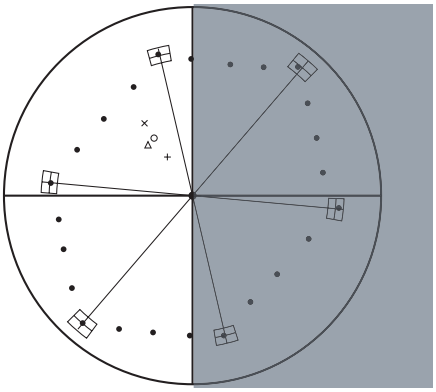
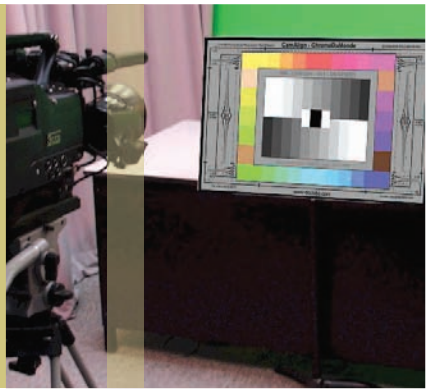




# Camera Setup, Alignment and Matching Measurements

Application Note

Tektronix®

## Introduction

Image quality all starts with the correct alignment of the camera which is used to capture the scene either on location or in the studio. The conversion of light into electrical signals involves many processes which can affect the quality of the image. Understanding these various adjustments that are necessary, using a suitable camera chart and waveform monitor, are critical to ensure a high quality image and prevent mistakes from occurring – mistakes that are costly to fix in the post production process.

## White shading

In setting up a camera, white shading is an important function that is often overlooked or even worse, performed by an unqualified person using inadequate equipment. The basic tools required are a high quality High Definition (HD) waveform monitor such as the Tektronix WFM8300/8200, WFM7120/7020 or the portable WFM5200/5000 and a very even light source such as the diffuser panel of the DSC Ambi Illuminator. In this application note, we will primarily use the Tektronix WFM5200 Waveform Monitor to illustrate the various measurements required. For optimum signal accuracy it is preferred to use an HD-SDI output from the camera, but the process can be similarly performed in standard definition (SD).

Every camera operator should be familiar with white shading techniques. Overall brightness must be even across the whole image. In the case of studio cameras with fixed lenses and shooting in the same controlled environment, white shading will invariably need to be checked less frequently than a digital filmmaker on location who is changing lenses frequently. These measurements should be done in a controlled environment where a qualified operator can ensure each channel is properly calibrated. The resulting adjustments can then be saved as scene files so that they can be quickly recalled on location when changing lenses or filters.

White shading is the process of electronically compensating for errors in brightness or color, primarily generated by the optical system of the camera. A frequent problem that is encountered is that the center of the image appears brighter than the edges. This type of aberration is caused by differences within the camera's optical system components such as the prism or optical block and is most commonly found within older lenses. Differences may also occur when changing from one filter to another. Note that there is a difference between shifts in color and neutral shifts in evenness of the image. For instance, adding a Wratten neutral density filter will invariably lower the brightness and give the image a warmer look. Changing lenses can also change coloration, but this effect is typically minimal. Larger differences in edge to edge brightness are often more common, with a hot spot in the center of the image.

To make white shading adjustments of the camera, a very even light source (such as the Ambi Illuminator from DSC Labs) will provide a precise illuminated field with evenness that can be controlled to close tolerances. Although a number of light sources could be used on the Ambi Illuminator, it is purposely illuminated by the industry standard 3200K tungsten source. Tungsten illumination has a spectral curvature that is flatter than an HMI (Hydrargyrum Medium-arc Iodide) or fluorescent. Gas discharge light sources may not evenly light the Ambi Diffuser and are not recommended for white shading.

**Figure 1a.** Ambi Illuminator with no pattern.

**Figure 1b.** Ambi Illuminator with grid over transparency.

## White shading measurement

Power up the camera, waveform monitor and DSC Ambi Illuminator and then connect the HD-SDI output of the camera to the WFM5200 Waveform Monitor. Allow a few minutes for the light source and the system to stabilize to normal operating temperature before starting your measurements.

The Ambi Diffuser has a vertically adjustable light source, Figure 1a. However, to achieve greater precision, measure the light output from the device with a luminance spot meter and adjust the AmbiMirror and light source. The optional AmbiGrid (Figure 1b shows equal rectangles on a transparency, sitting in front of the diffuser) facilitates separation of the diffuser area into equal quadrants. Aim the luminance spot meter at the center of each rectangle and record the luminance and color temperature values in each quadrant. Adjust the barn doors and vertical distance from the DSC AmbiLight to the AmbiMirror as required until the light output in each quadrant is as even as possible. Measurement deviations of +/- 0.5% are typical; however deviations of 1% or more are not uncommon.

The gain on the camera should be set to 0 dB. Also, ensure that the knee and other camera gamma controls are set to off. Position the camera in front of the Ambi Diffuser panel and zoom in to overshoot a bit in order to use the center of the panel. Ensure the camera lens is set to Manual Iris mode and the Zebra setting is adjusted to 95% so that the zebras cover the entire image. Note that if a spot meter has not been used to ensure evenness and the zebras do not cover the entire image, then the light may not be even and the above steps should be repeated until the zebras cover the entire image. The lens aperture of the camera should be adjusted to between f4 and f5.6. To do this, adjust the physical distance of the camera to/from the AmbiLight to achieve the f-stop range. In doing this process it may be necessary to adjust the AmbiLight source to produce an evenness of the light and the above steps may need to be repeated.

Once the set-up is complete, perform a White Balance of the camera and use the light meter and waveform monitor to check that the white balance has been properly performed. The color temperature readout after white balancing should read 3200K and it maybe necessary to adjust the camera's Red and Blue gain settings to achieve this.

Slightly defocus the lens to further soften any diffusion error. In the shading menu of the camera, adjust the vertical and horizontal saw to 50. The vertical and horizontal pars should be set to a 0 as a baseline. If these numbers are off, the gamma controls may be on and must be disabled.

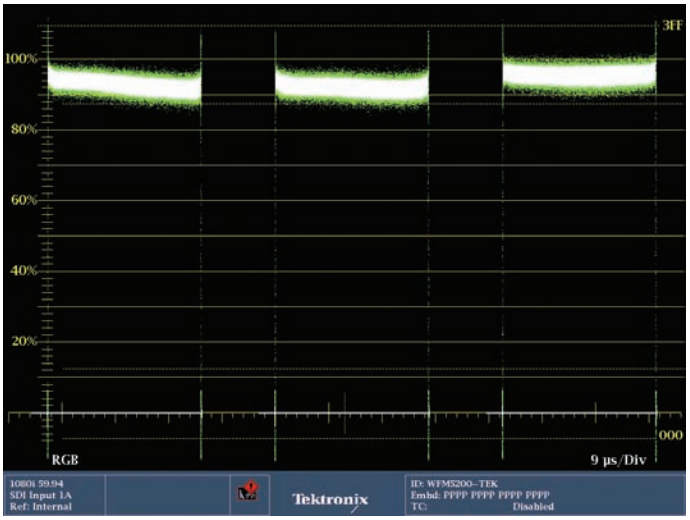



**Figure 2.** RGB Parade on WFM5200 before white shading adjustment.

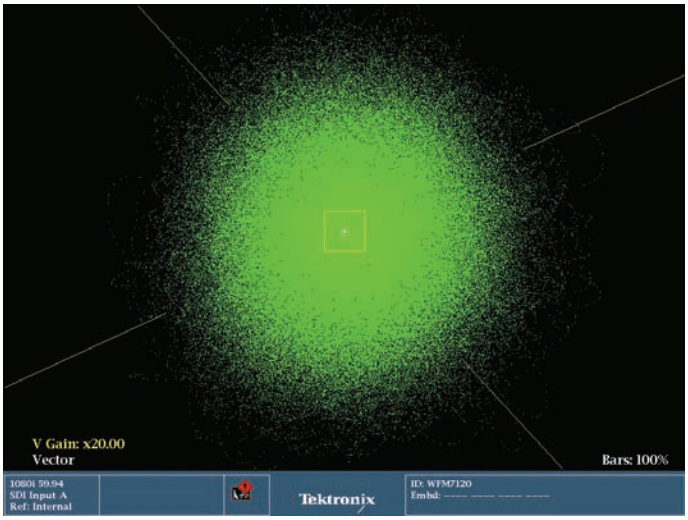



**Figure 3.** Vector 20X Gain of correctly adjusted white shaded camera.

Select the WFM waveform monitor mode on the WFM8300, WFM7120, WFM5200 or WFM5000. Push and hold the WFM button to display the menu and configure the display for RGB parade mode, ensure that all channels are selected on as shown in Figure 2. Please see *Appendix: Interpreting a waveform monitor display* for more information on how to understand this display.

