing pulses and addition of equalizing pulses. The vertical blanking interval (Figure 22 NTSC, Figure 23 PAL) is 20 to 25 video lines in time duration and is displayed center screen in the waveform monitor two-field display. The longer vertical blanking time allows the slower vertical return of the picture tube electron beam to the top of the screen.

The different patterns illustrated above and on the next page start the video line at left or middle at the top of the screen to provide a 2:1 interlace of the fields in PAL and NTSC formats. Frequencies are chosen to reduce visibility of the color subcarrier information, which is running at a visible video frequency. It takes eight fields for everything to come to the original phase relationship (a complete color frame) for a PAL signal, four fields for NTSC.
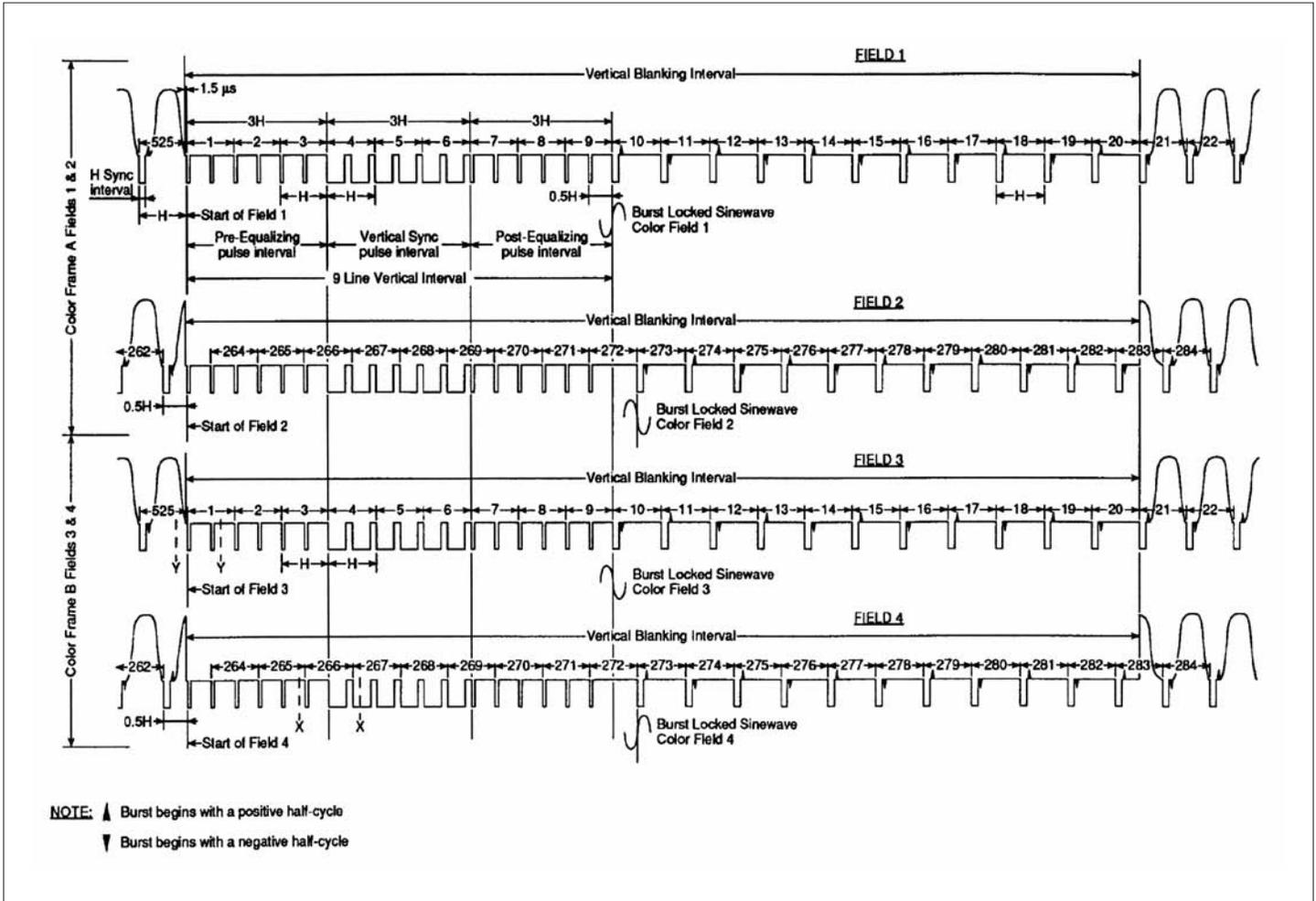
Figure 22. NTSC vertical blanking interval.

Figure 22 shows the alternating fields, and the four-field NTSC color frame. The color subcarrier comes back into the same relationship with the vertical sync after four fields.

The PAL vertical blanking interval, Figure 23, shows the alternating synchronizing patterns creating the interlaced frame. Because of the 25 Hz offset, the PAL subcarrier phase comes into the same relationship with the vertical sync every eight fields, for an eight-field color frame. SECAM horizontal and vertical sync timing is similar to PAL, but differs in the way chroma is modulated onto the luminance signal.

The phase relationship between the PAL or NTSC vertical sync pattern identifying the correct field, and the color subcarrier phase is important when one source video signal joins or is suddenly replaced by another source, as when edited or switched or combined by special effects equipment.
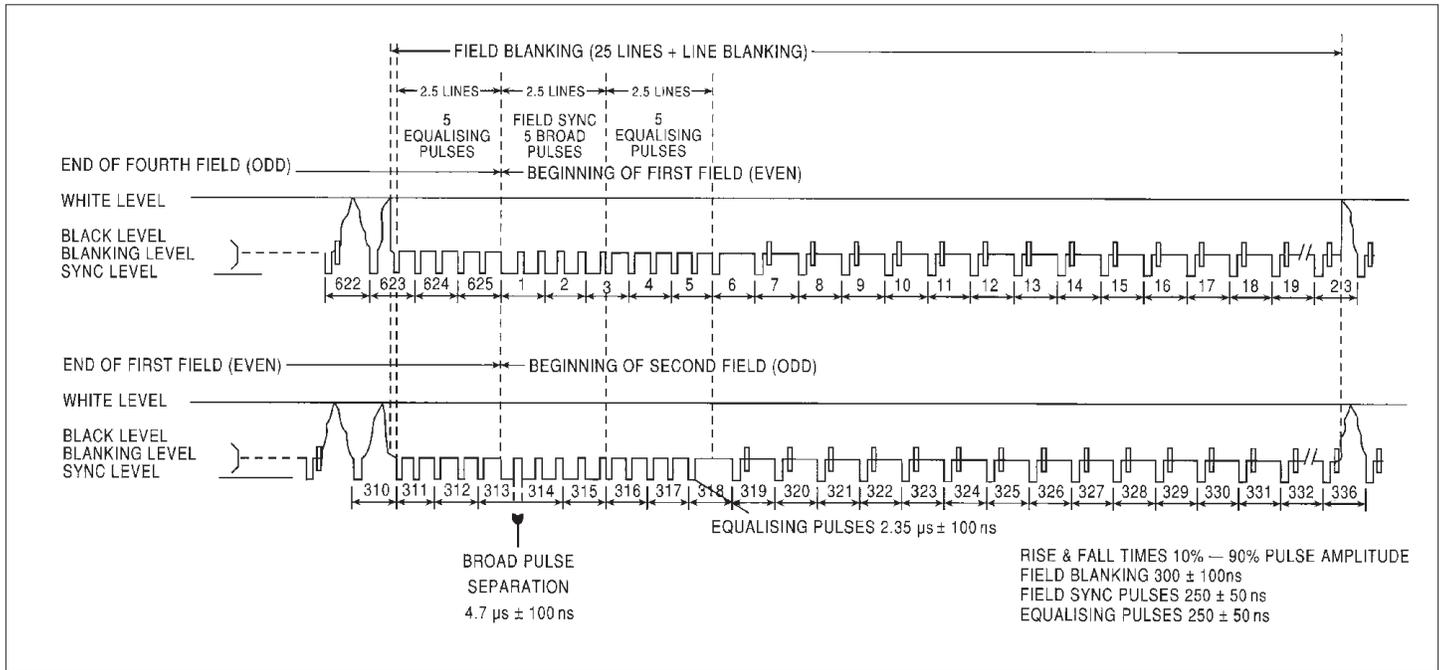
Figure 23. PAL vertical blanking interval.

This important relationship is referred to as SCH or Subcarrier-to-Horizontal phase. For component video we need only be concerned with the correct positioning of the three channels that make up the color picture as chroma information is not represented by a modulated subcarrier.

Line numbering in NTSC starts with the first vertical equalizing pulse after the last full line of video and continues through each field (263 lines for field one and three, 262 lines for field two and four). Line numbering for PAL and most analog high-definition formats starts with the first broad pulse after the last video half-line and the count continues through the full frame (625 lines for PAL).

In high-definition, there are progressive and interlaced scanning formats as shown in Figure 24. The five lines of the vertical interval broad pulses are slightly different than those of standard definition because of the tri-level sync pulse used in high-definition. The progressive format's vertical interval of 1080p (SMPTE 274M) is shown with appropriate line numbers. The interlaced line numbers of the 1080i format (SMPTE 274M) and 1035i format (SMPTE 240M) are shown.
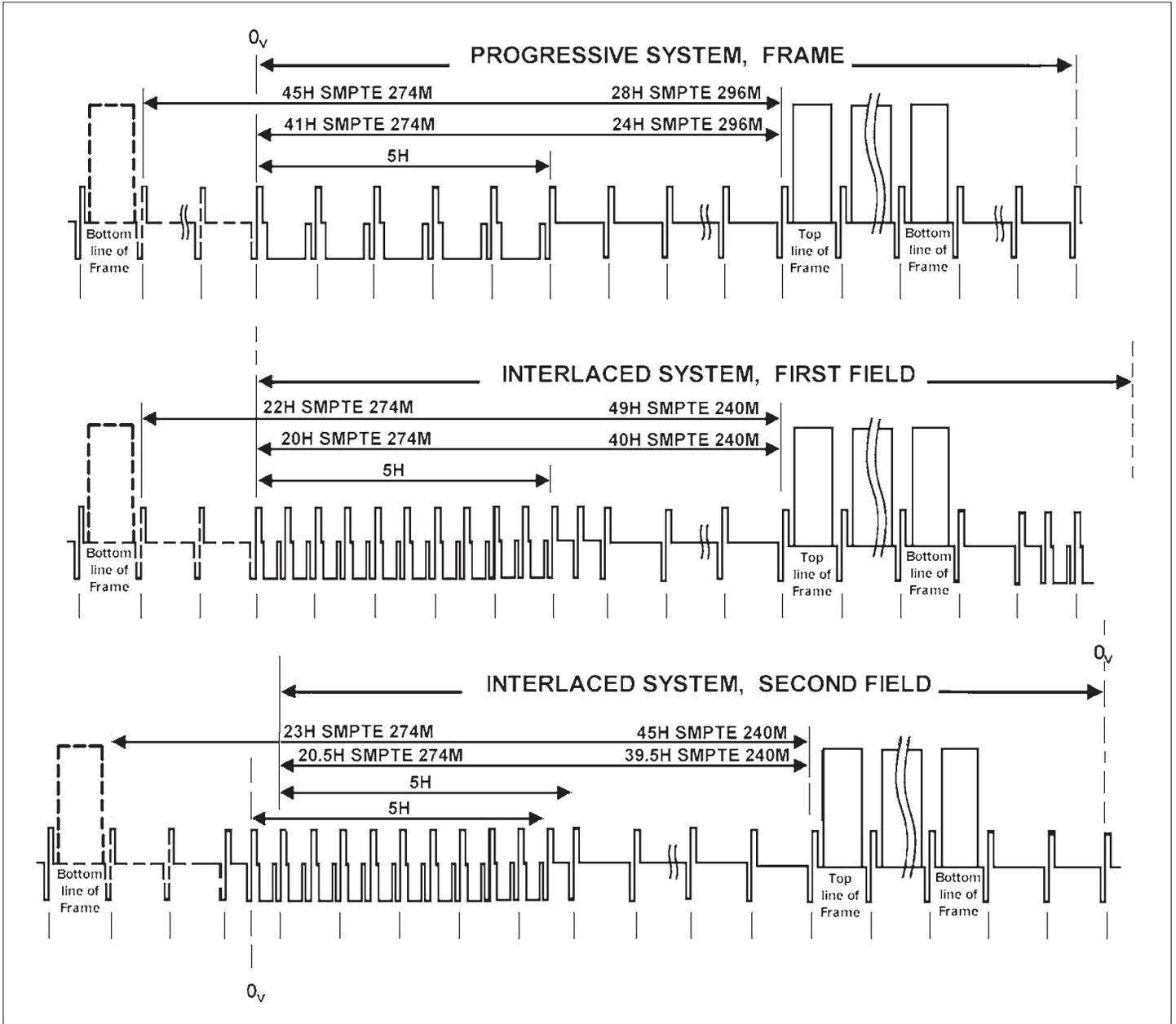
Figure 24. Analog high-definition vertical blanking interval.

	1125/60/2:1 (1125/59.94/2:1)	1125/50/2:1	750/60/1:1 (750/59.94/1:1)	750/50/1:1
Sync Type	Tri-level polar	Tri-level polar	Tri-level polar	Tri-level polar
Horizontal Timing Rising 50% edge	Timing 50% point, Rising 50% edge	Timing 50% point, Rising 50% edge	Timing 50% point, Rising 50% edge	Timing 50% point, Rising 50% edge
Total Lines/Frame	1125	1125	750	750
Active Video Lines/Frame	1080	1080	720	720
Field Frequency	60 (59.94) Hz	50 Hz	60 (59.94) Hz	50 Hz
Line Frequency	33.750 (33.7163) kHz	28.125 kHz	45 kHz (44.955) kHz	37.5 kHz
Line Period	29.6296 µs (29.6593) µs	35.556 µs	22.222 µs (22.244467) µs	22.667 µs
Line Blanking	3.771 ms (3.775) ms	9.697 ms	4.983 ms (4.988) ms	9.428 ms
Timing Reference to SAV	2.586 ms (2.589) ms	2.586 ms	3.502 ms (3.505) ms	3.502 ms
EAV to Timing Reference	1.185 ms	7.084 ms	1.481 ms	5.926 ms
Negative Sync Width	0.593 ms	0.593 ms	0.538 ms	0.538 ms
Positive Sync Width	0.593 ms	0.593 ms	0.538 ms	0.538 ms
Sync Amplitude	±300 mV	±300 mV	±300 mV	±300 mV
Sync Rise/Fall	0.054 ms	0.054 ms	0.054 ms	0.054 ms
Field Period	16.67 (16.68) ms	20 ms	16.67 (16.68) ms	20 ms
Field Blanking	45 lines	45 lines	30 lines	30 lines
Video Signal Amplitude	700 mV	700 mV	700 mV	700 mV
Nominal Signal Bandwidth	30 MHz R, G, B 30 MHz	30 MHz R, G, B 30 MHz	30 MHz R, G, B 30 MHz	30 MHz R, G, B 30 MHz

Table 6. Analog High-Definition Timing Parameters with Selected Digital Relationships.
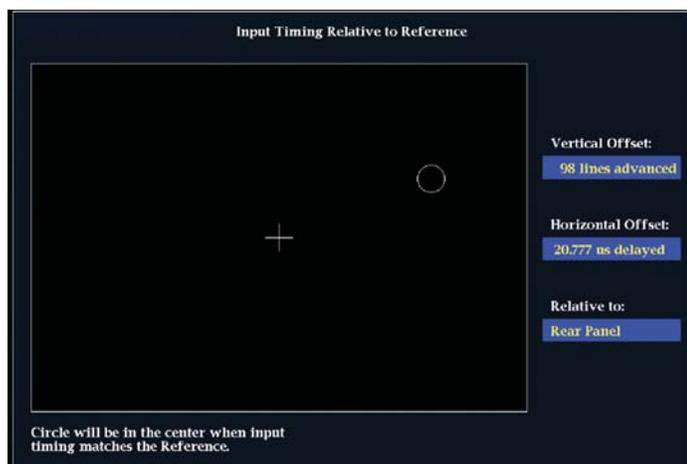
Figure 25. WVR7120/WFM7120 Series timing display.

Analog high-definition component video parameters

ANSI/SMPTE 240M defines analog high-definition video in 1125/60 (59.94)/2:1 format. ITU-R BT.709 (Part 1) recognizes both 1125/60/2:1 and 1250/50/2:1. (However, 1250/50/2:1 format is no longer used). These analog rates are shown in Table 6, along with some timings relative to their digital counterparts.

Tektronix has developed a simple proprietary method for timing of an analog and digital facility within the WFM and WVR series of waveform monitors and rasterizers. The Timing display provides both a simple graphical rectangle window which shows the relative timing between the external reference and input signal and measurement readouts in line and microseconds (µs) of the difference between the two signals as shown in Figure 25. The input signal can either be a HD-SDI, SD-SDI or analog composite signal and the input timing is compared to the analog black burst or tri-level sync external reference input.

The rectangle display represents one frame for SDI inputs, or a color frame for composite analog inputs. The crosshair in the center is zero offset and the circle represent the timing of the input signal. Lines of advance or delay are shown as vertical displacement while timing errors of less than a line are shown as horizontal displacement as shown in Figure 27. If the input is at the same time as the reference then the circle will be centered on the crosshair and it will change color from white to green.

The Relative to box indicates the chosen zero point for the timing display. The default is the rear panel. In this mode the offset is zero when the input and reference are at the same timing at the rear panel of the instrument. The other choice is to use the Saved offset, in this mode you can save the timing from one of the input signals and then display the timing relative to that saved offset. This
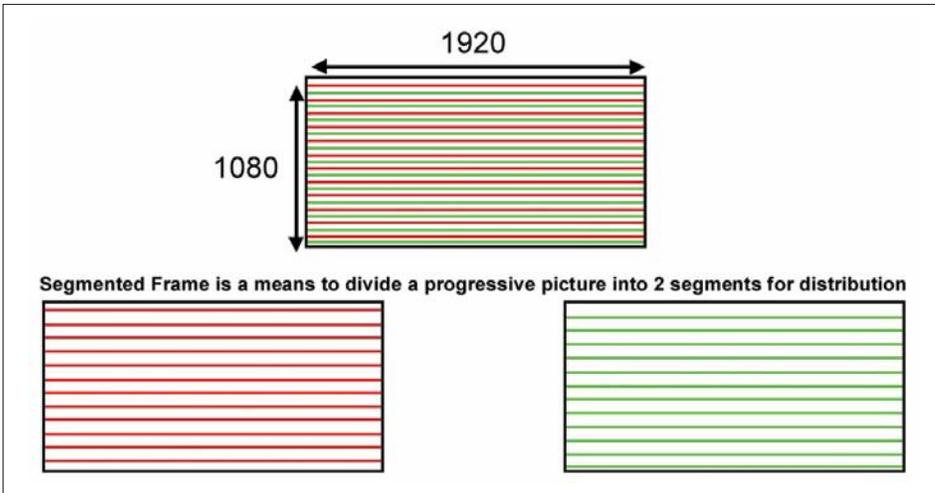
Figure 26. Conversion of a progressive frame into segments.
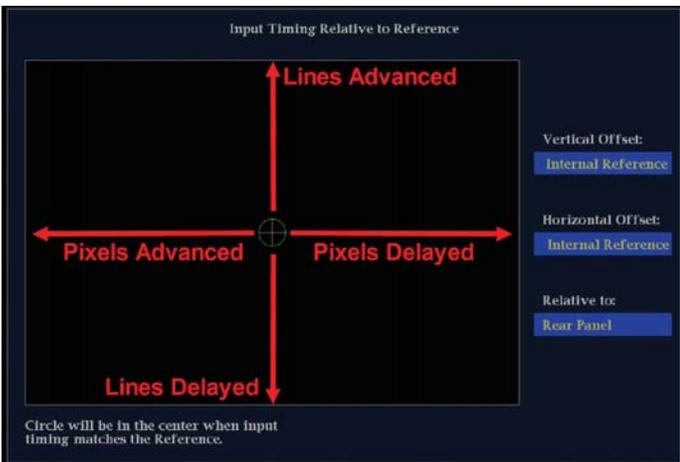
Figure 27. Interpretation of Timing Display.

is especially useful in timing together the inputs to a router. By selecting one of the inputs to the router as the master and applying this signal to the input along with the external reference signal being used by the router to the WVR series or the WFM7x20/6120 series. Once this measurement is obtained, save the timing offset for the master input and use the relative to saved offset mode. Now by selecting each of the other inputs to the router via the WVR series or the WFM7x20/6120 series, the measurement will show the relative offset between the master reference and the other video inputs. Simply adjust the horizontal and vertical timing controls of the input signal until the circle and the crosshair are overlaid and the circle turns green. Fine timing adjustment can be done directly from the number readouts of the right hand side of the display. Next, each of the inputs to the router is timed relative to the master input signal. This intuitive display can save considerable time in the timing of video systems.

Digital Studio Scanning Formats

It is apparent that video scanning standards can be written for a variety of formats. In practice, standards reflect what is possible with the goal of compatibility throughout an industry. At this time there is no one universal scanning format for standard or for high-definition television but there is a trend towards making the television receiver compatible with all of the scanning systems likely to be available within a region. This creates a unique problem for the video professional who must produce programs for a world-wide market.

Some digital rates are particularly well suited to standards conversion. ITU-R BT.709 Part 2 defines a digital, square pixel, common image format (CIF) with common picture parameter values independent of picture rate. This recommendation specifies picture rates of 60, 59.94, 50, 30, 29.97, 25, 24, and 23.976 Hz, all with 1080 active picture lines each with 1920 picture samples and an aspect ratio of 16 wide by 9 high. SMPTE RP 211 extends SMPTE 274M, the 1920x1080 family of raster scanning systems, implementing segmented frames for 1920 x 1080 in 30, 29.97, 25, 24, and 23.976 Hz production formats. These CIF rates are the 1920x1080 rates in Table 7. 1280x720 rates in this table are defined by ANSI/SMPTE 296M. SMPTE 293M defines 720x483 progressive rates. Note that the frame rates and sampling frequencies listed in this table have been rounded to two or three decimal places. For non-integer frame rate systems the exact frame and sampling frequency is the complementary integer rate divided by 1.001.

Segmented frame production formats

Several formats in the scanning formats table are nomenclated 1:1sF. The "sF" designates a "segmented frames" format per SMPTE recommended practice RP211. In segmented frame formats, the picture is captured as a frame in one scan, as in progressive formats, but transmitted as in an interlaced format with even lines in one field then odd lines in the next field. The assignment of lines is the same as in an interlaced system, but the picture is captured for both fields in one pass eliminating spatial mis-registration that occurs with movement in an interlaced system. This gives the advantages of progressive scan but reduces the amount of signal processing required and doubles the presentation rate (reducing 24 to 30 Hz visual flicker) in the analog domain. Segmented frame formats may be handled as is, or may be easily converted to progressive formats as shown in

System Nomenclature	Luma or R'G'B' Samples per Active Line	Active Lines per Frame	Frame Rate (Hz)	Scanning Format	Luma or R'G'B' Sampling Frequency (MHz)	Luma Samples per Total Line	Analog Sync Time Ref Word	Total Lines per Frame
1920x1080/60/1:1	1920	1080	60.00	Progressive	148.500	2200	2008	1125
1920x1080/59.94/1:1	1920	1080	59.94	Progressive	148.352	2200	2008	1125
1920x1080/50/1:1	1920	1080	50.00	Progressive	148.500	2640	2448	1125
1920x1080/60/2:1	1920	1080	30.00	2:1 Interlace	74.250	2200	2008	1125
1920x1080/59.94/2:1	1920	1080	29.97	2:1 Interlace	74.176	2200	2008	1125
1920x1080/50/2:1	1920	1080	25.00	2:1 Interlace	74.250	2640	2448	1125
1920x1080/30/1:1	1920	1080	30.00	Progressive	74.250	2200	2008	1125
1920x1080/29.97/1:1	1920	1080	29.97	Progressive	74.176	2200	2008	1125
1920x1080/25/1:1	1920	1080	25.00	Progressive	74.250	2640	2448	1125
1920x1080/24/1:1	1920	1080	24.00	Progressive	74.250	2750	2558	1125
1920x1080/23.98/1:1	1920	1080	23.98	Progressive	74.176	2750	2558	1125
1920x1080/30/1:1sF	1920	1080	30	Prog. sF	74.250	2200	2008	1125
1920x1080/29.97/1:1sF	1920	1080	29.97	Prog. sF	74.176	2200	2008	1125
1920x1080/25/1:1sF	1920	1080	25	Prog. sF	74.250	2640	2448	1125
1920x1080/24/1:1sF	1920	1080	24	Prog. sF	74.250	2750	2558	1125
1920x1080/23.98/1:1sF	1920	1080	23.98	Prog. sF	74.176	2750	2558	1125
1280x720/60/1:1	1280	720	60.00	Progressive	74.250	1650	1390	750
1280x720/59.94/1:1	1280	720	59.94	Progressive	74.176	1650	1390	750
1280x720/50/1:1	1280	720	50.00	Progressive	74.250	1980	1720	750
1280x720/30/1:1	1280	720	30.00	Progressive	74.250	3300	3040	750
1280x720/29.97/1:1	1280	720	29.97	Progressive	74.176	3300	3040	750
1280x720/25/1:1	1280	720	25.00	Progressive	74.250	3960	3700	750
1280x720/24/1:1	1280	720	24.00	Progressive	74.250	4125	3865	750
1280x720/23.98/1:1	1280	720	23.98	Progressive	74.176	4125	3865	750
625/50/2:1 (BT.601)	720	581	25.00	2:1 Interlace	13.500	864	732	625
525/59.94/2:1 (BT.601)	720	483	29.97	2:1 Interlace	13.500	858	736	525
720x483/59.94/1:1/4:2:2	720	483	59.94	Progressive	2 x 13.500	858	736	525
720x483/59.94/1:1/4:2:0	720	483	59.94	Progressive	18.000	858	736	525

Table 7. Scanning Formats for Studio Digital Video.

Figure 28. 270 Mb/s EAV timing reference packet viewed as an analog luma channel signal.
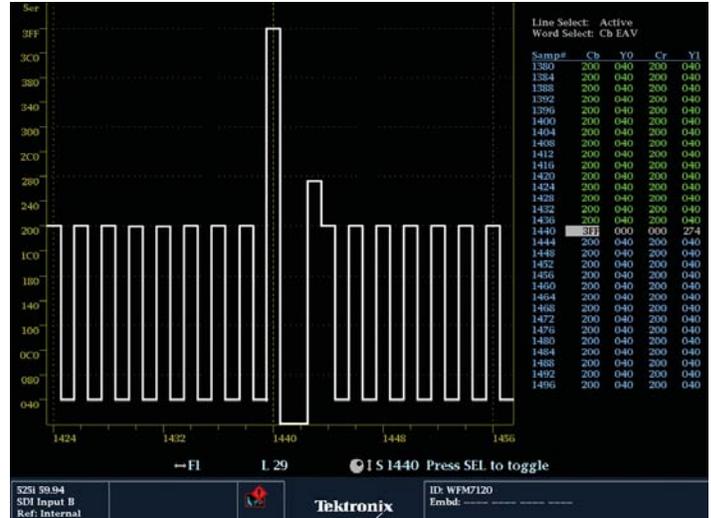
Figure 29. 270 Mb/s EAV timing reference packet viewed as multiplexed data.

Bit Number	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
Function	Fixed (1)	F	V	H	P3	P2	P1	P0	Fixed (0)	Fixed (0)

Table 8. Format of EAV/SAV "xyz" Word.

Digital Studio Synchronization and Timing

It is apparent from the review of analog formats that lots of non-video time is assigned just to pass along the synchronizing information and wait for the picture tube to properly retrace the beam. In a digital component studio format, sync is a short reserved-word pattern, and the balance of this time can be used for multi-channel audio, error check sums, and other ancillary data. Using a digital waveform monitor in PASS mode, these short digital timing packets appear to be short pulses at each end of the horizontal line of the decoded video waveform (Figure 28, also see Figure 11). Ringing will appear in the analog representation because the data words occur at the clock rate, well beyond the bandpass of the analog display system. The DAT option for the WFM7120/6120 provides a logic level DATA view (Figure 29) of these data words, precisely identifying each word and its value.

It is important to keep several interesting timing definitions in mind when comparing analog and digital video:

1. A line of digital video starts with the first word of the EAV (End of Active Video) data packet, 3FF, and ends with the last word of video data in the line. Digital line numbering starts with the first line of vertical blanking.

2. The sample numbers in the digital video line start (sample 0) with the first word of active video, which is the first word after the four-word pattern of the SAV sequence. So the line number does not change at the same time as the sample number goes back to zero.

3. Unlike digital timing, the analog line starts and ends at the timing reference point; the 50% point of the leading edge of bi-level sync, or the positive-going zero crossing for tri-level sync. The analog timing reference, then, is after the digital timing reference and before the digital line first sample, during the time allocated for ancillary data when the signal is digitized. The digital sample word corresponding to the analog timing reference is specified by the digital standard.

Digital video synchronization is provided by EAV and SAV sequences which start with a unique three-word pattern: $3FF_h$ (all bits in the word set to one), 000_h (all zeros), 000_h (all zeros), followed by a fourth "xyz" word with the format described in Table 8.
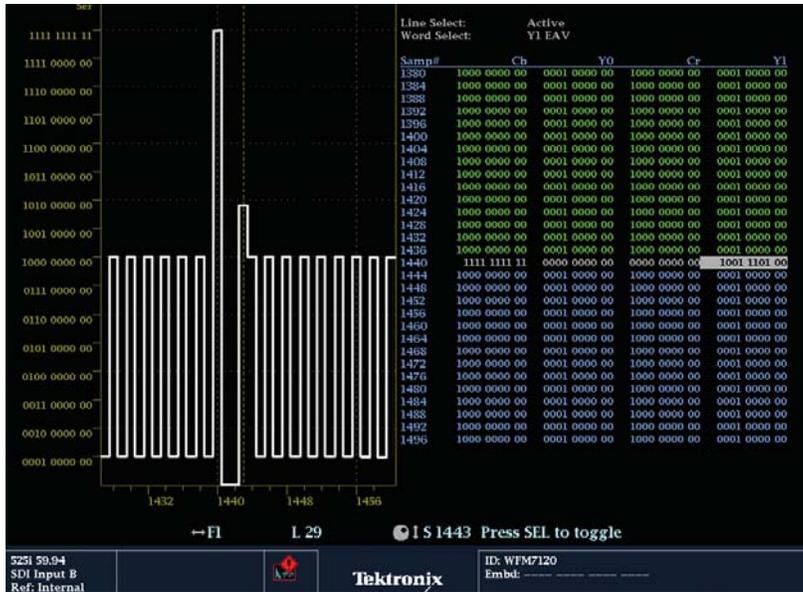
Figure 30. "xyz" word binary display.

The "xyz" word is a 10-bit word with the two least significant bits set to zero to survive a translation to and from an 8-bit system. Bits of the "xyz" word have the following functions:

- **Bit 9 –** (Fixed bit) always fixed at 1

- **Bit 8 –** (F-bit) always 0 in a progressive scan system; 0 for field one and 1 for field two of an interlaced system

- **Bit 7 –** (V-bit) 1 in vertical blanking interval; 0 during active video lines

- **Bit 6 –** (H-bit) 1 indicates the EAV sequence; 0 indicates the SAV sequence

- **Bits 5, 4, 3, 2 –** (Protection bits) provide a limited error correction of the data in the F, V, and H bits

- **Bits 1, 0 –** (Fixed bits) set to zero to have identical word value in 10 or 8 bit systems

Format	F = 0	F = 1	V = 1	V = 0
1920x1080P	Always = 0	NA	Lines 1-41, 1122-1125	Lines 42-1121
1280x720P	Always = 0	NA	Lines 1-25, 746-750	Lines 26-745
1920x1080I	Lines 1-563	Lines 564-1125	Lines 1-20, 561-583, 1124-1125	Lines 41-557, 603-1120
1035I	Lines 1-563	Lines 564-1125	Lines 1-40, 558-602, 1121-1125	Lines 41-557, 603-1120
525/60	Lines 4-255	Lines 1-3, 256-525	Lines 1-19, 264-282	Lines 20-263, 283-525
625/50	Lines 1-312	Lines 313-625	Lines 1-22, 311-335, 624-625	Lines 23-310, 336-623

Table 9. Vertical Timing Information for the Digital Signal.

	Field Line	525 Line	625 Line	1080P Line	1080i Line	1035i Line	720P	SAV	EAV	9	F	V	H	P3	P2	P1	P0	1	0
Active Video	1	20-236	23-310	42-1121	21-560	41-557	26-745	200		1	0	0	0	0	0	0	0	0	0
									274	0	0	1	1	1	0	1	0	0	
Field Blanking	1	4-19, 264-265	1-22, 311-312	1-41, 1122-1125	1-20, 561-563	1-40, 558-563	1-25, 746-750	2AC		1	0	1	0	1	0	1	1	0	0
									2D8	1	0	1	1	0	1	1	0	0	0
Active Video	2	283-525	336-623	NA	584-1123	603-1120	NA	31C		1	1	0	0	0	1	1	1	0	0
									368	1	0	1	1	0	1	0	0	0	
Field Blanking	2	1-3, 266-282	624-625, 313-335	NA	1124-1125, 564-583	1121-1125, 564-602	NA	3B0		1	1	1	0	1	1	0	0	0	0
									3C4	1	1	1	1	0	0	0	1	0	0

Table 10. Digital xyz Information for HD and SD formats.

Figure 31. High-definition digital vertical timing.

The xyz word in Figure 30 displays a binary value 1001110100, starting with bit 9, the most significant bit. In this example, bit 8, 7, and 6 indicate the xyz word is in field one of an interlaced format, in a line of active video, and in an EAV sequence. If we change the waveform monitor to display the next field, the new binary xyz word would be 1101101000, with bit 8 changing to a binary 1. The protection bits 5, 4, 3, and 2 would also change to provide limited error handling of the new binary word.

Several F-bit and V-bit examples following this xyz word pattern are provided in Table 9, and layout of the high-definition vertical interval is illustrated in Figure 31.
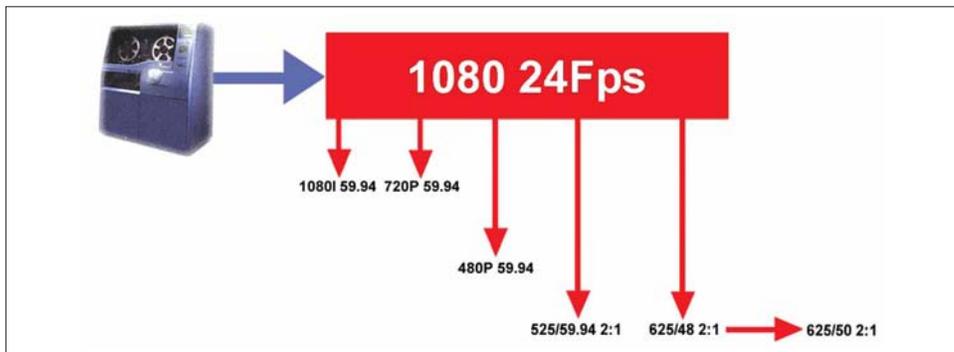
Figure 32. High-definition telecine transfer process.
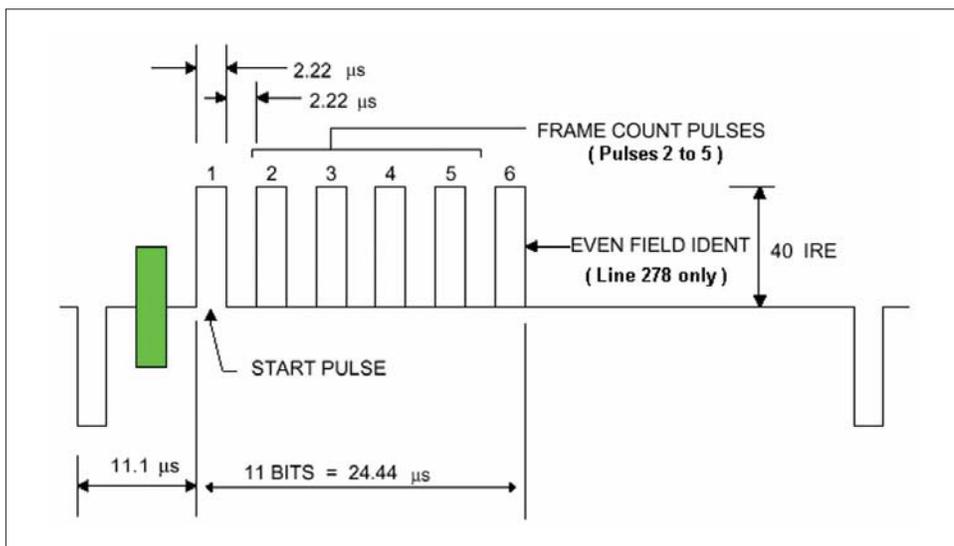
Figure 33. *SMPTE 318M timing reference synchronizing line.*

Telecine synchronization

The transition to high-definition video has provided several useful formats for the mastering and archiving of program material. For example, 1080 progressive at 23.976 Hz provides a means for a direct transfer of film frames to digital files. The colorist only has to produce one master during the telecine transfer process. This digital master can then be converted to any other of the required distribution formats.

