

# The Basics of Waveform Monitors and Vectorscopes

Application Note

What you will learn:

You will be introduced to the HSL color space and how it relates to waveform monitors and vector scopes. Then use these concepts to perform two key tasks in color grading: color gamut monitoring and determining color balance.

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## Introduction

Have you ever had a director ask you if you can fix a few bad shots? Have you ever wanted to make a final sequence look better? Have you ever wondered what colors you are really looking at? Do you ever worry about passing Quality Control (QC)? Color grading can be an intricate and complex process. The human visual system constantly adjusts to the surroundings, making it tricky to know what colors you are truly looking at. Combine that with the challenge of ensuring that your technical standards will pass QC. What's an editor or colorist to do?

Knowing how to use a great scope makes the job of editing and color grading easier and quicker. Editors can get fast results with less rework by keeping the material within the deliverable specifications. This application notes introduces the color space and how it relates to waveform monitors and vector scopes.

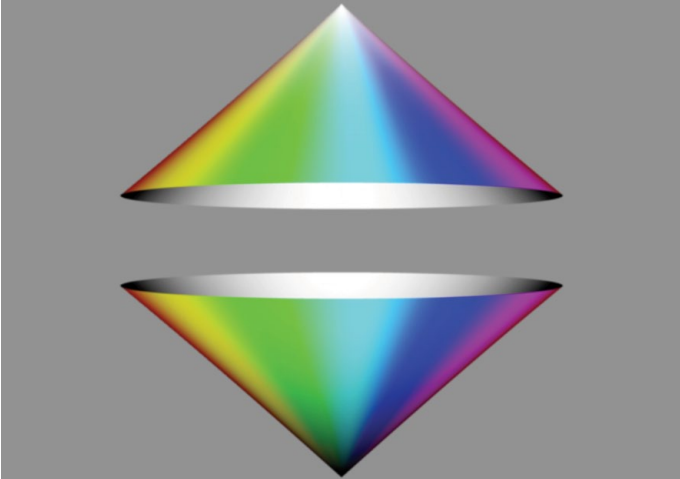


Figure 1. Color cones conceptualizing the HSL Color Space.



Figure 2. Top view of the Color Cones.

## Basic Color Theory and Color Gamut Monitoring

There are two things that are at the core of doing good color grading for video:

1. Insuring that the image on the screen looks great and is graded to best tell the story
2. Making sure that the image can be properly reproduced and delivered to a variety of media and screens

In Section 1, we'll concentrate on making sure that the image can be properly reproduced and delivered to a variety of media and screens. The main technical challenge with maintaining proper color reproduction across a variety of media and broadcast methods is to understand the importance of legal and valid gamut. Maintaining proper gamut is crucial in today's world of repurposed content and cross-platform redistribution of broadcast originated content. Without the ability to accurately monitor gamut issues, there can be problems with broadcast transmissions, recording devices and sponsors and clients whose images are compromised when viewed by certain audiences. Before we examine the concepts of "legal" and "valid", let's quickly review the concepts of color space.

## What is the HSL Color space?

Video is comprised of three color components Red, Green and Blue (RGB), and various combinations of these colors make up the colors we see. One way to understand the Hue Saturation and Luma (HSL), or RGB color space is to imagine it as two cones joined at their widest point (Figure 1).

This is what it would look like in three dimensions - the top of the joined cones is white. At the bottom is black. And as the joined cones widen in the middle, that is the representation of saturation. The points or angle around the width of the joined cones represent the hue.

If you look down from the top of the cones, you see a circle with white at the center, and black is directly under it (Figure 2). The chroma strength of the signal is indicated by its distance from the center. The closer the trace is to the outer edge, the greater the chrominance or the more vivid the color. The hue of the image is indicated by its rotational position around the circle.

In order to put these concepts into practice, we need to examine how color is measured, in both amplitude and the limits of amplitude.

