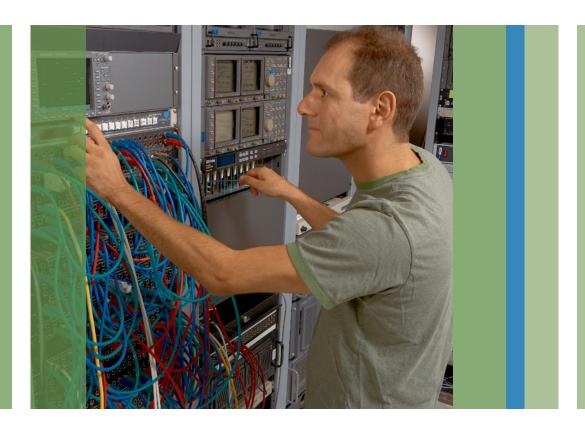
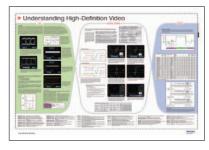
# Understanding Colors and Gamut





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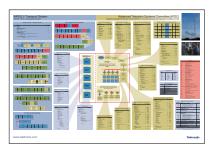


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04/12 EA/FCA 25W-15618-5



# Understanding Colors and Gamut

# Science Behind the Technology

set of primary XYZ tristimulus values. This set is a group of all-positive color cube. values converted from R'G'B' where Y is proportional to the luminance of the additive mix. This specification is used as the basis for color within today's

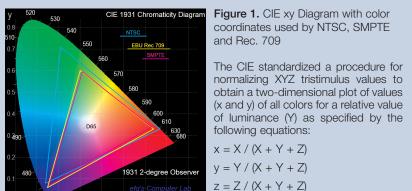


Figure 1. CIE xy Diagram with color oordinates used by NTSC, SMPTE nd Rec. 709 The CIE standardized a procedure for ormalizing XYZ tristimulus values to

= X / (X + Y + Z)= Y / (X + Y + Z)= Z / (X + Y + Z)

A color gamut is the complete range of colors allowed for a specific color space. This range is bounded by the xy coordinates of the primary red, green, and blue colors within the color space. The xy coordinates for these primary colors is given for several different gamuts in Table 1, and the range of each gamut is shown by the bounding triangle in Figure 1.

Gamut	Illuminant	Red	Green	Blue
SMPTE	D <sub>65</sub>	x = 0.630 y = 0.340	x = 0.310 y = 0.595	y = 0.155 y = 0.070
Rec. 709	D <sub>65</sub>	x = 0.640 y = 0.330	x = 0.300 y = 0.600	y = 0.150 y = 0.060
PAL/SECAM	D <sub>65</sub>	x = 0.640 y = 0.330	x = 0.290 y = 0.600	y = 0.150 y = 0.060
NTSC (1953)	С	x = 0.670	x = 0.210	x = 0.140

## Table 1. CIE xy Coordinate Values for Various Color Gamuts

The white point of the system within each format is defined by the for Y'P'bP'r are 0 to 700 mV for the luma (Y') addition of red, green, and blue in equal quantities. The CIE defined several channel, and ±350 mV for the color difference standard sources in 1931 as shown in Table 2.

y = 0.330 y = 0.710 y = 0.080

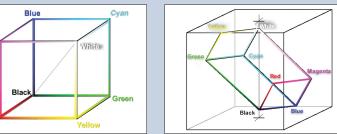
■ Source A: A tungsten filament lamp with a color temperature of 2854K ■ Source B: A model of noon sunlight with a color temperature of 4800K