On the camera, adjust the white shading settings in the following order; Green, Red and Blue. Depending upon the controls of the camera, you may be able to make individual adjustments on the Green, Red and Blue channels. Initially, view just the Green channel on the waveform monitor by turning off the other two channels and adjust the H and V Saw so that the trace is a flat as possible. Then make adjustments of the H and V Par so that the Green trace is as flat as possible. Repeat the adjustment process for the Red channel with the waveform monitor viewing just the Red channel on the display while the other two channels are turned off. Then turn on only the Blue channel on the waveform display and turn off the Green and Red channels. The Saw and Par adjustment should then be made on the Blue channel, so that the waveform trace is as flat as possible. Once these adjustments are complete select the Vector display on the waveform monitor and adjust the gain of the display to maximum. Push and hold the Gain button on the waveform monitor to access the menu. Select the 5X gain setting and enable variable gain. Then rotate the general knob in the vectorscope display until the lower left of the display indicates a maximum gain of 20X. The small circular trace should be observed directly in the center of the display as shown in Figure 3. Please see *Appendix: Understanding the vector display* that discusses how the vector display is formed.

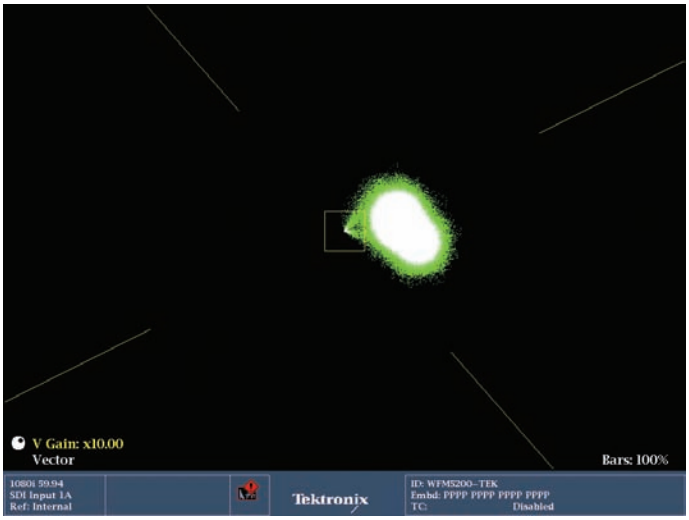



**Figure 4.** Vector display with incorrectly adjusted output from the camera.

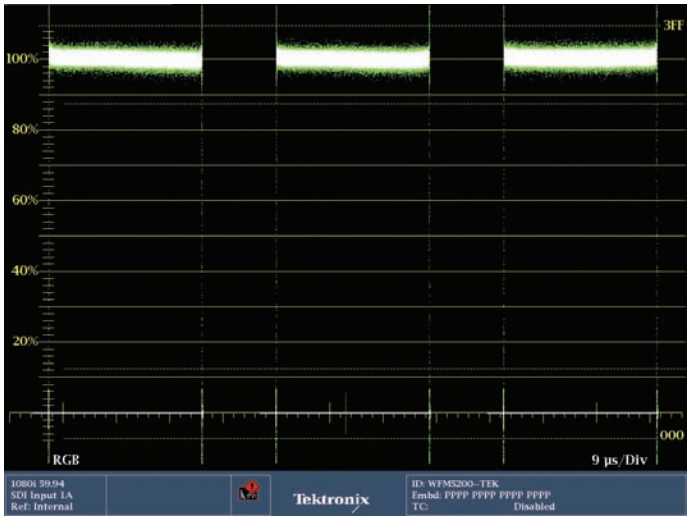



**Figure 5.** Completed white balance adjustment of camera shown on WFM5000.

On some cameras, it is not possible to adjust the RGB shading parameters individually, and an absolute master control is used instead. In this case use just the vectorscope display in maximum gains and make adjustment of the master control so that a circular trace is displayed. An ovular shape as shown in Figure 4, would suggest that the shading is incorrect and adjustment of the master control should be made to make it as circular as possible, as shown in Figure 3. Note that a deviation from the center of the vector display indicates a color cast to the image. In this case the white image would have a tint of a color; the type of hue would depend on the angle of the deviation. By adjusting the camera controls this error should be corrected. Once these adjustments have been completed, store this setup as a new lens file preset. Now the camera should be properly white shaded using this specific lens. The above procedure can be repeated with different lenses and filter configurations and these configurations can be saved for later use. Figure 5 shows the final paraded waveform display of the RGB signals after camera shading has been completed.

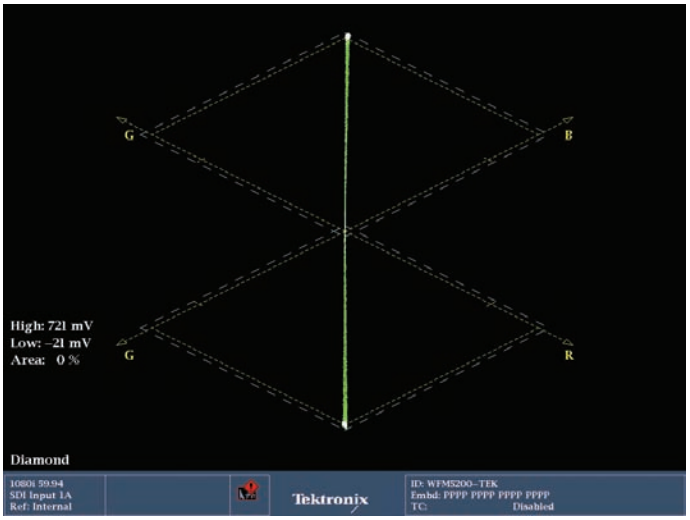



**Figure 6.** Diamond display with correctly white balanced camera.

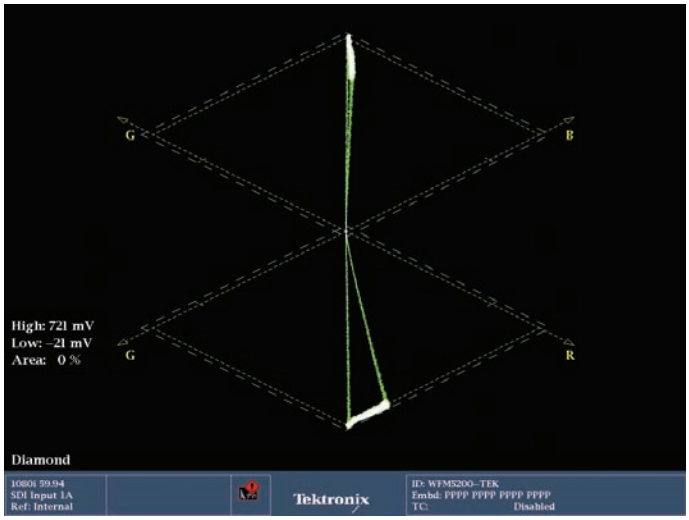



**Figure 7.** Diamond display with Red gain in balance.

The Diamond display can be used to aid in the adjustment of white balance and camera shading. The Diamond display processes the signal in the RGB color space just like the input processing of the camera. When the value of R', G' and B' (R'=B'=G') are equal, a gray value for the signal is produced. A resulting gray scale camera chart or evenly illuminated white field will therefore produce a vertical line in both the upper and lower diamonds if the camera is correctly aligned as shown in Figure 6. Please see *Appendix: Understanding the Tektronix diamond display* for more information on the display. Any deviation can easily be seen with the Diamond display. In Figure 7 there is a slight deviation in the upper Diamond representing the Green and Blue channels and a significant deviation in the lower diamond for the Green and Red channels. The camera should be adjusted such that the levels on Red, Green and Blue are equal and produce a more vertical trace as in Figure 6. Once the camera operator becomes familiar with this display, they will find it easier to see the interaction of all the channels within the one display.

There are many ways in which a camera can be erroneously white shaded, just as there are as many ways to incorrectly white balance a camera. White balancing to a piece of paper that has Blue spectral tones or uneven lighting is a problem often overlooked by operators. The same can be said for white shading. The characteristics of the saws and pars in each RGB channel require a perfectly illuminated or lit surface, as any fluctuations in evenness may cause geometric distortions.