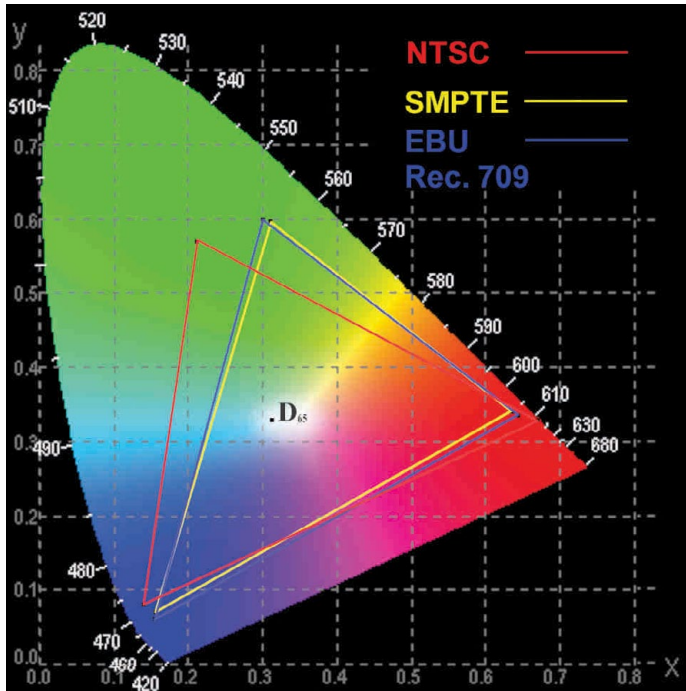


Figure 3. CIE xy Diagram with color coordinates used by NTSC, SMPTE and Rec. 709.

## Defining Legal and Valid Gamut

The simple definition is that “gamut” is simply a range. Applied to broadcast television, gamut is a range of reproducible colors defined by R'G'B' (red, green and blue) signal values. All colors within the gamut of reproducible colors are possible by independently adjusting the values of the R'G'B' signals. Figure 3 shows the color coordinates used by NTSC, SMPTE and Rec. 709.

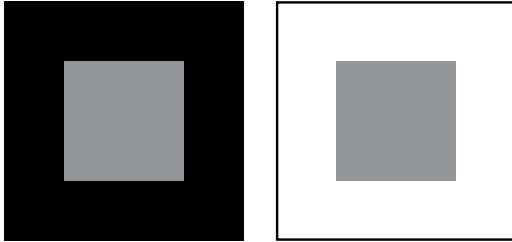
In broadcast video production, R'G'B' values are defined in terms of voltage ranges. R'G'B' signals extending outside the specified voltage range, or gamut, may become clipped or compressed in subsequent signal processing, distorting the color when displayed on another picture monitor. R'G'B' systems have an upper gamut limit of 700 mV and a lower gamut limit of 0 mV. Think of these values as 100% and 0% respectively. Legal broadcast video signals are signals that do not violate the signal voltage limits for a particular format. If any channel of an R'G'B' signal exceeds either the upper or lower limit, it is out of gamut, or out of range. That violation of gamut limits makes the signal “illegal”.

Another type of violation that is possible is called an invalid signal when a signal is converted from one format to another for instance from RGB to YPbPr. In color-difference formats like Y'P'bP'r, it is possible for the current format to be legal within the voltage limits of 700-0mv for Y and +/-350mv for color difference Pb/Pr, but for the gamut to be “invalid” when the current format is translated, transcoded or broadcast in a different format and exceeds the limits for that format and is illegal within this format.

## Gamut and Amplitude Monitoring

Maintaining proper “gamut” is crucial in today’s world of repurposed content and cross-platform re-distribution of broadcast originated content.

Colorist and editors use their eyes to assess the color and quality of the image. However what your eyes see is interpreted by the brain and this processing can sometimes deceive the viewer. For instance, look at the two simple images below. Which one of the center gray boxes is brighter?



This is a trick question - the gray boxes are actually the same color but the surrounding object influences the brain decision on the color and luma level of the object. Therefore to gauge what you actually see, a waveform monitor (scope) is essential in order to interpret the image information.

The waveform monitor, or rasterizer (scope) is a key tool to help you in providing a legal output of your creative product. Part of the responsibility of the colorist is to ensure that the luma and chroma signals are within certain technical limits. Being a brilliant editor and colorist doesn’t mean much if no one will air your product or if the dubs are not viewable. Legal limits are set by broadcasters and cable networks and vary from one to the next. But even if your product isn’t being broadcasted, legal levels affect the proper duplication of your project and the way it will look on a regular TV monitor.

Let’s take a look at how the waveform and vectorscope can help us as we analyze the images we are attempting to correct. There are probably two groups who are about to roll their eyes and flip ahead a few pages.

- The first group is experienced online videotape editors: veterans who’ve been using scopes forever. They know all about sync pulse, blanking, back porches, and breezeways, and they aren’t interested in sitting through the basics.
- The second group is the new wave of digital whiz kids who have no interest in all the hard-core video engineering stuff that is largely obsolete since the death of the quad machine.