In order to synchronize this multiformat system, the standard reference used is NTSC black burst with a field frequency of 59.94 Hz. In order to synchronize with equipment operating at 23.976 Hz (24/1.001) or 48 kHz, the black burst signal may carry an optional ten-field sequence for identification of the signal as specified in SMPTE 318M.

The timing reference synchronizing line is shown in Figure 33 and is inserted on line 15 and 278 of a NTSC 525/59.94 Hz signal. The first pulse (1) is always present at the start of the ten-field identification sequence. Pulses (2-5) which are between 0 and four-frame count pulses follow this. The end pulse (6) is always absent on line 15 and always present on line 278. Table 11 summarizes this information.

The Tektronix TG700 signal generator platform provides the ability to genlock to SMPTE 318M with the AGL7 analog genlock module and provides SMPTE 318M output references with the BG7 black burst generator with CB color bar option.

Ten-Field Sequence	Pulse Position						Line Position	
	1	2	3	4	5	6		
0	1	0	0	0	0	0	Line 15	Field 1
1	1	0	0	0	0	1	Line 278	Field 2
2	1	1	0	0	0	0	Line 15	Field 1
3	1	1	0	0	0	1	Line 278	Field 2
4	1	1	1	0	0	0	Line 15	Field 1
5	1	1	1	0	0	1	Line 278	Field 2
6	1	1	1	1	0	0	Line 15	Field 1
7	1	1	1	1	0	1	Line 278	Field 2
8	1	1	1	1	1	0	Line 15	Field 1
9	1	1	1	1	1	1	Line 278	Field 2

Table 11. SMPTE 318M Ten-field Timing Sequence.

Signal Format/sampling structure/pixel depth	Frames/field rates
4:2:2 Y'C'bC'r 10-bit	60 59.94 and 50 Progressive
4:4:4 R'G'B' 10-bit 4:4:4 R'G'B' + (A) 10-bit	30, 29.97, 25, 24, 23.98 Progressive PsF 60 59.94 and 50 Interlaced
4:4:4 Y'C'bC'r 10-bit 4:4:4 Y'C'bC'r + (A) 10-bit	
4:4:4 R'G'B' 12-bit	
4:4:4 Y'C'bC'r 12-bit	
4:2:2 Y'C'bC'r(A) 12-bit	

Table 12. Dual Link-supported formats defined in SMPTE 372M.

Mapping Structure	Image Format	Signal Format/sampling structure/pixel depth	Frames/field rates
1	1920x1080	4:2:2 (Y'C'BC'R)/10-bit	60, 59.94 and 50 Frames Progressive
2	1280x720	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B' +A)/10-bit	60, 59.94 and 50 Frames Progressive
		4:4:4 (Y'C'BC'R), 4:4:4:4 (Y'C'BC'R+A)/10-bit	30, 29.97, 25, 24 and 23.98 Frames Progressive
	1920x1080	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B' +A)/10-bit	30, 29.97, 25, 24 and 23.98 Frames Progressive
		4:4:4 (Y'C'BC'R), 4:4:4:4 (Y'C'BC'R+A)/10-bit	
3	1920x1080	4:4:4 (R'G'B')/12-bit	60, 59.94 and 50 Fields Interlaced
		4:4:4 (Y'C'BC'R)/12-bit	30, 329.97, 25, 24 and 23.98 Frames Progressive
	2048x1080	4:4:4 (X'Y'Z')/12-bit	24 Frames Progressive, PsF
4	1920x1080	4:2:2 (Y'C'BC'R)/12-bit	30, 29.97, 25, 24 and 23.98 Frames Progressive 60, 59.94 and 50 Fields Interlaced

Table 13. 3 Gb/s Source Image Formats defined in SMPTE 425M.

Dual Link and 3G Formats

Film still continues to dominate within high-end production as the main acquisition medium, despite all the advances in digital signal processing. However, several advances have been made within digital signal processing that are allowing higher and higher image resolutions such as 2K or 4K image formats to emulate the "film look" of the material. By having a high-resolution digital distribution master of the material, visual, effects, color correction and post-production process can be simplified. The final digital distribution master can be used to provide a wide range of duplication formats from Digital Cinema to HD and SD formats.

To achieve distribution of these high-resolution formats, various methods of transmitting the signal between pieces of equipment are necessary. One method to achieve this is by using multiple High-Definition (HD) Serial Digital Interfaces (SDI) such as defined in SMPTE 372M for the Dual Link formats (See Table 12.). Another approach is to multiplex the two virtual data streams into a single 3 Gb/s signal that is standardized by SMPTE 424M and 425M (See Table 13).

Figure 34. SDI data structure for a single line.

Digital Interface	1	...	20	...	560	561	562	563	564	...	1123	1124	1125	1
Link A	2	...	40	...	1120	1122	1124	1	3	...	1121	1123	1125	2
Link B	3	...	41	...	1121	1123	1125	2	4	...	1122	1124	1	3

Table 14. Progressive image format divided between Link A and Link B.

Link A	$C'b_0$: 0-9	Y'_0: 0-9	$C'r_0$: 0-9	Y'_1: 0-9	$C'b_2$: 0-9	Y'_2: 0-9	$C'r_2$: 0-9
Link B	$C'b_0$: 0-9	Y'_0: 0-9	$C'r_0$: 0-9	Y'_1: 0-9	$C'b_2$: 0-9	Y'_2: 0-9	$C'r_2$: 0-9

Table 15. Data structure of Link A and B for fast progressive formats.

Link A	B'_0: 0-9 (even)	G'_0: 0-9	R'_0: 0-9 (even)	G'_1: 0-9	B'_2: 0-9 (even)	G'_2: 0-9	R'_2: 0-9 (even)
Link B	B'_1: 0-9 (odd)	A_0: 0-9	R'_1: 0-9 (odd)	A_1: 0-9	B'_3: 0-9 (odd)	A_2: 0-9	R'_3: 0-9 (odd)

Table 16. Data structure for R'G'B' (A) 4:4:4:4 10-bit Dual Link format.
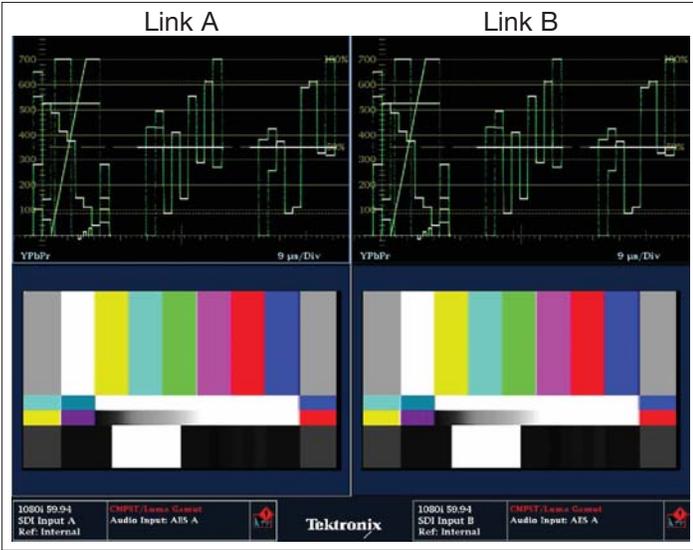
Figure 35. Link A and Link B of a 4:2:2 10-bit 1920x1080 59.94p SMPTE219 color bar signal.

Figure 36. Waveform displays of Dual Link A and B signal for R'G'B' (A) 4:4:4:4 format.

For the Dual Link signals, the various formats are mapped into the two HD-SDI signals. Therefore, the various mapping structures are constrained by the existing HD-SDI format. Figure 34 shows how the 10-bit sampled 4:2:2 Luma Y and Chroma C words are multiplexed together in the HD-SDI signal.

Dual Link Fast Progressive Formats (1920x1080 Y'C'bC'r 4:2:2 10-bit @ 60p, 59.94p, 50p)

For the fast progressive Dual Link formats (60p, 59.94p and 50p), the image structure of these formats are identical to that of the HD-SDI format, except that the high-bandwidth signal must be broken up into the two links. The primary link is defined as "Link A" and the secondary link is defined as "Link B." On an HD waveform monitor, the various trace displays of each link look no different than a similar single 1920x1080 interlaced signal as shown in Figure 35.

Within this format it is important to understand that the original image was scanned as a full-frame progressive image and has been divided between the two links for easy transport across an existing HD-SDI infrastructure. Therefore, the mapping of the lines between the two links is characterized within the standard. Notice the difference between how the image is divided up between the two digital fields of the HD-SDI signal as shown in Table 14. In order to maintain a constant data rate for these three fast progressive frame rates of 60/59.94p and 50p, the blanking interval is changed. For 60/59.94p a total of 2200 words are used per line, whereas in 50p format a total of 2640 words per line are used. Table 15 shows how each sample is transported within each link.

R'G'B' 4:4:4 and R'G'B' (A) 4:4:4:4 10-bit (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

The predominant use of the Dual Link format is to carry film-originated R'G'B' material at 23.98p/24p in order to maintain the quality of the original material. In this way there is no loss of resolution in format conversion to Y'C'b C'r color space. However, the R'G'B' signal has a sampling structure of 4:4:4 and this structure has to be constrained to fit within the two 4:2:2 HD-SDI data streams. To achieve this, Link A [Y'] data space is filled with the G' channel and the [C'b/C'r] data space is filled with the even-numbered B' and R' channels, respectively. In Link B the [Y'] channel data space can be optionally filled with Alpha channel data and the [C'b/C'r] data space is filled with the odd-numbered B' and R' channel samples as shown in Table 16. The Alpha channel can be used to carry a data stream or, alternatively, can be used to carry a key channel which can be used within the post-production process for digital compositing. If the Alpha channel is not present then its value should be set to a blanking level of 64_h. When each of these Dual Link signals is viewed on a waveform monitor, the resulting waveform displays are formed as shown in Figure 36 using the SIM option of the WFM7120, allowing both links to be viewed simultaneously. Notice the Y' channel values are of the correct levels but the C'b/C'r values are not representative of the true level of the signal and require that the two Dual Links signals are combined into a single display for correct representation of the signal.

Link A	$C'b_0$: 0-9 (even)	Y'_0: 0-9	$C'r_0$: 0-9 (even)	Y'_1: 0-9	$C'b_2$: 0-9 (even)	Y'_2: 0-9	$C'r_2$: 0-9 (even)
Link B	$C'b_1$: 0-9 (odd)	A_0: 0-9	$C'r_1$: 0-9 (odd)	A_1: 0-9	$C'b_3$: 0-9 (odd)	A_2: 0-9	$C'r_3$: 0-9 (odd)

Table 17. Data structure for Y'C'bC'r (A) 4:4:4:4 Dual Link format.

Link A	B'_0: 2-11	G'_0: 2-11	R'_0: 2-11	G'_1: 2-11	B'_2: 0-9	G'_2: 2-11	R'_2: 2-11
Link B	B'_1: 2-11	$R'G'B'_0$: 0-1	R'_1: 2-11	$R'G'B'_1$: 0-1	B'_3: 0-9	$R'G'B'_2$: 0-1	Rv_3: 2-11

Table 18. Channel representation for RGB 12-bit.

	Bit Number									
Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
	Not B8	EP	G'n:1	G'n:0	B'n:1	B'n:0	R'n:1	R'n:0	Reserved	Reserved

Table 19. Mapping structure for R'G'B' 0-1.
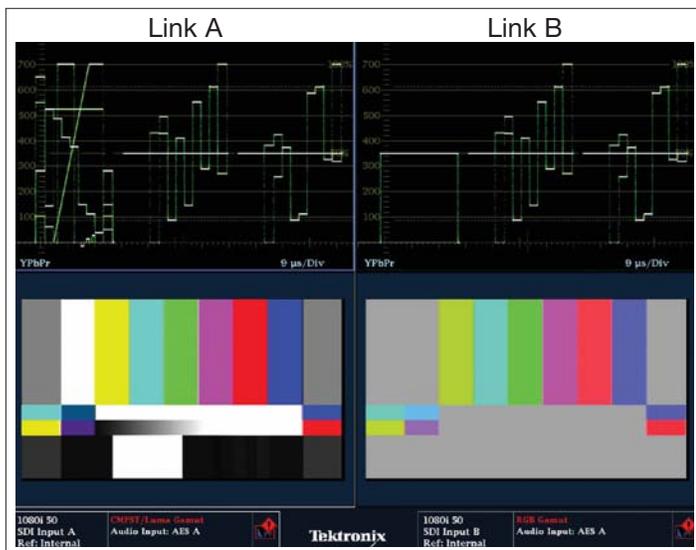
Figure 37. Waveform displays of Dual Link A and B signals for Y'C'bC'r (A) 4:4:4:4 10-bit format.

Y'C'bC'r 4:4:4 and Y'C'bC'r (A) 4:4:4:4 10-bit (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

The structure of this format is similar to R'G'B' (A) 4:4:4:4 as shown in Table 17. Link A [Y'] data space is filled with the Y' channel and the [C'b/C'r] data space is filled with the even-numbered C'b and C'r channels, respectively. In Link B the [Y'] channel data space can be optionally filled with Alpha channel data and the [C'b/C'r] data space is filled with the odd-numbered C'b and C'r channel samples. However, since this format conforms to the Y'C'bC'r format of the HD-SDI data stream, Link A is representative of the signal and can be viewed on a HD waveform monitor. The trace of the Link B signal is dependent on the value present in the Alpha channel, as shown in the picture tile in Figure 37. With the waveform monitor, it is possible to view the Alpha channel waveform traces by selecting the Alpha channel view in the picture menu of the instrument. In the WFM7120/7020, the signals can also be down-converted from the Dual Link signal into a single HD-SDI signal. This signal can be output from the waveform monitor and can be used for simple monitoring applications, without requiring a Dual Link picture monitor.

R'G'B' 4:4:4 12-bit (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

To achieve a greater dynamic range for the signal, a 12-bit data format can be accommodated within the Dual Link standard. The problem here is that the data structure of each link conforms to 10-bit words. Therefore, a method has been defined to carry the 12-bit data across multiple 10-bit words. In the case of R'G'B' 4:4:4 12-bits, the most significant bits (MSBs) 2-11 are carried within the 10-bit words. The additional two bits from each of the R'G'B' channels are combined into the Y' channel of Link B as shown in Table 18. Link A carries the G' channel bits 2-11 and even sample values of B' and R' bits 2-11. In Link B the alpha channel is replaced by the combined bits 0-1 of the R'G'B' samples. The odd samples of the B' and R' bits 2-11 are carried within the [C'b/C'r] words. The combined R'G'B' 0-1 data is mapped into the 10-bit word as defined in Table 19, where EP represents even parity for bits 7-0, the reserved values are set to zero and bit 9 is not bit 8.

Binary 12 Bit	Hex	Decimal		Voltage	Decimal	Hex	Binary 10 Bit		8 Bit Binary	Hex	Decimal
1111 1111 1111	FFF	4095 .... Excluded		766.3mv	1023	3FF	11 1111 1111 ⎤ reserved values		1111 1111	FF	255
		Highest Quantized Level		763.9mv	1020	3FC	11 1111 1100 ⎦				
				763.13mv	1019	3FB	11 1111 1011		1111 1110	FE	254
1110 1011 0000	EB0	3760 .... Peak		700.0mv	940	3AC	11 1010 1100		1110 1011	EB	235
0001 0000 0000	100	256 .... Black		0.0mv	64	040	00 0100 0000		0001 0000	10	16
		Lowest Quantized Level		–47.9mv	4	004	00 0000 0100		0000 0001	01	01
				–48.7mv	3	003	00 0000 0011 ⎤ reserved values				
0000 0000 0000	000	0 .... Excluded		–51.1mv	0	000	00 0000 0000 ⎦		0000 0000	00	00

Figure 38. Representation of 12-bit and 10-bit data values.
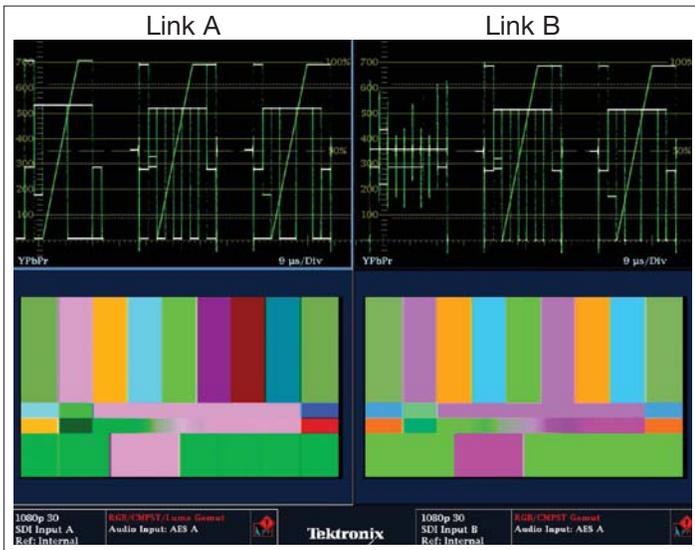
Figure 39. Waveform displays of Dual Link A and B signals for R'G'B' 4:4:4
12-bit format.

The SIM option of the WFM7120 shows the two separate links in Figure 39. Notice how the Y' channel of Link B does not resemble the other waveform displays since it comprises the 0-1 bit data of the R', G', and B' signals. Many people will already be familiar with 10-bit values used within the SDI format, since this is in common use today. However, many users may not be used to dealing with the video signal in 12-bit values. Therefore, the following diagram (Figure 38) provides some useful information regarding the level value differences between 10-bit and 12-bit values.

Link A	$C'b_0$: 2-11	Y'_0: 2-11	$C'r_0$: 2-11	Y'_1: 2-11	$C'b_2$: 0-9	Y'_2: 2-11	R'_2: 2-11
Link B	$C'b_1$: 2-11	$Y'C'bC'r_0$: 0-1	$C'r_1$: 2-11	$Y'C'bC'r_1$: 0-1	$C'b_3$: 0-9	$Y'C'bC'r_2$: 0-1	R'_3: 2-11

Table 20. Channel representation for Y'C'bC'r 12-bit.

	Bit Number								
Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
	Not B8	EP	Y'n:1	Y'n:0	C'b'n:1	C'b n:0	C'r n:1	C'r n:0	Res	Res

Table 21. Mapping structure for Y'C'bC'r 0-1.
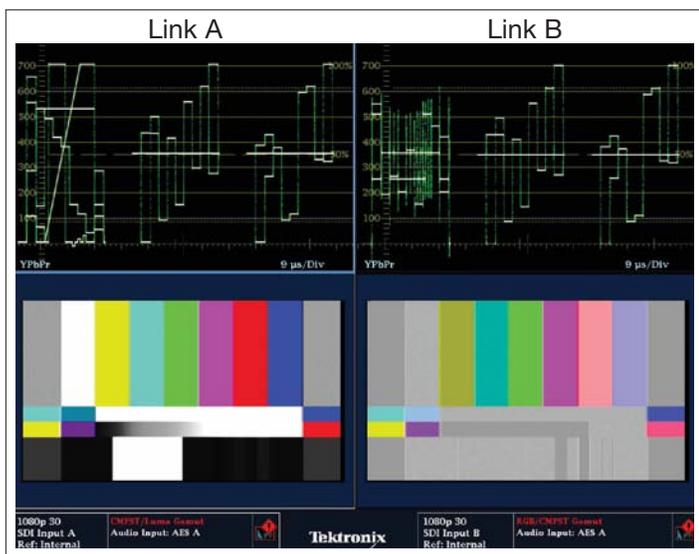
Figure 40. Waveform displays of Dual Link A and B signals for Y'C'bC'r 4:4:4 12-bit format.

Y'C'bC'r 4:4:4 12-bit (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

The structure of the Y'C'bC'r 12-bit data is similar to the G'B'R' 12-bit structure where G' is equivalent to Y', B' is equivalent to C'b and R' is equivalent to C'r. Table 20 shows the channel mapping for the Y'C'bC'r samples and Table 21 shows the bit 0-1 mapping structure within the 10-bit data word. Figure 40 shows the waveforms of both links using the SIM option on the WFM7120.

Link A	$C'b_0$: 2-11	Y_0: 2-11	$C'r_0$: 2-11	Y'_1: 2-11	$C'b_2$: 0-9	Y'_2: 2-11	R'_2: 2-11
Link B	A_0	$Y'C'bC'r_0$: 0-1	A_1	Y'_1: 0-1	A_2	$Y'C'bC'r_2$: 0-1	A_3

Table 22. Channel representation for Y'C'bC'r (A) 4:2:2:4 12-bit.

	Bit Number									
Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
	Not B8	EP	Y'n:1	Y'n:0	C'b n:1	C'b n:0	C'r n:1	C'r n:0	Res	Res

Table 23. Mapping structure for Y'C'bC'r 0-1.

	Bit Number									
Word	9 (MSB)	8	7	6	5	4	3	2	1	0 (LSB)
	Not B8	EP	Y'n:1	Y'n:0	Res	Res	Res	Res	Res	Res

Table 24. Mapping structure for Y' 0-1.

Y'C'bC'r (A) 4:2:2:4 12-bit (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

For those applications that need to transport the Alpha channel and Y'C'bC'r 12-bit data, the following data stream is defined for 12-bit within the constraints of the 10-bit SDI structure. The MSBs for Y'C'bC'r bits 2-11 are carried in Link A and conform to the C'bY'C'rY'* multiplex of the SDI signal. The 10-bit Alpha channel and the LSBs of theY'nC'bnC'rn and Yn+1 are carried in Link B and mapped according to the Table 22. The 0-1 bits of the Y'C'bC'r samples are carried in the 10-bit word as defined in Table 23 and the additional Y' samples are mapped as shown in Table 24.
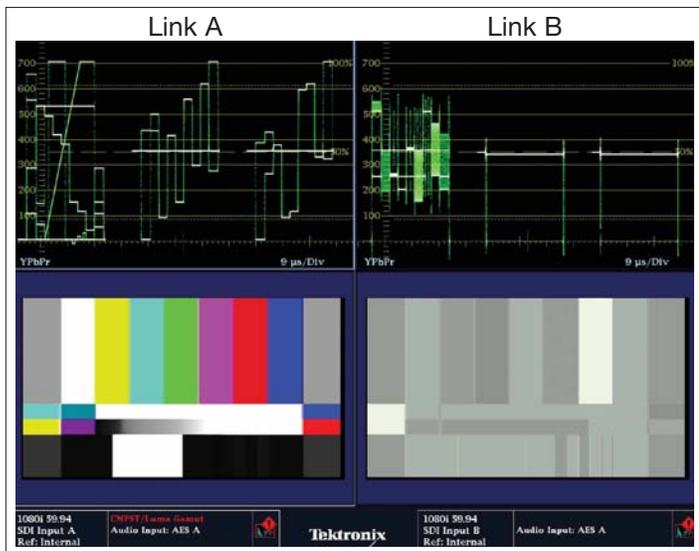
Figure 41. Waveform displays of Dual Link A and B signals for Y'C'bC'r (A) 4:2:2:4 12-bit format.

Figure 41 shows the waveforms of both links using the SIM option on the WFM7120. In this case, link A represents a standard Y'C'bC'r signal, whereas the Y' of link two just contains data bits of the 0-1 samples of Y'C'bC'r data and the C'b and C'r channels represent the Alpha data channel information.

To maintain the overall data rate of the SDI signal, the total number of words per line is varied for each of the different formats to achieve a constant data rate. Table 25 shows the various line lengths for each of the Dual Link formats.

Frame/Field Rate	Total Words per Line	Total Active Words per Line
60 or 59.94 fields 30 or 29.97 frames	2200	1920
50 fields 25 frames	2640	1920
24 or 23.98 frames	2750	1920

Table 25. Line length structure of Dual Link formats.

There are several challenges when dealing with Dual Link signals within a facility in part because the data is mapped between the two links. Within a video facility the two links can be routed along different paths. This can potentially introduce timing errors between the two links. The SMPTE 372M standard defines an allowable timing difference of 40 ns between the two links at the source of the output from the device, but does not define an allowable maximum difference for the timing between the two links. Therefore, it is important to check the specifications of each piece of equipment to know the allowable range of timing difference at the inputs to the device and to ensure that the electrical lengths of the paths carrying the two Dual Link signals are identical. In some cases, the internal buffer within the piece of equipment may be able to account for any inter-channel timing difference applied to its input. However, care should be taken not to exceed the specification of the device, or the Dual Link signal may not be combined correctly. If this timing difference is exceeded, a shift will occur between the channels and the data will not be combined correctly.
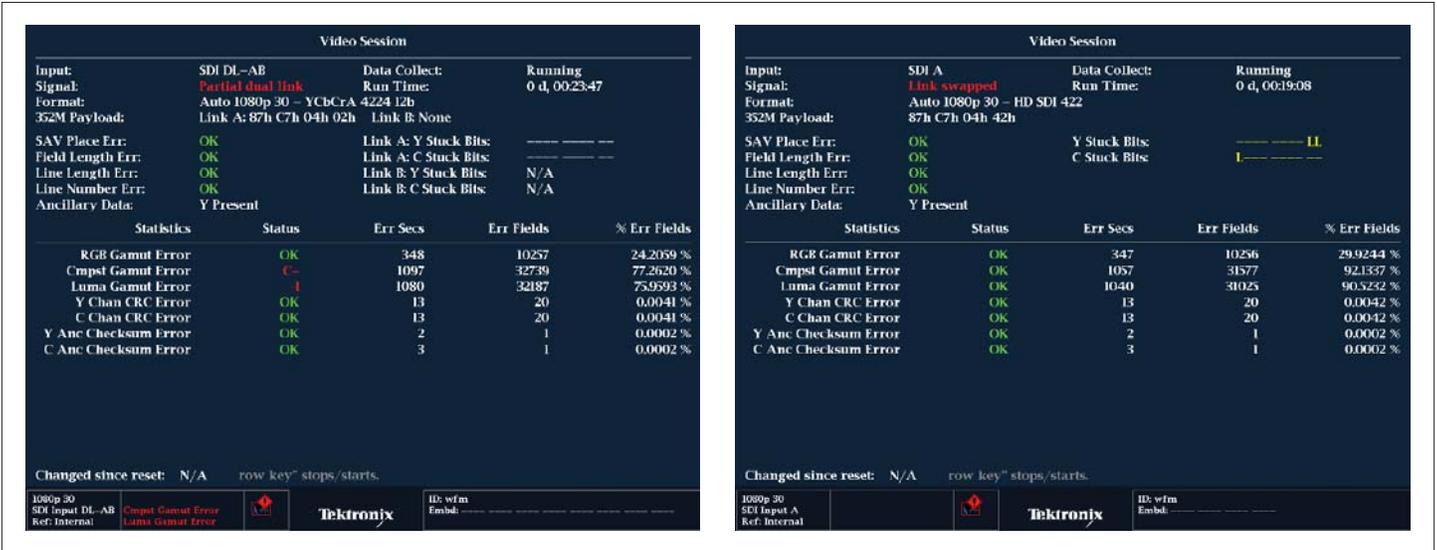
Figure 42. Video Session display showing incorrect connection of Dual Link signals.
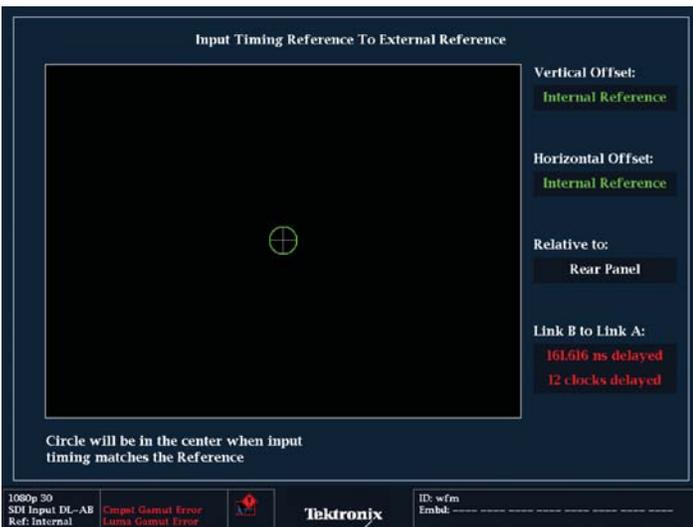
Figure 43. Inter-channel timing measurement of a Dual Link signal.

Within the WFM and WVR series, the timing display shows the inter-channel timing difference between Link B with respect to Link A when a Dual Link signal is applied to the input as shown in Figure 43. In this case, a total of 161ns (12 clocks) was measured as the inter-channel timing difference between Link B and Link A. Note that the inter-channel timing measurement measures the

timing between the two links themselves and does not directly affect the timing measurement between the reference and input signal. Within the instrument it is also possible to set up an alarm threshold for when the timing between the two channels exceeds a number of clock samples.

Another potential problem within the video facility is that the two links could become swapped at the input to the device or a link could be missing or corrupt. To verify the signal integrity, the Video Session display of the WFM or WVR series can be used to quickly identify problems. The assumption within the instrument is that Link A is the dominant signal and must be present in order for the Dual Link signals to be combined correctly. If Link B has the incorrect format or the wrong video payload identification, the Video Session display will indicate a link error. When Link B is missing, the error message displays "partial dual link." If the Link A and B are incorrectly connected to the instrument then the error message "Links swapped" will be displayed in the Video Session display, provided the video payload identification is present.

These types of path length and connection issues can be resolved by migrating to a single SDI cable. However, doing so requires that the data rate of the signal be double in order to carry the entire data stream. Advances in technology now allow for 3 Gb/s high-speed serial data to be carried on a single coaxial cable.
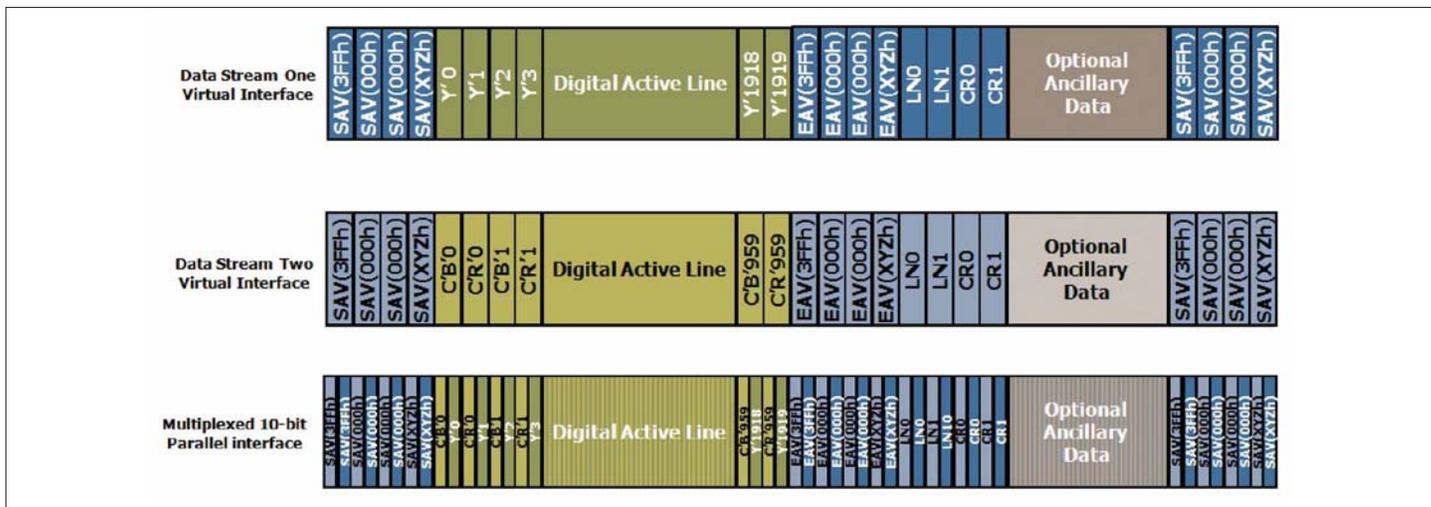
Figure 44. 3 Gb/s SDI data for mapping structure one.

Data Stream 1	Y'0	Y'1	Y'2	Y'3	Y'4	Y'5
Data Stream 2	C'b0	C'r0	C'b1	C'r1	C'b2	C'r2

Table 26. Mapping tructure one of the virtual interfaces.

3 Gb/s (SDI) High-Speed Data

SMPTE has standardized the 3 Gb/s format within two documents: SMPTE 424M discusses the Data Serial Interface and SMPTE 425M describes the Source Image Format Mapping. Table 14 shows the supported mapping structure which is mapped slightly differently than the Dual Link mapping structure. The SDI signal has an identical HD structure and contains two virtual interfaces into which the data is mapped. The definitions of EAV, SAV, Line Count (LN0,LN1 Table 3), and Checksum (CR0,CR1 Table 4) conform to the HD-SDI signal standards.

Mapping Structure One:
Fast Progressive Formats. (Y'C'bC'r 4:2:2 10-bit @ 60p, 59.94p, 50p)

Data stream one of the virtual interface for a fast progressive format contains the Y Luma data and data stream two contains the C chroma information as defined in Table 26. These two virtual interfaces are then multiplexed together to form the 10-bit parallel interface which is then converted into the serial signal as shown in Figure 44.
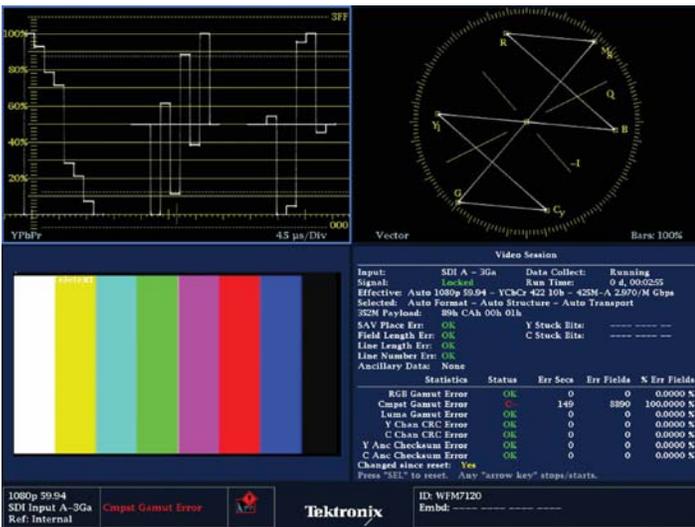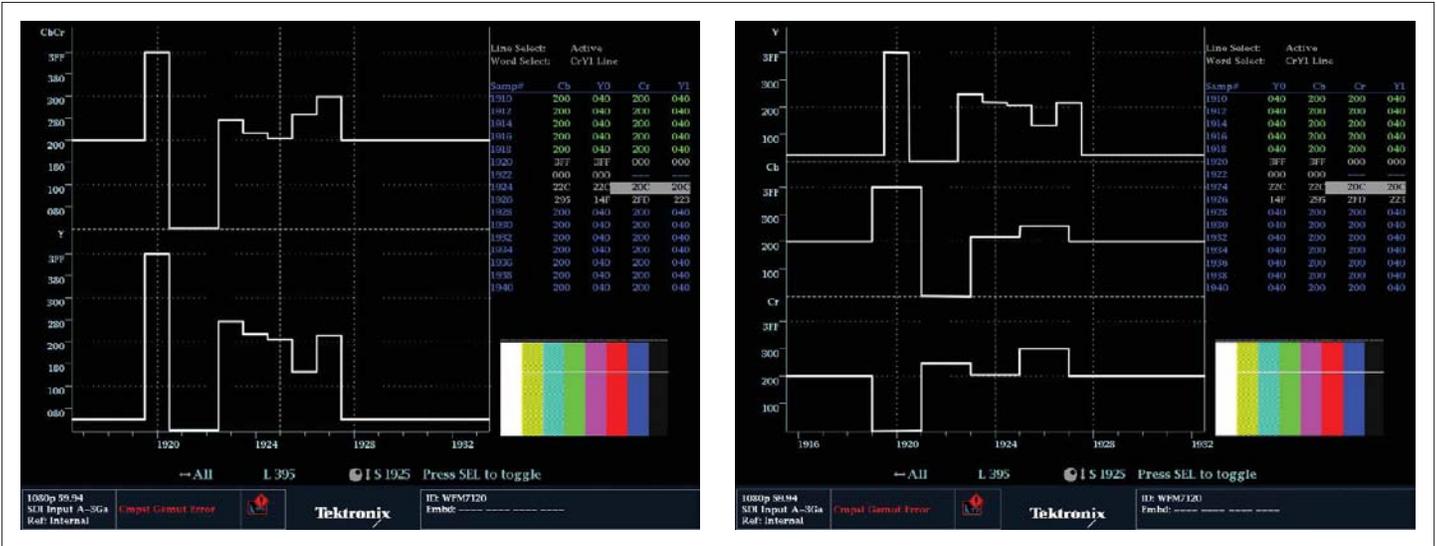
Figure 46. Fast progressive 1080p 59.94 3 Gb/s level A color bar signal shown on WFM7120.