■ 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<sub>65</sub>

with a color temperature of 6504K, and slightly different x, y coordinates, is predominately used today. illuminant A x = 0.4476 y = 0.4075 illuminant B x = 0.3484 y = 0.3516 Illuminants illuminant C x = 0.3101 y = 0.3162

illuminant  $D_{65}$  x = 0.3127 y = 0.3290

The television color specification is based on standards defined by the CIE The primary colors, red, green and blue, can be mapped onto a three-dimensional Valid color gamut is defined as all colors represented by all possible (Commission Internationale de L'Éclairage) in 1931. The CIE specified an idealized color cube. All colors can be represented within the bounds of the R'G'B' combinations of legal values of an R'G'B' signal. Signals in other formats



f luminance (Y) as specified by the Using the equations in Table 3 and Table 4 to convert the color values from R'G'B' space to Y'P'bP'r space limits the range of colors. Only about 25% of all possible signal values in the Y'P'bP'r domain are used to present the complete gamut of colors in the R'G'B' domain. Care must be taken when translating between formats to ensure that the dynamic gamut of the signal is not exceeded.

	Rec. 601	Rec. 709
Y'	0.299 R' + 0.587 G' + 0.114 B'	0.2126 R' + 0.7152 G' + 0.0722 B'
P'b	(B' - Y') / 1.772	(B' – Y') / 1.8556
D'r	(D' V') / 1 400	(D' V'\ / 1 5740

**Table 3.** Definition of luminance and color-difference signals

Y', R', G', B'  $L'_D$  = Round (876 L' + 64)  $L'_D$  = Round (3504 L' + 256) C'b, C'r  $C'_D$  = Round (896 C' + 512)  $C'_D$  = Round (3584 C' + 2048)

Table 4. Digital quantization of analog component signals Gamut is the range of colors allowed for a video signal.

A legal signal stays within the voltage limits specified for all signal channels for a given format. The allowed range for R'G'B' channels is 0 to 700 mV, while allowed ranges

(P'b/P'r) channels.

may represent colors outside valid gamut, but still remain within their legal limits. These signals, when transcoded to the R'G'B' domain,

will fall outside legal R'G'B' limits. This may lead to clipping,

A valid signal will remain legal when translated to R'G'B' or

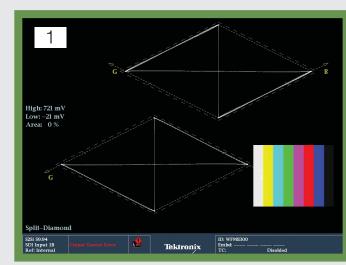
other formats. A valid signal is always legal, but a legal

signal is not necessarily valid. Signals that are not valid will be processed without problems in their current

format, but may encounter problems when

crosstalk, or other distortions.

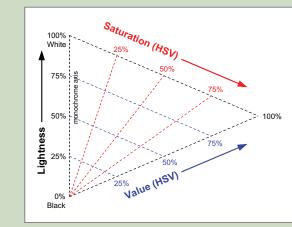
translated to another format.



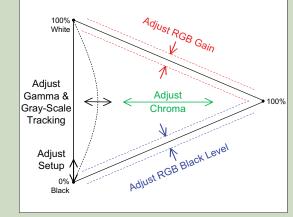
The Tektronix Diamond display provided on the WFM/WVR Series. The 0 to 700 mV signal range of a 100% color bars signal falls exactly within the graticule. The 100% color bars signal is said to be within the gamut of R'G'B' color space.

# Spearhead Display

The newest gamut display from Tektronix is the Spearhead display, which shows the artistic metrics of color saturation and color value or lightness combined with RGB gamut limits. This allows a colorist to adjust live video signals in the HSV (Hue, Saturation, Value) space within the valid signal gamut range.



The Spearhead display is constructed by plotting the maximum of the R', G', and B' color values for each sample versus the minimum of the three values. The resulting area is a triangle that represents the full RGB color gamut. This triangle is rotated and scaled such that the vertical axis (max + min / 2) represents Lightness and the horizontal axis (max - min) represents on-normalized Saturation.