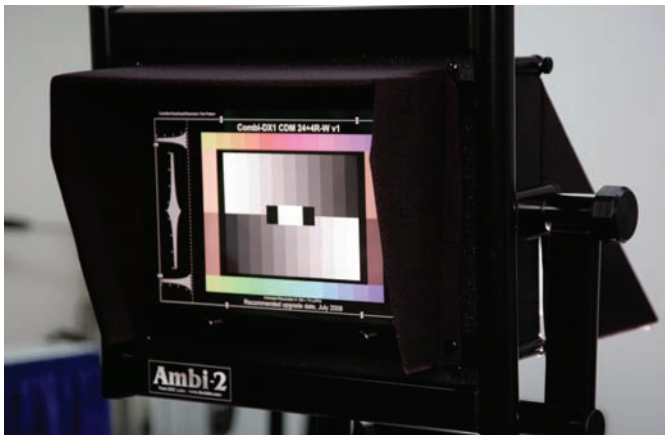



**Figure 8a.** CamAlign (Rear-lit).

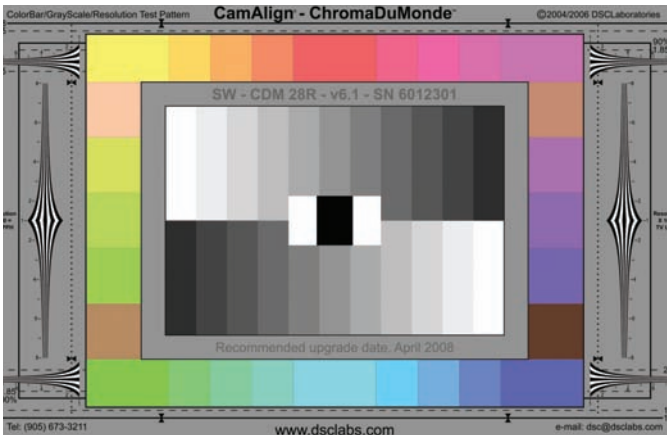



**Figure 8b.** Combi ChromaDuMonde (Front-lit).

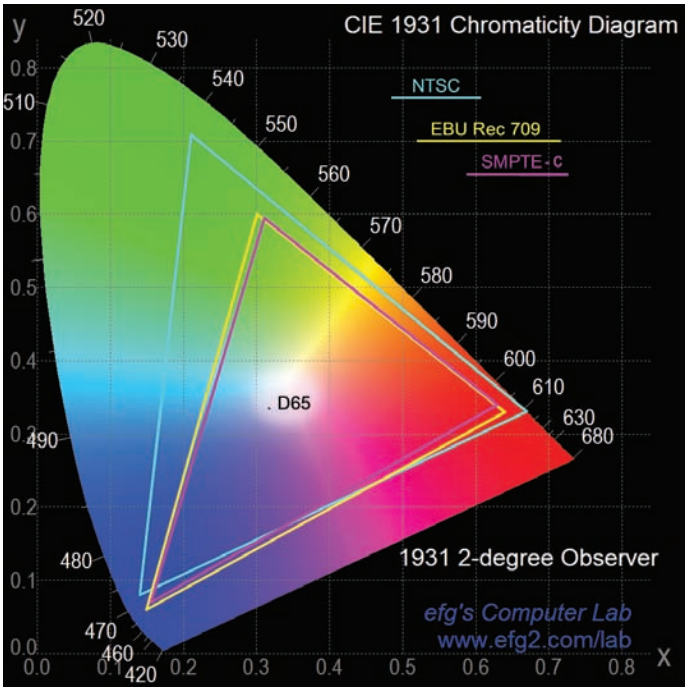



**Figure 9.** 1931 Chromaticity Diagram.

## Setting up correct colorimetry and exposure

Shading primarily deals with the luma adjustments of the signal, but it is also important to ensure the color fidelity of the image. Typically the aim is to reproduce the image on a monitor or television set as closely as possible to the original scene. To achieve this, an accurate test chart is required that produces a reference pattern. The camera converts this light image via, the CCD (Charged Coupled Device), to digital voltage levels. The camera then converts the signal to the HD-SDI output. This signal can then be measured using the Tektronix WFM8300, WFM7120, WFM5200/5000 to quantify the characteristics of the signal.

An accurate test chart does not negate, but complements, an electronic test pattern generator by including the camera's "Taking Characteristics". "Taking Characteristics" is a term frequently used to describe the many elements of the conversion of light by the camera to an electrical signal. These include the lens and adapters, the prism block, dichroic and trim filters and the color characteristics of the CCD or other image device. Taking Characteristics will also be affected by changes in the color temperature and spectral distribution of the scene lighting.

Accurate evaluation requires a precision test chart such as the Combi DX-1 (rear-lit Figure 8a) or (front-lit Figure 8b) ChromaDuMonde test patterns from DSC Laboratories. These unique test patterns provide meaningful test signals that facilitate camera alignment and image control. The characteristics of grayscale and color steps contained within the charts can be used to adjust the camera's set-up controls. Optimizing the image largely depends on the adjustment capabilities of the individual camera. The DSC color patterns are designed to the latest (International Telecommunications Union) ITU-R BT.709 colorimetry standard used with HD standards (SMPTE 274M and 296M). Note the excellent wide color gamut of the NTSC standard as shown in Figure 9. When television sets used this standard they did not sell well because the picture was too dim and had to be viewed in a darkened room. For this reason the colorimetry component of the NTSC standard was replaced by SMPTE C. This greatly reduced color gamut but provided a much brighter image.

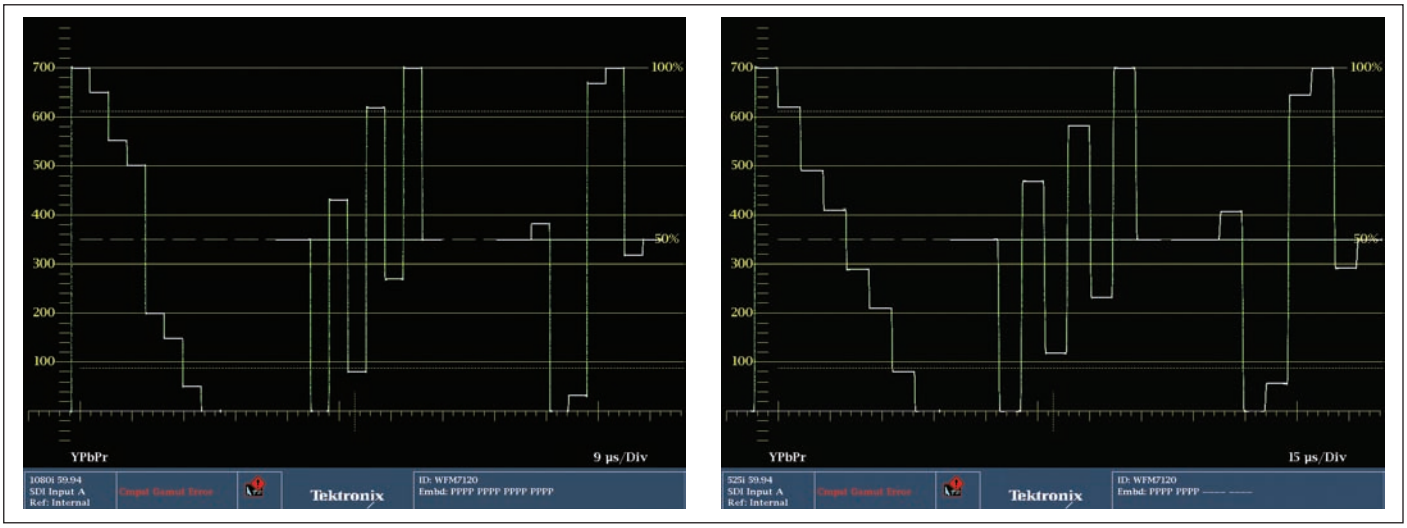



**Figure 10.** 100% Color bar signal shown in HD (left) and SD (right).

It is important to understand these differences in colorimetry between HD and SD when viewing the waveform monitor display. In Figure 10, a 100% color bar test signal is shown for both HD and SD formats, in a YPbPr waveform display. Notice the difference of the Y-channel Green-Magenta transitions between the HD and SD signals. Users who are familiar with SD signals may initially consider the HD signal to be incorrectly adjusted. This is not the case. This difference in levels of each color component is normal and due to the different colorimetry equations used between HD and SD formats.