Well, we’re not going to be discussing all that video engineering stuff, with the exception of a brief discussion on keeping levels legal. We want to show how these two pieces of engineering equipment can be put to good use as creative tools.

## Introducing the Waveform Monitor and Vectorscope

First, let’s explore the waveform monitor. To many editors and colorists, the waveform monitor is simply a way to look at the luma or brightness of the video signal, but it can also display the chrominance levels of the signal as well. This chrominance information can be used to minimize color casts in your images. One of the most basic uses of the waveform monitor is to allow you to see that your luma and setup levels are legal. This means that the brightest part of the luma signal does not extend beyond the 100% mark — with occasional specular highlights allowed to reach 105%, more or less, depending on the individual broadcaster’s specs — and that the darkest part of the picture does not drop below 0%

For composite NTSC video, the 100% level is equivalent to 100IRE with black level at 7.5IRE mark for NTSC video with setup or 0IRE for NTSC video without setup. So how do you know if your video should be with or without setup? Well, with virtually all analog NTSC video, you need to have setup with blacks at 7.5IRE. However, no digital format has setup. From DV to HDCAM, setup is not used anywhere in the world. In analog formats, only the United States still uses setup (broadcast specification RS170A). NTSC in other parts of the world may or may not have setup. PAL and SECAM do not use setup. Component analog video has different standards also. The SMPTE/EBU (N10) standard does not have setup and typical voltage levels range from 700mv for 100% to 0mv for 0%.. So what do you do if you have a digital VTR and are using the analog in/out connectors? You need to know what standards are being used by the other analog machines. Then match the In/Out settings for Add/Remove Setup to match the rest of the system. Allowing your video to extend outside of the range defined by whatever form of video you are using can cause broadcasters to refuse to air your finished tape until corrections are made or for dubs to have quality issues, like sparkling, bleeding, bearding, and buzzing. Sometimes, if video levels are far enough astray, they can even cause buzzing in the audio channels. There are also legal chrominance levels and other technical specifications regarding timing of the signals and other signal amplitudes and relationships. These all vary slightly from broadcaster to broadcaster. But let’s leave this technical stuff aside and concentrate on how to use the waveform monitor for the fun stuff.

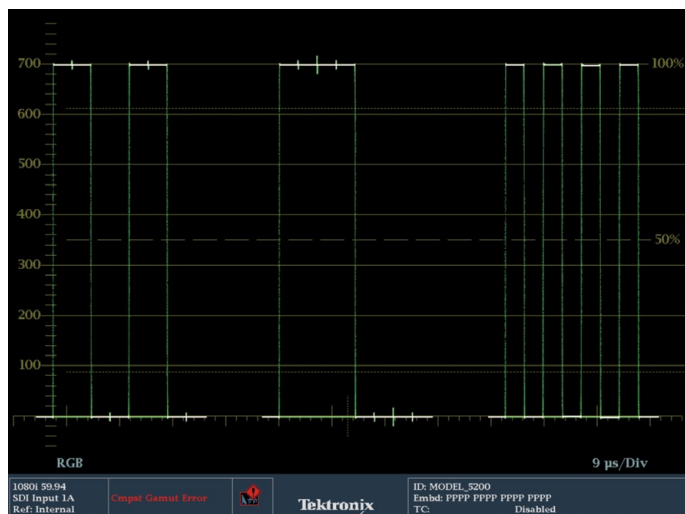


Figure 4. Example of an RGB Parade waveform display with 100% color bar signal.

## Using a Waveform Monitor to Determine Color Balance

Color balance is indicated by the relative strength of each color channel. With neutral (pure black, white and gray) colors, the strength of each color channel should, technically, be equal. The usual goal of color balancing is to achieve an image where neutral colors are represented without one channel being stronger than another. When color neutrality is achieved, the signal is said to be “balanced.”

The most common reason for unbalanced colors is usually related to how the camera is white balanced on location. For example, if a camera is set up to record in tungsten light when it is actually capturing a scene lit with daylight, the blue channel will be stronger than the red and green channels. Also, some camera sensors have a natural tendency to be more sensitive to certain colors in certain tonal ranges.

These errors, in sensitivity or white balance, can be corrected by monitoring the image with a waveform monitor and making adjustments to the signal until the signal strength of all three channels (red, green and blue) is equal when displaying a neutral color, like pure black, white or gray.

Color balance can also be intentionally misbalanced for artistic purposes, for example, increasing the strength of the red channel, or red and yellow channels to create the impression of a warm, “golden hour” scene.