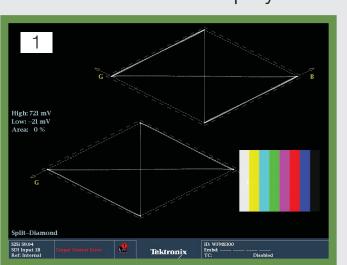


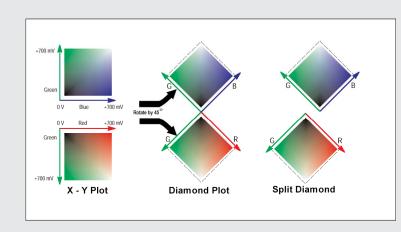
adjustments. The setup or black level is easily set by adjusting the image dot locations for alignment to the lower corner of the Spearhead triangle. The RGB White or Gain affects the image dot locations near the upper side of the triangle, increasing or decreasing the color Value or ntensity. The RGB black-level controls affect the image dot locations near the lower side of the Spearhead triangle increasing or decreasing color Saturation. A chroma level change stretches or compresses the image dot locations along the horizontal axis, changing both Saturation and Value. Lastly, the gray-scale balance of the RGB gamma controls affects the alignment of the monochrome omponents of the image to the left side of the

The Spearhead display can be used to quickly make color

# Diamond Display

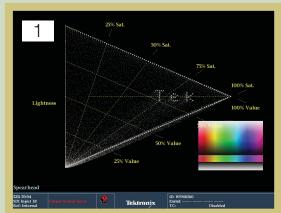
# Correct Diamond Display





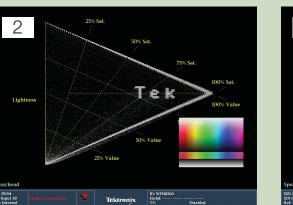
The Tektronix Diamond display is generated by combining R', G', and B' signals. If the video signal is in another format, the components are converted into R', G', and B'. (R'G'B' can be converted into a valid, legal signal in any format that can handle 100% color bars.) To predictably display all three components, they must lie between 700 mV to 0 V. 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 diamond, it is out of gamut. Errors in green amplitude affect both diamonds equally, while blue errors affect only the top diamond and red errors affect only the bottom diamond. Using a color bars test signal, timing errors can be seen as bending of the transitions.

# Correct Spearhead Display

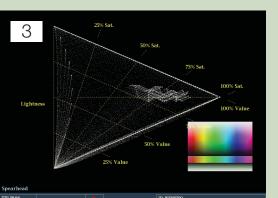


This rainbow pattern generated on the TG700 test signal A Hue error added to the rainbow pattern will A green gamma error has been added to the test generator contains a set of colors that completely fill the valid cause the text marker to blur. This type of color pattern, resulting in distortions in the text identifier. RGB gamut. Each line in the pattern spans the full range of color hues for a fixed Value and Saturation, with ramps from red to yellow to green to cyan to blue to magenta to red. The lines in the top portion of the pattern all have 100% Value, and range from 0% Saturation (white) to 100% Saturation (primary colors). The middle set of lines all have 100% Saturation, and range from 100% Value (primary colors) to 0% Value (black). The bottom portion of the image contains a text identification pattern and a monochrome

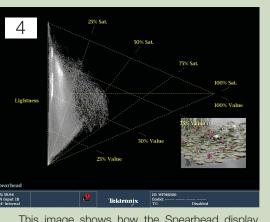
step pattern.



the vector display.

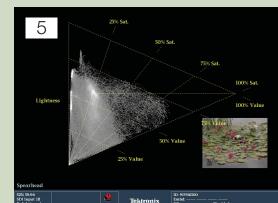


correction adjustment will also show as a rotation on Additionally, the points on the Lightness axis (from the monochrome step-scale portion of the test pattern) are bowed inwards, since these points now have some color. Proper gamma adjustment will remove the tint from monochrome parts of the image.



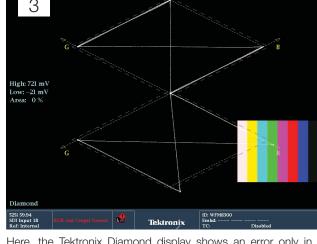
unsaturated colors. The thumbnail by the colorist. display of the picture shows that the flowers and lily pads appear

"washed out".