## Grayscale adjustments using the waveform monitor

While it is a relatively simple procedure to set-up correct exposure levels using a grayscale chart, failure to use a truly neutral grayscale can result in serious tracking errors. Typical grayscale charts are more yellow in the light steps, approaching neutral towards black. Use of such charts produces images that are artificially Blue or cold looking in the lighter tones. This is not desired in most images because viewers prefer warm looking images. Patented technology from DSC Labs has eliminated this problem by making every step of the grayscale neutral.

When using a grayscale test pattern, both dynamic range and progression between steps become important. In the early days of television, the dynamic range of a camera was limited to about 25:1 and grayscale patterns had a correspondingly low dynamic range. Today's modern charts have an 11 step pattern. The progression rate is different between the 9 step and 11 step patterns. The 9 step is logarithmic in terms of reflectivity while the 11 step is designed to produce steps that are linear in voltage. The lightest step on a 9 step chart

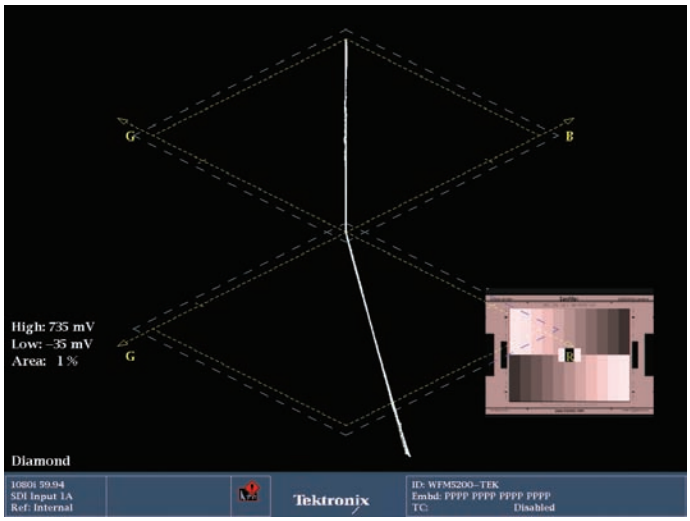



**Figure 11.** Tektronix Diamond display with Red grayscale error.

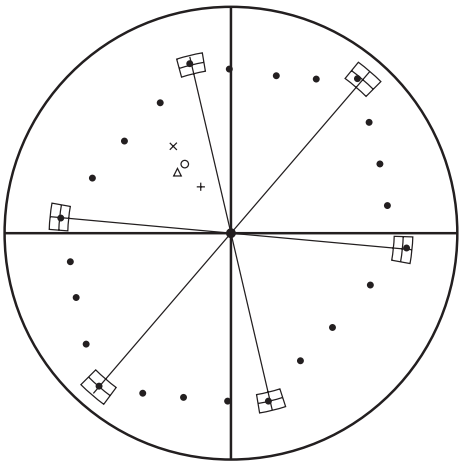
reflects 60% of the light falling on it. By comparison, 90% is reflected from the white chip on an 11 step chart. The DSC chart (Figure 8b) shows an 11 step grayscale. Note the 11 step pattern has a greater dynamic range with the white chip being lighter and the darkest chip being darker than a typical 9 step pattern. The different densitometric curves between test patterns result in significantly different image reproduction from camera aligned to a 9 or 11 step chart. Aligning to inaccurate grayscales of limited dynamic range can result in poor quality images that are virtually beyond redemption. The Diamond display can be used to aid in the alignment of a grayscale chart. If the signal is aligned correctly the trace will produce a straight vertical line as shown in Figure 6. A deviation from the straight line will show an error within the RGB components. Figure 11 shows the lower trace is bent towards the Red axis indicating incorrect adjustment of the Red channel.

DSC Laboratories - Calibrated HD Simulation

ITU-R BT.709 (SMPTE 274M) Colors at 0.45 Gamma

For CamAlign Pattern - SRW - CDM28R #SRW0632310

Recommended upgrade date, April 2008



× Light Caucasian, ○ Medium Caucasian, + Medium Black, △ Medium Asian

RGB signal levels of DSC Primary CamAlign Colors to 709 colorimetry

| Data | Yellow | Cyan | Green | Magenta | Red | Blue |
|---|---|---|---|---|---|---|
| Red(mv) | 557.16 | 275.41 | 278.81 | 562.85 | 562.98 | 280.16 |
| Green(mv) | 558.48 | 553.98 | 557.20 | 281.98 | 281.87 | 277.05 |
| Blue(mv) | 279.40 | 552.35 | 277.18 | 553.91 | 279.45 | 565.14 |
| Luma(mv) | 538.05 | 494.64 | 477.80 | 361.32 | 341.46 | 298.51 |
| Chrm(mv) | 279.83 | 285.28 | 332.59 | 329.53 | 289.16 | 288.32 |
| Vector Angle | 175.02 | 282.59 | 229.45 | 50.96 | 103..36 | 355.36 |

*For a calibrated simulation of this pattern for use on HD or SD vectorscopes, please contact:
Tel (905) 673-3211; www.dsclabs.com; e-mail dsc@dsclabs.com

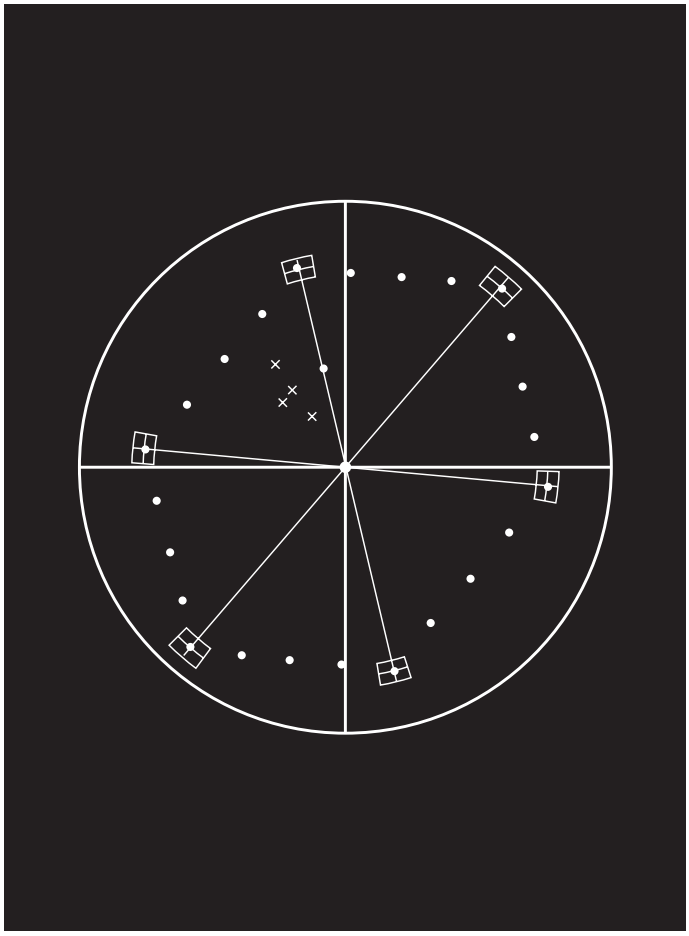


**Figure 12.** DSC CamAlign Color Primaries and vector representation.

While every engineer and DP (Director of Photography) has their own special techniques for aligning a camera, the following procedure is quite typical.

With a camera focused and framed on an evenly lit ChromaDuMonde or back lit Combi pattern, the iris is set to mid-scale (typically between f4 to f8) and the exposure/iris is adjusted to set the white chip of the DSC grayscale to 700 mv (100%). Tracking of the RGB channels should be checked to ensure neutral reproduction across the grayscale. White and black balances are then set. (Incidentally, because all DSC colors combine to produce a neutral color balance, most cameras will white balance on a DSC color chart as accurately as on a true white card). The true black chip on the CamAlign or ChromaDuMonde Grayscale is normally set close to 0 mv, while a test patterns equipped with a DSC CaviBlack will allow the black point to be set more accurately. Note: If monitoring an NTSC composite output from the camera, this uses a black level setup of 7.5IRE above true black in North America. However in Japan NTSC signals have no setup and therefore black will be referenced to 0 mv. The gamma or crossover step of the 11 step chart is typically adjusted to produce a straight line. This results in an accurate grayscale reproduction. It is important to note that while a camera may reproduce a grayscale perfectly, its color reproduction can still be very poor.