Two types of waveform displays to look at are both defined as “parade” displays because they show you different channels of information in a “parade” one after the next from left to right. The most common method is the RGB Parade, which shows the red, green, and blue channels of color information horizontally across the display (see Figure 4). The reference marks are referred to as the graticule. On a waveform monitor,

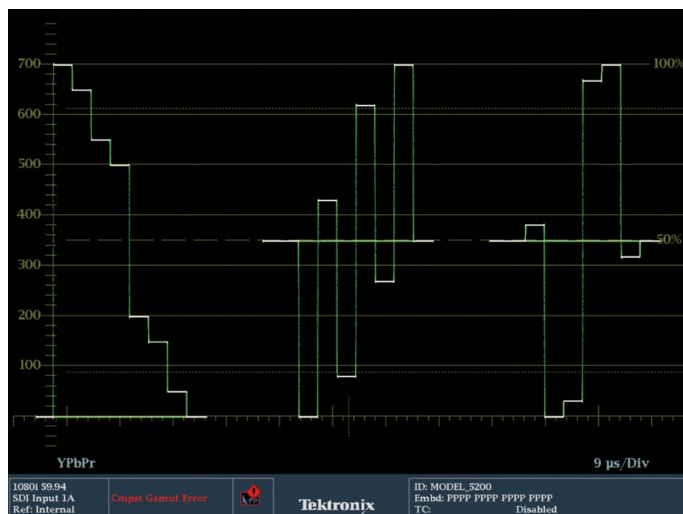


Figure 5. Example of an YPbPr Parade waveform display.

these are most obviously the horizontal lines describing the millivolts, IRE or percentages from black to full power (white). Component video levels are represented in terms of millivolts with black being set at 0mV and white at 700mv. This range of video levels is also represented in terms of a percentage scale with 0% equal to 0mv and 100% equal to 700mv. The scale on the waveform display typically has a millivolt scale on the left hand side and a percentage scale on the right-hand side. Within the Tektronix scopes, the user can also select a percentage scale within the Config menu under Graticules & Readouts. If you chose SDI Waveform Graticule to be Percent, then the left hand side of the graticule will show a percentage scale from 0 to 100 graduated in 10% steps.

You can also look at a YPbPr parade waveform, which shows the luma information in the first “cell” followed by the blue difference channel and the red difference channel (Figure 5).

This is the way component video is often encoded for video: The luma is sampled, then the color information is created by sampling the difference between the blue signal and the luma (Pb) and the red signal and luma (Pr). It is fairly difficult to ascertain what is wrong with the picture from this type of parade. This display is also sometimes called a YCbCr display. The first cell shows the luma, the second shows that the blue channel is higher than the center line, which indicates the difference in strength from the luma channel. The third cell shows that the red difference channel is lower than the center line, indicating that red is lower than luma. If you want to use this display to balance the blue cast, the goal would be to bring the Pb channel down

Note: For component video you may sometime see YPbPr and other times see YCbCr in reference to component video. Typically YPbPr denotes the analog component signal and YCbCr represents the same signal within the digital domain.





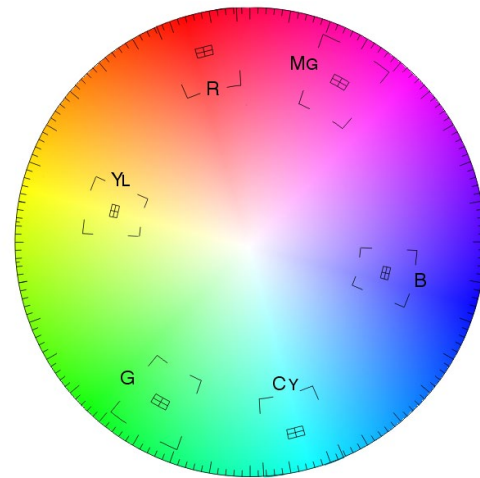
**Figure 6.** The graticule is the part colored gold and the trace is colored green. The colors of the graticule and trace are user selectable. These are the defaults. Many colorists prefer to use white or gray only to keep their eyes from being affected by the saturation of the colors.

## The Vectorscope

Whereas a waveform monitor normally displays a plot of signal vs. time, a vectorscope (Figure 6) is an XY plot of color (hue) as an angular component of a polar display, much like some familiar color wheels used in color graphics, with the signal amplitude represented by the distance from the center (black).

On a vectorscope graticule there are color targets and other markings that provide a reference as to which vector, or position, a specific color is in.