This image shows how the Spearhead display After correction, the colors appear vibrant but not can be used effectively by a colorist. Before excessively bright. The trace in the Spearhead display correction, this image has too much shows a wider range of color saturation, with lightness near-white brightness and relatively and color values kept within the 75% targets desired

The color bars signal exceeds both the upper and lower diamonds along the G' axis. Therefore there is an amplitude error within the green channel and the signal gain should be corrected so that the waveform falls within the graticule. Note that the B' and R' components fall within the graticule and are therefore within correct



Here, the Tektronix Diamond display shows an error only in the lower display along the R' axis. This indicates an amplitude error within the red channel. The gain of the red channel should be adjusted to fall within the graticule. Similarly if only the upper waveform falls outside the limits along the B' axis, this would indicate a blue amplitude error.

This signal has a significant red imbalance and falls outside the

lower diamond graticule. Note also that the trace is offset to the

right in the lower diamond. The red imbalance is caused by an

offset in the black level of the red channel and should be color

corrected. The black offset adjustment should be made before the

The Diamond display can be an essential tool for simplifying

camera balancing. When the value of R'=G'=B', this produces

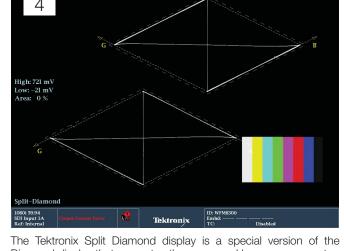
be observed within the Diamond display.

a gray value. A resulting gray scale will therefore produce a

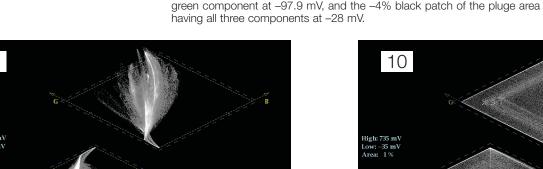
vertical line in both upper and lower diamonds, provided

the signal is aligned correctly. Any deviation can easily

gain level correction.



Diamond display that separates the upper and lower components facilitating observation of gamut errors within the black region.



The Diamond displays can be used for monitoring both standard definition

and high definition formats. In this example using a high definition format, the

NTSC SMPTE color bars signal is not legal when converted to R'G'B' color

space. The waveform exceeds the graticules in several areas. This is due to

the -I patch having a red component at -144.6 mV, the +Q patch having a

This signal shows an error indicating a green color imbalance. The signal is offset to the left in both upper and lower diamonds indicating a green setup error within the black region. Color correction of the signal is necessary to correct the imbalance.

With the lens of the camera capped, the signal should be black

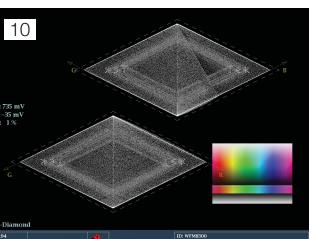
and the Diamond display should show a dot at the center of the

graticule. In this case, the capping produces a trace along

the red axis in the lower diamond, indicating that the red

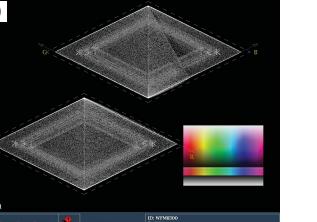
channel has a setup error and should be adjusted until

a dot is displayed at the center of the display.

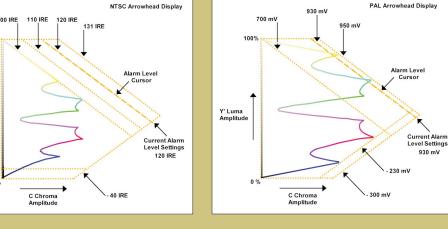


The Rainbow pattern generated on the TG700 test signal generator contains the complete range of high definition colors. This color range completely fills the graticules of

EBU R103 provides the recommended tolerance for illegal colors in television. Tektronix waveform monitors have configurable gamut limits, including a preset for R103 values. For RGB, these are 5% to 105% (-35 mV to 735 mV) and for the luma signal the limits are -1% to 103%.



the Split Diamond display.