## Color adjustment using the WFM5200 Vectorscope

The DSC color bars are designed to represent saturation levels found in real life. Consequently when using a vectorscope with the scale set to 75% the CamAlign and ChromaDuMonde color signals will fall short of the vector boxes. However by simply increasing the gain of the vectorscope to 2.0X this will place all primary colors signals within their boxes when a camera is reproducing color accurately. The ChromaDuMonde has a total of 28 color patches. The primary colors in the four corners and horizontal centers of the upper and lower rectangle will fall into the respective vectorscope boxes. The other colors form straight rows between the primaries. Figure 12 illustrates the color primaries as they are predicted to occur on a vectorscope display.

Today's modern camera has advanced multi-matrix settings and it is possible to line-up each primary to be in the vectorscope boxes, but inadvertently reduce the overall color gamut.

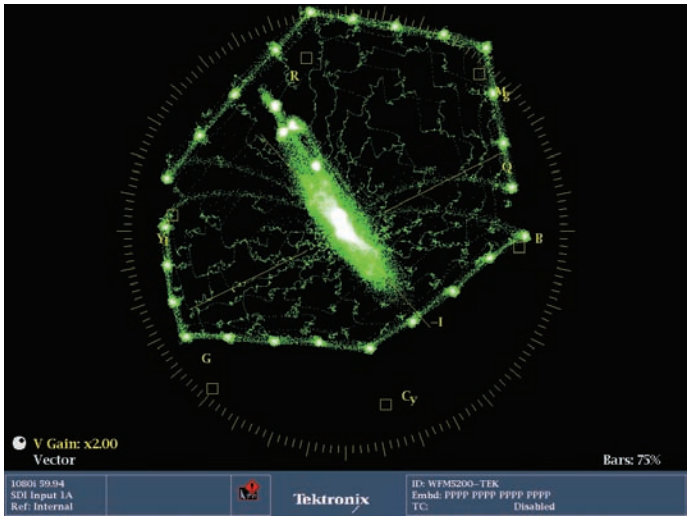



**Figure 13.** Default camera settings before alignment.

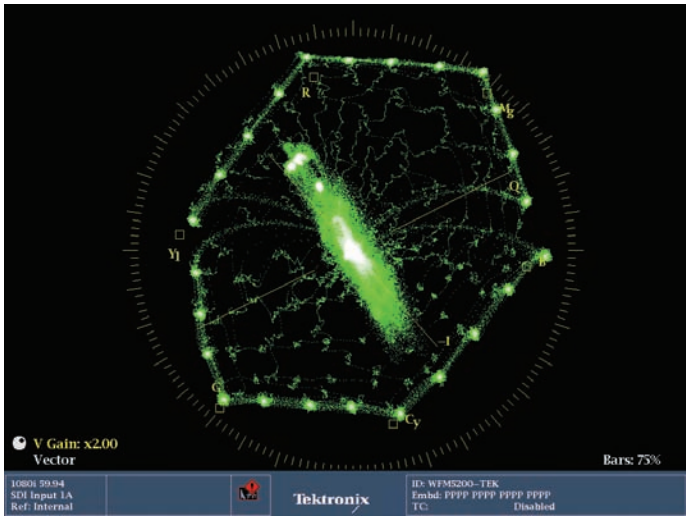



**Figure 14.** Camera output after adjustments.

Figure 13 shows the default setting of a camera output before adjustments were made. The vector display on the WFM5200 was setup for 75% color bar graticule and to a 2X gain setting. Notice that the camera default settings over emphasize the Red component and that the gain of the Green and cyan component are significantly less than the other color components. When aligning a camera's matrix, increasing the sensitivity of a particular color can affect the positioning of many other colors. Consequently, the process requires considerable patience and may require multiple iterations of the camera adjustments to correctly align the camera. The Combi DX-1 or ChromaDuMonde simplifies the process of alignment because every DSC primary has the same RGB level combination as every primary color. If patterns were made with different luminance relationships, color matrix adjustments would displace the gamut showing a false primary as a true primary further distorting the working color space. This is exemplified when going into the camera's matrix settings to adjust color sensitivity. Notice that in many instances a particular color cannot be selected on its own. Instead alterations can be made to the B-Y and R-B, etc. When these settings are increased or decreased, all of the other colors on the vectorscope will shift. Therefore adjusting one color incorrectly will affect the entire color space and this should always be taken into consideration. Figure 14 shows the vector display of the camera output after adjustments were made and alignment was performed. Notice that the color components do not exactly conform to the theoretical calculated values, but this was the best compromise that could be achieved with the settings of this camera after several iterations of the adjustments. Once all the adjustments have been completed the configuration of the camera can be saved as a preset for later use.

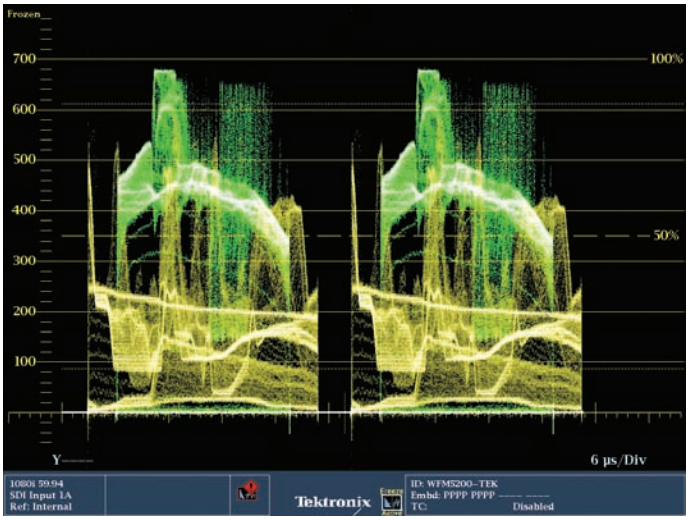



**Figure 15.** Freeze Function of WFM5200 allows comparison of video signals.

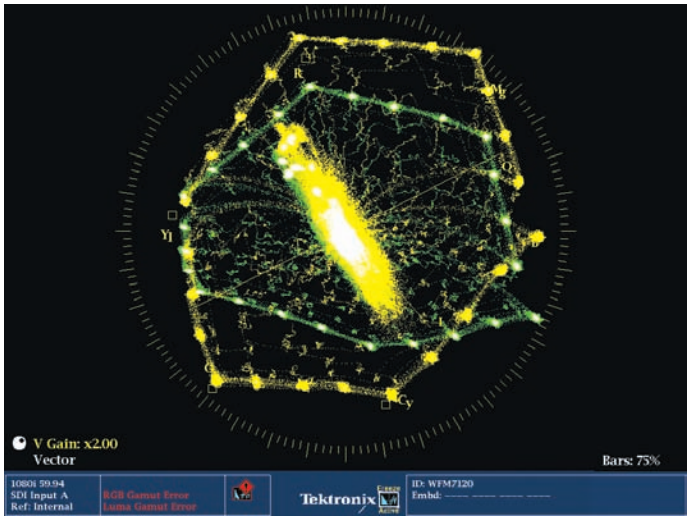



**Figure 16.** CaptureVu capabilities of WFM7120 comparing a live camera output (Green trace) and previously captured correctly aligned signal (Yellow trace).

## Camera matching

Now that we have aligned this camera, we may need to perform the same operation for other cameras in the studio. When using multiple cameras in the studio or location, it is important that the other cameras are matched to this aligned camera. This will ensure that scene to scene and camera to camera images look similar. Since no two cameras are identical, it is unreliable to simply upload the settings from one camera to another. The only way to match cameras effectively is to adjust the matrix settings of each camera using the same precision test chart under identical lightning conditions. One method to provide a consistent look is to follow the above procedure for camera alignment, set the exposure levels, set the white balance and then align the colors on the vectorscope.

To aid in camera matching, the freeze function available in the WFM5200/5000 can be used to compare signals between live and frozen display. This allows for comparison of different inputs or camera presets to be viewed. To configure the instrument, apply the reference camera input to the instrument and press the freeze button to grab the current screenshot of the display. The frozen image is then displayed as a yellow trace and the user can switch between Live, Frozen or Live and Frozen as shown in Figure 15. This mode can then be used to compare another camera input against the frozen signal to aid in visualizing the matching of the two cameras. This allows the operator to make quick adjustments of the camera so that they are matched from scene to scene and ensure a consistent look throughout the production.