The signal being monitored generates the trace on the waveform, vectorscope or gamut display. This trace is the representation of the signal itself, often seen in live video as moving, squiggly green lines, though many colorists prefer to change the settings in the waveform monitor so that the trace is viewed as white lines instead.



**Figure 7.** The graticule of a vectorscope superimposed with a color wheel.

In color grading applications, the vectorscope helps analyze hue and chroma levels, keeping colors legal and helping to eliminate unwanted color casts. With the gain, setup, and gamma corrections done while monitoring primarily the waveform monitor, the colorist's attention focuses more on the vectorscope for the hue and chroma work. The chroma strength of the signal is indicated by its distance from the center of the vectorscope. The closer the trace is to the outer edge of the vectorscope, the greater the chrominance or the more vivid the color. The hue of the image is indicated by its rotational position around the circle. The easiest way to imagine these relationships is to picture a color wheel superimposed over the face of the vectorscope as in Figure 7.

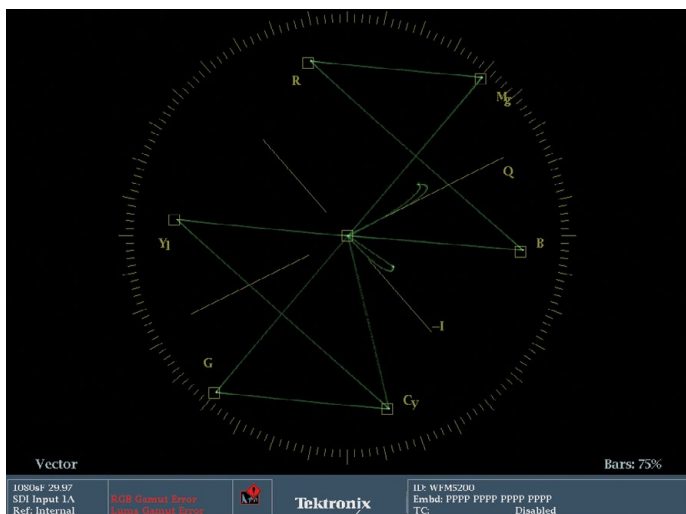


Figure 8. Color bar signal to the vector display.

One of the important relationships to understand is the position of the various colors around the periphery of the vectorscope (see Figure 7). The targets for red, blue, and green form a triangle. In between each of these primary colors are the colors formed by mixing those primaries. So the color between red and blue is magenta. The color between blue and green is cyan, and the color between red and green is yellow. These secondary colors form another triangle. The other interesting relationship that is formed on the vectorscope is that complementary colors are directly opposite each other. Red is opposite cyan, magenta is opposite green, and yellow is opposite blue. These relationships will play a pivotal role as you begin to manipulate colors. For example, if you are trying to eliminate a magenta cast in an image, a glance at the vectorscope will tell you that you need to add green, which is opposite magenta. Or you could reduce red and blue in equal amounts (the two colors that make magenta). If an image has yellows that are too cyan, then adding red will begin to solve the problem. Eventually, you should not even need the graticule (the graphic part of the vectorscope that identifies color targets) to know where the colors lie on the face of the vectorscope.

The chroma information presented on the vectorscope is instrumental in trying to eliminate color casts in images. As stated earlier, chroma strength is represented by its distance from the center of the vectorscope. Because white, black, and pure grays are devoid of chroma information, they all should sit neatly in the center of the vectorscope. While most video images will have a range of colors, they also usually have some amount of whites, blacks, and neutral grays. The key is to be able to see where these parts of the picture sit on the vectorscope and then use the color correction tools at your disposal to move them toward the center of the vectorscope.

Apply a color bar signal to the vector display with White, Yellow, Cyan, Green, Magenta, Red, Blue and Black bars. You can follow this pattern within the vector display (Figure 8) starting from the center trace the display to yellow vector (YL) then Cyan (CY) and follow on to Green (G), Magenta (MG), Red (R), Blue (B) and then back to the center of the display.

For nearly all professional colorists, the various waveform displays — Flat, Low Pass, Luma only, RGB Parade, and YCbCr Parade — plus the vectorscope are the main methods for analyzing your image. While experienced colorists often rely on their eyes, they use these scopes to provide an unchanging reference to guide them as they spend hours color correcting. Without them, their eyes and grades would eventually drift off course. Spend time becoming comfortable with these scopes, and knowing what part of the video image corresponds to the images on the scopes.





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