The WFM7120 with the 3G option provides the ability to input a fast progressive signal and displays the traditional waveform displays of the signal. A maximum of two waveform traces can be displayed simultaneously along with the variety of picture and status displays as shown in Figure 46. The Video Session display provides useful information regarding the format of the signal and quickly identifies the format of the signal by using the video payload identifier (SMPTE 352M) which should be present within the signal.

By using the data list display of the DAT option of the WFM7120, the user can view the data structure of the fast progressive signal in two ways. Either as a data format, that views the data in the two virtual interfaces; or as the Video format, that shows the data as the way in which the final video signal is assembled.
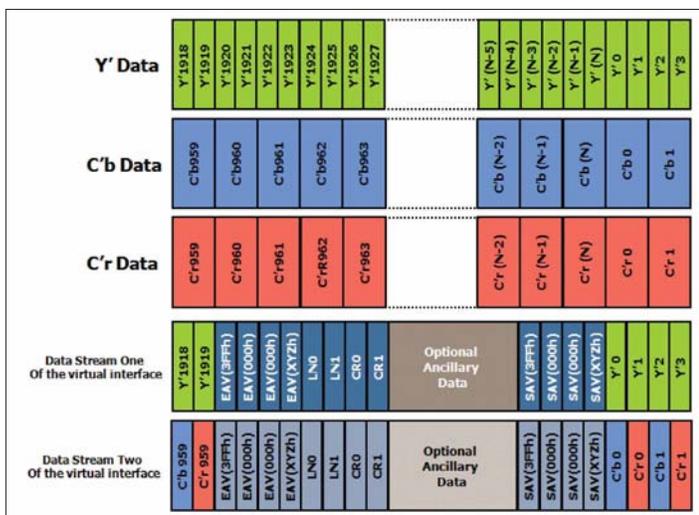
Figure 47. Mapping structure one for the fast progressive signals.
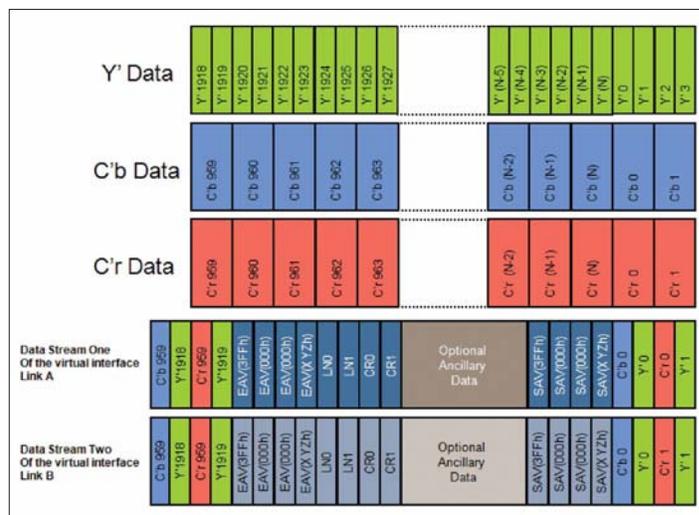
Figure 48. Level B mapping structure for Dual Link fast progressive signals in a 3 Gb/s interface.
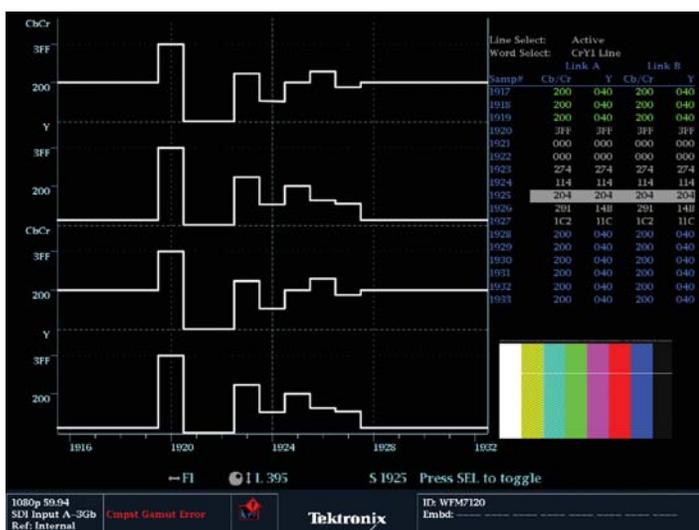
Figure 49. Data list display of a fast progressive level B signal.

The Y data of the fast progressive signal is sampled at 148.5MHz or (148.5/ 1.001)MHz depending on the format. The color difference signals are sampled at half the clock rate of 74.25MHz or (74.25/ 1.001)MHz for each C'b and C'r sample to produce the 4:2:2 sampling structure. Figure 47 shows how the Y', C'b and C'r samples are combined into the two virtual interfaces. There are a total of 1920 (0-1919) samples for the active picture and the blanking width is changed for the various formats to maintain a constant data rate, Table 29 (page 44) shows the samples per line for the various frame rates.

Level A and level B

Level A within the SMPTE 425M standard defines the specific direct image format mapping as initially discussed for the fast progressive format. This mapping structure is different than the Dual Link SMPTE 372M standard. However, within the SMPTE 425M the provision is made to allow for the carriage of a Dual Link signal mapped into a 3 Gb/s signal and this is defined as Level B. In this case the data from Link A is mapped into virtual interface one and Link B information is mapped into virtual interface two. Figure 48 shows how the Dual Link data is mapped into the two virtual interfaces of the 3 Gb/s signal. Within the data list display of the WFM7120, the data mode shows the data of both links A and B as transported over the 3 Gb/s interface (Figure 49).

Mapping Structure Two: 4:4:4 R'G'B'/Y'C'bC'r and 4:4:4:4 R'G'B'(A)/Y'C'bC'r(A) 10-bit signals (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

Mapping structure two supports the carriage of 4:4:4 sampled R'G'B' or Y'C'bC'r data and has application for both 1080 and 720 formats. Data stream one carries all of the G' and R' samples and data stream two carries all of the Alpha and B' samples. Each of the channels is sampled at 74.25MHz or 74.25MHz/1.001. In the case of the YC'bC'r format the G samples are replaced by Y' and the color difference values C'b/C'r are replace the B'/R' samples, respectively.

	Bit Number										
	9	8	7	6	5	4	3	2	1	0
Data Stream one first word of sample (a)/(n)	----B8		R'(a)/(n) [11:9]			G'(a)/(n) [11:9]			B'(a)/(n) [11:9]	
Data Stream one second word of sample (a)/(n)	----B8		R'(a)/(n) [5:3]			G'(a)/(n) [5:3]			B'(a)/(n) [5:3]	
Data Stream two first word of sample (a)/(n)	----B8		R'(a)/(n) [8:6]			G'(a)/(n) [8:6]			B'(a)/(n) [8:6]	
Data Stream two second word of sample (a)/(n)	----B8		R'(a)/(n) [2:0]			G'(a)/(n) [2:0]			B'(a)/(n) [2:0]	

Table 27. 12-Bit mapping structure of R'G'B into the 10-bit virtual interface.

Figure 50. (Level A) R'G'B' mapping structure two.
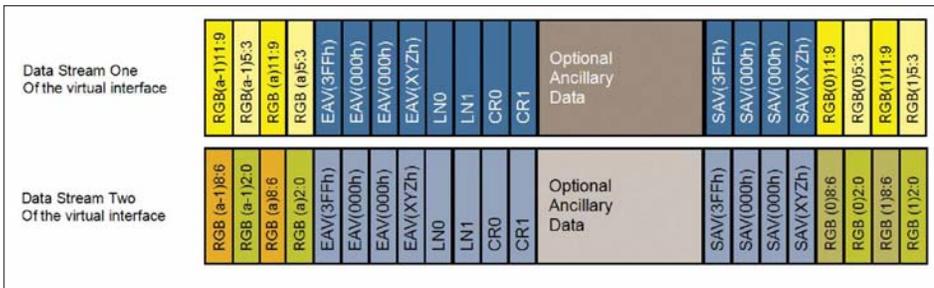
Figure 51. Level A R'G'B' mapping structure three.

Mapping Structure Three:
4:4:4 R'G'B'/Y'C'bC'r 12-bit signals (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)
4:4:4 X'Y'Z' 12-bit signals (24 Frames Progressive, PsF)

Mapping structure three allows for 12-bit data to be carried within the SDI transport as either R'G'B', Y'C'bC'r or X'Y'Z' formats. The 12-bit data represented as [11:0] has to be mapped into a 10-bit

structure and each 12-bit sample is separated into four parts ([11:9],[8:6], [5:3], [2:0]). Each of these values is then combined into a 10-bit word for each of the components R'G'B', Y'C'bC'r or X'Y'Z' as defined in Table 27. These data words are then distributed across the two virtual interfaces and the bits [11:9] and [5:3] are carried by virtual interface one. The remaining data words [8:6] and [2:0] are carried by virtual interface two as shown in Figure 51. In the case of the Y'C'bC'r format the G' samples are replaced by Y' and the color difference values C'b/C'r are replace the B'/R' samples, respectively. In digital cinema application, a different color space of X'Y'Z' is used to give a greater dynamic range to the representation of color to replicate the color depth available from film. SMPTE 428 defines the various parameters of this color space. In the case of the X'Y'Z' format the R' samples are replaced by X', the G' samples are replaced by Y' and the B' samples are replaced by Z'.

Each of the channels is sampled at 74.25MHz or 74.25MHz/1.001. To maintain the constant 3 Gb/s data rate for the various supported formats the blanking width is changed. Table 29 defines the total words per line for each of the formats.

	Bit Number									
	9	8	7	6	5	4	3	2	1	0
Data Stream one first word of sample (a)/(n)	----B8	Reserved			Y'(a)/(n) [11:6]					
Data Stream one second word of sample (a)/(n)	----B8	Reserved			Y'(a)/(n) [5:0]					
Data Stream two first word of sample (a)/(n)	----B8	Reserved			C'b (a)/(n) [11:6]					
Data Stream two second word of sample (a)/(n)	----B8	Reserved			C'b (a)/(n) [5:0]					
Data Stream two third word of sample (a)/(n)	----B8	Reserved			C'r (a)/(n) [11:6]					
Data Stream two fourth word of sample (a)/(n)	----B8	Reserved			C'r (a)/(n) [5:0]					

Table 28. 12-bit mapping structure of Y' C'b C'r into the 10-bit virtual interface.
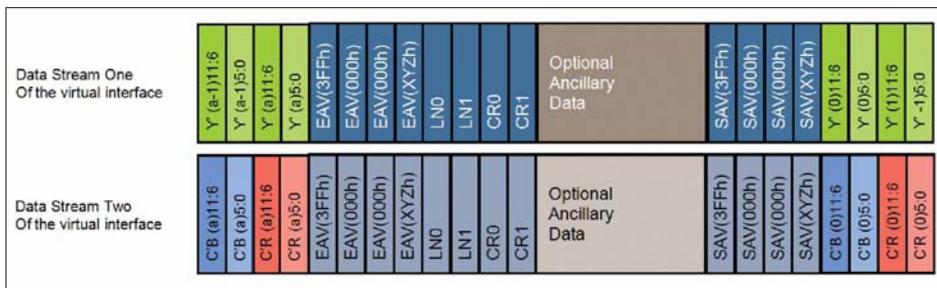
Figure 52. Level A Y'C'bC'r mapping structure four.

Mapping Structure Four: Y'C'bC'r 12-bit signals (30, 29.97, 25, 24, 23.98 Progressive PsF, 60 59.94 and 50 Interlaced)

In order to map this 12-bit data into the 10-bit infrastructure of the SDI interface, the 12-bit data represented as [11:0] has to be divided into different words. In mapping structure four, the first half of the Y' data bits [11:6] are carried in virtual interface one and the subsequent Y' data bits [5:0] are carried in the next packet of the virtual interface one as shown in Table 21. Figure 52 shows how the data packets are combined into the two virtual interfaces. The luma signal (Y') is sampled at 74.25MHz or 74.25MHz/1.001 and the chroma channels (C'b/C'r) are sampled at half this rate of 37.125MHz or 37.125MHz/1.001.

Frame Rate	Total Words per Line	Total Active Words per Line
24 or 23.98	4125	1280
25	3960	1280
30 or 29.97	3300	1280
50	1980	1280
60 or 59.94	1650	1280
24 or 23.98	2750	1920
24 or 23.98	2750	1920
25	2640	1920
30 or 29.97	2200	1920
24 or 24PsF	2750	2048

Table 29. Sampling structure of the video line for the various frame rates.

Digital Audio

One of the advantages of the digital interface is the ability to embed (multiplex) several channels of digital audio into the digital video. This is particularly useful in large systems where separate routing of digital audio becomes a cost consideration and the assurance that the audio is associated with the appropriate video is an advantage. In smaller systems, such as a post production suite, it is generally more economical to maintain separate audio, thus eliminating the need for numerous multiplexer and demultiplexer modules. Handling of digital audio is defined in ANSI/SMPTE Standard 272M, Formatting AES/EBU Audio and Auxiliary Data into Digital Video Ancillary Data Space, for 525/60 and 625/50 ANSI/SMPTE 259M formats, and in ANSI/SMPTE 299M, 24-Bit Digital Audio Format for HDTV Bit-Serial Interface for ANSI/SMPTE 292M formats.

Two to sixteen AES/EBU audio channels are transmitted in pairs and combined where appropriate into groups of four channels. Each group is identified by a unique ancillary data ID. Audio is sampled at a video synchronous clock frequency of 48 kHz, or optionally at a synchronous or asynchronous rates from 32 kHz to 48 kHz.

Ancillary data is formatted into packets prior to multiplexing it into the video data stream as shown in Figure 53. Each data block may contain up to 255 user data words provided there is enough total data space available to include the seven (for component video) words of overhead. For composite digital, only the vertical sync broad pulses have enough room for the full 255 words. Multiple data packets may be placed in individual data spaces.
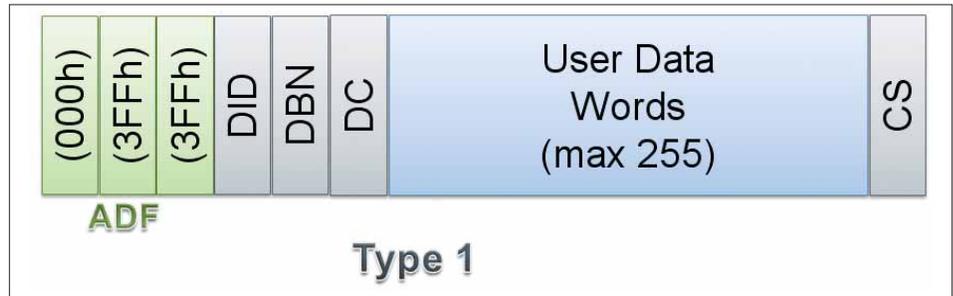
Figure 53. Ancillary data formatting.

At the beginning of each data packet is a header using word values that are excluded for digital video data and reserved for synchronizing purposes. For component video, a three-word header 000_h, $3FF_h$, $3FF_h$ is used. Each type of data packet is identified with a different Data ID word. Several different Data ID words are defined to organize the various data packets used for embedded audio. The Data Block Number (DBN) is an optional counter that can be used to provide sequential order to ancillary data packets allowing a receiver to determine if data is missing. As an example, with embedded audio, an interruption in the DBN sequence may be used to detect the occurrence of a vertical interval switch, thereby allowing the receiver to process the audio data to remove the likely transient "click" or "pop." Just prior to the data is the Data Count word indicating the amount of data in the packet. Finally, following the data is a checksum that is used to detect errors in the data packet.
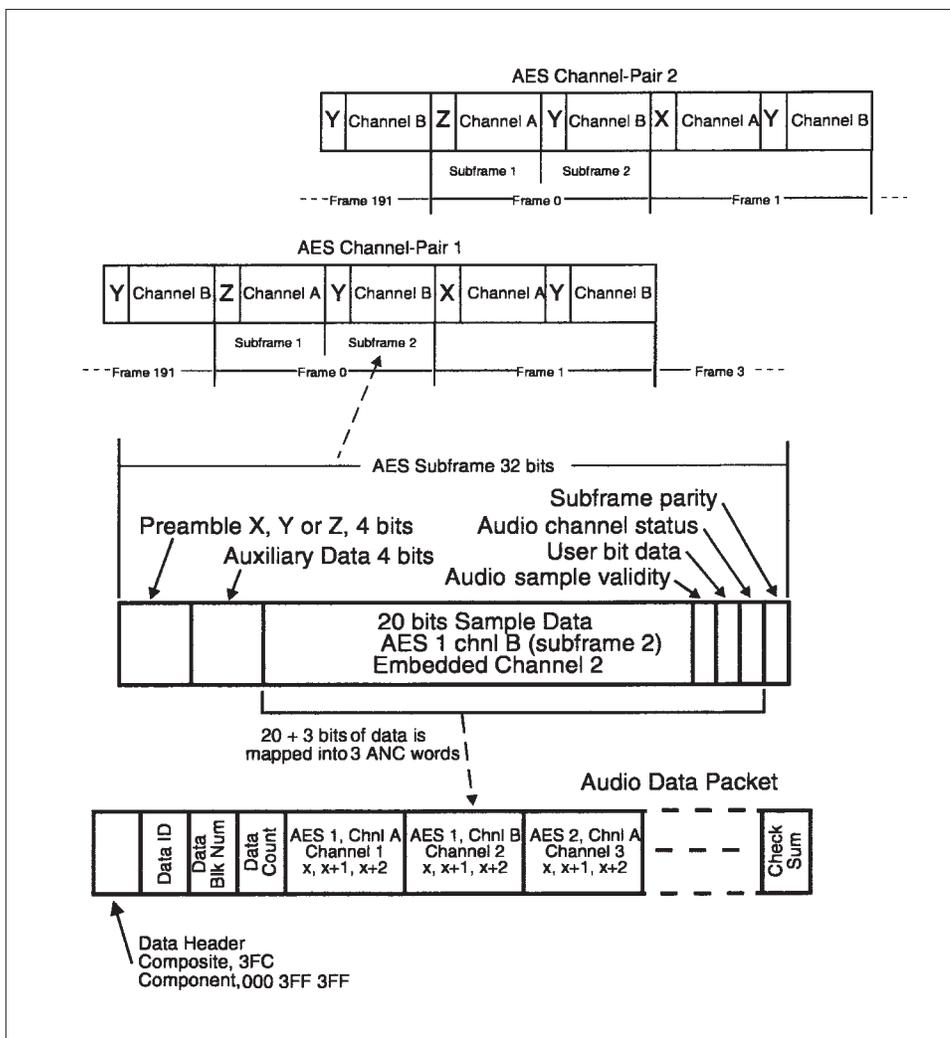
Figure 54. Basic embedded audio.

Bit	X	X + 1	X + 2
b9	not b8	not b8	not b8
b8	AUD 5	AUD 14	Parity
b7	AUD 4	AUD 13	C
b6	AUD 3	AUD 12	U
b5	AUD 2	AUD 11	V
b4	AUD 1	AUD 10	AUD 19 (msb)
b3	AUD 0	AUD 9	AUD 18
b2	ch bit-1	AUD 8	AUD 17
b1	ch bit-2	AUD 7	AUD 16
B0	Z-bit	AUD 6	AUD 15

Table 30. Embedded Audio Bit Distribution.

Embedded audio in component digital video

Embedded audio and available options are defined in ANSI/SMPTE Standard 272M for standard definition and ANSI/SMPTE 299M for high-definition studio digital formats. Please refer to the most current version of those documents. A basic embedded audio configuration with two AES channel-pairs as the source is shown in Figure 54.

The Audio Data Packet contains one or more audio samples from up to four audio channels. 23 bits (20 audio bits plus the C, U, and V bits) from each AES sub-frame are mapped into three 10-bit video words (X, X+1, X+2) as shown in Table 30.

Bit-9 is always the inverse of bit-8 to ensure that none of the excluded word values ($3FF_h$ through $3FC_h$ or 003_h through 000_h) are used. The Z-bit is set to "1" corresponding to the first frame of the 192-frame AES block. Channels of embedded audio are essentially independent (although they are always transmitted in pairs) so the Z-bit is set to a "1" in each channel even if derived from the same AES source. C, U, and V bits are mapped from the AES signal; however, the parity bit is not the AES parity bit. Bit-8 in word X+2 is even parity for bits 0-8 in all three words.

There are several restrictions regarding distribution of the audio data packets although there is a "grandfather clause" in the standard to account for older equipment that may not observe all the restrictions. Audio data packets are not transmitted in the horizontal ancillary data space following the normal vertical interval switch as defined in RP 168. They are also not transmitted in the ancillary data space designated for error detection checkwords defined in RP 165. Taking into account these restrictions, data should be distributed as evenly as possible throughout the video field. This is important to minimize receiver buffer size for transmitting 24-bit audio in composite digital systems. This results in either three or four audio samples in each audio data packet.

Extended embedded audio

Full-featured embedded audio is defined in the aforementioned standards to include:

- Carrying the 4 AES auxiliary bits (which may be used to extend the audio samples to 24-bit)

- Allowing non-synchronous clock operation

- Allowing sampling other than 48 kHz

- Providing audio-to-video delay information for each channel

- Documenting Data IDs to allow up to 16 channels of audio in component digital systems

- Counting "audio frames" for 525 line systems

Figure 55. Extended embedded audio.

To provide these features, two additional data packets are defined. Extended Data Packets carry the 4 AES auxiliary bits formatted such that one video word contains the auxiliary data for two audio samples (Figure 55).

Extended data packets must be located in the same ancillary data space as the associated audio data packets and must follow the audio data packets.

The Audio Control Packet (shown in Figure 56) is transmitted once per field in the second horizontal ancillary data space after the vertical interval switch point. It contains information on audio frame number, sampling frequency, active channels, and relative audio-to-video delay of each channel. Transmission of audio control packets is optional for 48 kHz synchronous operation and required for all other modes of operation (since it contains the information as to what mode is being used).

Audio frame numbers are an artifact of 525 line, 29.97 frame/second operation. There are exactly 8008 audio samples in five frames, which means there is a non-integer number of samples per frame. An audio frame sequence is the number of frames for an integer number of samples (in this case five) and the audio frame number indicates where in the sequence a particular frame belongs. This is important when switching between sources

Figure 56. Audio control packet formatting.

because certain equipment, most notably digital video recorders, require consistent synchronous operation to prevent buffer over/under flow. Where frequent switching is planned, receiving equipment can be designed to add or drop a sample following a switch in the four out of five cases where the sequence is broken. The challenge in such a system is to detect that a switch has occurred. This can be facilitated by use of the data block number in the ancillary data format structure and by including an optional frame counter with the unused bits in the audio frame number word of the audio control packet.

	Audio Channels	Audio Data Packet	Extended Data Packet	Audio Control Packet
Group 1	1-4	$2FF_h$	$1FE_h$	$1EF_h$
Group 2	5-8	$1FD_h$	$2FC_h$	$2EE_h$
Group 3	9-12	$1FB_h$	$2FA_h$	$2ED_h$
Group 4	13-16	$2F9_h$	$1F8_h$	$1EC_h$

Table 31. Data Identifiers for up to 16-Channel Operation of SD embedded audio.

Audio delay information contained in the audio control packet uses a default channel-pair mode. That is, delay-A (DELA0-2) is for both channel 1 and channel 2 unless the delay for channel 2 is not equal to channel 1. In that case, the delay for channel 2 is located in delay-C. Sampling frequency must be the same for each channel in a pair, hence the data in "ACT" provides only two values, one for channels 1 and 2 and the other for channels 3 and 4.

In order to provide for up to 16 channels of audio in component digital systems, the embedded audio is divided into audio groups corresponding to the basic four-channel operation. Each of the three data packet types are assigned four data IDs as shown in Table 31.

In component digital video, the receiver buffer in an audio demultiplexer is not a critical issue since there's much ancillary data space available and few lines excluding audio ancillary data. The case is considerably different for composite digital video due to the exclusion of data in equalizing pulses and, even more important, the data packet distribution required for extended audio. For this reason the standard requires a receiver buffer of 64 samples per channel with a grandfather clause of 48 samples per channel to warn designers of the limitations in older equipment.

Systemizing AES/EBU audio

Serial digital video and audio are becoming commonplace in production and post-production facilities as well as television stations. In many cases, the video and audio are married sources; and it may be desirable to keep them together and treat them as one data stream. This has, for one example, the advantage of being able to keep the signals in the digital domain and switch them together with a serial digital video routing switcher. In the occasional instances where it's desirable to break away some of the audio sources, the digital audio can be demultiplexed and switched separately via an AES/EBU digital audio routing switcher.

At the receiving end, after the multiplexed audio has passed through a serial digital routing switcher, it may be necessary to extract the audio from the video so that editing, audio sweetening, or other processing can be accomplished. This requires a demultiplexer that strips off the AES/EBU audio from the serial digital video. The output of a typical demultiplexer has a serial digital video BNC as well as connectors for the two-stereo-pair AES/EBU digital audio signals.

Basic HD embedded audio

There are some similarities and several differences in the implementation of AES/EBU within an HD environment. The formatting of the ancillary data packets is the same between SD and HD. The information contained within the user data is different because the full 24 bits of audio data are sent as a group and not split-up into 20 bits of audio data and an extended packet containing the 4 auxiliary bits. Therefore, the total number of bits used in HD is 29 bits (compared with 23 bits in SD), the 24 bits of audio data are placed in 4 ancillary data words along with C, V, U and Z-bit flag. Additionally, the CLK and ECC words are added to the packet as shown in Figure 57. Since the full 24 bits of audio data are carried within the user data there is no extended data packet used within HD.

Figure 57. Structure of HD audio data packet.

Conformance to the ancillary data packet structure means that the Ancillary Data Flag (ADF) has a three-word value of 000_h,$3FF_h$, $3FF_h$, as SMPTE 291M. The one-word DID (Data Identification) have the following values to identify the appropriate group of audio data as shown in Table 32. DBN is a one-word value for data block number and DC is a one-word data count which is always 218_h. The User Data Words (UDW) always contains 24 words of data and is structured as shown in Figure 57. The first two words, UDW0 and UDW1 are used for audio clock phase data and provide a means to regenerate the audio sampling clock. The data within these two words provides a count of the number of video clocks between the first word of EAV and the video sample corresponding to the audio sample.

	Audio Channels	Audio Data Packet	Audio Control Packet
Group 1	1-4	$2E7_h$	$1E3_h$
Group 2	5-8	$1E6_h$	$2E2_h$
Group 3	9-12	$1E5_h$	$2E1_h$
Group 4	13-16	$2E4_h$	$1E0_h$

Table 32. Data Identifiers for up to 16-Channel Operation of HD embedded audio.

Bit	UDW2	UDW3	UDW4	UDW5
B9	NOT B8	NOT B8	NOT B8	NOT B8
B8	EVEN PARITY	EVEN PARITY	EVEN PARITY	EVEN PARITY
B7	AUD1 3	AUD 111	AUD 119	P1
B6	AUD1 2	AUD 110	AUD 118	C1
B5	AUD1 1	AUD 1 9	AUD 1 17	U1
B4	AUD1 0	AUD 18	AUD 116	V1
B3	Z	AUD1 7	AUD1 15	AUD1 23 (MSB)
B2	0	AUD1 6	AUD1 14	AUD1 22
B1	0	AUD1 5	AUD1 13	AUD1 21
B0	0	AUD1 4	AUD1 12	AUD1 20
Bit	UDW6	UDW7	UDW8	UDW9
B9	NOT B8	NOT B8	NOT B8	NOT B8
B8	EVEN PARITY	EVEN PARITY	EVEN PARITY	EVEN PARITY
B7	AUD2 3	AUD 2 11	AUD 219	P2
B6	AUD2 2	AUD 2 10	AUD 218	C2
B5	AUD2 1	AUD 2 9	AUD 2 17	U
B4	AUD2 0	AUD 2 8	AUD216	V2
B3	0	AUD2 7	AUD2 15	AUD2 23 (MSB)
B2	0	AUD2 6	AUD2 14	AUD2 22
B1	0	AUD2 5	AUD2 13	AUD2 21
B0	0	AUD2 4	AUD2 12	AUD2 20
Bit	UDW10	UDW11	UDW12	UDW13
B9	NOT B8	NOT B8	NOT B8	NOT B8
B8	EVEN PARITY	EVEN PARITY	EVEN PARITY	EVEN PARITY
B7	AUD3 3	AUD 311	AUD 319	P3
B6	AUD3 2	AUD 310	AUD 318	C3
B5	AUD3 1	AUD 3 9	AUD 3 17	U3
B4	AUD3 0	AUD 38	AUD 316	V3
B3	Z	AUD3 7	AUD3 15	AUD3 23 (MSB)
B2	0	AUD3 6	AUD3 14	AUD3 22
B1	0	AUD3 5	AUD3 13	AUD3 21
B0	0	AUD3 4	AUD3 12	AUD3 20
Bit	UDW14	UDW15	UDW16	UDW17
B9	NOT B8	NOT B8	NOT B8	NOT B8
B8	EVEN PARITY	EVEN PARITY	EVEN PARITY	EVEN PARITY
B7	AUD4 3	AUD 4 11	AUD 419	P4
B6	AUD4 2	AUD 410	AUD 418	C4
B5	AUD4 1	AUD 4 9	AUD 4 17	U4
B4	AUD4 0	AUD 4 8	AUD416	V4
B3	0	AUD4 7	AUD4 15	AUD2 23 (MSB)
B2	0	AUD4 6	AUD4 14	AUD4 22
B1	0	AUD4 5	AUD4 13	AUD4 21
B0	0	AUD4 4	AUD4 12	AUD4 20

Table 33. Bit Assignment of audio data.

Each audio data subframe is distributed across 4 UDW samples as described in Table 33.

Note that the full preamble data is not carried within the 4 words, only a reference to the start of the 192 frame by use of the Z-bit indicator. Also, the parity bit is that used within the 32-bit sub-frame unlike standard definition.

The Error Correction Codes (ECC) is a set of 6 words that are used to detect errors within the first 24 words from ADF to UDW17. The value is calculated by applying the 8 bits of data B0-B7 of the 24 words through a BCH code information circuit that produces the 6 words of the ECC (Error Correction Code.)

The ancillary data information is multiplexed within the color difference Cb/Cr data space only. Unlike the standard definition structure which applies the ancillary audio data across CbYCrY*, the Y data space is only used for the audio control packet that occurs once per field and is placed on the second line after the switching point of the Y data. No ancillary data is placed within the signal on the line subsequent to the switching point. The switching point location is dependent on the format of the high-definition signals, for example in the 1125/60 system no ancillary data is put on line 8.
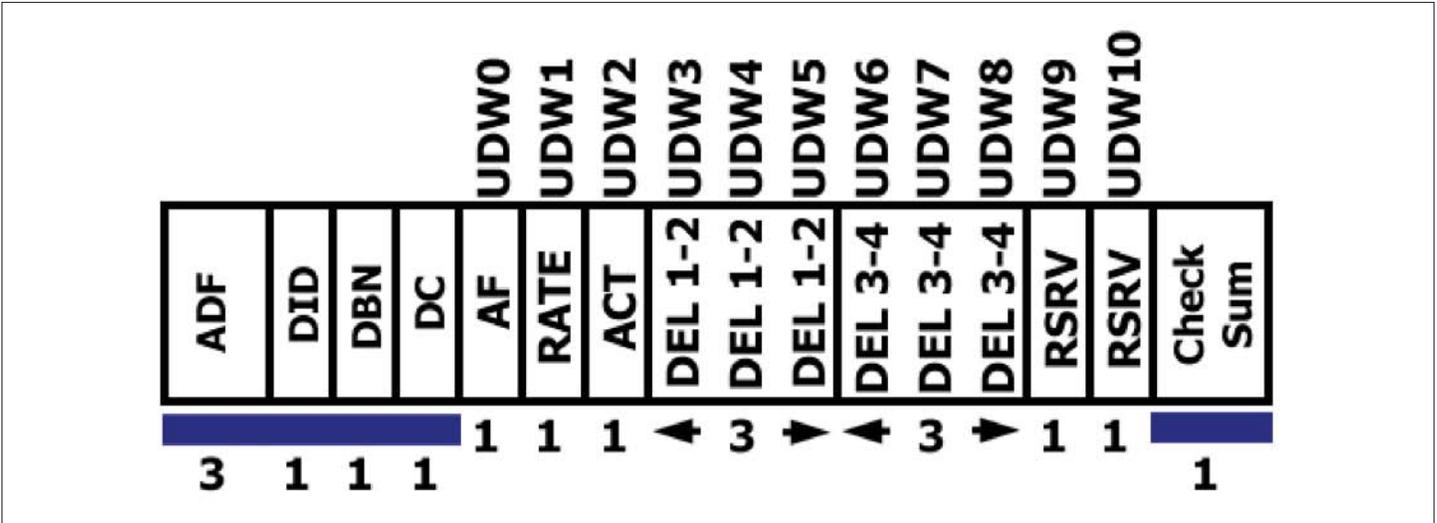
Figure 58. Structure of audio control packet.

Audio control packet

The audio control packet carries additional information used in the process of decoding the audio data and has a similar structure to standard definition. Its structure is shown in Figure 58 and contains the following information. The Ancillary Data Flag has a three-word value of 000_h, $3FF_h$, $3FF_h$. The one-word DID has the following values to identify the appropriate group of audio data as shown in Table 31 & 32. DBN is always 200_h and DC is always $10B_h$. The UDW contains 11 words of data structured into five different types of data. The Audio Frame (AF) number data provides a sequential number of video frames to assist in indicating the position of the audio samples when using a non-integer number of audio samples per frame. The one-word value RATE indicates the sampling rate of the audio data and whether the data is synchronous or asynchronous. The ACT word indicates the number of active channels within the group. DEL_{m-n} indicates the amount of accumulated audio processing delay relative to video measured in audio sample intervals for each channel pair 1&2 and 3&4. Figure 59 shows the decode audio control packet display on the WVR series. This provides decoded information on the audio control packet data.

This is a slightly different format than that used in standard definition. The two-word value RSRV is reserved for future use at this time.

Figure 59. Audio Control Packet Display.

How to monitor multi-channel audio

Audio monitor has typically been done by monitoring the audio levels of the signal and ensuring they remain within reasonable limits. When stereo was introduced the need to monitor the interaction between the channels became important to ensure a correctly balanced stereo image. The phase (Lissajous) display is used to monitor the interaction of the two channels. (The Audio Monitoring application note 21W-16463-01 provides detail on how to use the Lissajous display.)