The WFM8300 or WFM7120 Waveform Monitor offers advanced capture capabilities by using the CaptureVu™ feature. The CaptureVu feature will save a complete frame of video data to a buffer memory. This saved data can be reconstituted into any one of the trace or picture displays. The CaptureVu stored data is displayed similarly to the freeze function as a yellow captured trace, so that it can be easily compared with the live trace. Figure 16 shows how a previously aligned camera is compared to another camera still to be adjusted. The user can then adjust this next camera so that it closely matches the previously aligned camera. The CaptureVu data can also be saved to a USB memory stick on the front of the WFM8300 or WFM7120 for use at a later date. This allows the user to compare camera alignment between different cameras and also to see if, over time, the camera has become misaligned and needs to be realigned. Note that when the captured data is restored back to the WFM8300 or WFM7120, the instrument needs to be in the same video format as the current video input. Therefore it is useful to name the saved file with an indication of the video format. The ability to save a full video frame capture on the WFM8300 or WFM7120 with CaptureVu can aid the user in matching cameras, and provides a data record of the camera's output (saved to a USB stick) for monitoring any degradation that may happen over time.

A test signal of the ChromaDuMonde pattern has been created for the TG700 and HD3G7 module. This test pattern can be used as a reference for comparison against the output of the camera and aid in the adjustment of the camera for optimal performance.

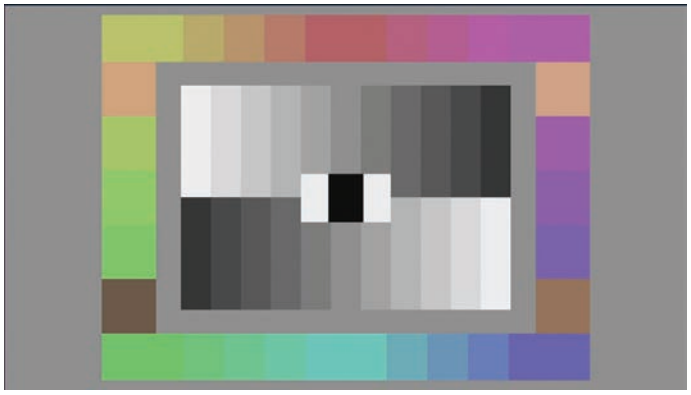


**Figure 17.** ChromaDuMonde test pattern from TG700 HD3G7 module.

On location recording of a few seconds of a DSC test pattern, at the head or tail of a scene, captures virtually everything a colorist needs to know to color correct or match scenes during the post-production process. This can help simplify the post-production process and avoid costly mistakes.

## Multiple Camera Matching

During the production of the program, adjustments will be needed to be continually made to each camera to maintain a consistent look. In the studio, the cameras will be moved to get the best shot and these changes may affect the overall brightness or color fidelity of the images that the camera produces. Therefore it may be necessary to make quick adjustments of each individual camera to maintain the overall look of the production. To aid the operator in being able to quickly compare the video level output from each camera, the camera balance mode was developed for the WFM5200 with option CAM and is also available on the WFM8300 or WFM8200. The camera balance mode allows the operator to view up to four waveform traces simultaneously in full

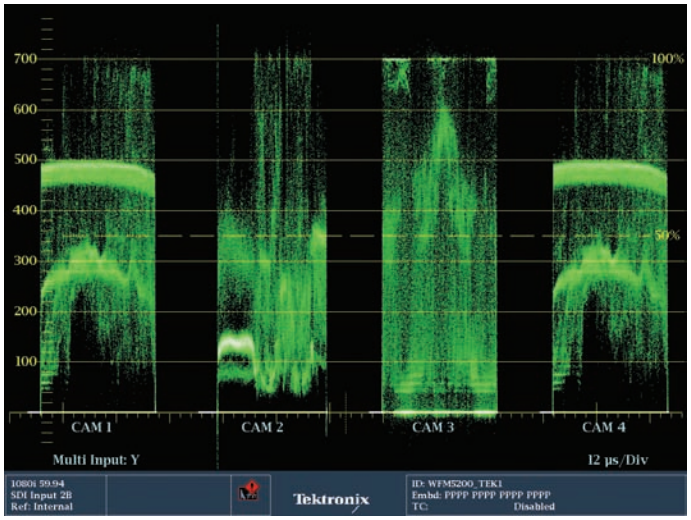



**Figure 18.** Camera Balance mode showing luma traces of four camera inputs in parade mode.

screen mode (option 2SDI is required for the WFM8300 or WFM8200 to monitor 4 SDI inputs). This allows the operator to easily compare the video level of the four camera inputs simultaneously to ensure that the white and black balances of all the cameras are similar. User labels can be created and enabled for each channel to allow for a quick identification of the camera and to allow the operator to make appropriate adjustment to an individual signal easily. Figure 18 shows the camera balance mode on the WFM5200. Here we can quickly see that one of the cameras has a black setup error and is different than the rest of the camera inputs. The identification label indicates that CAM-1, CAM-2 and CAM-4 need to have their black levels adjusted to be consistent with the other camera CAM-3. Alternatively a setup could be added to CAM-3 such that it matched the response of the other three cameras for a consistent look.

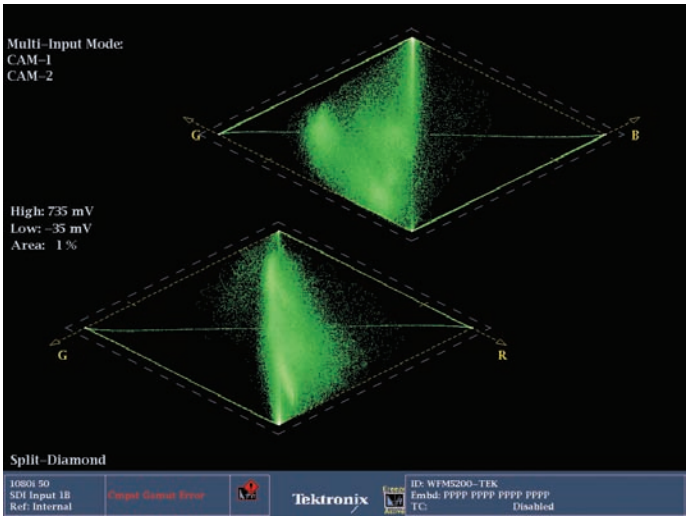



**Figure 19.** Diamond display of multiple inputs overlaid.

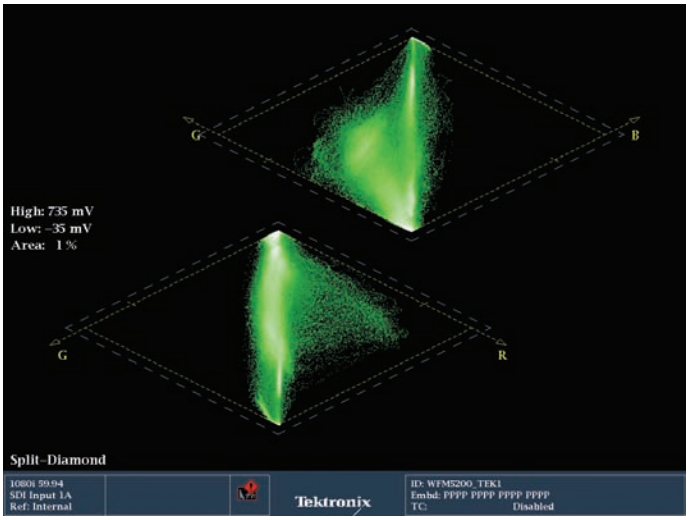



**Figure 20.** Diamond display live image.

The camera balance mode can be used within other trace displays such as vector, lightning, diamond, split diamond, spearhead and arrowhead. In these displays, the multiple inputs are overlaid on top of each other to make comparison. Simply selecting the appropriate input button to quickly enable or disable the input allows the user to select certain inputs to compare as shown in Figure 19.

In live production, whether in the studio, or on location, the Diamond and Split-Diamond displays are ideal tools for performing quick alignment of the cameras and for ensuring balancing of the image whether in the shadows of a stadium or in the bright sunlight. The vertical axis from the center to the outer apex is the luma component of the signal. A well balance image will have a more vertical luma component. If a deviation occurs in the upper half of the display, the blue channel should be adjusted, and alternatively if the deviation occurs in the lower display, then the red channel should be adjusted.

Additionally, the diamond display shows how much headroom you have for making your adjustment before it will exceed gamut limits. The horizontal axis of the Diamond display indicates the amount of chroma present in the signal and can be used for matching between cameras or to maximize the color fidelity of the image. To aid in black level adjustment, the split diamond display can be used to see parts of the signal that go below black level. Figure 20 shows the split diamond displays of a live signal. In this image you can quickly see that the overall luma trace is vertical from the center to the upper and lower apex of the split Diamond display, illustrating a well-balanced image. However in the upper Diamond apex it appears as if some clipping has been applied to limit the gamut range of the signal since the trace is much brighter. Additionally the similar clipping has been applied to the black of each channel as indicated by the brighter parts of the trace at the center black.