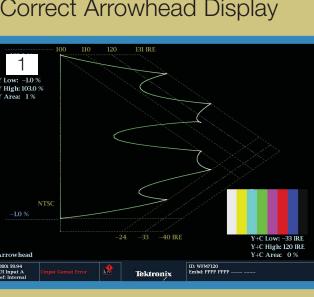


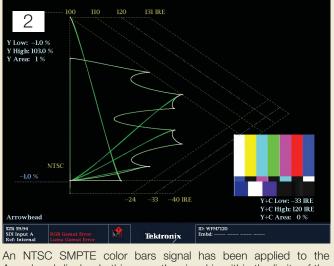
Arrowhead Display

Tektronix developed the Arrowhead display to show out-of-gamut conditions in composite color space, without requiring a composite encoder. The Arrowhead display plots luma on the vertical axis, with blanking at the lower left corner of the arrow. The magnitude of the chroma subcarrier at each luma 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 bars total luma + subcarrier amplitudes. The lower sloping graticule indicates luma + subcarrier extending toward sync tip (maximum transmitter power). An adjustable modulation depth alarm setting offers the capability to warn the operator that the composite signal may be approaching a limit.

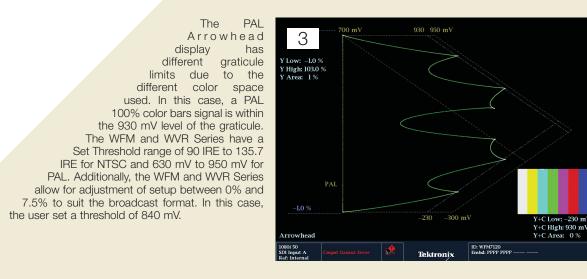
# Correct Arrowhead Display

display shows constructed luma and chromamplitudes of a 100% color ba signal. Notice that the 120 IRE alarm threshold is exceeded by the 100% color bars. Within NTSC color space a 100% color bars signal is not suitable for transmission and will saturate the system Typically, therefore, 75% bars (such as SMPTE color bars) are used for NTSC systems. Th Arrowhead display can be used for standard definition and also for high definition video signals which may be down-converted to standard definition for broadcast

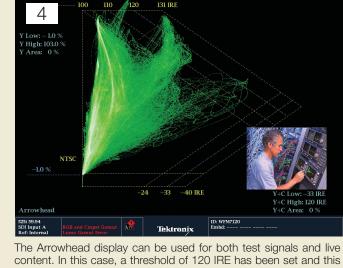




Arrowhead display. In this case, the signal is within the limits of the graticule and will be passed easily through the transmission system. Note that the display indicates that SMPTE color bars are out of gamut within R'G'B' color space.



or distribution.



The Arrowhead display can be used for both test signals and live content. In this case, a threshold of 120 IRE has been set and this signal exceeds valid composite NTSC color space. The level of the signal should be adjusted to prevent clipping within NTSC

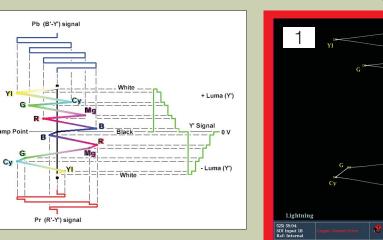


waveform mode that digitally recreates the composite signal waveform from the digital input. This feature allows the operator to visualize the familiar composite signal.

# Lightning Display

information for the three channels of a component signal – within a single display. This unique display requires only a single test signal, standard color bars, to make definitive measurements. Plotting luma versus P'b in the upper half of the screen and inverted luma versus P'r in the lower half like two vector displays sharing the same screen – generates the Lightning display. The bright dot at the center of the screen is blanking (zero signal level). Increasing luma is plotted upward in the upper half of the screen and downward in the lower half.