The development of multi-channel, surround sound audio technology has greatly enhanced the viewing experience. Surround-sound technology has emerged within digital television and digital video technologies to create the home theater experience. The combination of enhanced picture quality and surround sound gives viewers a sense of total immersion and complete involvement in the program.

In audio production, a visual representation of the sound image complements the auditory experience, helping audio engineers create the desired audio mix or more precisely adjust the audio content in post production. In broadcast facilities, such a visual display helps operators notice problems in multi-channel audio content more quickly and assist engineering in rapidly isolating the problem.

Audio channels in 5.1 surround sound

For several years, the film industry has used a multi-channel audio system as a standard format for cinema-based audio. Increasingly, to reproduce this surround sound experience in the home and give consumers a more cinematic effect, 5.1 multi-channel audio has replaced stereo in home entertainment systems. DVDs typically have 5.1 audio, and the television industry has started distributing and broadcasting this audio format in DTV systems. In conventional use, a 5.1 multi-channel audio system does not try to locate sound at precise, arbitrary locations. Rather, the different channels have particular roles (see Figure 60).

– The left (L) and right (R) channels drive the speaker pair in front of the listener (the mains) and carry most of the music. They typically operate like a stereo system.

– The center (C) channel primarily carries dialog and drives a speaker positioned in front of the listener and between the mains.

– The left surround (Ls) and right surround (Rs) channels drive the left and right speaker pair placed to the side or behind the listener (the "surrounds"). They typically handle sound effects or ambient sounds that create the aural illusion of a particular environment or space.
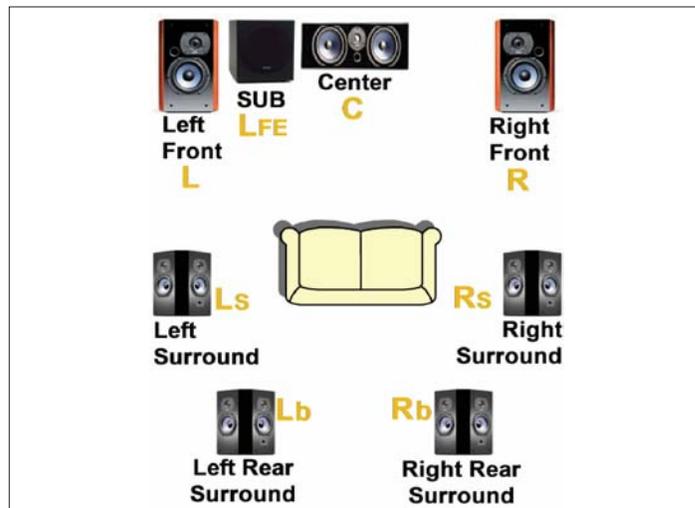
Figure 60. Multi-Channel Surround Sound Speaker Placement.

– The low frequency effects (L_{FE}) channel delivers low-frequency special effects, e.g. explosions, and drives a higher power, restricted frequency speaker (a subwoofer), typically positioned in front of the listener.

The L, R, C, Ls, and Rs channels form the "5" part of 5.1 multi-channel audio. They create the overall surround sound experience and handle the dialog and many special effects. They also exploit the sound localization characteristics of the auditory system to create appropriately located phantom sound sources. Below 150 Hz, the sound localization cues become much less effective. The L_{FE} channel (the '.1' in 5.1 audio) has a relatively restricted role in creating these dramatic, non-localized effects.

Although the speaker device is called a Subwoofer, in a surround sound system it is referred to as a Low Frequency Effects channel because, depending on the size of the speaker system being used by the viewer, the L_{FE} will have different responses. For instance a system with small satellite speakers will not have enough response to provide all the bass sounds and in this case these sounds can be directed to the L_{FE} channel. In the other case of large speakers in the room, they have more dynamic range to allow them to carry the lower frequency response of the bass sounds and there is less need to direct them to the L_{FE} channel.

Continuing extensions to the multi-channel audio system add further channels to the configuration. Systems are now being used which are 6.1 or 7.1 channel systems. In 6.1 channel audio, an additional speaker is added to provide a mono back surround channel. In 7.1 audio systems two speakers are used to carrier the mono back surround channel to the Left Rear Surround (L_b) and a Right Rear Surround (R_b). Additionally, it may be necessary to monitor the down-mix of the multi-channel audio to a stereo pair. This can be denoted as L_o-R_o for a standard stereo mix or as Lt (Left-total) - Rt (Right-total) for a stereo down-mix which is Dolby Pro-Logic™ encoded.

The surround sound display[1]

The surround sound display associates an audio level with each of the five primary channels in a 5.1 audio system by determining the channel's RMS signal level. It can compute an un-weighted RMS value or can apply a filter that produces a frequency-weighted RMS value. Applying this A-weighting filter adjusts for the frequency response of the human auditory system and yields an audio level value that better approximates the perceived loudness of the audio signal.

The display shows the audio level in the L, R, Ls, and Rs channels on four scales originating from the display center and oriented toward the display corners. The upper left, upper right, lower left, and lower right corners of the display correspond to a 0 dB level in the L, R, Ls and Rs channels, respectively. The display center represents -65 dBFS. As the signal level in a channel increases, the cyan-colored level indicator lengthens from the center towards the display corner for that channel. Each scale has marks at 10 dB intervals, with a mark at the user defined test alignment level, typically defined at -20d BFS or -18 dBFS.

The display connects the ends of the audio level indicators to form a polygon called the Total Volume Indicator (TVI). The TVI indicates the level balance among the main and surround channels and gives an indication of the total surround sound balance. The TVI indicates the amount of correlation between signals in adjacent channels using the following conventions.

– A straight line connecting the level indicators of two adjacent channels indicates that these channels have uncorrelated signals, i.e., a correlation value of 0.0.

Figure 61. Surround Sound Display with test tones for L, R, Ls and Rs.

– As the correlation between the two signals increases toward +1.0, the line connecting the level indicators bends outward, away from the center and towards the potential phantom sound source.

– As the signals move towards an out-of-phase condition, i.e., correlation values approach -1.0, the line bends inwards, towards the center, indicating the destructive interference and reduction in total sound volume associated with out-of-phase signals.

Figure 61 shows audio test signals applied to each of the inputs of the L, R, Ls and Rs channels. This forms an octagon shape if the signals have the same amplitude and frequency and so the operator can quickly see if the channels are correctly aligned.

The center channel has a special role in a surround sound system. The surround sound display handles this channel differently. The display indicates the center channel audio level as a yellow vertical line positioned between the left and right channel audio level indicators. The display forms a Center Volume Indicator (CVI) by connecting the ends of the L and C level indicators and the ends of the C and R level indicators. The TVI and CVI operate

1 Audio Surround Sound Display licensed from Radio-Technische Werkstätten GmbH & Co. KG (RTW) of Cologne, Germany.

Phantom Source Indicators (PSIs) positioned around the perimeter of the display offer additional help in visualizing sound localization. Four PSIs placed on each side of the display indicate the nature of potential phantom sound sources formed by the L/R, L/Ls, Ls/Rs, and R/Rs adjacent channel pairs. These four PSIs operate in the same manner. Each PSI consists of a white tic mark, called the phantom source location pointer, which indicates the location of a potential phantom sound source. A variable length line extending on both sides of this location pointer indicates the listener's ability to localize this source. If the signals in an adjacent channel pair have a +1 correlation, they create a phantom sound source in a precise location between the two speakers. The phantom source location pointer appears on the side associated with the adjacent channel pair.

The position of the white tic mark depends on the level relationship between the signals in the adjacent channel. A decrease in correlation between signals in an adjacent channel pair introduces some uncertainty in the location of the associated phantom sound source.

To indicate this, the PSI becomes a variable-length line extending from the white tic mark toward the display corners associated with the channel pair. As an additional visual aid, the line changes color as the correlation value crosses different threshold values.

For signal correlations above 0.9, the PSI is a very short white line, indicating a highly localized phantom sound source. For correlation values below 0.9, the line becomes green. It continues to lengthen on each side of the phantom source location pointer as the correlation decreases, indicating increasing uncertainty in the location of the phantom sound source. Once the line reaches a display corner, it will no longer lengthen with decreasing signal correlation. The location pointer remains in the position determined by the level balance between the adjacent channels. Consequently, unless the mark falls at the midpoint of a side, one end of the line will stop lengthening before the other.

For signal correlations below 0.2, the line turns yellow. When the signals become fully uncorrelated, i.e., the correlation value equals 0, the line will span the entire side of the display. This indicates that these adjacent channels will create a diffuse, ambient sound perception. Although the channel pair does not create a phantom
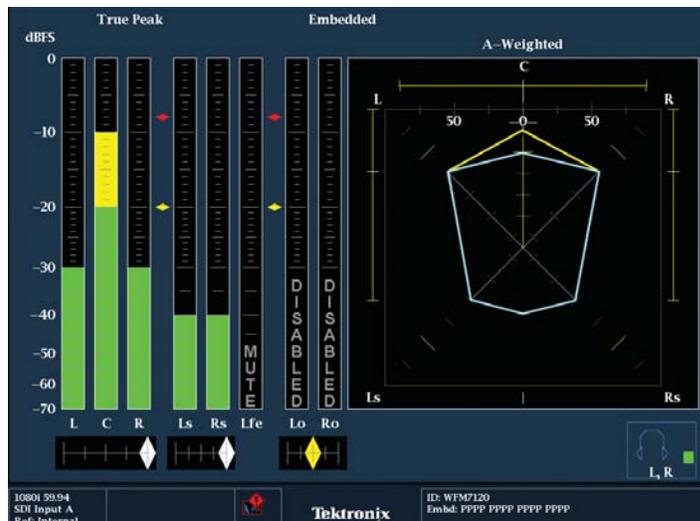

Figure 62. Surround Sound Display with live audio signal.

sound source, the white tic mark still indicates the level balance between the channels. A further decrease in the signal correlation towards a -1 value does not change the length of the PSI or the position of the phantom source location pointer. The PSI will change color to red if the correlation falls below -0.3, indicating a possibly undesirable out-of-phase condition.

Figure 62 shows a live signal with dominate sound from the center channel compared to left and right channel. The L-R L-Ls and R-Rs have straight lines connecting them, indicating uncorrelated signal between the channels. There is a slight dominance in the sound between the front L-R and the surround channels Ls-Rs as shown by the stretching of the polygon shape. Also, the white tic marks on each side of the surround sound display indicate that L and R front speakers are currently carrying the more dominant sound. The connection line between the Ls and Rs channels is bending outwards and the PSI is a white tic mark between the channels indicating that these channels are correlated and identical. The surround sound display is an intuitive interface to show the interaction between the multiple channels in a surround sound system.
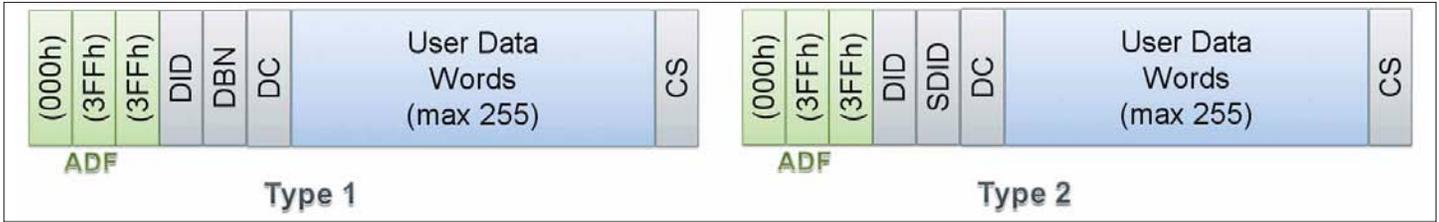
Figure 63. Ancillary data types 1 and 2.

Ancillary Data

Today a variety of ancillary data can be carried within the blanking interval. The addition of this ancillary data to the SDI signal allows for the same transport to carry associated data with the video signal and this data can be synchronized to the video. This ancillary data allows for the carriage of up to 16 channels of embedded audio in HD-SDI and up to 32 channels in Dual Link and 3 Gb/s formats. Additional metadata can be carried within the stream that provides additional information associated with the video or audio signals such as the Video Payload Identification, or Timecode.

SMPTE 291M defines the process for the format and location of this ancillary data within the SDI signal. There are two defined types of ancillary data as shown in Figure 63.

The Ancillary Data Flag (ADF) is used to identify the start of the ancillary data packet and uses the codeword 000_h, $3FF_h$, $3FF_h$. This is the reverse of the code words used for EAV and SAV data. A Data Identification word (DID) is used to signify the type of data being carried so that equipment can quickly identify the type of data present within the signal.

For type 1 ancillary data, the Data Block Number (DBN) signifies the count of this particular data series. For instance, this packet has a DBN of 12 then the next packet should have a DBN of 13, otherwise a data packet has been lost. This type 1 structure is used for embedded audio packets.

For the type 2 ancillary data there is a Secondary Data ID (SDID), which replaces the DBN that provides a wider range of allowed values and can be used for a series of data to be grouped, for instance, the Dolby Vertical Ancillary (VANC) data has a series of SDID to identify the audio channels the data is associated with.
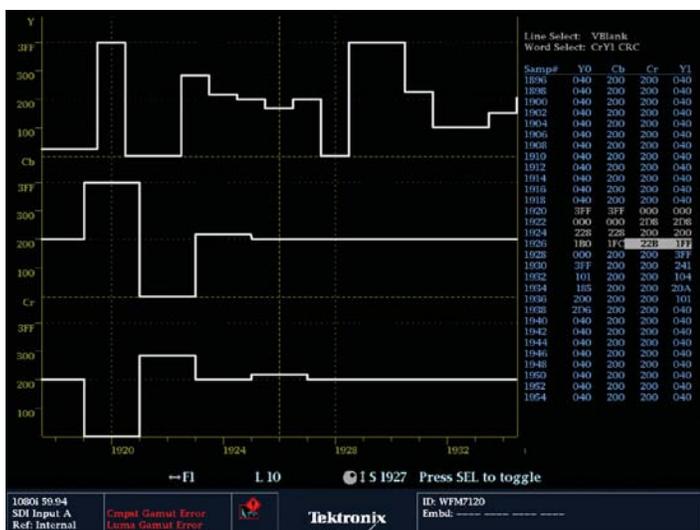
Figure 64. Data list display of the WFM7120 showing the ancillary data of a SMPTE352M packet.

The Data Count (DC) provides information on the number of User Data Words (UDW) within this ancillary data packet. The amount of user data that can be contained within the ancillary data packets is variable up to a maximum of 255 words. Finally, a Checksum is added to ensure the integrity of the data packet.

By using the data list display of the WFM7120, the user can look through the data display to find the ancillary data packets which are identified by the Ancillary Data Flag 000h, 3FFh, 3FFh. In this case, following the ADF are the values 241h and 101h that indicate this is an SMPTE 352M Video Payload Identification. There are a wide variety of ancillary data packets each with a unique DID and SDID (for type 2). SMPTE RP291 provides information on each of these Identifiers in use. Table 34 shows the values for type 1 and Table 35 shows the values for type 2.

Standard	Description	DID	Location
S291M	Undefined Data	00_h (200_h)	-
S291M	Packet Marked for Deletion	80_h (180_h)	-
S291M	Start packet	88_h (288_h)	-
S291M	End Packet	84_h (284_h)	-
RP165	Error Detection Handling	$F4_h$ ($1F4_h$)	VANC
S272M	SD Group 1 Audio Data Packet	FF_h ($2FF_h$)	HANC
S272M	SD Group 2 Audio Data Packet	FD_h ($1FD_h$)	HANC
S272M	SD Group 3 Audio Data Packet	FB_h ($1FB_h$)	HANC
S272M	SD Group 4 Audio Data Packet	$F9_h$ ($2F9_h$)	HANC
S272M	SD Group 1 Extended Audio Data Packet	FE_h ($1FE_h$)	HANC
S272M	SD Group 2 Extended Audio Data Packet	FC_h ($2FC_h$)	HANC
S272M	SD Group 3 Extended Audio Data Packet	FA_h ($2FA_h$)	HANC
S272M	SD Group 4 Extended Audio Data Packet	$F8_h$ ($1F8_h$)	HANC
S272M	SD Group 1 Audio Control Packet	EF_h ($1EF_h$)	HANC
S272M	SD Group 2 Audio Control Packet	EE_h ($2EE_h$)	HANC
S272M	SD Group 3 Audio Control Packet	ED_h ($2ED_h$)	HANC
S272M	SD Group 4 Audio Control Packet	EC_h ($1EC_h$)	HANC
S299M	HD Group 1 Audio Data Packet	$E7_h$ ($2E7_h$)	HANC
S299M	HD Group 2 Audio Data Packet	$E6_h$ ($1E6_h$)	HANC
S299M	HD Group 3 Audio Data Packet	$E5_h$ ($1E5_h$)	HANC
S299M	HD Group 4 Audio Data Packet	$E4_h$ ($2E4_h$)	HANC
S299M	HD Group 1 Audio Control Packet	$E3_h$ ($1E3_h$)	HANC
S299M	HD Group 2 Audio Control Packet	$E2_h$ ($2E2_h$)	HANC
S299M	HD Group 3 Audio Control Packet	$E1_h$ ($2E1_h$)	HANC
S299M	HD Group 4 Audio Control Packet	$E0_h$ ($1E0_h$)	HANC
S315M	Camera Position Information	$F0_h$ ($2F0_h$)	HANC or VANC

Table 34. Ancillary identification codes for type 1.

Standard	Description	DID	SDID	DC
S291M	Undefined Data	00h (200$_h$)	00$_h$ (200$_h$)	xxx
S291M	8-Bit Application	04$_h$ (104$_h$)	10$_h$ (110$_h$)	xxx
S291M	Packet Marked for Deletion	80$_h$ (180$_h$)	00$_h$ (200$_h$)	xxx
S291M	Start Packet	88$_h$ (288$_h$)	00$_h$ (200$_h$)	xxx
S291M	End Packet	84$_h$ (284$_h$)	00$_h$ (200$_h$)	00$_h$ (200$_h$)
S353	MPEG Recording Data	08$_h$ (108$_h$)	08$_h$ (104$_h$)	80$_h$ (180$_h$)
S305M	SDTI Transport	40$_h$ (140$_h$)	01$_h$ (101$_h$)	2A$_h$ (22A$_h$)
S348	HD-SDTI Transport	40$_h$ (140$_h$)	02$_h$ (102$_h$)	Variable
S	Link Encryption Message 1	40$_h$ (140$_h$)	04$_h$ (104$_h$)	-
S	Link Encryption Message 2	40$_h$ (140$_h$)	05$_h$ (205$_h$)	-
S	Link Encryption Metadata	40$_h$ (140$_h$)	06$_h$ (206$_h$)	-
S 352M	Payload Identification	41$_h$ (241$_h$)	01$_h$ (101$_h$)	04$_h$ (104$_h$)
S2016-3	AFD and Bar Data	41$_h$ (241$_h$)	05$_h$ (205$_h$)	08$_h$ (108$_h$)
S2016-4	Pan Scan Data	41$_h$ (241$_h$)	06$_h$ (206$_h$)	60$_h$ (260$_h$)
RP2010	ANSI/SCTE 104 Message	41$_h$ (241$_h$)	07$_h$ (107$_h$)	Variable
S2031	DVB/SCTE VBI Data	41$_h$ (241$_h$)	08$_h$ (108$_h$)	Variable
ITU-R	Inter Station Control Data	43$_h$ (143$_h$)	01$_h$ (101$_h$)	Variable
RDD8	Subtitling Distribution Packet	43$_h$ (143$_h$)	02$_h$ (102$_h$)	Variable
RDD8	Transport of ANC Packet	43$_h$ (143$_h$)	03$_h$ (203$_h$)	Variable
RP214	KLV Metadata VANC	44$_h$ (244$_h$)	04$_h$ (104$_h$)	Variable
RP214	KLV Metadata HANC	44$_h$ (244$_h$)	14$_h$ (214$_h$)	Variable
RP223	Package of UMID Data	44$_h$ (244$_h$)	44$_h$ (144$_h$)	Variable
S2020-1	Compressed Audio Metadata	45$_h$ (145$_h$)	01$_h$ (101$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	02$_h$ (102$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	03$_h$ (203$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	04$_h$ (104$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	05$_h$ (205$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	06$_h$ (206$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	07$_h$ (107$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	08$_h$ (108$_h$)	Variable
S2020	Compressed Audio Metadata	45$_h$ (145$_h$)	09$_h$ (209$_h$)	Variable
RDD8	WSS Data	50$_h$ (250$_h$)	01$_h$ (101$_h$)	Variable
RP215	Film Codes in VANC	51$_h$ (151$_h$)	01$_h$ (101$_h$)	Variable
S12M	Timecode (ATC) in VANC	60$_h$ (260$_h$)	60$_h$ (260$_h$)	10$_h$ (110$_h$)
S334M	Closed Caption (EIA-708-B)	61$_h$ (161$_h$)	01$_h$ (101$_h$)	Variable
S334M	Closed Caption (EIA 608)	61$_h$ (161$_h$)	02$_h$ (102$_h$)	03$_h$ (203$_h$)
S334M	Program Description (DTV)	62$_h$ (162$_h$)	01$_h$ (101$_h$)	Variable
S334M	Data Broadcast (DTV) VANC	62$_h$ (162$_h$)	02$_h$ (102$_h$)	Variable
RP208	VBI Data in VANC Space	62$_h$ (162$_h$)	03$_h$ (203$_h$)	Variable
RP196	Timecode (LTC) HANC	64$_h$ (164$_h$)	64$_h$ (164$_h$)	8$_h$ (108$_h$)
RP196	Timecode (VITC) HANC	64$_h$ (164$_h$)	7F$_h$ (17F$_h$)	9$_h$ (209$_h$)

Table 35. Ancillary identification codes for type 2.

Figure 65. Ancillary data on the WFM7120: (a) ANC Data Inspector; (b) Watch List configuration.

With this wide array of ancillary data, it can be difficult to find these data packets within the HD or SD signal. The Ancillary Data Inspector available in the DAT option of the WFM7120 simplifies this task (Figure 65(a)). Users can create a Watch List in the configuration menu of the instrument which can check for a certain type of ancillary data (Figure 65(b)). Alternatively, if no selection is made then the Watch List will only show the present ancillary data within the signal. The user can scroll through each of the available ancillary data types present. The Ancillary Data Display provides information on the type of ancillary data present, the location of the packet, Data Count and Checksum. Pressing MAG on the instrument will allow the user to see a real-time view of the user data words within the ancillary data packet.
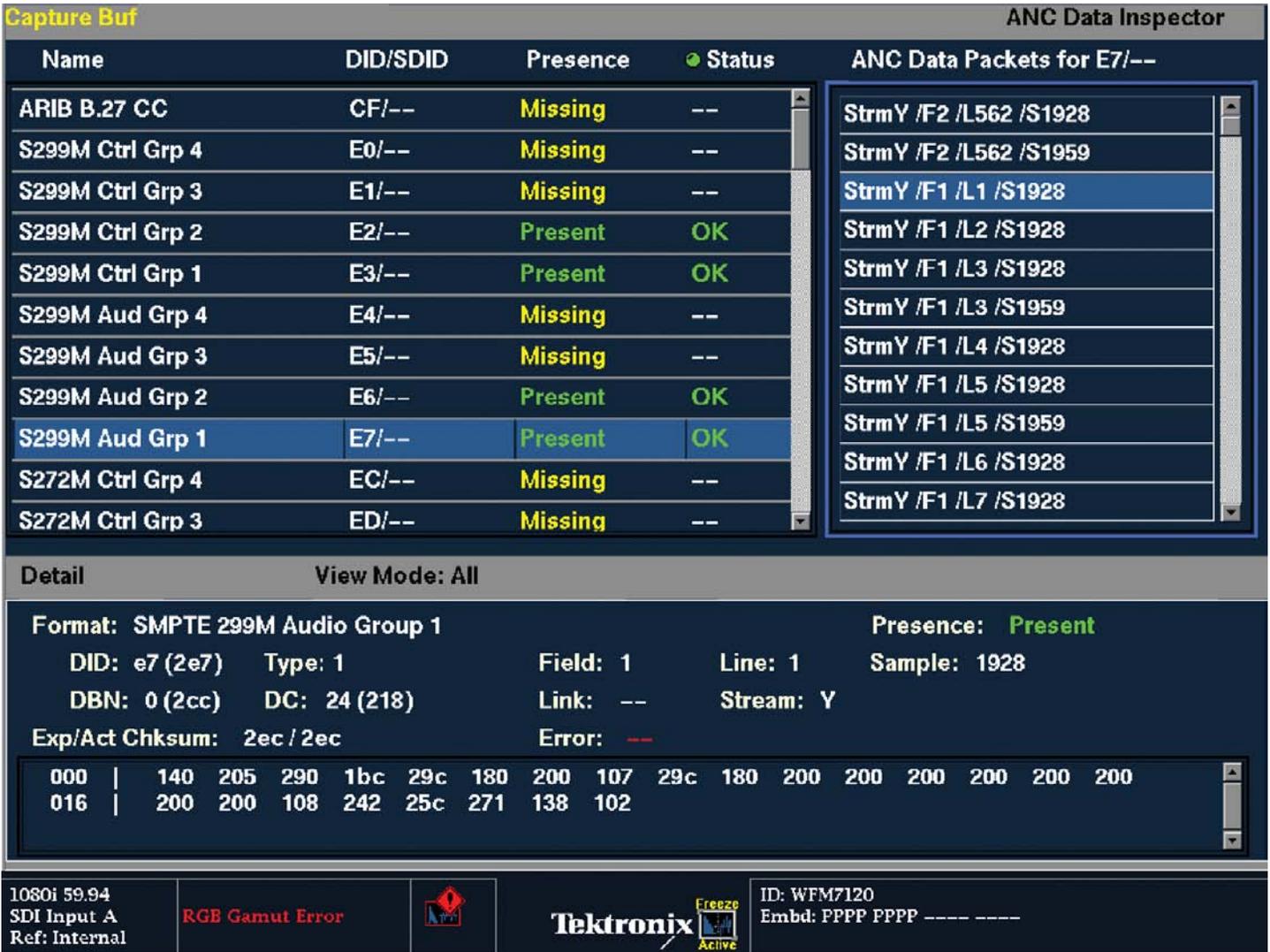
Figure 66. Capture Buffer display using Ancillary Data Inspector.

For further analysis in deferred time, the user can use CaptureVu™ to capture a complete frame of the video signal that is then internally stored in the instrument. By selecting to use the Capture Buffer in the Ancillary Data Inspector, the complete frame of data is loaded into the display and the user can then search through all the ancillary data packets that were captured within the buffer. Figure 66 shows the Capture Buffer data within the Ancillary Data Inspector display.

Format	525	525p	625	625p	1080i	1080p	720p
S 272M SD Embedded Audio	HANC C'bY'C'rY* Not Present Lines 9, 10, 272, 273	--------	HANC C'bY'C'rY' Not Present Lines 5, 6, 318, 319	--------	--------	--------	--------
S 299M HD Embedded Audio	--------	--------	--------	--------	HANC C'b/C'r only Not Present Lines 7, 569	HANC C'b/C'r only Not Present Lines 7	HANC C'b/C'r only Not Present Lines 7
RP 165 EDH	Before SAV Line 9, 272	--------	Before SAV Line 5, 318	--------	--------	--------	--------
S 352	After EAV Line 13, 273	After EAV Line 13	After EAV Line 9, 322	After EAV Line 9	After EAV Line 10, 572	After EAV Line 10	After EAV Line 10
S 334	The data packets are located in the active line portion of one or more lines in the vertical ancillary space. Data may be located in any lines in the area from the second line after the line specified for switching to the last line before active video, inclusively.						
RP 215	The data packets are located in the active line portion of one line in the vertical ancillary space. Data may be located in any lines in the area from the second line after the line specified for to the last line before active video, inclusively. On segmented frame progressive formats, the film transfer descriptor data packet shall occur in the vertical blanking area at thestart of the frame.						
RP 188	The preferred location for insertion of Ancillary Time Code (ATC) packets into a digital video signal stream shall be within the available ancillary space located within vertical blanking after the vertical interval switching point defined in S RP 168 and before the beginning of active video.						
RP 196	Transmission of HANC time code packets shall be at least once per frame for LTC data. Within the television frame/field, the LTC and VITC data words shall be transmitted between lines 10-20 for 525-line systems and 6-22 for 625-line systems.						

Table 36. ANC data placement.

Format	525	525p	625	625p	1080i	1080p	720p
Line Number	10, 273	10	6, 319	6	7, 569	7	7

Table 37. Vertical Interval Switching line numbers.

Each ancillary data packet has a specified location where the data can reside within the SDI signal. In some cases, like embedded audio, this can be located in most of the Horizontal Ancillary (HANC) data space, or in other formats it can be a specific set of lines in the vertical ancillary (VANC) data space. Table 36 summarizes a few of the locations for ancillary data placement. Ancillary data should not reside in the vertical interval around the switching point of the video signal. SMPTE RP 168 specifies the switching point for each video format which is summarized in Table 37.

Video Measurements

Monitoring and measuring tools

We know that digital television is a stream of numbers, and this may lead to some unnecessary apprehension. Everything seems to be happening really fast, and we need some help to sort everything out. Fortunately, video, and especially the ancillary information supporting video, is quite repetitive, so all we need is the hardware to convert this high-speed numeric data to something we can study and understand. Why not just convert it to something familiar, like analog video?

Digital video, either standard definition or the newer high-definition studio formats, is very much the same as its analog ancestor. Lots of things have improved with time, but we still make video with cameras, from film, and today, from computers. The basic difference for digital video is the processing early in the chain that converts the analog video into numeric data and attaches ancillary data to describe how to use the video data. For live cameras and telecine, analog values of light are focused on sensors, which generates an analog response that is converted somewhere along the line to numeric data. Sometimes we can get to this analog signal for monitoring with an analog waveform monitor, but more often the video will come out of the equipment as data. In the case of computer generated video, the signal probably was data from the beginning. Data travels from source equipment to destination on a transport layer. This is the analog transport mechanism, often a wire, or a fiber-optic path carrying the data to some destination. We can monitor this data directly with a high-bandwidth oscilloscope, or we can extract and monitor the data information as video.

Operationally, we are interested in monitoring the video. For this we need a high-quality waveform monitor equipped with a standards-complaint data receiver to let us see the video in a familiar analog display. Tektronix provides several digital input waveform monitors including the WVR7120/7020/6020 series 1RU rasterizer (Figure 67) for standard/high-definition component digital video and the WFM6120/7020/7120 (Figure 68) series 3RU half-rack monitor which is configurable for any of the digital formats in common use today.

Figure 67. WVR series standard and high-definition digital waveform monitors.

Figure 68. WFM6120/7020/7120 standard and high-definition digital waveform monitors.

Figure 69. Tektronix TG700 Signal Generator Platform.

Technically, we may want to know that the camera or telecine is creating correct video data and that ancillary data is accurate. We may also want to evaluate the analog characteristics of the transport layer. The Tektronix VM700T with digital option, the WFM6120 and WFM7120 allow in-depth data analysis and a direct view of the eye-pattern shape of the standard definition transport layer. The new WFM7120/6120 series high-definition monitors provide tools for both transport and data layer technical evaluation.

A test signal generator serves two purposes. It provides an ideal reference video signal for evaluation of the signal processing and transmission path, and it provides an example of the performance you should expect of today's high-quality system components. Some generation equipment, such as the Tektronix TG700 signal generator platform shown in Figure 69, provides options for both analog and digital, standard and high-definition signal formats.

These tools allow an operator to generate video that is completely compatible with the transmission system, video processing devices, and finally with the end viewer's display. Perhaps most important, these tools provide an insight into the workings of the video system itself that increase technical confidence and awareness to help you do your job better.

Monitoring digital and analog signals

There is a tendency to think of any video signal as a traditional time/amplitude waveform. This is a valid concept and holds for both analog and digital. For analog video, the oscilloscope or waveform monitor displays a plot of signal voltage as time progresses. The waveform monitor is synchronized to show the desired signal characteristic as it occurs at the same horizontal position on the waveform monitor display each time it occurs, horizontally in the line, or vertically in the field. A digital waveform monitor shows the video information extracted from the incoming data signal in the same manner as the analog waveform monitor.

You see the same information in the same way from the analog or digital signals. For analog you see the direct signal; for digital you see the signal described by the data. Operationally, you use the monitor to make the same video evaluations.

Additional measurements may be unique to the system being monitored. You may want to demodulate the NTSC or PAL color information for display on an analog vectorscope. You may want to see an X vs. Y display of the color-difference channels of a digital component signal to simulate an analog vector display without creating or demodulating a color subcarrier. You may want to observe the data content of a digital signal directly with a numeric or logic level display. And you will want to observe gamut of the analog or digital signal. Gamut is covered in greater detail in Appendix A – Gamut, Legal, Valid.

Assessment of video signal degradation

Some of the signal degradations we were concerned with in analog NTSC or PAL are less important in standard definition component video. Degradations become important again for even more basic reasons as we move to high-definition video. If we consider the real analog effects, they are the same. We sought signal integrity in analog to avoid a degradation of color video quality, but in high-definition we can start to see the defect itself.

Video amplitude

The concept of unity gain through a system has been fundamental since the beginning of television. Standardization of video amplitude lets us design each system element for optimum signal-to-noise performance and freely interchange signals and signal paths. A video waveform monitor, a specialized form of oscilloscope, is used to measure video amplitude. When setting analog video amplitudes, it is not sufficient to simply adjust the output level of the final piece of equipment in the signal path. Every piece of equipment should be adjusted to appropriately transfer the signal from input to output.

In digital formats, maintenance of video amplitude is even more important. Adequate analog video amplitude into the system assures that an optimum number of quantization levels are used in the digitizing process to reproduce a satisfactory picture. Maintaining minimum and maximum amplitude excursions within limits assures the video voltage amplitude will not be outside the range of the digitizer. Aside from maintaining correct color balance, contrast, and brightness, video amplitude must be controlled within gamut limits legal for transmission and valid for conversion to other video formats. In a properly designed unity-gain video system, video amplitude adjustments will be made at the source and will be correct at the output.

In the analog domain, video amplitudes are defined, and the waveform monitor configured to a standard for the appropriate format. NTSC signals will be 140 IRE units, nominally one volt, from sync tip to white level. The NTSC video luminance range (Figure 70) is 100 IRE, nominally 714.3 mV, which may be reduced by 53.5 mV to include a 7.5 IRE black level setup. Depending on color information, luminance plus chrominance components may extend below and above this range. NTSC sync is –40 IRE units, nominally –285.7 mV from blanking level to sync tip. The NTSC video signal is generally clamped to blanking level and the video monitor is set to extinguish at black level.

PAL signals are also formatted to one-volt sync tip to white level, with a video luminance range of 700 mV, with no setup. PAL sync is –300 mV. The signal is clamped, and the monitor brightness set to extinguish at black level. Chrominance information may extend above and below the video luminance range.

Video amplitude is checked on a stage-by-stage basis. An analog test signal with low-frequency components of known amplitude (such as blanking and white levels in the color bar test signal) will be connected to the input of each stage and the stage adjusted to replicate those levels at the output stage.

Regulatory agencies in each country, with international agreement, specify on-air transmission standards. NTSC, PAL, and SECAM video transmitters are amplitude-modulated with sync tip at peak power and video white level plus chroma extending towards minimum power. This modulation scheme is efficient and reduces visible noise, but is sensitive to linearity effects. Video levels must be carefully controlled to achieve a balance of economical full-power sync tip transmitter output and acceptable video signal distortion as whites and color components extend towards zero carrier power. If video levels are too low, the video signal/noise ratio suffers and electric power consumption goes up. If video levels are too high, the transmitter performs with greater distortion as the carrier nears zero power, and performance of the inter-carrier television audio receiver starts to fail.