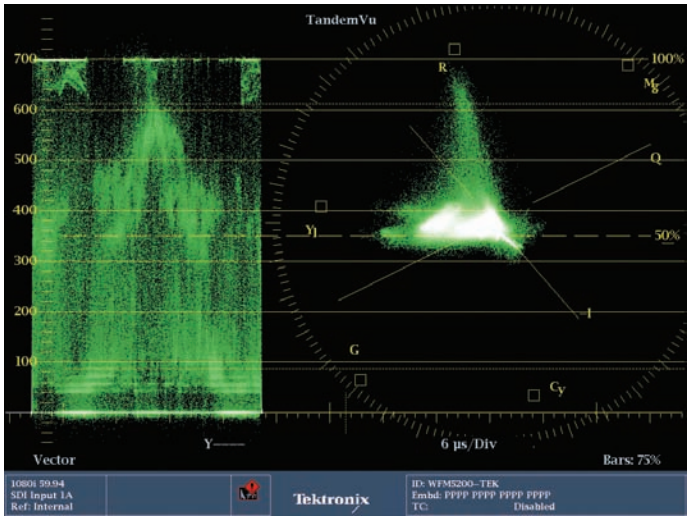



**Figure 21.** TandemVu display showing Luma (Y channel) and chroma signal within the vector display.

## TandemVu™

Operators often like to view the luma (Y) and chroma (C) at the same time so that they can adjust the camera levels to ensure that the flesh tones of the onscreen talent camera are at the appropriate video level and the vectorscope shows appropriate hue and saturation. Within the Tektronix WFM5200 and other 5000 series instruments, the TandemVu display was developed to allow the user to see the maximum waveform and vector displays simultaneously. The overlay of waveform and vector displays can be configured in a variety of ways to suit the user application. For adjustment of a camera, a useful setup is to show the luma Y channel in a 2 line sweep display with the waveform trace moved to the far left so that only one line is displayed. The vector display can then be moved to the far right of the display as shown in Figure 21. In this display configuration, the user can easily see adjustments that need to be made to the camera for both the luma level and chroma signal within the same display.

## Conclusion

By using these techniques to shade and align the camera, and becoming familiar with the correct use of the DSC Precision Test Patterns and Ambi Illuminator, the user will ensure that the image captured by the camera is calibrated and adjusted correctly. The user can monitor the output of these images from the camera with Tektronix waveform monitors to ensure that the camera is producing the correct video levels, is properly color aligned, and matched to other cameras. Understanding the various waveform displays (waveform, vector, diamond and spearhead) can aid the user in making the correct adjustments, ensuring correct and optimal fidelity of the video image during the setup of the camera. The waveform, vector and diamond displays can be used to ensure correct balance of the camera during live production in the studio or on location.

Thank you to Michael Kent of DSC Laboratories (www.dsclabs.com) for his assistance and contribution to this application note.

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# Appendix

**Figure 1a.** Waveform display.

## Interpreting a waveform monitor display

A waveform monitor is a means to visualize the video signal by displaying the amplitude level in the vertical axis with lower levels representing the black parts of the image and the upper axis representing the brighter higher luma levels of the signal. Black level is shown at the 0% point and white is represented at the 100% graticule mark (700 mv).

Time is displayed in the horizontal axis increasing from left to right. There are a variety of methods to display the individual components of the signal either as a parade with each component side by side for comparison or as an overlay where each component is overlaid on top of each other. The time per division is indicated within the lower part of the display.

A video signal is comprised of a number of lines which make up the complete image; these lines can be displayed in a number of different ways on a waveform monitor. In Line mode all the lines of the signal are overlaid on top of each other to show the overall magnitude of the signal the bright the area of a region within the display the more often the signal is present at that level. In Field mode the lines of the signal are displayed one after the other to show the variation of the signal through the image.

## Understanding the vector display

The vector display is an X-Y plot of the color difference components with Pb (B'-Y') plotted on the horizontal axis and Pr (R'-Y') plotted on the vertical axis (Figure 1b). Within the instruments vector display the user can select a 75% or 100% graticule. When taking measurements make certain the source signal amplitude matches the vector graticule. When the user applies a 100% or 75% color bar signal and uses the appropriate graticule selection the waveform monitor trace display should fit within the graticule boxes for each color component. 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 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. 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.