# Correct Lightning display



This example shows a luma amplitude error: both the upper and

lower traces fall outside the individual graticules boxes and are

stretched vertically. Decrease the amplitude of the luma signal until each components fits within the boxes. If the trace was distorted horizontally this would indicate a Chroma error within the signal.

isplay. This indicates

timing error in the

o channel where

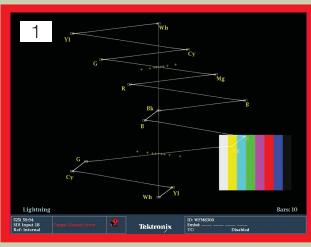
he P'b signal is leading

the luma signal. The

nird cross-hair and

indicates a timing error

of 74 ns, or one luma



lisplay is an ideal ool for performing ape alignments quickly easily. With a standard pars signal at either 75% 0%, select the appropriate ale on the waveform monitor and nsure that all the color components fall within the boxes.

he upper half of this Lightning display hows an error for a standard definition ignal: the traces are not within the graticule oxes. Specifically, this indicates a P'b amplitude error requiring adjustment of the P'b channel gain until each trace fits within the appropriate box.

Similarly, if only the lower half of the display was in error, then his would point to a gain error within the P'r channel. Using a color bars signal, and assuming correct gain and amplitude in the reen-magenta transitions, the Lightning display can be used for erchannel timing measurement. On the screen there are nine crossnair graticules positioned spanning each green-magenta transition that can be used for timing measurements.

The Diamond and Split Diamond displays can be used for

both live signals and test signals and provide unsurpassed

ability to simplify R'G'B' gamut monitoring. In this signal,

there is a minor violation along both the upper and

their production standards.

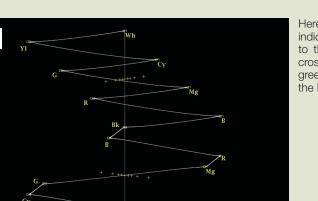
lower G' axes. The operator can decide if this

condition is acceptable for their requirements.

With the WFM and WVR Series, the user can

select gamut threshold limits appropriate for

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 tween luma and color-difference signal. The upper half of the display measures the P'b to Y' timing, while the bottom half measures the P'r to Y' timing. If the transition bends in toward black, 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.



ere the trace is bowing inward from the center in the upper half of the display ndicating a timing error in the P'b channel. The P'b signal is delayed with respect o the luma signal. The trace intersects the markers between the second and third ross-hairs and indicates a timing error of about 55 ns. In the lower half of the display, the reen-magenta transition crosses the center crosshair, thus there is no timing error between the luma and P'r signals.

Graticule	HD Signal	SD Signal
Center	Aligned	Aligned
1st Mark	2 ns	20 ns
2nd Mark	5 ns	40 ns
3rd Mark	13.5 ns <i>(1 luma sample)</i>	74 ns <i>(1 luma sample)</i>
4th Mark	27 ns (1 chroma sample)	148 ns (1 chroma sample)

Timing Cross-Hair Positions on Lightning Display.

component in error.

to make adjustment of the appropriate

The WFM and WVR Series provide simple indication of Gamut

errors within the status bar display at the bottom of the instrument

screen. The type of errors can be identified by viewing the video

session display. Lower case and uppercase letters indicate which

gamut limits have been exceeded. For instance the image above

This signal has a significant blue imbalance and falls outside the

upper diamond graticule. Note that the trace is offset to the right in

the upper diamond. The blue imbalance is caused by an offset in the

black level of the blue channel and should be color corrected.

In this case, the camera has a red imbalance that is shown by the

axis. The camera should be adjusted to correct for this imbalance.

deviation of the lower diamond from the vertical axis toward the red

100.0000 9 100.0000 9 100.0000 9 0.0000 9 0.0000 9

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