Signal amplitude

In an analog system, the signal between studio components is a changing voltage directly representing the video. An analog video waveform monitor of the appropriate format makes it easy to view the voltage level of the analog video signal in relation to distinct timing patterns.
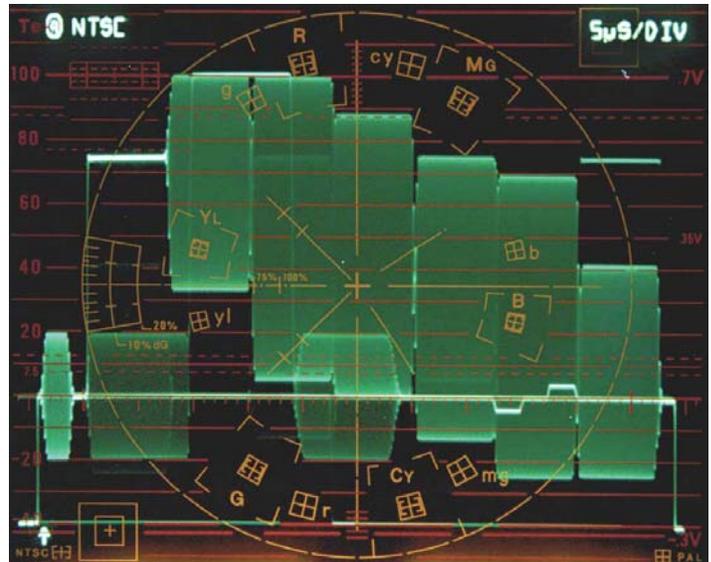

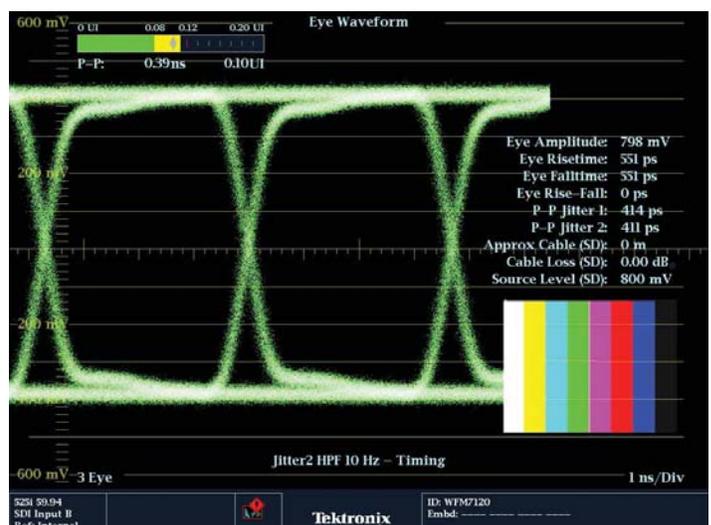Figure 70. Correctly adjusted composite video amplitude, NTSC, no setup.

Figure 71. Correct 270 Mb/s data signal viewed with WFM7120.

In a digital video system, the signal is a data "carrier" in the transport layer; a stream of data representing video information. This data is a series of analog voltage changes (Figures 71 and 72) that must be correctly identified as high or low at expected times to yield information on the content. The transport layer is an analog signal path that just carries whatever is input to its destination. The digital signal starts out at a level of 800 mV and its spectral content at half the clock frequency at the destination determines the amount of equalization applied by the receiver.

Digital signals in the transport layer can be viewed with a high-frequency oscilloscope or with a video waveform monitor such as the Tektronix WFM7120/WFM6120 or WVR7120 with EYE option for either standard or high-definition formats. In the eye pattern mode, the waveform monitor operates as an analog sampling oscilloscope with the display swept at a video rate. The equivalent bandwidth is high enough, the return loss great enough, and measurement cursors appropriately calibrated to accurately measure the incoming data signal. The rapidly changing data in the transport layer is a series of ones and zeros overlaid to create an eye pattern. Eye pattern testing is most effective when the monitor is connected to the device under test with a short cable run, enabling use of the monitor in its non-equalized mode. With long cable runs, the data tends to disappear in the noise and the equalized mode must be used. While the equalized mode is useful in confirming headroom, it does not provide an accurate indicator of the signal at the output of the device under test. The PHY option also provides additional transport layer information such as jitter display and automated measurements of eye amplitude and provides a direct measurement readout of these parameters.

Since the data transport stream contains components that change between high and low at rates of 270 Mb/s for standard definition ITU-R BT.601 component video, up to 1.485 Gb/s for some high-definition formats (SMPTE 292M), the ones and zeros will be overlaid (Figure 72) for display on a video waveform monitor. This is an advantage since we can now see the cumulative data over many words, to determine any errors or distortions that might intrude on the eye opening and make recovery of the data high or low by the receiver difficult. Digital waveform monitors such as the Tektronix WFM7120/6120 series for multiple digital formats provide a choice of synchronized sweeps for the eye pattern display so word, line, and field disturbances may be correlated.

The digital video waveform display that looks like a traditional analog waveform (baseband video) is really an analog waveform recreated by the numeric data in the transport layer. The digital data is decoded into high-quality analog component video that may be displayed and measured as an analog signal. Although monitoring in the digital path is the right choice, many of the errors noted in digital video will have been generated earlier in the analog domain.
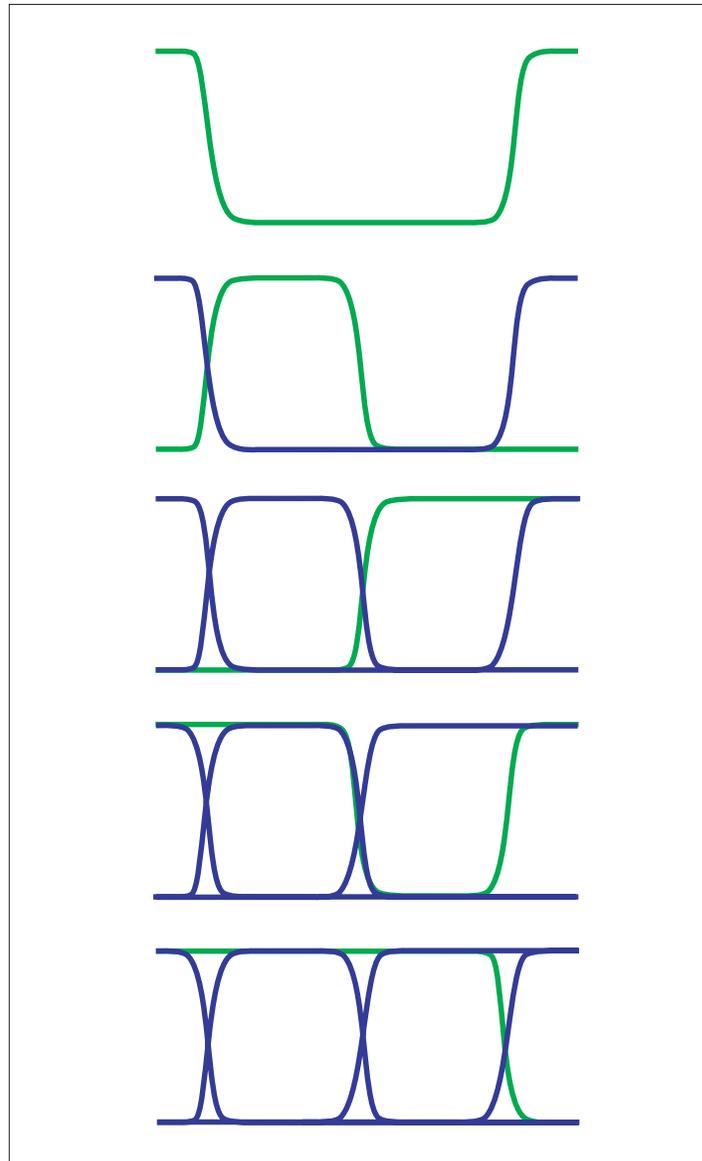

Figure 72. Development of the eye diagram.

Frequency response

In an analog video system, video frequency response will be equalized where necessary to compensate loss of high-frequency video information in long cable runs. The goal is to make each stage of the system "flat" so all video frequencies travel through the system with no gain or loss. A multiburst test signal (Figure 73) can be used to quickly identify any required adjustment. If frequency packets in the multiburst signal are not the same amplitude at the output stage (Figure 74), an equalizing video distribution amplifier may be used to compensate, restoring the multiburst test signal to its original value.

In a digital system, high-frequency loss affects only the energy in the transport data stream (the transport layer), not the data numbers (the data layer) so there is no effect on video detail or color until the high-frequency loss is so great the data numbers cannot be recovered. The equalizer in the receiver will compensate automatically for high-frequency losses in the input. The system designer will take care to keep cable runs short enough to achieve near 100% data integrity and there is no need for frequency response adjustment. Any degradation in video frequency response will be due to analog effects.

Figure 73. Multiburst test signal with equal amplitude at each frequency, 1H display.

Group delay

Traditional analog video designs, for standard definition systems, have allowed on the order of 10 MHz bandwidth and have provided very flat frequency response through the 0-6 MHz range containing the most video energy. Group-delay error, sometimes referred to as envelope delay or frequency-dependent phase error, results when energy at one frequency takes a longer or shorter time to transit a system than energy at other frequencies, an effect often associated with bandwidth limitations. The effect seen in the picture would be an overshoot or rounding of a fast transition between lower and higher brightness levels. In a composite NTSC or PAL television system, the color in the picture might be offset to the left or right of the associated luminance. The largest contributors to group-delay error are the NTSC/PAL encoder, the sound-notch filter, and the vestigial-sideband filter in the high-power television station transmitter, and of course the complementary chroma bandpass filters in the television receiver's
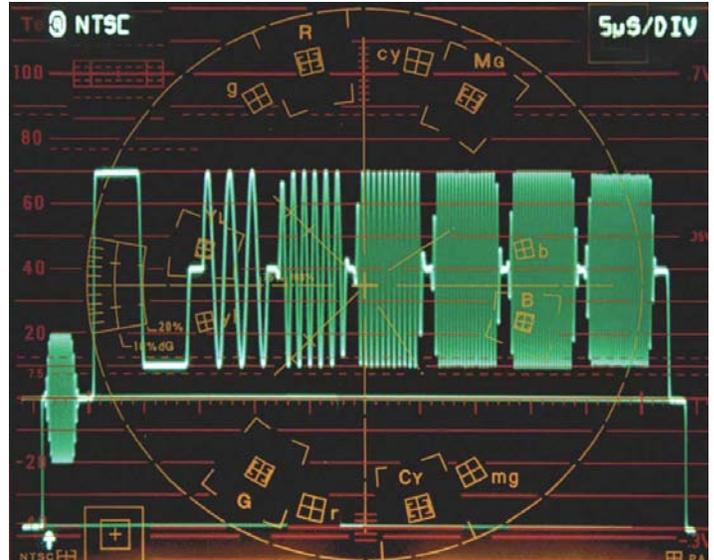

Figure 74. Multiburst with frequency response rolloff, 2H display.
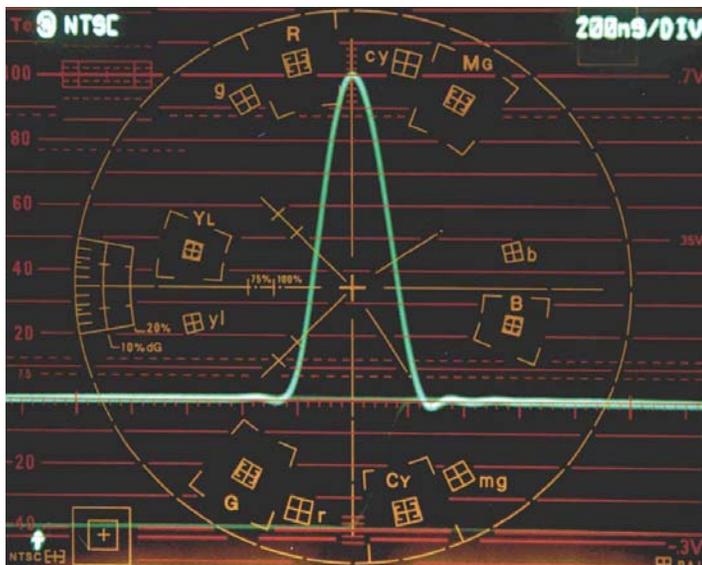
Figure 75. Correct 2T pulse, 1H MAG display.

Figure 76. 2T pulse and bar, degraded.

NTSC or PAL decoder. From an operational standpoint, most of the effort to achieve a controlled group delay response centers in the analog transmitter plant. It is routine, however, to check group delay, or phase error, through the analog studio plant to identify gross errors that may indicate a failure in some individual device. Group delay error in a studio plant is easily checked with a pulse and bar test signal (Figure 75). This test signal includes a half-sinusoidal 2T pulse and a low-frequency white bar with fast, controlled rise and fall times. A 2T pulse with energy at half the system bandwidth causes a low level of ringing which should be symmetrical around the base of the pulse. If the high-frequency energy in the edge gets through faster or slower than the low-frequency energy, the edge will be distorted (Figure 76). If high-frequency energy is being delayed, the ringing will occur later, on the right side of the 2T pulse.

The composite pulse and bar test signal has a feature useful in the measurement of system phase response. In composite system testing, a 12.5T or 20T pulse modulated with energy at subcarrier frequency is used to quickly check both chroma-luma delay and relative gain at subcarrier frequency vs. a low frequency. A flat baseline indicates that both gain and delay are correct. Any bowing upward of the baseline through the system indicates a lower gain at the subcarrier frequency. Bowing downward indicates higher gain at the subcarrier frequency. Bowing upward at the beginning and downward at the end indicates high-frequency energy has arrived later and vice versa. In a component video system, with no color subcarrier, the 2T pulse and the edge of the bar signal is of most interest.
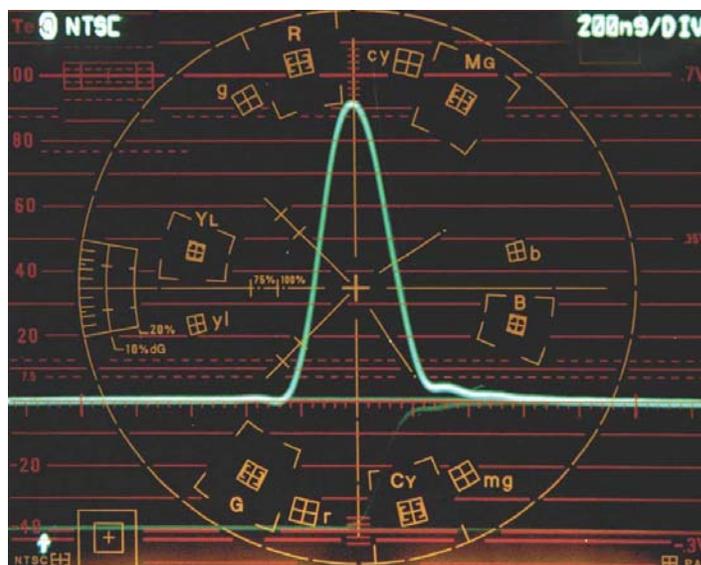
A more comprehensive group delay measurement may be made using a multi-pulse or sin x/x pulse and is indicated when data, such as teletext or Sound-in-Sync is to be transmitted within the video signal.

Digital video system components use anti-alias and reconstruction filters in the encoding/decoding process to and from the analog domain. The cutoff frequencies of these internal filters are about 5.75 MHz and 2.75 MHz for standard definition component video channels, so they do react to video energy, but this energy is less than is present in the 1 MHz and 1.25 MHz filters in the NTSC or PAL encoder. Corresponding cutoff frequencies for filters in digital high-definition formats are about 30 MHz for luma and 15 MHz for chroma information. The anti-alias and reconstruction filters in digital equipment are well corrected and are not adjustable operationally.

Non-linear effects

An analog circuit may be affected in a number of ways as the video operating voltage changes. Gain of the amplifier may be different at different operating levels (differential gain) causing incorrect color saturation in the NTSC or PAL video format. In a component analog format, brightness and color values may shift.

Differential gain

Differential gain is an analog effect, and will not be caused or corrected in the digital domain. It is possible, however, that digital video will be clipped if the signal drives the analog-to-digital converter into the range of reserved values. This gamut violation will cause incorrect brightness of some components and color shift. Please refer to Appendix A – Gamut, Legal, Valid.

Differential phase

Time delay through the circuit may change with the different video voltage values. This is an analog effect, not caused in the digital domain. In NTSC this will change the instantaneous phase (differential phase) of the color subcarrier resulting in a color hue shift with a change in brightness. In the PAL system, this hue shift is averaged out, shifting the hue first one way then the other from line to line. The effect in a component video signal, analog or digital, may produce a color fringing effect depending on how many of the three channels are affected. The equivalent effect in high definition may be a ring or overshoot on fast changes in brightness level.

Digital System Testing

Stress testing

Unlike analog systems that tend to degrade gracefully, digital systems tend to work without fault until they crash. To date, there are no in-service tests that will measure the headroom of the SDI signal. Out-of-service stress tests are required to evaluate system operation. Stress testing consists of changing one or more parameters of the digital signal until failure occurs. The amount of change required to produce a failure is a measure of the head-room. Starting with the specifications in the relevant serial digital video standard (SMPTE 259M or SMPTE 292M), the most intuitive way to stress the system is to add cable until the onset of errors. Other tests would be to change amplitude or risetime, or add noise and/or jitter to the signal. Each of these tests is evaluating one or more aspects of the receiver performance, specifically automatic equalizer range and accuracy and receiver noise characteristics. Experimental results indicate that cable-length testing, in particular when used in conjunction with the SDI check field signals
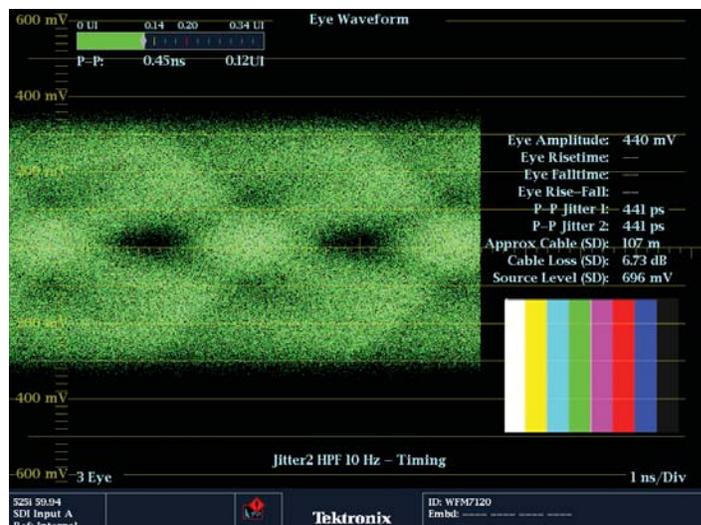

Figure 77. WFM7120 display of eye closure with long length of cable.

described in the following sections, is the most meaningful stress test because it represents real operation. Stress testing the receiver's ability to handle amplitude changes and added jitter are useful in evaluating and accepting equipment, but not too meaningful in system operation. Addition of noise or change in risetime (within reasonable bounds) has little effect on digital systems and is not important in stress tests.

Cable-length stress testing

Cable-length stress testing can be done using actual coax or a cable simulator. Coax is the simplest and most practical method. The key parameter to be measured is onset of errors because that defines the crash point. With an error measurement method in place, the quality of the measurement will be determined by the sharpness of the knee of the error curve. An operational check of the in-plant cabling can be easily done using the waveform monitor. This in-service check displays key information on the signal as it leaves the previous source and how it survives the transmission path. Figure 77 shows the effect of additional length of cable to the signal.
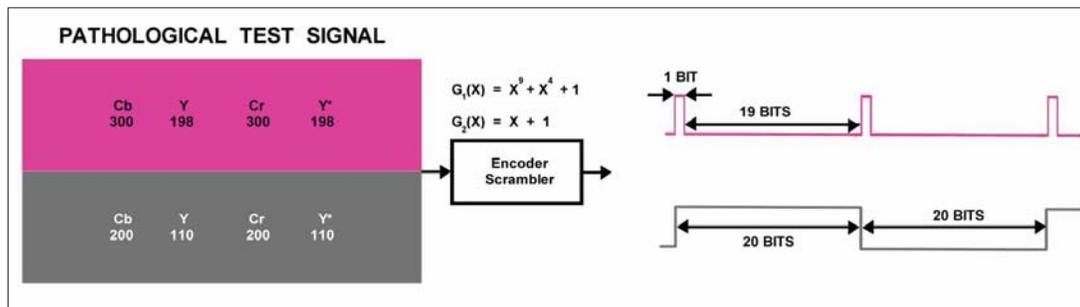
Figure 78. SDI Check Field "Pathological Test Signal."

SDI check field

The SDI Check Field (also known as a "pathological signal") is a full-field test signal and therefore must be done out-of-service. It's a difficult signal for the serial digital system to handle and is a very important test to perform. The SDI Check Field is specified to have a maximum amount of low-frequency energy, after scrambling, in two separate parts of the field. Statistically, this low-frequency energy will occur about once per frame. One component of the SDI Check Field tests equalizer operation by generating a sequence of 19 zeros followed by a 1 (or 19 ones followed by 1 zero). This occurs about once per field as the scrambler attains the required starting condition, and when present it will persist for the full line and terminate with the EAV packet. This sequence produces a high DC component that stresses the analog capabilities of the equipment and transmission system handling the signal. This part of the test signal may appear at the top of the picture display as a shade of purple, with the value of luma set to 198_h, and both chroma channels set to 300_h. The other part of the SDI Check Field signal is designed to check phase locked loop performance with an occasional signal consisting of 20 zeros followed by 20 ones. This provides a minimum number of zero crossings for clock extraction. This part of the test signal may appear at the bottom of the picture display as a shade of gray, with luma set to 110_h and both chroma channels set to 200_h. Some test signal generators will use a different signal order, with the picture display in shades of green. The results will be the same. Either of the signal components (and other statistically difficult colors) might be present in computer-generated graphics so it is important that the system handle the SDI Check Field test signal without errors. The SDI Check Field is a fully legal signal for component digital but not for the composite domain. The SDI Check Field (Figure 78) is defined in SMPTE Recommend Practice RP178 for SD and RP198 for HD.

In-service testing

CRC (Cyclic Redundancy Coding) can be used to provide information to the operator or even sound an external alarm in the event data does not arrive intact. A CRC is present in each video line in high-definition formats, and may be optionally inserted into each field in standard definition formats. A CRC is calculated and inserted into the data signal for comparison with a newly calculated CRC at the receiving end. For standard definition formats, the CRC value is inserted into the vertical interval, after the switch point. SMPTE RP165 defines the optional method for the detection and handling of data errors in standard definition video formats (EDH Error Detection Handling). Full Field and Active Picture data are separately checked and a 16-bit CRC word generated once per field. The Full Field check covers all data transmitted except in lines reserved for vertical interval switching (lines 9-11 in 525, or lines 5-7 in 625 line standards). The Active Picture (AP) check covers only the active video data words,

Figure 79. Video Session screen of SD signal showing EDH values on WVR7120.

Figure 80. Video Session screen of HD signal showing CRC values on WFM7120.

between but not including SAV and EAV. Half-lines of active video are not included in the AP check. Digital monitors may provide both a display of EDH CRC values and an alarm on AP or FF (Full Field) CRC errors (Figure 79). In high-definition formats, CRCs for luma and chroma follow EAV and line count ancillary data words. The CRC for high-definition formats is defined in SMPTE 292M to follow the EAV and line number words, so CRC checking is on a line-by-line basis for Y-CRC and C-CRC. The user can then monitor the number of errors they have received along the transmission path. Ideally, the instrument will show zero errors indicating an error-free transmission path. If the number of errors starts to increase, the user should start to pay attention to the increase in errors. As the errors increase to one every hour or minute, this is an indication that the system is getting closer to the digital cliff. The

transmission path should be investigated further to isolate the cause of the error before the system reaches the digital cliff and it becomes difficult to be able to isolate the error within the path. Figure 80 shows the video session display of the WFM7120 and the accumulated CRC errors are shown for both the Y and C channels of the high-definition signal. Within the display, not only are the number of errors counted, but the errors are also displayed in relation to the number of fields and seconds of the time interval being monitored. Resetting the time will restart the calculation and monitoring of the signal. If significant CRC errors start to be seen, the transmission path should be investigated further by using the eye and jitter displays. If errors occur every minute or every second, the system is approaching the digital cliff and significant CRC errors would be seen in the display.
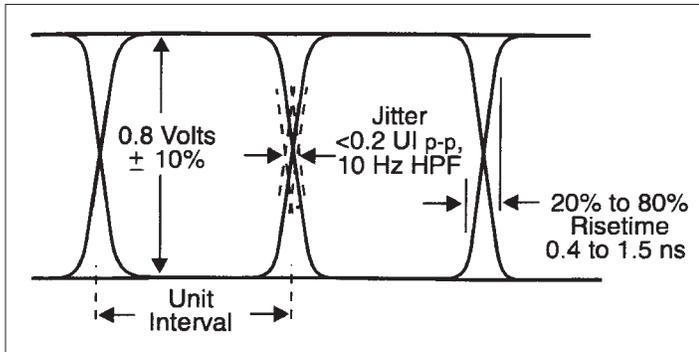
Figure 81. Eye-pattern display of data signal in the analog transport layer.

Figure 82. Data recovery of serial signal.

Eye-pattern testing

The eye pattern (Figures 81) is an oscilloscope view of the analog signal transporting the data. The signal highs and lows must be reliably detectable by the receiver to yield real-time data without errors. The basic parameters measured with the eye-pattern display are signal amplitude, risetime, and overshoot. Jitter can also be measured with the eye pattern if the clock is carefully specified. The eye pattern is viewed as it arrives, before any equalization. Because of this, most eye-pattern measurements will be made near the source, where the signal is not dominated by noise and frequency rolloff. Important specifications include amplitude, risetime, and jitter, which are defined in the standards, SMPTE259M, SMPTE292, and RP184. Frequency, or period, is determined by the television sync generator developing the source signal, not the serialization process. A unit interval (UI) is defined as the time between two adjacent signal transitions, which is the reciprocal of clock frequency. The unit interval is 3.7 ns for digital component 525 and 625 (SMPTE 259M) and 673.4 ps for Digital High Definition (SMPTE 292M). A serial receiver determines if the signal is a "high" or a "low" in the center of each eye, thereby detecting the serial data. As noise and jitter in the signal increase through the transmission channel, certainly the best decision point is in the center of the eye (as shown in Figure 82). Some receivers select a point at a fixed time after each transition point. Any effect which closes the eye may reduce the usefulness of the received signal. In a communications system with forward error correction, accurate data recovery can be made with the eye nearly closed. With the very low error rates
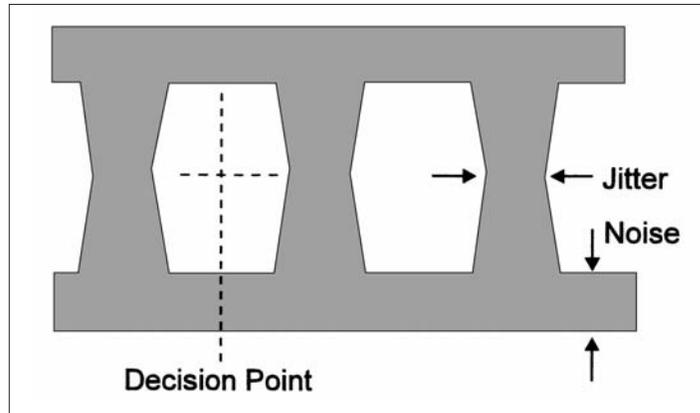
required for correct transmission of serial digital video, a rather large and clean eye opening is required after receiver equalization. This is because the random nature of the processes that close the eye have statistical "tails" that would cause an occasional, but unacceptable error. Allowed jitter is specified as 0.2 UI. This is 740 ps for digital component 525 and 625 and 134.7 ps for digital high definition. Digital systems will work beyond this jitter specification, but will fail at some point. The basics of a digital system are to maintain a good-quality signal to keep the system healthy and prevent a failure which would cause the system to fall off the edge of the cliff. Signal amplitude is important because of its relationship to noise, and because the receiver estimates the required high-frequency compensation (equalization) based on the half-clock-frequency energy remaining as the signal arrives. Incorrect amplitude at the sending end could result in an incorrect equalization being applied at the receiving end, causing signal distortions. Rise-time measurements are made from the 20% to 80% points as appropriate for ECL logic devices. Incorrect rise time could cause signal distortions such as ringing and overshoot, or if too slow, could reduce the time available for sampling within the eye. Overshoot will likely be caused by impedance discontinuties or poor return loss at the receiving or sending terminations. Effective testing for correct receiving end termination requires a high-performance loop-through on the test instrument to see any defects caused by the termination under evaluation. Cable loss tends to reduce the visibility of reflections, especially at

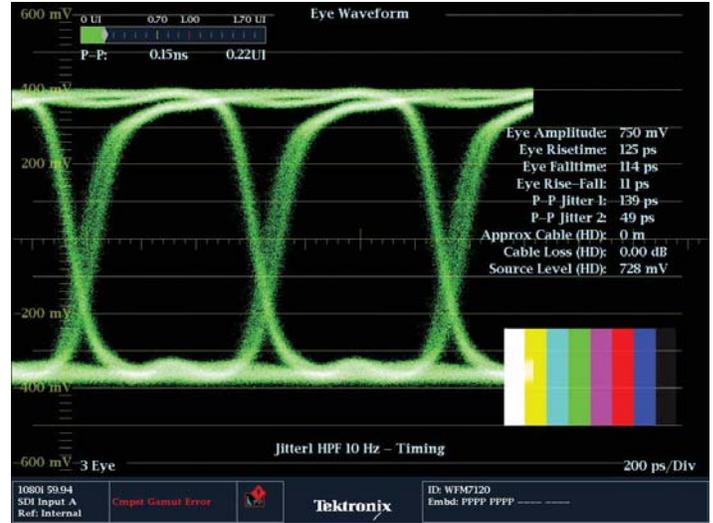**Figure 83.** Unterminated Eye display on the WFM7120.

Figure 84. Non-symmetrical eye display on WFM7120.

high-definition data rates of 1.485 Gb/s and above. High-definition digital inputs are usually terminated internally and in-service eye-pattern monitoring will not test the transmission path (cable) feeding other devices. Out-of-service transmission path testing is done by substituting a test signal generator for the source, and a waveform monitor with eye-pattern display in place of the normal receiving device. Eye-pattern testing requires an oscilloscope with a known response well beyond the transport layer data rate and is generally measured with sampling techniques. The Tektronix VM700T, WVR7120, and WFM7120/WFM6120 provide eye-pattern measurement capability for standard definition (270 Mb/s data) and the WVR7120 or WFM7120 allows eye-pattern measurements on high-definition 1.485 Gb/s data streams. These digital waveform monitors provide several advantages because they are able to extract and display the video data as well as measure it. The sampled eye pattern can be displayed in a three-data-bit overlay (3 Eye mode), to show jitter uncorrelated to the 10-bit/20-bit data word, or the display can be set to show ten bits for SD signals or twenty bits for high-definition signals of word-correlated data. By synchronizing the waveform monitor sweep to video line and field rates, it is easy to see any DC shift in the data stream correlated to horizontal or vertical video information.

Understanding certain characteristics of the eye display can help in troubleshooting problems within the path of the signal. Proper termination within an HD-SDI system is even more critical because of the high clock rate of the signal. Improper termination will mean

that not all of the energy will be absorbed by the receiving termination or device. This residual energy will be reflected back along the cable creating a standing wave. These reflections will produce ringing within the signal and the user will observe overshoot and undershoots on the eye display as shown in Figure 83. Note that this termination error by itself would not cause a problem in the signal being received. However, this error added cumulatively to other errors along the signal path will narrow the eye opening more quickly and decrease the receiver's ability to recover the clock and data from the signal.

The eye display typically has the cross point of the transition in the middle of the eye display at the 50% point. If the rises time or fall time of the signal transitions are unequal then the eye display will move away from the 50% point depending on the degree of inequality between the transitions. AC-coupling within a device will shift the high signal level closer to the fixed-decision threshold reducing noise margin. Typically, SDI signals have symmetric rise and fall times, but asymmetric line drivers and optical signal sources (lasers) can introduce non-symmetric transitions as shown in Figure 84. While significant, these source asymmetries do not have especially large impacts on signal rise and fall times. In particular, cable attenuation will generally have a much larger impact on signal transition times. Without appropriate compensation or other adjustments, asymmetries in SDI signals can reduce noise margins with respect to the decision threshold used in decoding and can lead to decoding errors.

Adding lengths of cable between the source and the measurement instrument results in attenuation of the amplitude and frequency losses along the cable producing longer rise and fall time of the signal. With increase in cable length, the eye opening closes and is no longer clearly visible within the display. However, this signal is still able to be decoded correctly because the equalizer is able to recover the data stream. When the SDI signal has been degraded by using a long length of cable as in Figure 77, the eye opening is no longer clearly visible. In this case the equalized eye mode on the WFM7120/WFM6120 will allow the user to observe the eye opening after the equalizer has performed correction to the signal as shown in Figure 85. Therefore, it is likely that a receiver with a suitable adaptive equalizer will be able to recover this signal. However, it should be remembered that not all receivers use the same designs and there is a possibility that some device may still not be able to recover the signal. If the equalizer within the instrument is able to recover data, the equalized eye display should be open. If this display is partially or fully closed then the receiver is going to have to work harder to recover the clock and data. In this case there is more potential for data errors to occur in the receiver. Data errors can produce sparkle effects in the picture, line drop outs or even frozen images. At this point, the receiver at the end of the signal path is having problems extracting the clock and data from the SDI signal. By maintaining the health of the physical layer of the signal, we can ensure that these types of problems do not occur. The Eye and Jitter displays of the instrument can help troubleshoot these problems.

Jitter testing

Since there is no separate clock provided with the video data, a sampling clock must be recovered by detecting data transitions. This is accomplished by directly recovering energy around the expected clock frequency to drive a high-bandwidth oscillator (i.e., a 5 MHz bandwidth 270 MHz oscillator for SD signals) locked in near-real-time with the incoming signal. This oscillator then drives a heavily averaged, low-bandwidth oscillator (i.e., a 10 Hz bandwidth
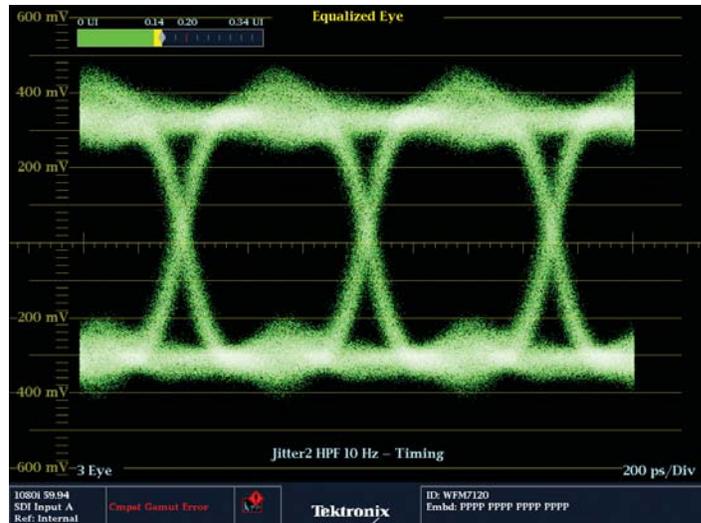

Figure 85. Equalized Eye mode on the WFM7120.

270 MHz oscillator for SD signals). In a jitter measurement instrument, samples of the high- and low-bandwidth oscillators are then compared in a phase demodulator to produce an output waveform representing jitter. This is referred to as the "demodulator method." Timing jitter is defined as the variation in time of the significant instances (such as zero crossings) of a digital signal relative to a jitter-free clock above some low frequency (typically 10 Hz). It would be preferable to use the original reference clock, but it is not usually available, so the heavily averaged oscillator in the measurement instrument is often used. Alignment jitter, or relative jitter, is defined as the variation in time of the significant instants (such as zero crossings) of a digital signal relative to a hypothetical clock recovered from the signal itself. This recovered clock will track in the signal up to its upper clock recovery bandwidth, typically 1 kHz for SDI and 100 kHz for HD signals. Measured alignment jitter includes those terms above this frequency. Alignment jitter shows signal-to-latch clock timing margin degradation.