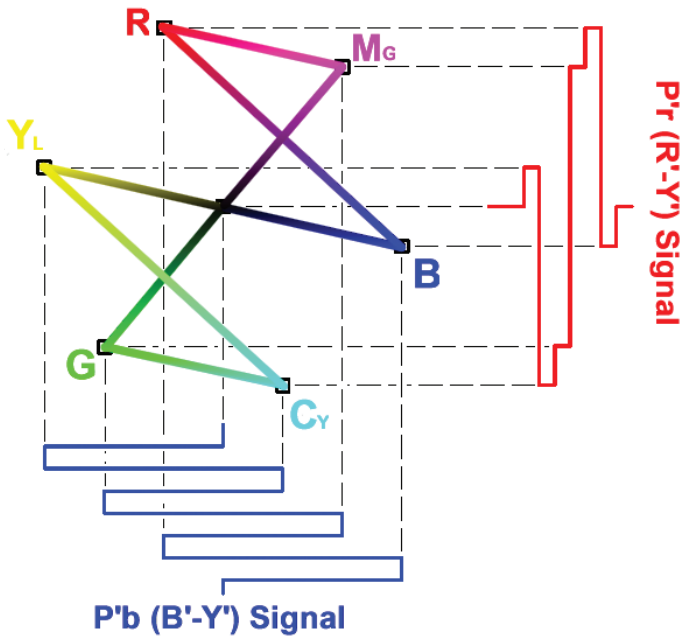


**Figure 1b.** X-Y plot of the component vector display.

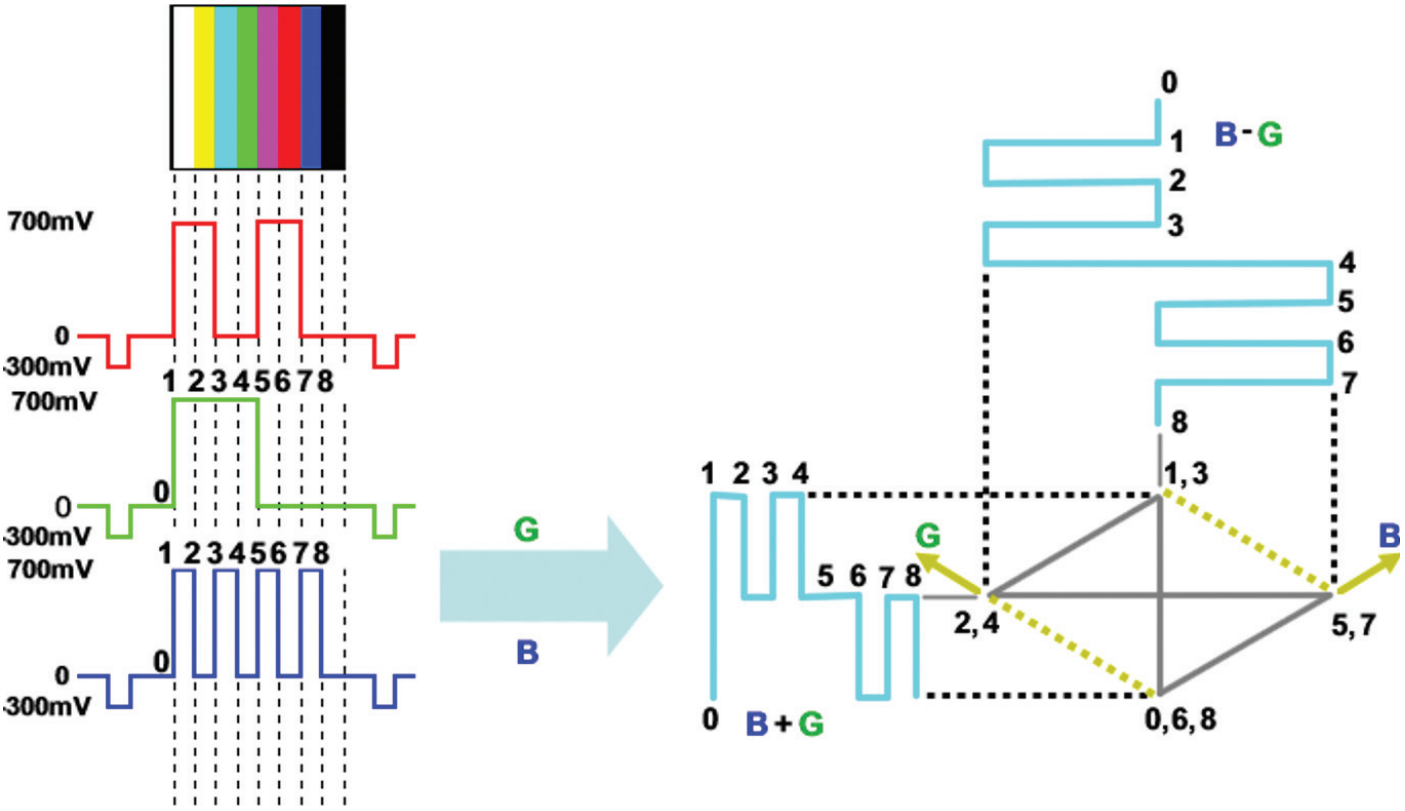


**Figure 1c.** Shows how a 100% color bar signal is plotted in the upper G' & B' Diamond.

## Understanding the Tektronix diamond display

The Tektronix diamond display was created to help visualize the interaction of the Red, Green and Blue components. The Diamond display is generated by combining the R', G' and B' signals in to a two dimensional display.

When first looking at a 100% color bar signal on the Diamond display it may not be immediately obvious how the signals are combined to produce the display, but understanding how the Diamond display is constructed and how it can be used for RGB color space can greatly simplify camera adjustments.

If the video signal is in another format, such as YPbPr, the components are first converted into R', G' and B' colorspace. The upper diamond is formed from the transcoded signal by applying B'+G' to the vertical axis and B'-G' to the horizontal axis as an X-Y plot. 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. Appropriate low pass filters are applied to the signal to eliminate short-term out-of-limits signals that are usually the product of combining different bandwidth signals between the luma and color difference components.

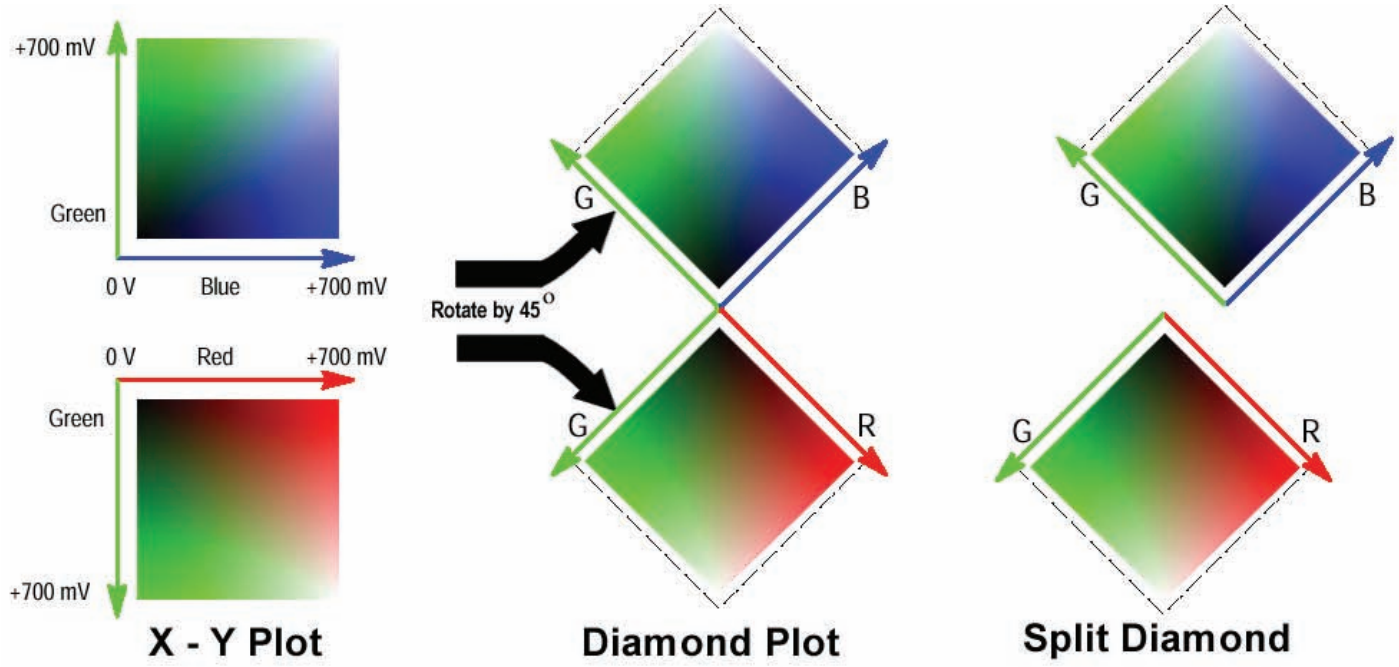


**Figure 1d.** Construction of the Diamond and Split Diamond displays.

By forming these X-Y plots of G' & B' in the upper diamond and G' & R' in the lower diamond. The display provide an easily way to visualize components within RGB gamut as the trace falls within the graticule bounding box. If the trace falls outside the graticule it is out of gamut. Errors in the Green signal affect both diamonds equally. While Blue errors affect the upper diamond and Red errors affect the lower diamond. An enhancement to the Tektronix Diamond display is the Split Diamond display which allows errors in the black region of the signal to be more easily observed as shown in Figure 1d.

The Diamond display can be an ideal tool for camera adjustments of the luma signal. If the camera is pointed at a white chart of gray scale chart and is properly balanced the trace will be a straight vertical line from the center (Black) to the top and bottom (White). Any imbalance in the signals components will cause a bend of the trace.

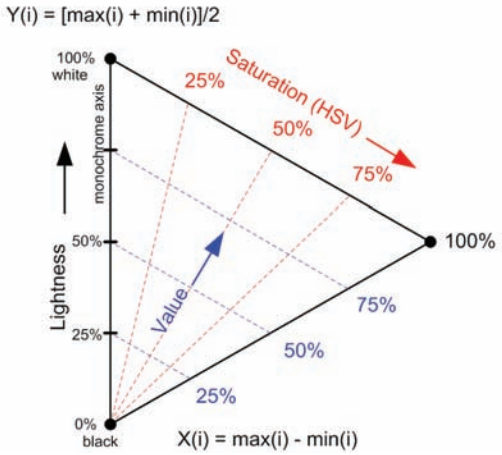


**Figure 1e.** Spearhead display with graticule lines of constant saturation and value.

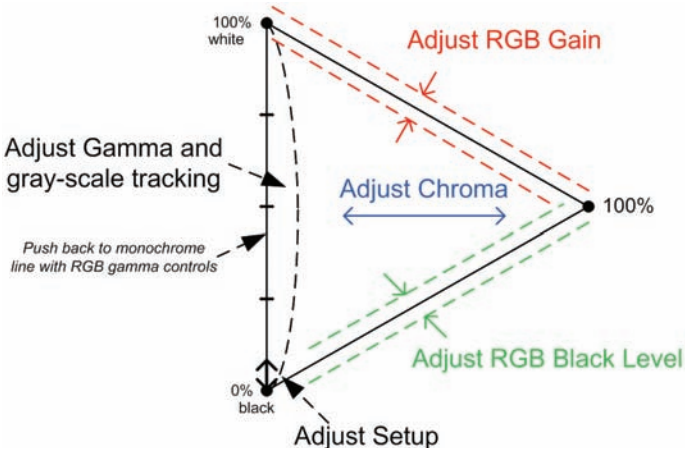


**Figure 1f.** Using the Spearhead display for color correction.

## Color Correction with the Tektronix 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, as shown in Figure 1e, is a triangle that represents the full RGB color gamut. This triangle is rotated and scaled such that the vertical axis (max(i) + min(i) / 2) represents Lightness and the horizontal axis (max(i) – min(i)) represents non-normalized Saturation.

The Spearhead display can be used to quickly make color correction adjustments, as shown in Figure 1f. 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 R'G'B' White or Gain affects the image dot locations near the upper side of the triangle, increasing or decreasing the color Value or intensity. The R'G'B' 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 R'G'B' gamma controls affects the alignment of the monochrome components of the image to the left side of the Spearhead.

Note: max(i) = maximum r(i), g(i), b(i) in millivolts
min(i) = minimum r(i), g(i), b(i) in millivolts

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