Tektronix instruments such as the WFM6120 (Figure 86), WFM7120 and VM700T provide a selection of high-pass filters to isolate jitter energy. Jitter information may be unfiltered (the full 10 Hz to 5 MHz bandwidth) to display Timing Jitter, or filtered by a 1 kHz (–3 dB) high-pass filter to display 1 kHz to 5 MHz Alignment Jitter. Additional high-pass filters may be selected to further isolate jitter components. These measurement instruments provide a direct readout of jitter amplitude and a visual display of the demodulated jitter waveform to aid in isolating the cause of the jitter. It is quite common for a data receiver in a signal path to tolerate jitter considerably in excess of that specified by SMPTE recommendations but the build-up of jitter (jitter growth) through multiple devices could lead to unexpected failure. Jitter in bit-serial systems is discussed in SMPTE RP184, EG33, and RP192.

Jitter within the SDI signal will change the time when a transition occurs and cause a widening of the overall transition point. This jitter can cause a narrowing or closing of the eye display and make the determination of the decision threshold more difficult. It is only possible to measure up to one unit interval of jitter within the eye display by the use of cursors manually or by automated measurement readout. It can also be difficult within the eye display to determine infrequently occurring jitter events because the intensity of these events will be more difficult to observe compared to the regular repeatable transitions within the SDI signal.

Within the WFM7120 and WFM6120 EYE option, a jitter readout is provided within the eye display. The readout provides a measurement in both unit intervals and time. For an operational environment a jitter thermometer bar display provides simple warning of an SDI signal exceeding a jitter as shown in Figure 87. When the bar turns red it can alert the user to a potential problem in the system. This threshold value is user selectable and can be set at a defined limit by the user.

Figure 86. Jitter display mode in two-field sweep on WFM7120.
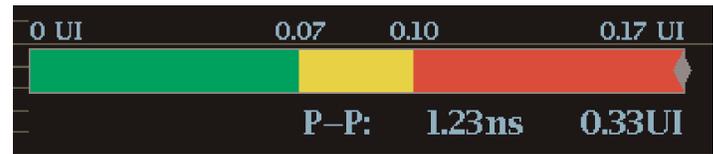

Figure 87. Jitter Bar Measurement.

Jitter Display with 10 Hz Filter

Jitter Display with 100 Hz Filter

Jitter Display with 1 kHz Filter

Jitter Display with 100 kHz Filter

Figure 88. Jitter display with different filter selections.

To characterize different types of jitter, the jitter waveform display available with the PHY option on the WFM6120 and WFM7120 allows a superior method to investigate jitter problems within the signal than the eye display and jitter readout. The jitter waveform can be displayed in a one-line, two-line, one-field or two-field display related to the video rate. When investigating jitter within the system it is useful to select the two-field display and increase the gain within the display. A small amount of jitter is present within all systems but the trace should be a horizontal line. Increasing the gain to ten times will show the inherent noise within the system. This should be random in nature, if not then there is likely to be a deterministic component of jitter present within the signal.

Within the instrument, one can apply 10 Hz, 100 Hz, 1 kHz, 10 kHz and 100 kHz filters for the measurement. These can aid in the isolation of jitter frequency problems. In this example as shown in Figure 88, different filters were used and the direct jitter readout and jitter waveform display are shown. With the filter set to 10 Hz the measurement of jitter was 0.2UI and there are disturbances to the trace at field rates. There are also some occasional vertical shifts in the trace when viewed on the waveform display. This gives rise to larger peak to peak measurements than actually measured from the display itself. When a 100 Hz filter is applied some of the components of jitter are reduce and the vertical jumping of the trace is not present, giving a more stable display. The measurement now reads 0.12UI, the disturbances at field rate are still present however. Application of the 1 kHz reduces the components of jitter and the trace is more of a flat line, the presence of the disturbances at field rate can still be observed and are still present. The jitter readout did not drop significantly between the 100 Hz

and 1 kHz filter selections. With the 100 kHz filter applied the display now shows a flat trace and the jitter readout is significantly lower at 0.07UI. In this case, the output of the device is within normal operating parameters for this unit and provides a suitable signal for decoding of the physical layer. Normally, as the band-pass gets narrower and the filter selection is increased, you will expect the jitter measurement to become smaller as in this case. Suppose that as the filter value is increased and the band-pass bandwidth narrowed that the jitter readout actually increased. What would this mean was occurring in the SDI signal?

In this case, an explanation of these measurement results could indicate that a pulse of jitter was present within the signal and this pulse of jitter was within the band-pass edge of one of the filter selections. Instead of this component being removed by the filter selection it was actually differentiated, producing a ringing at the rising and falling transitions of the pulse producing a larger value of jitter within the bandwidth filter selection.

By use of these filter selections, the user can determine within which frequency band the jitter components are present. Most of the frequency components present will be multiples of the line or field rate and can be helpful in understanding which devices produce significant amounts of jitter within the SDI transmission path. Typically, the Phase Lock Loop (PLL) design of the receiver will pass through low frequency of jitter from input to output of the device as the unit tracks the jitter present within the input to the device. High-frequency jitter components are more difficult for the PLL to track and can cause locking problems in the receiver.

SDI status display

The SDI Status display provides a summary of several SDI physical layer measurements as shown in Figure 89. Within the WFM7120/6120 and WVR7120 with the Eye option it is possible to configure the two jitter readouts to show Timing and Alignment jitter simultaneously by configuring tiles one and two for Timing jitter and tiles three and four for Alignment jitter. The instruments will automatically change the filter setting for alignment jitter between HD (100kHz) and SD (1kHz) depending on the type of SDI signal applied. Additionally, a cable-length estimation measurement bar is also shown within the SDI Status display. If the unit has the PHY option, automatic measurements of eye amplitude, eye risetime, eye falltime and eye rise-fall are made by the instrument. These automatic measurement provide a more accurate and reliable method of measuring the physical layer.

Cable-length measurements

The cable-length measurement is useful to quantify equipment operational margin within a transmission path. Most manufacturers specify their equipment to work within a specified range using a certain type of cable. For instance [Receiver Equalization Range - Typically SD: to 250m of type 8281 cable HD: to 100m of type 8281 cable.] As shown in this example the cable type specified is 8281 cable. However, throughout your facility a different type of cable may be used. In this case, set the waveform monitor to the cable type specified by the equipment manufacturer and then measure the cable length. If the reading from the instrument is 80 meters, we known that this piece of equipment will work to at least 100 meters and have 20 meters of margin within this signal path. If the measurement was above 100 meters then we would have exceed the manufacturers recommendation for the device. Manufacturers specify their equipment to one of the most popular cable types and it is not necessary to have that specific type of cable used in your facility when making this measurement. The WFM7120 and WFM6120 support the following cable types which are typically used within specifications (Belden 8281, 1505, 1695A, 1855A, Image 1000 and Canare L5-CFB). Simply select the appropriate cable type from the configuration menu for the

Figure 89. SDI Status display from WFM7120.

physical layer measurement. Once the cable type has been selected, apply the SDI signal to the instrument and it will provide measurements of Cable Loss, Cable Length and Estimated Source Signal Level.

– Cable Loss shows the signal loss in dB (deciBels) along the cable length. The value of 0dB indicates a good 800mV signal whereas a value of -3dB would indicates a source with 0.707 of the expected amplitude. If we assume that the launch amplitude of the signal was 800mv then the amplitude of the signal at the measurement location would be approximately 565mv.

– Cable Length indicates the length of the cable between the source signal and the waveform monitor. The instrument calculates the cable length based on the signal power at the input and the type of cable selected by the user.

– Source Level shows the calculated launch amplitude of the signal source, assuming a continuous run of cable, based on the specified type of cable selected by the user.

These types of measurements can be particularly useful when qualifying a system and verify equipment performance. By knowing the performance specification of the equipment, the user can gauge if the device is operating within the allowable range. For instance, if the instrument is measuring 62 meters for the cable length of the signal as shown in Figure 89, then the user can compare this measurement with the operating margin for the equipment which stated that the equalization range of the device will operate to at least 100m of Belden 8281 cable. Therefore, the signal path has 38 meters of margin for the operation of this device. Remember that this measurement assumes a continuous run of cable. In some case this measurement may have been made with a number of active devices within the signal path. If this is the case then each link in turn should be measured separately with a test signal source applied at one end of the cable and the measurement device at the other end. This will give a more reliable indication of the measurement of cable length within each part of the system and ensure that the system has sufficient headroom between each signal path. If the transmission distance exceeds the maximum length specified by the cable manufacturer, then additional active devices need to be inserted within the signal path to maintain the quality of the signal.

Timing between video sources

In order to transmit a smooth flow of information, both to the viewer and to the system hardware handling the signal, it is necessary that any mixed or sequentially switched video sources be in step at the point they come together. Relative timing between serial digital video signals that are within an operational range for use in studio equipment may vary from several nanoseconds to a few television lines. This relative timing can be measured by synchronizing a waveform monitor to an external source and comparing the relative positions of known picture elements.
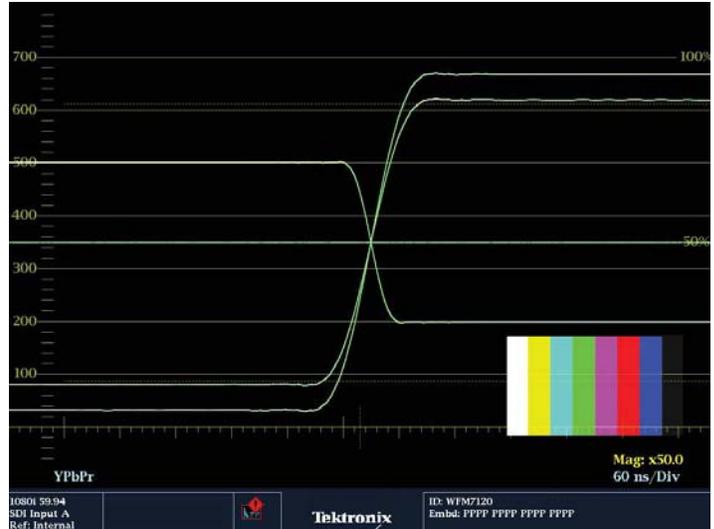
Figure 90. Interchannel timing measurement using green/magenta transition.

Measurement of the timing differences in operational signal paths may be accomplished using the Active Picture Timing Test Signal available from the TG700 Digital Component Generator in conjunction with the timing cursors and line select of an externally referenced WFM6120 or WFM7120 series serial component waveform monitor. The Active Picture Timing Test Signal will have a luminance white bar on the following lines:

- 525-line signals: Lines 21, 262, 284, and 525

- 625-line signals: Lines 24, 310, 336, and 622

- 1250-, 1125-, and 750-line formats: first and last active lines of each field

To set relative timing of signal sources such as cameras, telecines, or video recorders, it may be possible to observe the analog representation of the SAV timing reference signal, which changes amplitude as vertical blanking changes to active video. The waveform monitor must be set to "PASS" mode to display an analog representation of the timing reference signals, and be locked to an external synchronizing reference (EXT REF).
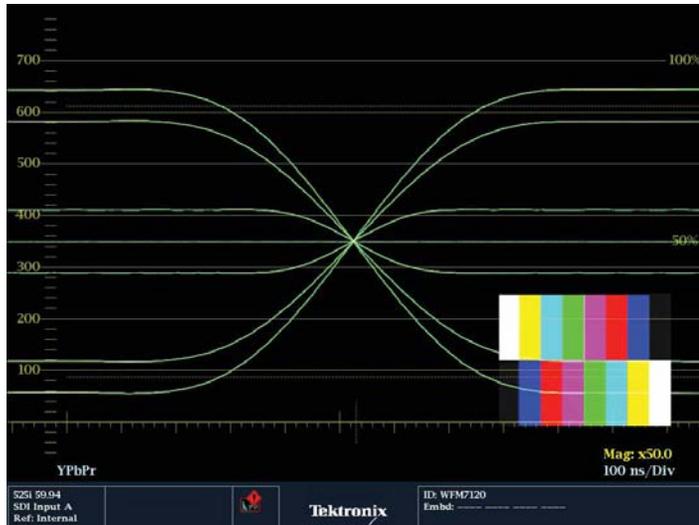
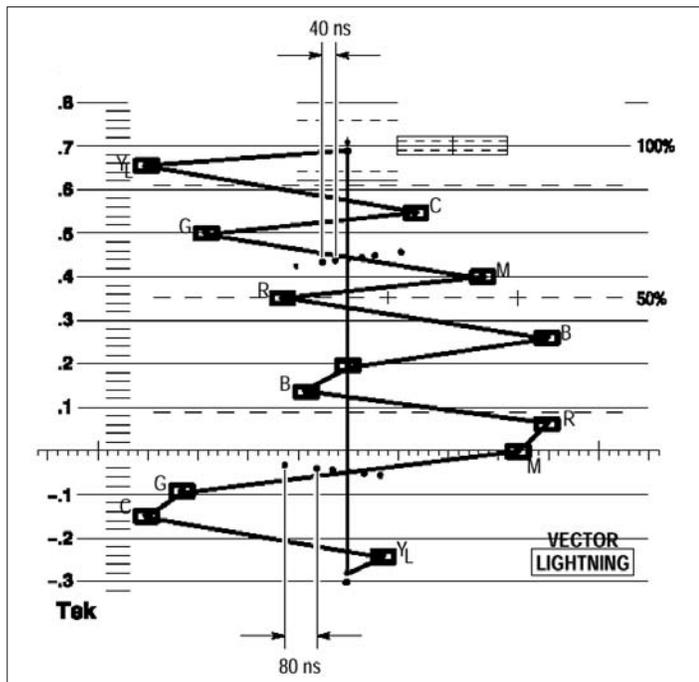**Figure 91.** TG700 reverse color bar signal, H MAG, OVERLAY.

Figure 92. Lightning display for a 100% color bar signal.

Interchannel timing of component signals

Timing differences between the channels of a single component video feed will cause problems unless the errors are very small. Signals can be monitored in the digital domain, but any timing errors will likely be present from the original analog source. Since analog 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. Transitions in the color bar test signal can be used with the waveform method described below. Tektronix component waveform monitors, however, provide two efficient and accurate alternatives: the Lightning display, using the standard color bar test signal; and the bowtie display, which requires a special test signal generated by Tektronix component signal generators.

Waveform method

The waveform technique can be used with an accurately calibrated three-channel waveform monitor 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 (Figure 91).

To use 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 OVERLAY 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.

The Tektronix TG700 and TG2000 test signal generators can be programmed to generate a special reverse bars test signal, with the color bar order reversed for half of each field. This signal makes it easy to see timing differences by simply lining up the crossover points of the three signals. The result is shown in Figure 91.

Timing using the Tektronix Lightning display

The Tektronix Lightning display provides a quick, accurate check of interchannel timing. Using a color bar test signal, the Lightning display includes graticule markings indicating any timing errors. Each of the Green/Magenta transitions should pass through the center dot in the series of seven graticule dots crossing its path. Figure 92 shows the correct timing.

The closely spaced dots provide a guide for checking transitions. These dots are 40 ns apart while the widely spaced dots represent 80 ns. The electronic graticule eliminates the effects of CRT nonlinearity. If the color-difference signal is not coincident with luma, the transitions between color dots will bend. The amount of this bending represents the relative signal delay between luma and color-difference signal. The upper half of the display measures the Pb to Y timing, while the bottom half measures the Pr to Y timing. If the transition bends in towards the vertical center of the black region, the color-difference signal is delayed with respect to luma. If the transition bends out toward white, the color-difference signal is leading the luma signal.

Bowtie method

The bowtie display requires a special test signal with signals of slightly differing frequencies on the chroma channels than on the luma channel. For standard definition formats, a 500 kHz sine-wave packet might be on the luma channel and a 502 kHz sine-wave packet on each of the two chroma channels (Figure 93). Other frequencies could be used to vary the sensitivity of the measurement display.

Higher packet frequencies may be chosen for testing high-definition component systems. Markers generated on a few lines of the luma channel serve as an electronic graticule for measuring relative timing errors. The taller center marker indicates zero error, and the other markers are spaced at 20 ns intervals when the 500 kHz and 502 kHz packet frequencies are used. The three sine-wave packets are generated to be precisely in phase at their centers. Because of the frequency offset, the two chroma channels become increasingly out of phase with the luma channel on either side of center.

The waveform monitor subtracts one chroma channel from the luma channel for the left half of the bowtie display and the second chroma channel from the luma channel for the right half of the display. 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 one chroma channel and luma, for

Figure 93. Bowtie test signal.

example, changes the relative phase between the two channels, moving the null off center on the side of the display for that channel. A shift of the null to the left of center indicates the color-difference channel is advanced relative to the luma channel. When the null is shifted to the right, the color-difference signal is delayed relative to the luma channel.

The null, regardless of where it is located, will be zero amplitude only if the amplitudes of the two sine-wave packets are equal. A relative amplitude error makes the null broader and shallower, making it difficult to accurately evaluate timing. If you need a good timing measurement, first adjust the amplitudes of the equipment under test. A gain error in the luma (CH1) channel will mean neither waveform has a complete null. If the gain is off only in Pb (CH2), the left waveform will not null completely, but the right waveform will. If the gain is off only in Pr (CH3) the right waveform will not null completely, but the left waveform will.

Figure 94. Y & Pb Left and Y & Pr right.

Figure 95. Bowtie display, Pb delayed 55ns, Pr advanced 50ns Y.

Figure 96. Bowtie display Pr gain error vs. Y.

The bowtie test method can be used to evaluate relative amplitudes and relative timing using component waveform monitors such as the Tektronix 1765 VM700T option 30, WFM601 Series, and WFM7120/6120 series which have bowtie display modes.

The left side of the display (Figure 94) compares Y and Pb; the right side compares Y and Pr. The 5 ns advance of the Pr component vs. Y is generally acceptable.

To use the bowtie display, route the 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, the relative amplitudes and interchannel timing are correct. Interchannel timing errors will move the position of the null (Figure 95). A relative amplitude error (Figure 96) will decrease the depth of the null. An incomplete null combined with an offset from center indicates both amplitude and timing problems between the channels being compared.

The bowtie test signal and display offers two benefits; it provides better timing resolution than the waveform and Lightning methods, and the display is readable at some distance from the waveform monitor screen.

Note that the bowtie test signal is an invalid signal, legal only in color-difference format. It becomes illegal when translated to RGB or composite formats and could create troublesome side effects in equipment that processes internally in RGB. (The concept of legal and valid signals is discussed in Appendix A – Gamut, Legal, Valid.

Operating a Digital Television System

Figure 97. WFM7120 R'G'B' parade display of 100% color bars.

Figure 98. WFM7120 Y'/C'b/C'r display of 100% color bars.

RGB and color-difference waveforms

Although the colorist will make equipment adjustments in the familiar red, green, blue format, the engineer may wish to see an analog representation of the signal matrixed for digital encoding. The digital signal is usually a direct quantization and time multiplex of the luma, or Y' signal, and the two chroma components, C'b and C'r. These three digital components can be converted to analog and directly displayed as a color-difference waveform parade, or matrixed back to red, green, and blue for the colorist. Examples of the two display formats are shown in Figure 97 and Figure 98.

Component gain balance

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. Since in color-difference formats, different colors contain different signal amplitudes from the red, green, and blue channels, it is not always obvious how individual channel gains should be adjusted. Several displays have been developed to help the operator make these adjustments.

The vector display

The vector display (Figure 99) has long been used for monitoring chrominance amplitude in composite NTSC or PAL systems. When the demodulation phase is adjusted correctly, usually by the operator, to place the color synchronizing burst pointing left along the horizontal axis, the composite vector display is a Cartesian (x,y) graph of the two decoded color components. Demodulated R-Y on the vertical axis and B-Y on the horizontal axis.
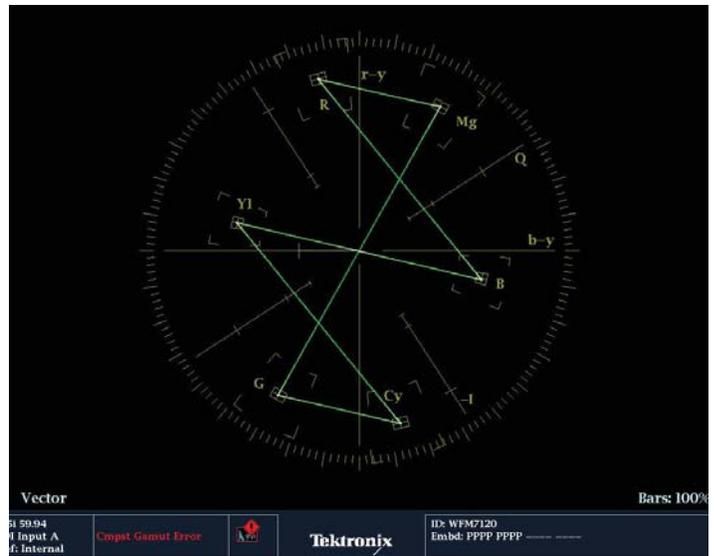
Figure 99. NTSC vectorscope display.
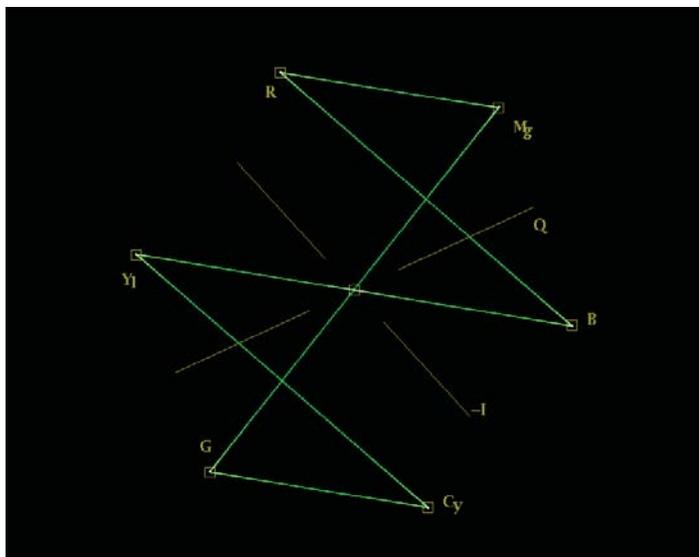
Figure 100. Component vector display.
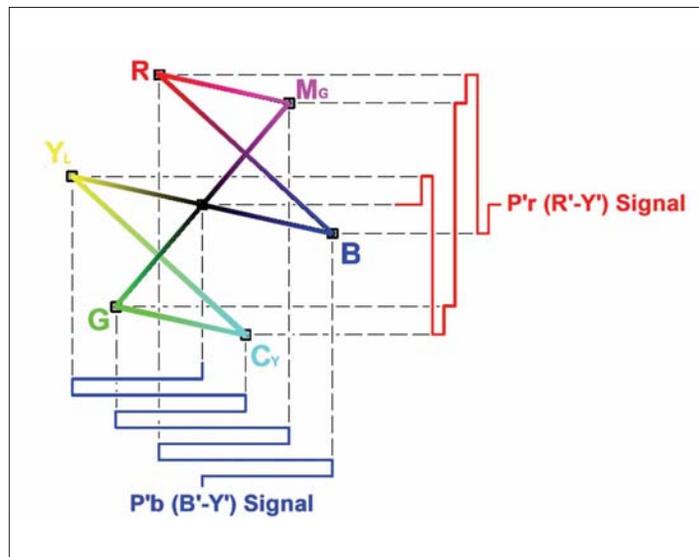
Figure 101. Development of the component vector display.

A similar display (Figure 100) for digital or analog component systems can be formed by plotting P'r or C'r on the vertical axis and P'b or C'b on the horizontal axis (Figure 101). Internal gains and display graticule box positions are adjusted in the monitoring instrument's design so the plot will fit the boxes for the chosen amplitude of color bars. If either color component has the wrong amplitude, the dots they produce will not fall in the graticule boxes. For example, if the P'r or C'r gain is too high, the dots will fall above the boxes in the top half of the screen and below the boxes in the bottom half. Either 75% or 100% color bars may be used. When taking measurements, make certain the source signal amplitude matches the vector graticule.

The polar display permits measurement of hue in terms of the relative phase of the chroma signal. Amplitude of the chroma signal is the displacement from center towards the color point. The transitions from one point to another also provide useful timing information. These timing differences appear as looping or bowing of the transitions, but can more easily be measured using Lightning or bowtie methods.

The two-axis vector display is convenient for monitoring or adjusting the set of two color-difference components, but makes no provision for evaluating luma gain or for making chroma/luma gain comparisons. The vector display would look the same if the luma channel were completely missing.
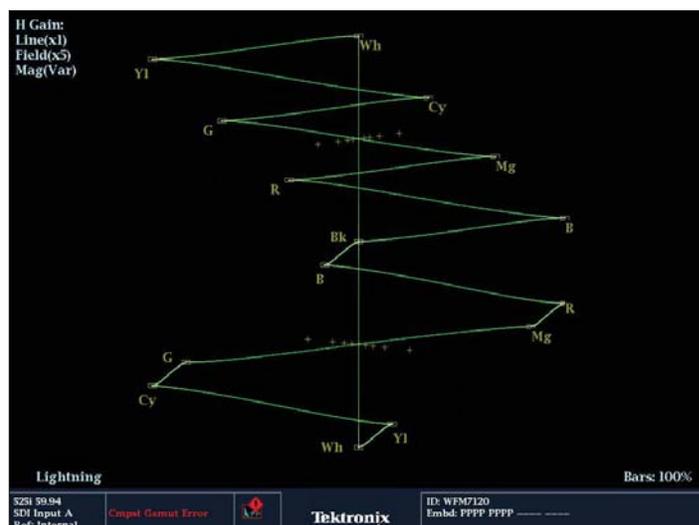
Figure 102. The Tektronix Lightning display.
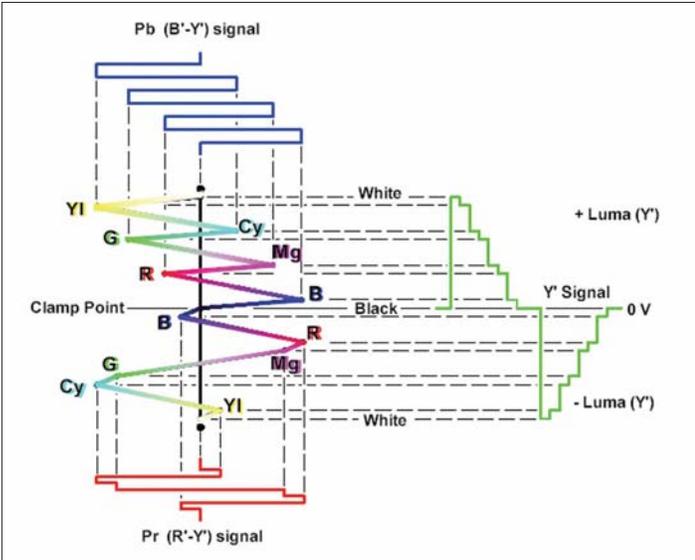
Figure 103. Development of the Tektronix Lightning display.

Figure 104. Lightning display with P'r gain error.

The Lightning display

Recognizing that a three-dimensional method would be desirable for monitoring the complete set of component signals, Tektronix developed a display (Figure 102) that provides both amplitude and interchannel timing information for the three-signal channels on a single display. The only test signal required for definitive measurements is standard color bars.

The Lightning display is generated by plotting luma vs. P'b or C'b in the upper half of the screen and inverted luma vs. P'r or C'r in the lower half (Figure 103) – like two vector displays sharing the same screen. The bright dot at the center of the screen is blanking level (signal zero). Increasing luma is plotted upward to the upper half of the screen and downward in the lower half. If luma gain is too high, the plot will be stretched vertically. If P'r or C'r gain is too high (Figure 104), the bottom half of the plot will be stretched horizontally. If P'b or C'b is too high, the top half of the display will be stretched horizontally. The display also provides interchannel timing information by looking at the green/magenta transitions. When the green and magenta vector dots are in their boxes, the transition should intercept the center dot in the line of seven timing dots.
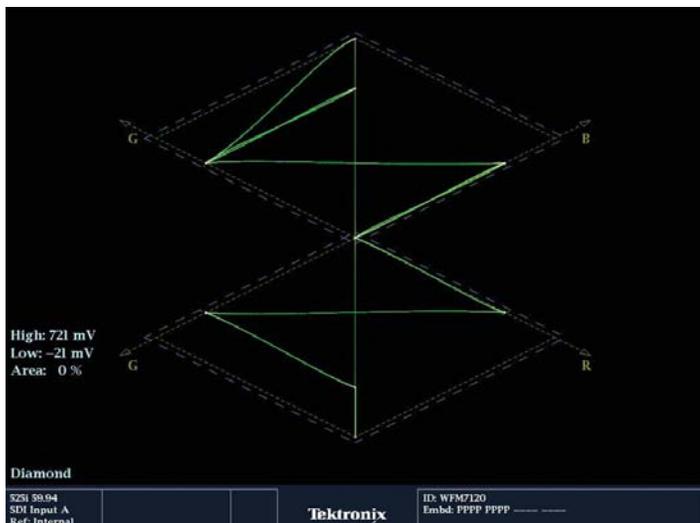
Figure 105. Tektronix Diamond display of 75% color bars.
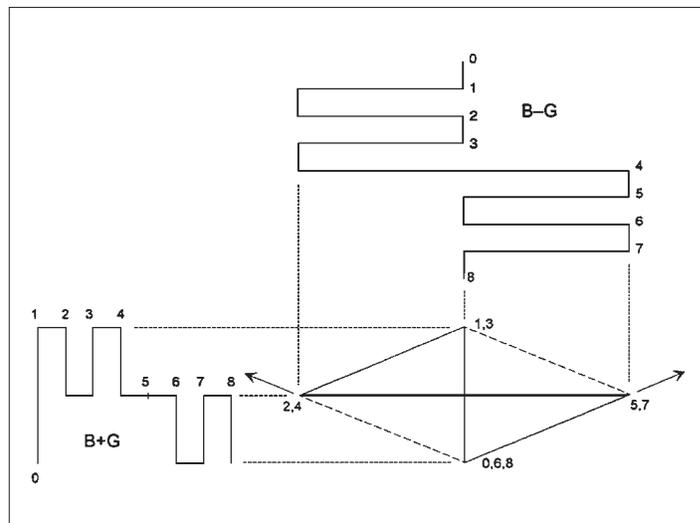
Figure 106. Development of the Diamond display, upper half.

The Diamond display

The Tektronix Diamond display (Figure 105) provides a reliable method of detecting invalid colors before they show up in a finished production. Color is usually developed and finally displayed in R'G'B' format. If it were handled through the system in this format, monitoring to detect an illegal signal would be quite simple – just ensure that the limits are not exceeded. But most studio systems use a Y', C'b, C'r format for data transmission and processing, and the signal is often converted to PAL or NTSC for on-air transmission. Ultimately, all color video signals are coded as RGB for final display on a picture monitor.

Figure 107. Diamond display of legal color space.

The Tektronix Diamond display is generated by combining R', G', and B' signals. If the video signal is in another format, the components are converted to R', G', and B' which can be converted into a valid and legal signal in any format that can handle 100% color bars. (A notable exception is the NTSC transmission standard where regulatory agencies have set the white level too close to zero RF carrier to accommodate 100% color bars. See Arrowhead display.)

The upper diamond (Figures 105 and 106) is formed from the transcoded signal by applying B'+G' to the vertical axis and B'–G' to the horizontal axis. The lower diamond is formed by applying

–(R'+G') to the vertical axis and R'–G' to the horizontal axis. The two diamonds are displayed alternately to create the double diamond display. 1.5 MHz (standard definition, wider for high definition) low-pass filters are applied to each to eliminate the short-term out-of-limit signals that are usually the product of combining different bandwidth signals in color-difference formats.

To predictably display all three components, they must lie between peak white, 700 mV, and black 0 V (Figure 107). Picture monitors handle excursions outside the standard range (gamut) in different ways. For a signal to be in gamut, all signal vectors must lie within the G-B and G-R diamonds. If a vector extends outside the
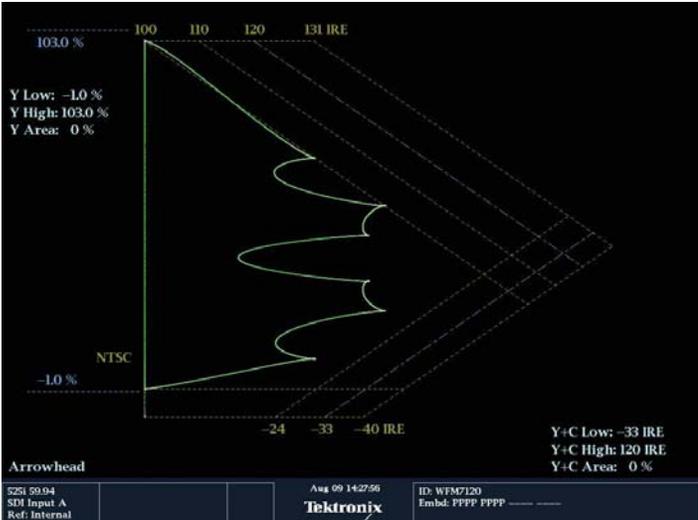
Figure 108. Tektronix Arrowhead display, 75% component color bars for NTSC.

Figure 109. NTSC Arrowhead graticule values.

diamond, it is out of gamut. Errors in green amplitude affect both diamonds equally, while blue errors only affect the top diamond and red errors affect only the bottom diamond. Timing errors can be seen using a color bar test signal as bending of the transitions. In the Diamond display, monochrome signals appear as vertical lines. However, excursions below black can sometimes be masked in the opposite diamond. Therefore, it can be useful to split the diamond into two parts to see excursions below black in either of the G-B or G-R spaces.

By observing the Diamond display, the operator can be certain the video components being monitored can be translated into legal and valid signals in RGB color space. The Diamond display can be used for live signals as well as test signals.

The Arrowhead display

NTSC transmission standards will not accommodate 100% color bars, so you cannot be sure video that appears to be correct in the R', G', B' format can be faithfully transmitted through an amplitude-modulated NTSC transmitter. Traditionally, the signal had to be encoded into NTSC and monitored with an NTSC waveform monitor. The Tektronix Arrowhead display (Figures 108, 109, and 110) provides NTSC and PAL composite gamut information directly from the component signal.

The Arrowhead display plots luminance on the vertical axis, with blanking at the lower left corner of the arrow. The magnitude of the chroma subcarrier at every luminance level is plotted on the horizontal axis, with zero subcarrier at the left edge of the arrow. The upper sloping line forms a graticule indicating 100% color
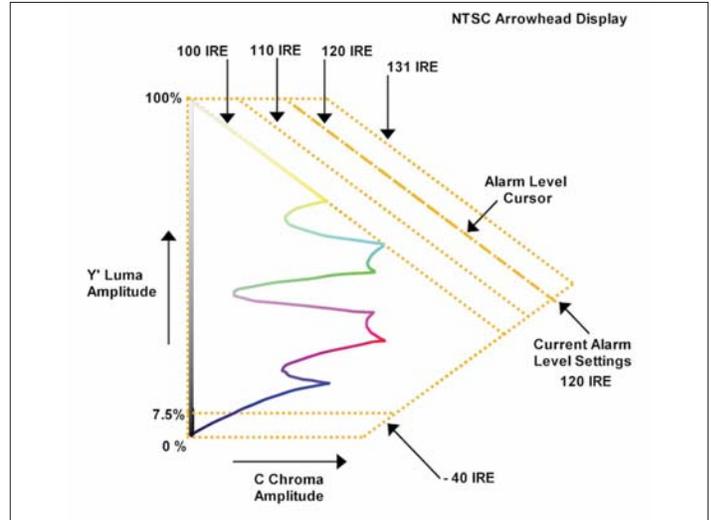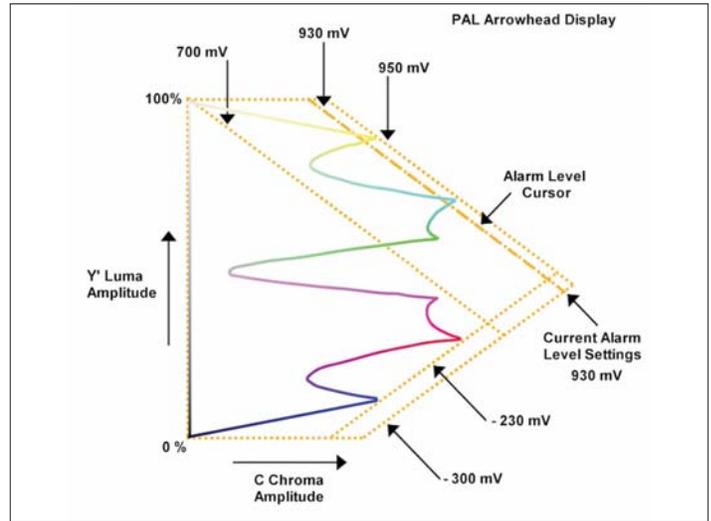

Figure 110. PAL Arrowhead graticule values.

bar total luma + subcarrier amplitudes. The lower sloping graticule indicates a luma + subcarrier extending towards sync tip (maximum transmitter power). The electronic graticule provides a reliable reference to measure what luminance plus color subcarrier will be when the signal is later encoded into NTSC or PAL. An adjustable modulation depth alarm capability is provided to warn the operator that the composite signal may be approaching a limit. The video operator can now see how the component signal will be handled in a composite transmission system and make any needed corrections in production.

Figure 111. 100% color bar signal YPbPr for HD.

100% color bar signal YPbPr for SD.

How to Monitor Gamut

Gamut monitoring is important to do during the post production process and during evaluation and ingest of the program material into the broadcast facility. The original video material can go through a variety of format and color space conversions as it is processed, from HD RGB to HD YPbPr to SD YPbPr to composite. Each of these conversions has different valid ranges for the color space and allowed voltage levels of the signal. A simple illustration of this is to look at 100% color bars in both high definition and standard definition for the YPbPr signal, as shown in Figure 111. Notice the difference in levels of the signals, especially the green to magenta transition. If you were only familiar with standard definition you might consider the high-definition signal needs adjustment but this is not the case. The different colorimetry equations, as shown in Table 1 give rise to the different video levels of the two signals. Both signals are correctly aligned. Remember that high-definition signals typically use colorimetry equations based on ITU BT-R709, and standard definition signal use colorimetry equations based on ITU BT-R601 (SMPTE125M). These sets of equations give rise

to the differences in the video levels of the color bar signal. Transposing them from one video format to another can introduce artifacts into the video image.

During the post production process it is important to ensure that the video image, graphics and titles are produced within gamut throughout all the variety of formats and color conversions processes the signal goes through. It is important to ensure that the color fidelity of material is maintained. For instance, if a deep magenta background is produced in RGB for the graphic used in an high-definition production. This signal can go through a variety of color space conversions during the post production process. The color fidelity of the image could be lost, when it is finally broadcast as a composite signal and the background image will appear as a muddy magenta because the video process has caused the image to become distorted. The conversion, from the original RGB color, could not be carried in that form through the video chain and results in the final color not being representative of the original intentions.
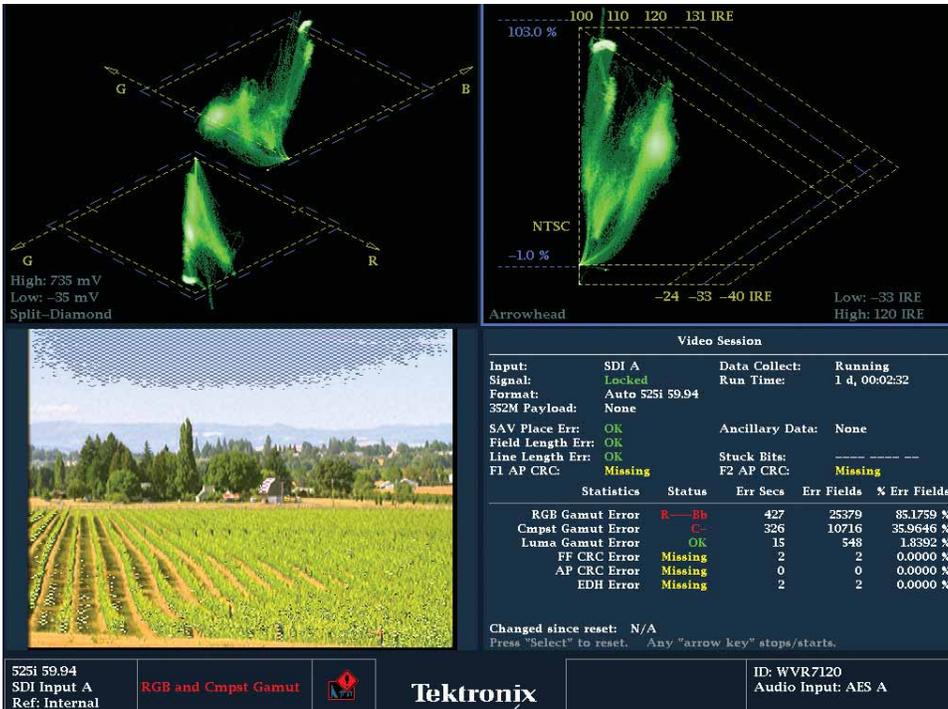
Figure 112. WVR7120 showing gamut errrors.

The waveform monitor can be used to identify gamut errors within the video signal. There are several approaches to take depending on the processing of the video signal.

Simple gamut alarm indications are given in the status bar display of the instrument. The type of errors can be identified by viewing the video session display. Lowercase and uppercase letters indicate which gamut limits have been exceeded. For instance, Figure 112 shows the status bar with RGB and Composite gamut errors highlighted in red. Viewing the video sessions display shows R---Bb. The uppercase letters "R---B" show the upper limit of gamut has been exceeded for red and blue and the lowercase letter "b" shows that the lower gamut limit has been exceeded for the blue channel. By using the split Diamond display on the WVR7120, the user could simply adjust the gain of the red and blue components to bring the high amplitudes signals within the blue dashed bounding box limits of the display by using a color corrector. Adjusting the lower black level control for the blue channel will adjust the lower limits of the blue channel within the

dashed bounding box limits of the display. During this process the user should monitor the adjustment they are making to ensure they do not introduce any other gamut violations into the signal. These errors would also be indicated in the status bar and within the video session display. The picture display can be enabled by the user to highlight the region where the gamut errors are occurring by the hashed area, shown in Figure 112 of the picture display.

A similar process can be done for the composite gamut errors. In this case, the Luma signal is within limits. But the uppercase "C" indicates the upper limit of chroma has been exceeded. By using the Arrowhead display, the user can adjust the proc-amp controls to bring the waveform trace within the bounding box of the display. The user needs to ensure that during this adjustment they do not introduce other errors into the signal. The digital processing of the instrument allows the user to make composite gamut adjustments without the need for the signal to be converted into the analog composite domain.

Tape Quality Assurance (QA) is an important part of the video chain. Broadcasters and program providers typically have a specification which provides details on the requirements that the program should meet in order to be compliant, and to maintain the limits set by the broadcasters or program provider. These specifications can contain requirements on the position of logos, titles and graphics relating to the artistic look of the program, but can also contain technical requirements on video and audio levels. There is currently a European document (EBU-R103) which provides a specification of the RGB gamut and Luma limits for the video signal (Figure 113). The latest Tektronix waveform monitors and rasterizers have a predefined limit for EBU-R103 specifications which sets the limits for the gamut parameters. This specification allows a +/-5% threshold for RGB gamut (735mv to -35mv) with an area limit of 1% and 103% and -1% limit for the luma signal. The thresholds are completely configurable within the instrument. Different specifications for gamut can be selected by the user to conform to the appropriate producer or broadcaster requirements. Note EBU R103 does not specify limits for composite gamut.

Figure 113. Gamut Limits for EBU-R103 on the WVR7120.

Definition of Limits

	Description	Allowed Range	EBU R103 limits	Tek Defaults
Diamond High	This sets the level above which RGB components are considered too large and out of gamut.	756mv 630mv	735mv	721mv
Diamond Low	This sets the level below which RGB components are considered too negative and out of gamut.	+35mv -50mv	-35mv	-21mv
Area	Specifies the percentage of the total image pixels that can be outside the current gamut limits, yet not be reported as a gamut error.	0-10%	1%	0%
Arrowhead NTSC Min	This sets the minimum allowed level for a NTSC composite signal derived from the SDI signal.	-10IRE -50IRE		-24IRE
Arrowhead NTSC Max	This sets the maximum allowed level for a NTSC composite signal derived from the SDI signal.	135IRE 90IRE		120IRE
Arrowhead PAL Min	This sets the minimum allowed level for a PAL composite signal derived from the SDI signal.	-100mv -400mv		-230mv
Arrowhead PAL Max	This sets the maximum allowed level for a PAL composite signal derived from the SDI signal.	950mv 630mv		930mv
Arrowhead Area	Specifies the percentage of the total image pixels that can be outside the current gamut limits, yet not be reported as a gamut error.	0-10%	0%	
Luma Min	This sets the minimum allowed level for Luminance on the incoming SDI and on a composite signal derived from the SDI signal.	+5% -6%l	-1%	-1%
Luma Max	This sets the maximum allowed level for Luminance on the incoming SDI and on a composite signal derived from the SDI signal.	108% 90%	103%	103%
Luma Area	Specifies the percentage of the total image pixels that can be outside the current luma limits, yet not be reported as an error.	0-10%	1%	0%

Table 39.

VIDEO CONTENT	Screen Text/Icon	Logging	Beep	SNMP Trap	Ground Closure
RGB Gamut	☒	☒	☐	☐	☐
Composite Gamut	☒	☒	☐	☐	☐
Luma Gamut	☒	☒	☐	☐	☐
◼ Return					

Figure 114. Video Content alarm configuration.

Once the limits to be used have been defined, it is important to ensure that the appropriate alarms are selected for gamut and other conditions. These alarms will alert the user to problems within the material. These alarms can trigger a variety of conditions (Screen/Text icon, Beep, Log, SNMP or Ground closure) as shown in Figure 114. Ensuring that the log is selected will provide an error log of when these conditions occurred related either to the internal clock of the instrument or to timecode if present. The logging of errors related to timecode allows the error occurrence to be more easily located in the program material. The error log can be downloaded via the network connection from the instrument to a computer, which allows the log to be printed or attached to a report.

Conclusion

It has been the goal of this primer to provide background information on the transition of the television studio from analog to digital and high-definition video formats.

Today's video professional faces many challenges and the transition to digital should be one of those providing a great long-term return. The typical broadcaster and production studio will operate in both standard and high-definition video formats. The new digital formats, natural extensions of familiar analog video, offer a superior channel for the video professional's creativity, a higher level of performance and reliability for the engineer, and a new, exciting viewing experience for the consumer that will continue the industry's growth and success.

There will be many changes in your future. The authors hope you find the transition from analog to digital video among the most rewarding.

Appendix A – Color and Colorimetry

The television color specification is based on standards defined by the CIE (Commission Internationale de L'Éclairage) in 1931. This system is based on experiments with a group of observers matching a color to an additive mix of three primaries – red, green and blue. The average of this experiment results in a graph that shows the color matching function (Figure A1) of a standard (average) observer. RGB tristimulus values are restricted by gamut restraint and cannot produce all colors. In order to produce the full range of colors, negative values of RGB would be required. This is an inappropriate model for television colorimetry. The CIE specified an idealized set of primary XYZ tristimulus values. These values are a set of all-positive values converted from the RGB tristimulus values where the value Y is proportional to the luminance of the additive mix. This specification is used as the basis for color within today's video standards.

The CIE standardized a procedure for normalizing XYZ tristimulus values to obtain a two-dimensional plot of values x and y of all colors for a relative value of luminance as specified by the following equations. A color is plotted as a point in an (x, y) chromaticity diagram, illustrated in Figure A2.

$$x = X / (X + Y + Z)$$
$$y = Y / (X + Y + Z)$$
$$z = Z / (X + Y + Z)$$
$$1 = x + y + z$$

Limits are defined for various video formats that show all possible colors for that format. Color-coded triangles (SMPTE = yellow, EBU/PAL/SECAM = blue, NTSC 1953 = green) in Figure A3 are specified by x, y coordinates in Table A1.

The x, y coordinates chosen are dependent on the phosphors used in manufacture of the CRT. NTSC phosphors specified in 1953 have been superceded by those of EBU and SMPTE because of the requirement for brighter displays.
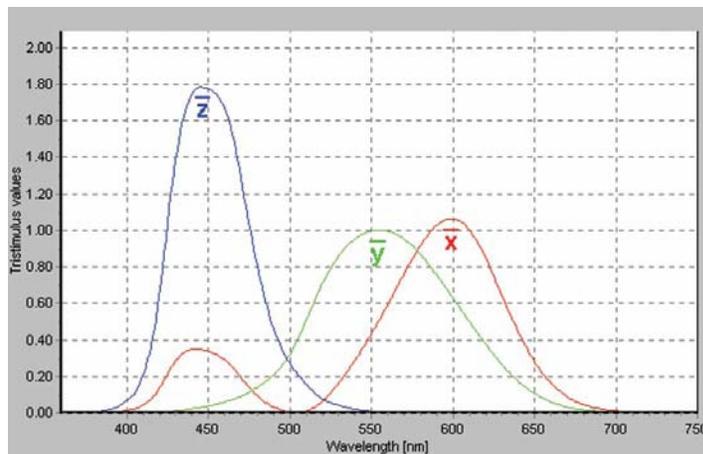

Figure A1. CIE 1931 Color matching function (2 degree observer).
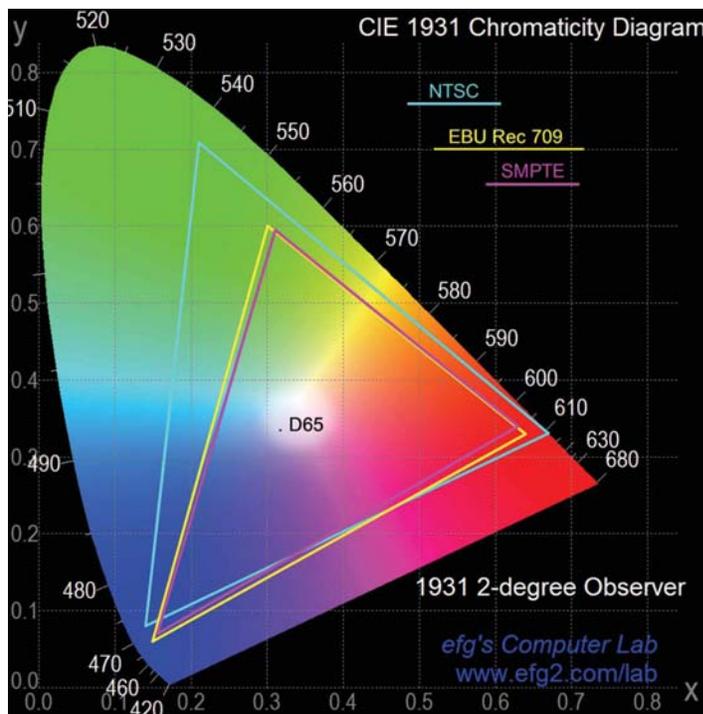

Figure A2. CIE x y Chromaticity with coordinate values for SMPTE, EBU/PAL/SECAM, and NTSC 1953.

White

An important consideration in the definition of colors is the white point of the system, and therefore, within each format a white point is defined which is the addition of red, green, and blue in equal quantities.

The CIE defined several standard sources in 1931:

- Source A: A tungsten-filament lamp with a color temperature of 2854K

- Source B: A model of noon sunlight with a color temperature of 4800K

- Source C: A model of average daylight with a color temperature of 6504K

Illuminant C (Source C) was used in the original definition of NTSC. The CIE later defined a series of daylight illuminants called the Daylight D series. Illuminant D_{65} with a color temperature of 6504K, and slightly different x, y coordinates are predominately used with video standards today.

Each of the sources has a white point and is given a x, y value on the chromaticity diagram.

Illuminant A	x = 0.4476	y = 0.4075
Illuminant B	x = 0.3484	y = 0.3516
Illuminant C	x = 0.3101	y = 0.3162
Illuminant D_{65}	x = 0.3127	y = 0.3290

Current standards assume the television studio is illuminated by a source with Illuminant D_{65}. In practice, studio lighting may not be Illuminant D_{65} and adjusting the gain of the red, green, blue components will compensate the white balance of the camera.

SMPTE	RED		GREEN		BLUE	
	Xr	Yr	Xg	Yg	Xb	Yb
	0.630	0.340	0.310	0.595	0.155	0.070
Illuminant D_{65}	x = 0.3127		y = 0.3290			
EBU	**RED**		**GREEN**		**BLUE**	
Rec 709	Xr	Yr	Xg	Yg	Xb	Yb
	0.640	0.330	0.300	0.600	0.150	0.060
Illuminant D_{65}	x = 0.3127		y = 0.3290			
PAL/SECAM	**RED**		**GREEN**		**BLUE**	
	Xr	Yr	Xg	Yg	Xb	Yb
	0.64	0.330	0.290	0.60	0.150	0.060
Illuminant D_{65}	x = 0.3127		y = 0.3290			
NTSC	**RED**		**GREEN**		**BLUE**	
(1953)	Xr	Yr	Xg	Yg	Xb	Yb
	0.670	0.330	0.210	0.710	0.140	0.080
Illuminant C	x = 0.3101		y = 0.3162			

Table A1. CIE x, y Coordinate Values for Various Formats.

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 gamma-corrected R'G'B' 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 signal. As in the more generic use of the term, each component is a necessary, but not sufficient, part of the whole. The basic R'G'B' component signals are used again at the output of a television system to display the image on a monitor or TV set. Therefore, it makes sense to say that one of the primary tasks of a television plant is to convey these component signals

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, 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.

Another means of representing Red, Green, and Blue primary colors is by a three-dimensional R'G'B' color cube representation. All colors can be represented within the bounds of the RGB color cube as shown in Figure A3.

The color television system was developed to be compatible with existing black and white television receivers. The gamma-corrected luma signal, Y', is created from the red, green, and blue camera signals, for transmission to black and white or color receivers as a monochrome picture. By knowing the difference between the monochrome or luma channel and any two color channels, we can recover red, green, and blue to drive the color picture tube. Since human vision green response most closely tracks brightness, a majority of that color information is used to make up the luma signal, and the remaining red and blue color-difference channels can be transmitted at a lower bandwidth.

The luma 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') by a simple matrix as shown in Figure A4. The color-difference component form has two advantages over R'G'B'. First, substantially less bandwidth is required to convey necessary information: a color-difference system needs only one high-bandwidth channel because all the fine detail in the image is carried by the luma signal. An R'G'B' 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 R'G'B'. A low level on any one channel in
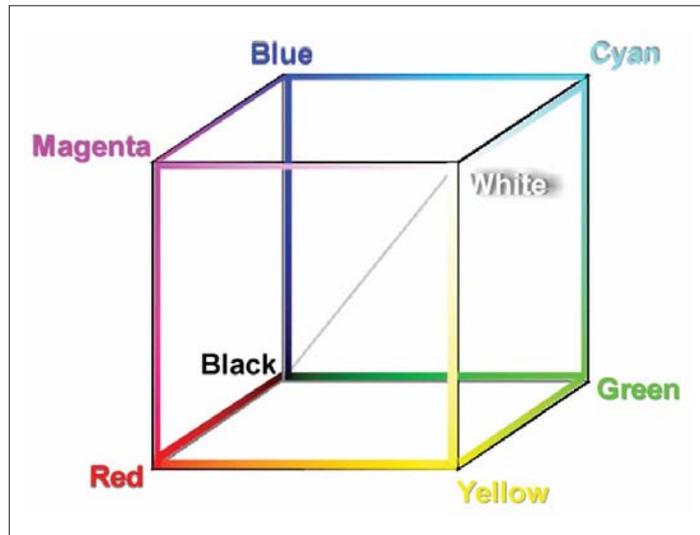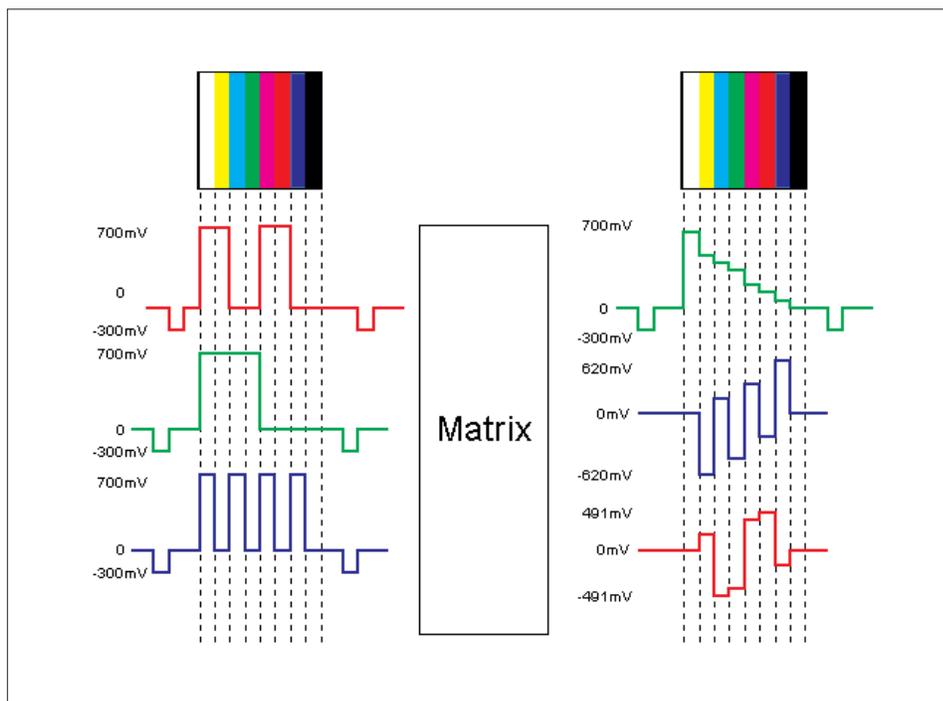

Figure A3. R'G'B' color cube.

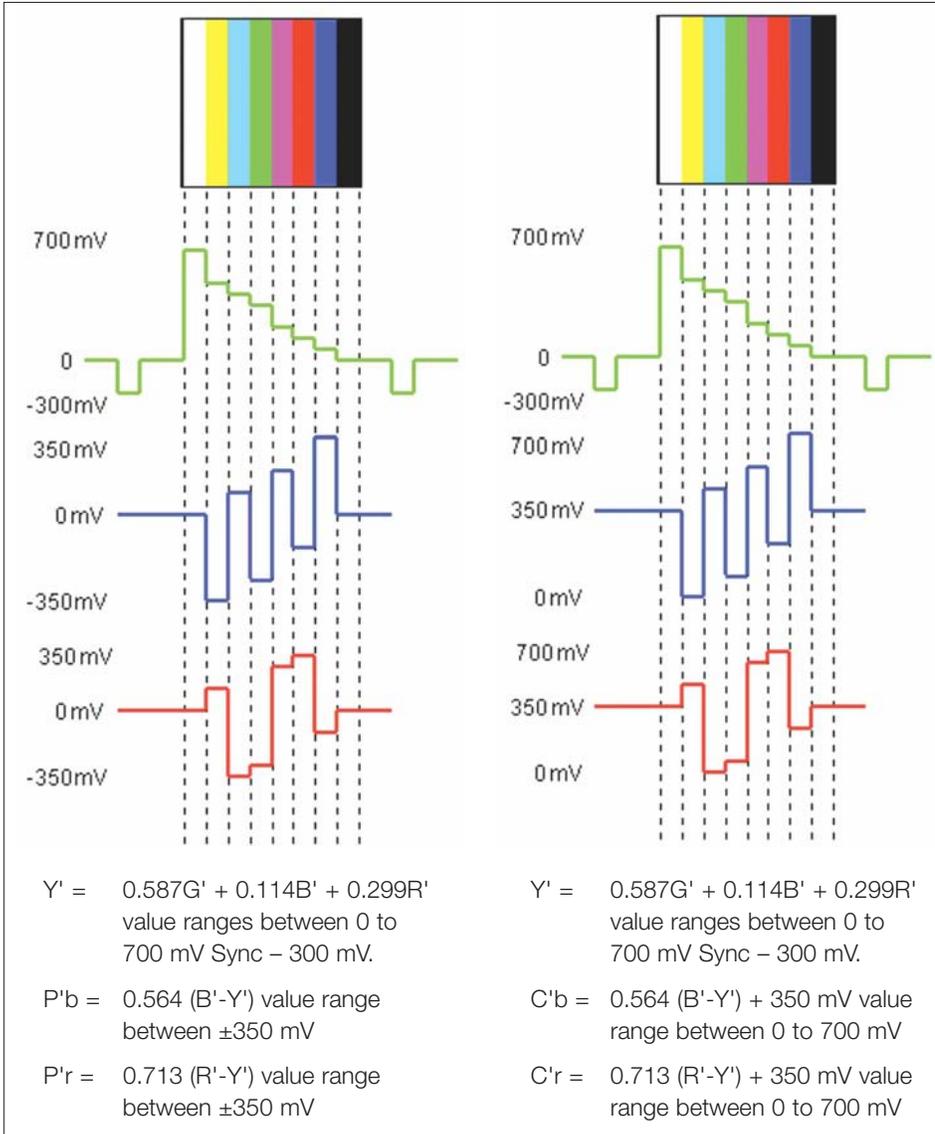**Figure A4.** Matrix of R'G'B' signal-to-color difference.

Figure A5. Color-difference signals scaled and offset for digital quantizing.

a color-difference set will produce subtle changes in hue or changes in saturation only. A low level in R'G'B', however, will produce a distinctly wrong-colored image. The concept of transcoding R'G'B' to one luma and two color-difference signals has proven very useful. Such signals, with relatively minor variations, are the basis for all existing component video formats and also for composite broadcast standards throughout the world.

For standard definition (Figure A5):

- $Y' = 0.587G' + 0.114B' + 0.299R'$
  value ranges between 0 to 700 mV
  Sync – 300 mV

- $B'-Y' = -0.587G' + 0.866B' - 0.299R'$
  value ranges between ±620 mV

- $R'-Y' = -0.857G' - 0.114B' + 0.701R'$
  value ranges between ±491 mV

In the component video domain, component R'G'B' signals are often referred to as G'B'R' because the majority of the luminance signal is made up of green channel information. Therefore, there is a correspondence between Y'P'bP'r and G'B'R'.

Color-difference values (Figure A5) are first scaled to produce an equal dynamic range of ±350 mV for ease of processing within various systems. The analog component signal is denoted Y'P'bP'r and the digital component system, which introduces an offset to the color-difference signals to allow similar processing ranges for the Y and color-difference signals values, is denoted Y'C'bC'r.

Performing this matrixing and scaling prevents all possible values of Y'C'bC'r signals being used when the signal is converted back to RGB. As illustrated in Figure A6, only about 25% of all possible signal values in the Y'C'bC'r domain are used to present the entire gamut of colors in the RGB domain. Because of this, care must be taken when translating between formats that the dynamic range is not exceeded in the conversion process.

Gamut, legal, valid

The term gamut has been used to refer to the range or gamut of reproducible colors by a television system when the scene is illuminated by a reference white (illuminant D_{65} for NTSC/PAL). This gamut is defined by the chromaticity value or CIE chromaticity coordinates for a given system. This range of colors of variable saturation is reproduced in the picture monitor by red, green, and blue or R'G'B' signal values. When equal valued, (i.e., R' = G' = B') the image is colorless to the extent it represents shades of gray on a properly-adjusted picture monitor. Otherwise, a colored hue of nonzero saturation results and all colors in the gamut of reproducible colors are possible by independently adjusting the values of the R'G'B' signals.

Since the values of the R'G'B' signals directly represent these colors, the term gamut is often used to refer to the range of colors represented by all combinations of R'G'B' signals that lie within the legal limits of 0 and 700 mV. R'G'B' signals extending outside this voltage range may produce desirable color on a given picture monitor, but are outside the valid color gamut. They may be clipped or compressed in subsequent signal processing, distorting the color when displayed on another picture monitor.
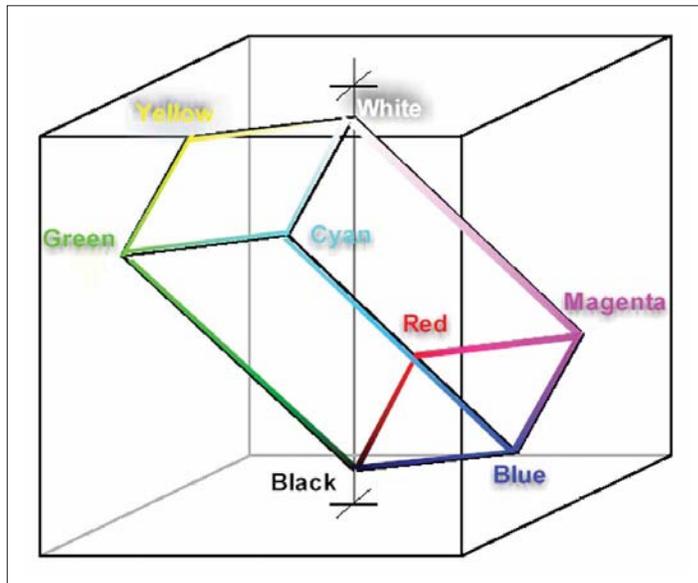

Figure A6. Y'C'bC'r 3D color space.

So in the R'G'B' domain, any channel exceeding either the upper or lower limit represents an invalid signal, since the color falls outside the valid color gamut. It is also illegal since one or more of the components exceeds the legal limits.

Legal signals are simply those signals that do not violate the signal-voltage limits for the particular format in use, i.e., signals within the allowed signal limits for that format. So a legal signal in a color-difference format like Y'C'bC'r can be invalid in that it can represent a color outside the valid color gamut. Such an invalid signal will always produce an illegal signal when transcoded to R'G'B'.
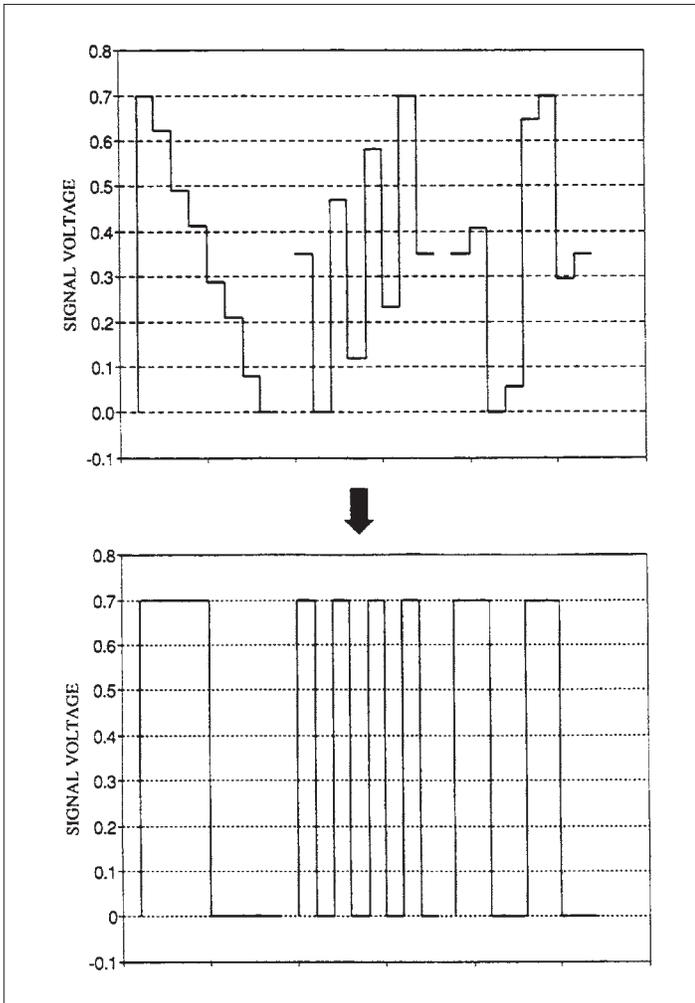
Figure A7. A valid color-difference signal can be converted to a legal RGB signal.
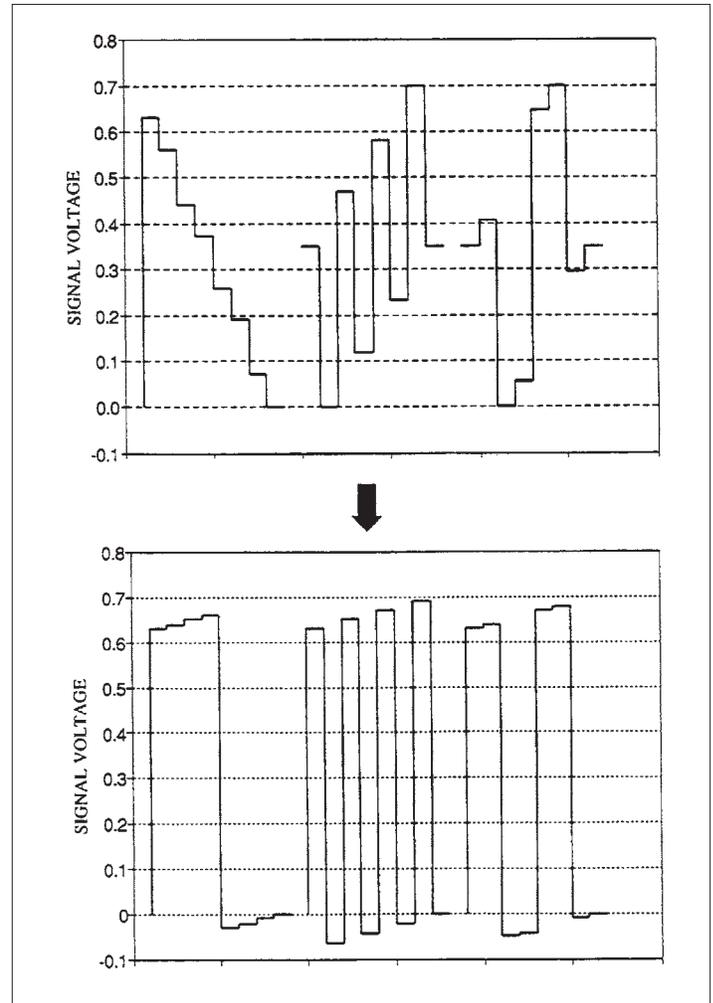

Figure A8. An invalid signal, legal in one format but illegal when converted.

A valid signal is one that is within color gamut and remains legal when translated into any other format. A valid signal is always legal, but a legal signal is not necessarily valid. The latter case most often occurs with a color-difference format component signal, where the signal levels are not independent, as they are in RGB systems. Figures A7 and A8 show how a simple gain distortion in a color-difference component signal can make the signal invalid, though not illegal.

Figure A7 shows a legal and valid color-difference signal (top) and the legal RGB signal (bottom) to which it translates. In Figure A8, however, the luma channel of the color-difference signal (top) is distorted; it has a relative gain of only 90 percent. When this distorted signal is transcoded to the RGB format (bottom), the result is an illegal signal – all three components extend below the minimum allowed signal level. Since the distorted color-difference signal cannot be translated into a legal RGB signal, it is invalid. Other forms of distortion can also create invalid signals.

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

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Primer

Format conversion tables

The following conversion tables show how translation between Y'P'bP'r values and G'B'R' products can be calculated. In Table A2, the values of 100% color bars are translated from G'B'R' into Y'P'bP'r. The dynamic range of R'G'B' (0 to 700 mV) is not exceeded and the conversion process results in signals that do not exceed the analog dynamic range of Y'P'bP'r (0 to 700 mV for the luma channel and ±350 mV for the color-difference channels). This signal is said to be Legal and Valid. A signal is Legal if it falls within the dynamic range of that format. A signal is Valid if it represents a color that is within the valid color gamut. Such a signal, when transcoded to R'G'B' will always produce an R'G'B' signal that is legal.

When a signal exceeds the dynamic range of a format, it becomes illegal. Table A3 shows signals which are legal in the Y'P'bP'r domain; however, when these values are converted to G'B'R', some of the values fall outside of the 0 to 700 mV threshold set for G'B'R' indicating that they are invalid and represent colors outside the valid gamut. Distortion of the signals could likely occur by processing equipment which is expected to only process the signal within the specified format range and may clip the signal if it exceeds these values. Tektronix has developed specific displays to assist operators and engineers in maintaining Legal and Valid signals.

100% Color Bars

Color	G' (mV)	B' (mV)	R' (mV)	Y' (mV)	P'b (mV)	P'r (mV)
White	700	700	700	700	0	0
Yellow	700	0	700	620.2	–350	56.7
Cyan	700	700	0	490.7	118.3	–350
Green	700	0	0	410.9	–231.7	–293.3
Magenta	0	700	700	289.1	231.7	293.3
Red	0	0	700	209.3	–118.3	350
Blue	0	700	0	79.8	350	–56.7
Black	0	0	0	0	0	0

Table A2. Legal and Valid G'B'R' Signal with Equivalent Legal and Valid Y'P'bP'r Signal.

Y' (mV)	P'b (mV)	P'r (mV)	G' (mV)	B' (mV)	R' (mV)	Color
700	350	350	330	1320	1911	Illegal GBR
700	–350	–350	1070	80	160	Illegal GBR
700	0	350	450	700	1191	Illegal GBR
700	0	–350	950	700	160	Illegal GBR
700	350	0	580	1320	700	Illegal GBR
700	–350	0	820	80	700	Illegal GBR
700	0	0	700	700	700	White
0	350	350	–370	620	491	Illegal GBR
0	–350	–350	370	–620	491	Illegal GBR
0	0	350	–250	0	491	Illegal GBR
0	0	–350	250	0	–491	Illegal GBR
0	350	0	–120	620	0	Illegal GBR
0	–350	0	120	–620	0	Illegal GBR
0	0	0	0	0	0	Black

Table A3. Legal but Invalid Y'P'bP'r Signals with Equivalent Illegal G'B'R' Signals.

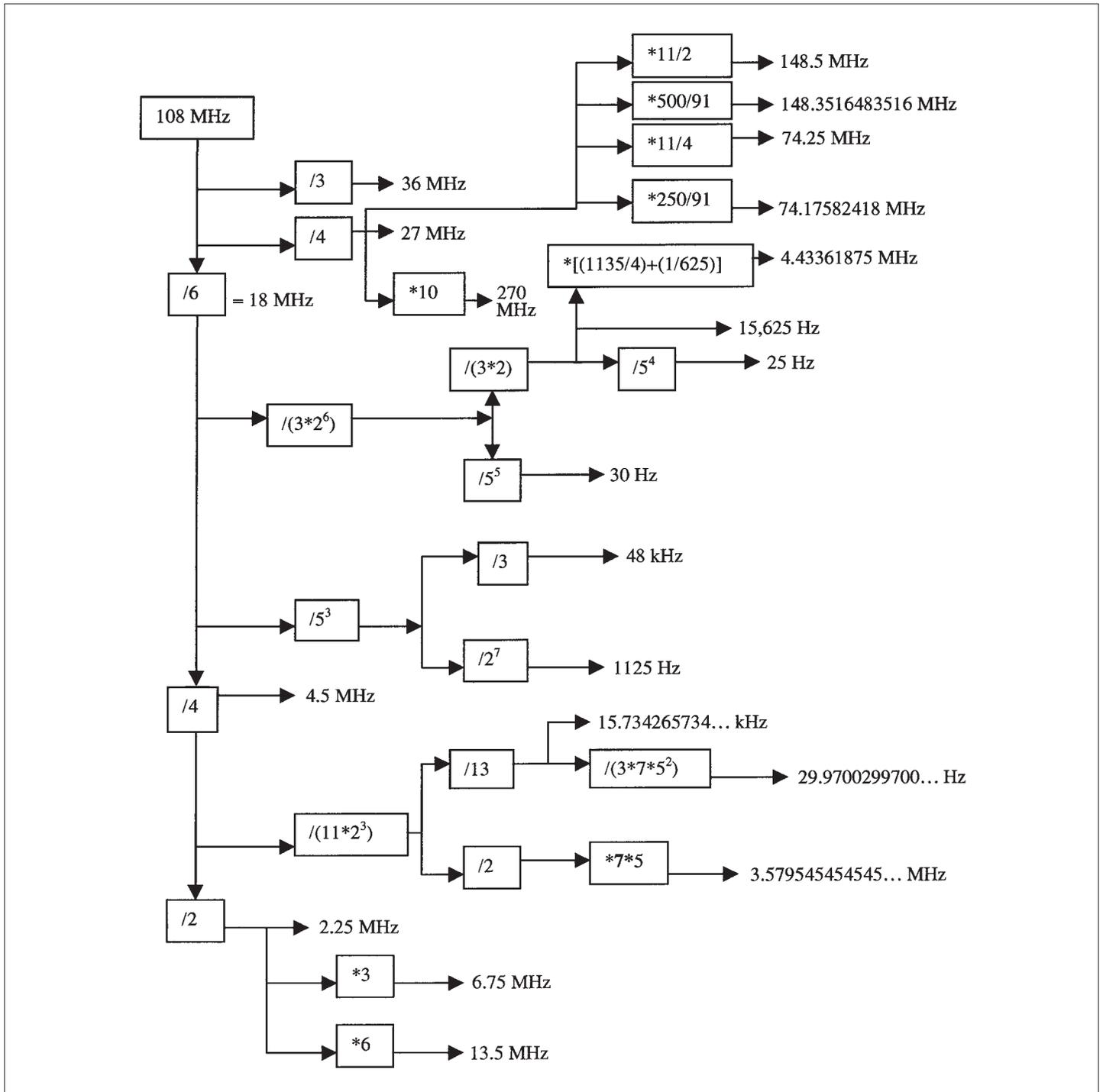# Appendix B – Television Clock Relationships

Figure B1. Video clock derivations.

Appendix C – Standard Definition Analog Composite Video Parameters

	PAL B/G	NTSC	SECAM	PAL-M	PAL-N
Sync Type	negative bi-level	negative bi-level	negative bi-level	negative bi-level	negative bi-level
Subcarrier Freq. (MHz)	4.43361875	3.579545 4.250000	4.406250	3.57561149	3.58205625
Lines/Frame	625	525	625	525	625
Field Freq. (Hz)	50.00	59.94	50.00	59.94	50.00
Line Freq. (kHz)	15.625	15.734264	15.625	15.734264	15.625
Line Period (μ)	64.000	63.555	64.000	63.555	64.000
Line Blanking (μ)	12.05	10.90	12.05	10.90	12.05
Back Porch (μ)	5.8	4.7	5.8	4.7	5.8
Front Porch (μ)	1.55	1.50	1.55	1.50	1.55
Sync Width (μ)	4.7	4.7	4.7	4.7	4.7
Sync Amplitude (mV)	–300	–286	–300	–286	–300
Sync Amplitude (IRE)	–43	–40	–43	–40	–43
Sync Rise/Fall (μ)	0.200	0.250	0.200	0.250	0.200
Sync to Burst (μ)	5.6	5.3	–	5.8	5.6
Burst Duration (μ)	2.25 ±0.28	2.23 to 3.11	–	2.25 ±0.28	2.51 ±0.28
Burst Duration (Cycles of SC)	10 ±1	9 ±1	–	9 ±1	9 ±1
Burst Ampl. (mV)	300	286	166	286	300
Field Period (μ)	20	16.6833	20	16.6833	20
Field Blanking (lines)	25	21	25	21	25

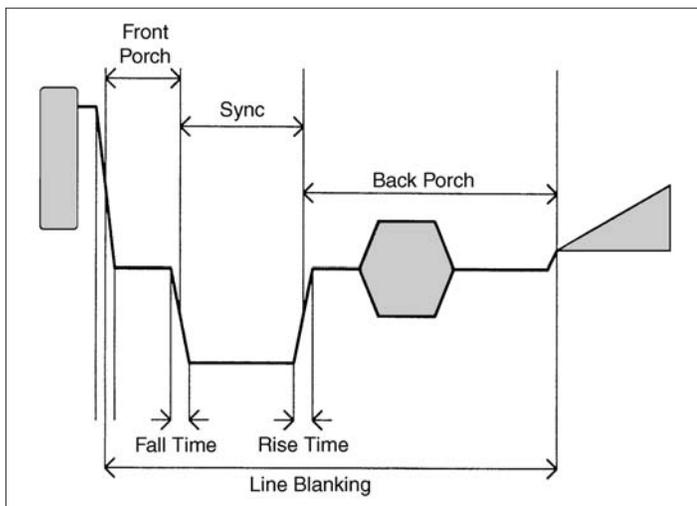**Table C1.** Standard Definition Composite Video Parameters.

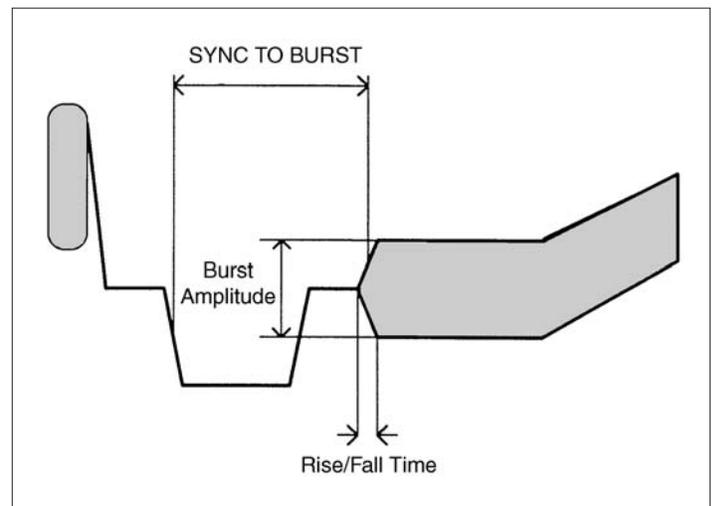**Figure C1.** PAL and NTSC system horizontal interval.

Figure C2. SECAM system horizontal interval.

Appendix D – Reference Standards and Practices for Television

ANSI S4.40-1992, Digital Audio Engineering - Serial Transmission Format for Two-Channel Linearly Represented Digital Audio Data (AES-3)

ANSI/SMPTE 125M-1995, Television - Component Video Signal 4:2:2 - Bit-Parallel Digital Interface

ANSI/SMPTE 170M-2004, Television - Composite Analog Video Signal - NTSC for Studio Applications

ANSI/SMPTE 240M-1999 (Archive 2004), Television - Signal Parameters - 1125-Line High-Definition Production Systems

ANSI/SMPTE 259M-2008, Television - SDTV Digital Signal/Data Serial Digital Interface

SMPTE 260M-1999 (Archive 2004), Television - Digital Representation and Bit - Parallel Interface - 1125/60 High-Definition Production System

ANSI/SMPTE 272M-2004, Television - Formatting AES/EBU Audio and Auxiliary Data into Digital Video Ancillary Data Space

ANSI/SMPTE 274M-2008, Television - 1920 x 1080 Scanning and Analog and Parallel Digital Interfaces for Multiple Picture Rates

ANSI/SMPTE 291M-2006, Television - Ancillary Data Packet and Space Formatting

ANSI/SMPTE 292M-2008, Television - 1.5 Gb/s Signal/ Data Serial Interface

ANSI/SMPTE 293M-2003, Television - 720 x 483 Active Line at 59.94-Hz Progressive Scan Production - Digital Representation

ANSI/SMPTE 294M-2001, Television - 720 x 483 Active Line at 59.94-Hz Progressive Scan Production - Bit-Serial Interfaces

ANSI/SMPTE 295M-1997, Television - 1920 x 1080 50 Hz - Scanning and Interface

ANSI/SMPTE 296M-2001, Television - 1280 x 720 Scanning, Analog and Digital Representation and Analog Interface

ANSI/SMPTE 299M-2004, Television - 24-Bit Digital Audio Format for HDTV Bit-Serial Interface

ANSI/SMPTE 305M- 2005, Television - Serial Data Transport Interface (SDTI)

ANSI/SMPTE 310M- 2004, Television - Synchronous Serial Interface for MPEG-2 Digital Transport Stream

SMPTE 318M-1999 - Synchronization of 59.94 or 50 Hz Related Video and Audio Systems in Analog and Digital Areas - Reference Signals

ANSI/SMPTE 320M- 1999, Television - Channel Assignments and Levels on Multichannel Audio Media

ANSI/SMPTE 346M- 2000 (Archive 2006), Television - Time Division Multiplexing Video signals and Generic Data over High-Definition Television Interfaces

ANSI/SMPTE 347M- 2001 (Archive 2006), Television - 540 Mb/s Serial Digital Interface - Source Image Format Mapping

ANSI/SMPTE 348M- 2005 (Archive 2006), Television - High Data rate Serial Data Transport Interface (HD-SDTI)

ANSI/SMPTE 349M- 2001 (Archive 2006), Television - Transport of Alternate Source Image Formats through SMPTE292

ANSI/SMPTE 352M- 2002, Television - Video Payload Identification for Digital Television Interfaces

ANSI/SMPTE 372M- 2002, Television - Dual-Link 292M Interface for 1920x1080 Picture Raster

ANSI/SMPTE 424M- 2006, Television - 3 Gb/s Signal/Data Serial Interface

ANSI/SMPTE 425M- 2008, Television - 3 Gb/s Signal/Data Serial Interface - Source Image Format Mapping

ANSI/SMPTE 428-1- 2006, D-Cinema – Distribution Master (DCDM) - Image Characterisitcs

ANSI/SMPTE 428-9- 2008, D-Cinema – Distribution Master - Image Pixel Structure Level 3 – Serial Distribution Interface Signal Formatting

SMPTE 2010-2008, Vertical Ancillary Data Mapping of ANSI/SCTE 104 Messages (Revision of RP 2010-2007)

ANSI/SMPTE 2016-1- 2007, Television – Format for Active Format Description and Bar Data

ANSI/SMPTE 2016-2- 2007, Television – Format for Pan-Scan Information

ANSI/SMPTE 2016-3- 2007, Television – Vertical Ancillary Data Mapping of Active Format Description and Bar Data

ANSI/SMPTE 2016-4- 2007, Television – Vertical Ancillary Data Mapping of Pan-Scan Information

ANSI/SMPTE 2020-1- 2008, Television – Format of Audio Metadata and Description of the Asynchronous Serial Bitstream Transport

ANSI/SMPTE 2020-2- 2008, Television – Vertical Ancillary Data Mapping of Audio Metadata – Method A

ANSI/SMPTE 2020-3- 2008, Television – Vertical Ancillary Data Mapping of Audio Metadata – Method B

CIE Publication No 15.2, Colorimetry - Second Edition (1986), Central Bureau of the Commission Internationale de L'Eclairage, Vienna, Austria.

ITU-R BT.601-6-2007 - Studio Encoding Parameters of Digital Television for Standard 4:3 and Wide-Screen 16:9 Aspect Ratios ITU-R BT.656-4 - Interfaces for Digital Component Video Signals in 525-line and 625-line Television Systems Operating at the 4:2:2 Level of Recommendation ITU-R BT-601 (Part A)

ITU-R BT.709-5-2002 - Parameter Values for the HDTV Standards for Production and International Programme Exchange ITU-R BT.1120-2 - Digital Interfaces for 1125/60 and 1250/50 HDTV Studio Signals

SMPTE Engineering Guideline EG33-1998 - Jitter characteristics and measurements

SMPTE RP160-1997 - Three-Channel Parallel Analog Component High-Definition Video Interface

SMPTE RP165-1994 - Error Detection Checkwords and Status Flags for Use in Bit-Serial Digital Interfaces for Television

SMPTE RP168-2002 - Definition of Vertical Interval Switching Point for Synchronous Video Switching

Appendix D – Reference Standards and Practices for Television (Continued)

SMPTE RP177-1993 - Derivation of Basic Television Color Equations

SMPTE RP178-1996 - Serial Digital Interface Checkfield for 10-Bit 4:2:2 Component and 4fsc Composite Digital Signals

SMPTE RP184-1996 - Specification of Jitter in Bit-Serial Digital Interfaces

SMPTE RP186-2008 - Video Index Information Coding for 525- and 625- Line Television Systems

SMPTE RP187-1995 - Center, Aspect Ratio and Blanking of Video Images

SMPTE RP192-2003 - Jitter Measurement Procedures in Bit-Serial Digital Interfaces

SMPTE RP198-1998 - Bit-Serial Digital Checkfield for Use in High-Definition Interfaces

SMPTE RP211-2000 (Archive 2006) - Implementation of 24P, 25P, and 30P Segmented Frames for 1920 x 1080 Production Format

SMPTE RP218-2002 - Specification for Safe Area and Safe Title Areas for Television Systems

SMPTE RP219-2002 - High Definition, Standard Definition Compatible Color Bar Signal

SMPTE RP221-2008 - Specification for Extraction of 4x3 Areas from Digital 16x9 Images for Television Systems

SMPTE RP291-2006 - Assigned Ancillary Identification Codes

SMPTE RP2010-2007 - Vertical Ancillary Data Mapping of ANSE/SCTE 104 Messages

SMPTE RDD6-2008 - Television – Description and Guide to the Use of the Dolby E Audio Metadata Serial Bitstream

SMPTE RDD8-2008 - Storage and Distribution of Teletext Subtitles and VBI Fata for High Definition Television

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Appendix F – Glossary

4:2:2 – A commonly used term for a component digital video format. The details of the format are specified in the ITU-R BT.601 standard document. The numerals 4:2:2 denote the ratio of the sampling frequencies of the single luminance channel to the two color-difference channels. For every four-luminance samples, there are two samples of each color-difference channel. See ITU-R BT.601.

4fsc – Four-times subcarrier sampling rate used in composite digital systems. In NTSC, this is 14.3 MHz. In PAL, this is 17.7 MHz. Standard definition component sampling is 13.5 MHz for luma, 6.75 for chroma in both 535/60 and 625/50 format.

AES/EBU audio – Informal name for a digital audio standard established jointly by the Audio Engineering Society and European Broadcasting Union organizations.

algorithm – A set of rules or processes for solving a problem in a finite number of steps.

aliasing – Defects in the picture typically caused by insufficient sampling or poor filtering of digital video. Defects are typically seen as jaggies on diagonal lines and twinkling or brightening in picture detail.

analog – An adjective describing any signal that varies continuously as opposed to a digital signal that contains discrete levels representing the binary digits 0 and 1.

ancillary data – Data supporting the video signal or program. Time multiplexed into the video signal during the horizontal and/or vertical blanking intervals. Ancillary data may be sent between the EAV and SAV packets in horizontal blanking and in larger blocks during vertical blanking. Ancillary data may include checksums, multi-channel digital audio, and other data.

asynchronous – A transmission procedure that is not synchro-nized by a clock. Digital video is not asynchronous because sampling clock information must be extracted from data signal transitions for decoding.

A-to-D Converter (analog-to-digital) – A circuit that uses digital sampling to convert an analog signal into a digital representation of that signal.

bandwidth – 1) The difference between the upper and lower limits of a frequency, often measured in megahertz (MHz). 2) The complete range of frequencies over which a circuit or electronic system can function with less than a 3 dB signal loss. 3) The information carrying capability of a particular television channel.

baseline shift – A form of low-frequency distortion resulting in a shift in the DC level of the signal.

bit – A binary representation of 1 or 0. One of the quantized levels of a pixel.

bit parallel – Byte-wise transmission of digital video down a multi-conductor cable where each pair of wires carries a single bit. This standard is covered under SMPTE 125M, EBU 3267-E and ITU-R BT.656.

bit serial – Bit-wise transmission of digital video down a single conductor such as coaxial cable. May also be sent through fiber optics. This standard is covered under ITU-R BT.656.

bit slippage – 1) Occurs when word framing is lost in a serial signal so the relative value of a bit is incorrect. This is generally reset at the next serial signal, TRS-ID for composite and EAV/SAV for component. 2) The erroneous reading of a serial bit stream when the recovered clock phase drifts enough to miss a bit. 3) A phenomenon which occurs in parallel digital data buses when one or more bits gets out of time in relation to the rest. The result is erroneous data. Differing cable lengths is the most common cause.

bit stream – A continuous series of bits transmitted on a line.

BNC – Abbreviation of "baby N connector." A cable connector used extensively in television.

brightness signal – Same as the luminance signal (Y). This signal carries information about the amount of light at each point in the image.

byte – A complete set of quantized levels containing all of the bits. Bytes consisting of 8 to 10 bits per sample are typical.

cable equalization – The process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

CCIR – International Radio Consultative Committee (Comité Consultatif International en Radiodiffusion), an international standards committee, now replaced by International Telecommunication Union (ITU).

CCIR-601 – See ITU-R BT.601.

CCIR-656 – See ITU-R BT.656.

channel coding – Describes the way in which the "1"s and "0"s of the data stream are represented on the transmission path.

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.

clock jitter – Timing uncertainty of the data cell edges in a digital signal.

clock recovery – The reconstruction of timing information from incoming digital data.

coaxial cable – A transmission line with a concentric pair of signal carrying conductors. There's an inner conductor and an outer conductive metallic sheath. The sheath aids in preventing external radiation from affecting the signal on the inner conductor and minimizes signal radiation from the transmission line.

coding – Representing each level of a video signal as a number, usually in binary form.

coefficients – A number (often a constant) that expresses some property of a physical system in a quantitative way.

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, Pr and Pb, 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, 1, and Q; or Y, R-Y, and B-Y.

component analog – The unencoded output of a camera, videotape recorder, etc., consisting of three primary color signals: green, blue, and red (GBR) that together convey all necessary picture information. In some component video formats, these three components have been translated into a luminance signal and two color-difference signals, for example, Y, B-Y, and R-Y.

component digital – A digital representation of a component analog signal set, most often Y'C'bC'r. The encoding parameters are specified by ITU-R BT.601. For standard definition formats, the parallel interface is specified by ITU-R BT.656 and SMPTE 125M (1991).

composite analog – An encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

composite digital – A digitally encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

contouring – Video picture defect due to quantizing at too coarse a level.

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.

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. Also used to represent a device for extracting video from a compressed signal.

delay – The time required for a signal to pass through a device or conductor.

demultiplexer (demux) – A device used to separate two or more signals that were previously combined by a compatible multiplexer and transmitted over a single channel.

deserializer – A device that converts serial digital information to parallel.

differential gain – A change in chrominance amplitude of a video signal caused by a change in luminance level of the signal.

differential phase – A change in chrominance phase of a video signal caused by a change in luminance level of the signal.

digital components – Component signals in which the values for each pixel are represented by a set of numbers.

digital word – The number of bits treated as a single entity by the system.

discrete – Having an individual identity. An individual circuit component.

dither – Typically a random, low-level signal (oscillation) which may be added to an analog signal prior to sampling. Often consists of white noise of one quantizing level peak-to-peak amplitude.

dither component encoding – A slight expansion of the analog signal levels so that the signal comes in contact with more quantizing levels. The results are smoother transitions. This is done by adding white noise (which is at the amplitude of one quantizing level) to the analog signal prior to sampling.

drift – Gradual shift or change in the output over a period of time due to change or aging of circuit components. Change is often caused by thermal instability of components.

D-to-A converter (digital-to-analog) – A device that converts digital signals to analog signals.

DVTR – Abbreviation of digital videotape recorder.

EAV – End of active video in component digital systems. One of two (EAV and SAV) timing reference packets.

EBU – European Broadcasting Union. An organization of European broadcasters that, among other activities, produces technical statements and recommendations for the 625/50 line television system.

EBU TECH.3267-E – The EBU recommendation for the parallel interface of 625-line digital video signal. A revision of the earlier EBU Tech.3246-E, which in turn was derived from CCIR-601 (now ITU-R BT.601) and contributed to CCIR-656 (ITU-R BT.656) standards.

EDH (error detection and handling) – Proposed SMPTE RP 165 for recognizing inaccuracies in the serial digital signal. It may be incorporated into serial digital equipment and employ a simple LED error indicator.

equalization (EQ) – Process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

embedded audio – Digital audio is multiplexed onto a serial digital data stream at the time allocated for ancillary data.

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. Also represents a device used for video compression.

error concealment – A technique used when error correction fails (see error correction). Erroneous data is replaced by data synthesized from surrounding pixels.

error correction – A scheme that adds overhead to the data to permit a certain level of errors to be detected and corrected.

eye pattern – An oscilloscope waveform view of overlaid highs and lows of the data signal. The changing data vs. the clock-synchronized sweep creates the look of an eye. The waveform is used to evaluate transport layer analog performance.

field-time (linear) distortion – An unwarranted change in video signal amplitude that occurs in a time frame of a vertical scan (i.e., 16.66 Ms at 60 Hz).

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

format, scanning – In analog and standard definition digital, the total number of lines and the field rate, i.e., 625/50. In digital high-definition, the number of luma pixels, the number of active video lines, the field rate, and the number of fields per frame, i.e., 1280/720/59.94/2:1.

format conversion – The process of both encoding/decoding and resampling of digital rates.

frequency modulation – Modulation of a sinewave or "carrier" by varying its frequency in accordance with amplitude variations of the modulating signal.

frequency response rolloff – A distortion in a transmission system where the higher frequency components are not conveyed at their original full amplitude and create a possible loss of color saturation.

gain – Any increase or decrease in strength of an electrical signal. Gain may be expressed in decibels.

gamma – The transfer characteristic, input vs. output. In a television system, gamma correction is applied at the source to provide additional gain in dark areas so as to compensate for the CRT and human vision. Gamma correction at the source avoids enhancing noise at the destination and reduces the number of bits necessary to convey a satisfactory picture.

gamut – The range of colors allowed for a video signal. Valid color gamut is defined as all colors represented by all possible combinations of legal values of an R'G'B' signal. Signals in other formats may represent colors outside valid gamut but still remain within their legal limits. These signals, when transcoded to R'G'B', will fall outside legal limits for R'G'B'. This may lead to clipping, crosstalk, or other distortions.

G'B'R', G'B'R' format – The same signals as R'G'B'. The sequence is rearranged to indicate the mechanical sequence of the connectors in the SMPTE standard. Often parade displays

group delay – A signal defect caused by different frequencies having differing propagation delays (delay at 1 MHz is different from delay at 5 MHz).

horizontal interval (horizontal blanking, interval) – The time period between lines of active video.

interconnect format – See format.

interconnect standard – See standard.

interlace scanning – A scanning format where the picture is captured and displayed in two fields. The second field is offset one-half line horizontally from the first field to present the lines of each field vertically interposed between the lines of the other.

interpolation – In digital video, the creation of new pixels in the image by some method of mathematically manipulating the values of neighboring pixels.

invalid signal – See valid signal.

I/O – Abbreviation of input/output. Typically refers to sending information or data signals to and from devices.

ITU-R – The International Telecommunication Union, Radio Communication Sector (replaces the CCIR).

ITU-R BT.601 – An international standard for component digital television from which was derived SMPTE 125M (was RP-125) and EBU 3246E standards. ITU-R BT.601 defines the sampling systems, matrix values, and filter characteristics for both Y, B-Y, R-Y and GBR component digital television.

ITU-R BT.656 – The physical parallel and serial interconnect scheme for ITU-R BT.601. ITU-R BT.656 defines the parallel connector pinouts as well as the blanking, sync, and multiplexing schemes used in both parallel and serial interfaces. Reflects definitions in EBU Tech 3267 (for 625-line signals) and in SMPTE 125M (parallel 525) and SMPTE 259M (serial 525).

jaggies – Slang for the stair-step aliasing that appears on diagonal lines. Caused by insufficient filtering, violation of the Nyquist Theory, and/or poor interpolation.

jitter – An undesirable random signal variation with respect to time.

keying – The process of replacing part of one television image with video from another image; i.e., chroma keying and insert keying.

legal/illegal – A signal is legal if it stays within the gamut appropriate for the format in use. A legal signal does not exceed the voltage limits specified for the format of any of the signal channel. An illegal signal is one that is sometimes outside those limits in one or more channels. A signal can be legal but still not be valid.

luma, luminance (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.

MAC – Multiplexed Analog Component video. This is a means of time multiplexing component analog video down a single transmission channel such as coax, fiber, or a satellite channel. Usually involves digital processes to achieve the time compression.

microsecond (μs) – One millionth of a second: 1×10^{-6} or 0.000001 second.

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.

MPEG – Motion pictures expert group. An international group of industry experts set up to standardize compressed moving pictures and audio.

multi-layer effects – A generic term for a mix/effects system that allows multiple video images to be combined into a composite image.

multiplexer (mux) – Device for combining two or more electrical signals into a single, composite signal.

nanosecond (ns) – One billionth of a second: 1×10^{-9} or 0.000000001 second.

neutral colors – The range of gray levels, from black to white, but without color. For neutral areas in the image, the R'G'B' signals will all be equal; in color-difference formats, the color-difference signals will be zero.

NICAM (near instantaneous companded audio multiplex) – A digital audio coding system originally developed by the BBC for point-to-point links. A later development, NICAM 728 is used in several European countries to provide stereo digital audio to home television receivers.

nonlinear encoding – Relatively more levels of quantization are assigned to small amplitude signals, relatively fewer to the large signal peaks.

nonlinearity – Having gain vary as a function of signal amplitude.

NRZ – Non-return to zero. A coding scheme that is polarity sensitive. 0 = logic low; 1 = logic high.

NRZI – Non-return to zero inverse. A data coding system scheme that is polarity insensitive. 0 = no change in logic; 1 = a transition from one logic level to the other.

NTSC (National Television Systems Committee) – The organization that formulated the "NTSC" system. Usually taken to mean the NTSC color television system itself, or its interconnect standards. NTSC is the television standard currently in use in the U.S., Canada and Japan. NTSC image format is 4:3 aspect ratio, 525 lines, 60 Hz and 4 MHz video bandwidth with a total 6 MHz of video channel width. For detailed specifications of this format see Appendix C

Nyquist sampling theorem – Intervals between successive samples must be equal to or less than one-half the period of highest frequency.

orthogonal sampling – Sampling of a line of repetitive video signal in such a way that samples in each line are in the same horizontal position (co-timed).

PAL format – A color television format having 625 scan lines (rows) of resolution at 25 frames per second (25 Hz). For detailed specifications of this format see Appendix C

PAL (Phase Alternate Line) – The name of the color television system in which the V component of burst is inverted in phase from one line to the next in order to minimize hue errors that may occur in color transmission.

PAL-M – Uses a 3.57561149MHz subcarrier and 525 scanning lines. One frame is produced every 1/30 of a second. This format is primarily used within Brazil. For detailed specifications of this format see Appendix C

PAL-N – Uses a 3.58205625 MHz subcarrier and 625 scanning lines. One frame is produced every 1/25 of a second. This format is primarily used within Argentina. For detailed specifications of this format see Appendix C

parallel cable – A multi-conductor cable carrying parallel data.

patch panel – A manual method of routing signals using a panel of receptacles for sources and destinations and cables to interconnect them.

peak to peak – The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

phase distortion – A picture defect caused by unequal delay (phase shifting) of different frequency components within the signal as they pass through different impedance elements – filters, amplifiers, ionospheric variations, etc. The defect in the picture is "fringing," like diffraction rings, at edges where the contrast changes abruptly.

phase error – A picture defect caused by the incorrect relative timing of a signal in relation to another signal.

phase shift – The movement in relative timing of a signal in relation to another signal.

pixel – The smallest distinguishable and resolvable area in a digital video image. A single point on the screen. A single sample of the picture. Derived from the words picture element.

PRBS – Pseudo random binary sequence.

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.

production switcher (vision mixer) – A device that allows transitions between different video pictures. Also allows keying and matting (compositing).

progressive scanning – A scanning format where the picture is captured in one top-to-bottom scan.

propagation delay (path length) – The time it takes for a signal to travel through a circuit, piece of equipment, or a length of cable.

quantization – The process of converting a continuous analog input into a set of discrete output levels.

quantizing noise – The noise (deviation of a signal from its original or correct value) which results from the quantization process. In serial digital, a granular type of noise only present in the presence of a signal.

rate conversion – 1) Technically, the process of converting from one sample rate to another. The digital sample rate for the component format is 13.5 MHz; for the composite format it's either 14.3 MHz for NTSC or 17.7 MHz for PAL. 2) Often used incorrectly to indicate both resampling of digital rates and encoding/decoding.

Rec. 601 – See ITU-R BT.601.

reclocking – The process of clocking the data with a regenerated clock.

resolution – The number of bits (four, eight, ten, etc.) determines the resolution of the digital signal:

> 4-bits = A resolution of 1 in 16
> 8-bits = A resolution of 1 in 256
> 10-bits = A resolution of 1 in 1024

Eight bits is the minimum acceptable for broadcast TV. RP 125 – See SMPTE 125M.

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.

routing switcher – An electronic device that routes a user-supplied signal (audio, video, etc.) from any input to any user-selected output(s).

sampling – Process where analog signals are captured (sampled) for measurement.

sampling frequency – The number of discrete sample measurements made in a given period of time. Often expressed in Megahertz for video.

SAV – Start of active video in component digital systems. One of two (EAV and SAV) timing reference packets.

scan conversion – The process of resampling a video signal to convert its scanning format to a different format.

scope – Short for oscilloscope (waveform monitor) or vectorscope devices used to measure the television signal.

scrambling – 1) To transpose or invert digital data according to a prearranged scheme in order to break up the low-frequency patterns associated with serial digital signals. 2) The digital signal is shuffled to produce a better spectral distribution.

SECAM – See Sequential Color and Memory. The French developed color encoding standard similar to PAL. The major differences between the two are that in SECAM the chroma is frequency modulated and the R'-Y' and B'-Y' signals are transmitted line sequentially. The image format is 4:3 aspect ratio, 625 lines, 50 Hz and 6 MHz video bandwidth with a total 8 MHz of video channel width. For detailed specifications of this format see Appendix C

segmented frames – A scanning format in which the picture is captured as a frame in one scan, as in progressive formats, but transmitted even lines as one field then odd lines as the next field as in an interlaced format.

serial digital – Digital information that is transmitted in serial form. Often used informally to refer to serial digital television signals.

serializer – A device that converts parallel digital information to serial digital.

SMPTE (Society of Motion Picture and Television Engineers) – A professional organization that recommends standards for the television and film industries.

SMPTE Format, SMPTE Standard – In component television, these terms refer to the SMPTE standards for parallel component analog video inter-connection.

standard, interconnect standard – 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.

still store – Device for storage of specific frames of video.

synchronous – A transmission procedure by which the bit and character stream are slaved to accurately synchronized clocks, both at the receiving and sending end. In serial digital video, the synchronous receiver sampling clock is extracted from incoming data signal transitions.

sync word – A synchronizing bit pattern, differentiated from the normal data bit patterns, used to identify reference points in the television signal; also to facilitate word framing in a serial receiver.

telecine – A device for converting motion picture film to a video signal.

temporal aliasing – A visual defect that occurs when the image being sampled moves too fast for the sampling rate. An example is a wagon wheel that appears to rotate backwards.

time base corrector – Device used to correct for time base errors and stabilize the timing of the video output from a tape machine.

TDM (time division multiplex) – The management of multiple signals on one channel by alternately sending portions of each signal and assigning each portion to particular blocks of time.

time-multiplex – In the case of digital video, a technique for sequentially interleaving data from the three video channels so they arrive to be decoded and used together. In component digital formats, the sequence might be Y, Cb, Y, Cr, Y, Cb, etc. In this case Y has twice the total data capacity (detail) as either of the color-difference channels. Ancillary data would be time-multiplexed into the data stream during non-video time.

TRS – Timing reference signals in composite digital systems (four words long). For component video, EAV and SAV provide the timing reference.

TRS-1D (timing reference signal identification) – A reference signal used to maintain timing in composite digital systems. It's four words long.

truncation – Deletion of lower significant bits on a digital system.

valid signal – A video signal where all colors represented lie within the valid color gamut. A valid signal will remain legal when translated to RGB or other formats. 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.

valid/invalid – A valid signal meets two constraints: It is legal in the current format, and it will remain legal when properly translated to any other color signal format.

VTR (video tape recorder) – A device which permits audio and-video signals to be recorded on magnetic tape.

waveform – A graphical representation of the relationship between voltage or current and time.

word – See byte.

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', C'b, C'r – A gamma-corrected set of color-difference signals used in digital component formats.

Y, I, Q – The set of CAV signals specified in 1953 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, Pb, Pr, – 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 composite encoder and most composite decoders 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. Often imprecisely used in conversation as an alternative to Y', P'b, P'r.

A Glossary of video terms and acronyms is available from the Tektronix website. Literature Number 25W-15215-1.

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Disclaimer

Throughout this booklet, we describe ways digital television could be done. Devices will improve, and clever engineers will invent new ways to do things better and more economically. The important thing is to comply with standards as they evolve in order to maintain a high degree of economical compatibility. Enjoy the transition!

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