Achieve Accurate Color-Critical Performance With Affordable Monitors

Image Rendering Accuracy to Industry Standards

Reference quality monitors are able to very accurately render video, film, and graphics content in color-critical content creation and editing applications, but those expensive monitors aren't cost-effective in many applications. Professional and commercial monitors and video displays are more affordable, but usually don't provide the level of accuracy needed in these critical applications for rendering images to industry standards.

An ideal solution for accurate color-critical monitor performance would meet these requirements:

- Provide image rendering accuracy to industry standards with any display that provides a minimum level of native performance.
- Easily incorporate into current content creation and editing workflows.
- Provide higher accuracy than traditional display profiling methods.
- Provide a fast display calibration method that doesn't require an overnight display measurement process.
- Automatically provide measured verification of calibration accuracy.
- Provide a convenient process to automate all hardware interfaces.

CalMAN Dynamic Profiling™ is a revolutionary new 3D LUT display calibration system that has been specifically designed to produce more accurate image rendering from any display than was ever before possible.

The display profiling and 3D LUT targeting engine in CalMAN Dynamic Profiling addresses every point within a display's 3D color space and enables the ultimate calibration accuracy of optimized 3D cube lookup table (LUT) calibration. The new Dynamic Profiling process creates the most accurate display correction data possible in a 3D cube LUT.

This allows CalMAN to produce more accurate calibration for professional and commercial displays than previous profiling products, with faster calibration time. Now, even more affordable displays can provide image rendering accuracy in color-critical applications.

Accurate, Affordable Monitors are Crucial

Business owners and technical professionals in video production, post-production, broadcast, photography, and business graphics facilities face a difficult choice today when selecting monitors for color-critical image analysis workstations. They can equip their color-critical content creation or editing workstations with very expensive reference monitors that very accurately render video, film, and graphics content. Or, they can use more affordable professional or commercial displays that may compromise the color and luminance accuracy of the image content they are creating or editing.

Reference Quality Monitors are Cost-Prohibitive

Current flat panel and projector displays don't inherently provide the industry standard performance that reference or even professional CRT video monitors used to provide, largely through the consistent nature of their CRT design. Factory-calibrated reference quality video monitors are available, but their high cost makes them a prohibitive solution for accurate screening of entertainment or business content in all but the most critical applications.

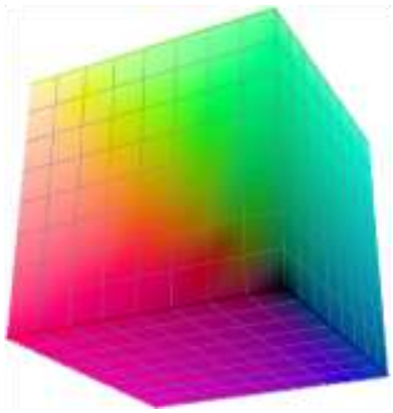
Professional and Commercial Displays are Less Accurate

The lower cost of professional and commercial displays make them a more cost-effective solution for deployment in image analysis workstations. However, even with the display's available picture controls adjusted for optimum picture accuracy, performance irregularities such as non-standard color gamut plus gamma and color saturation nonlinearity cause inaccurate image rendering and poor conformance to industry standards, which can lead to poor content interchange and client dissatisfaction.

The image controls available within these more affordable displays are usually insufficient to produce the required image accuracy to meet image rendering standards.

3D Display Color Space

To better visualize the range of colors that a video signal is able to represent or the range of colors that a display is designed to render, we often use a three dimensional color space representation. We typically use an RGB color cube to visually represent the three dimensional color space of an RGB video signal (Figure 1).



Fig, 1: An RGB color cube, with the pure primary and secondary colors at six corners of the cube, and white and black at the remaining corners, helps us visualize the range of colors that an RGB video signal can represent.

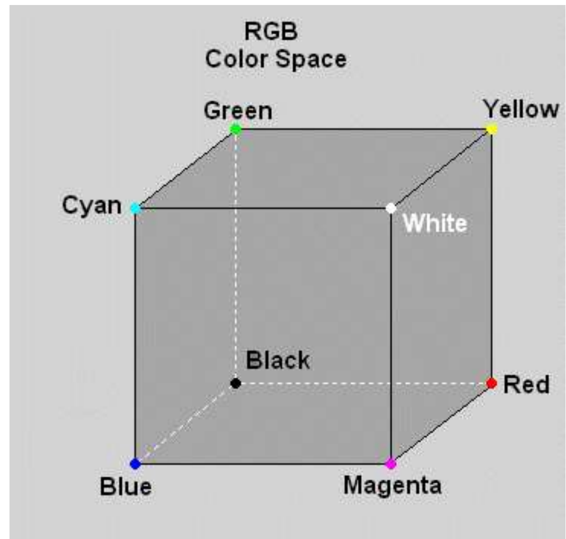
With an 8-bit RGB signal, there are 256 color points along each edge of the cube, with 16,777,216 total color points in the RGB cube, corresponding to the 16.78 million possible colors in an 8-bit digital image (1,073,741,824 values in a 10-bit image).

Each of these 16.78 million or 1.07 billion different colors has a unique combination of hue, saturation, and brightness, and the accuracy of each color is uniquely important for realistically rendering photographic images.

RGB Color Space Basics

In RGB color space, black is at one of the eight cube corners, with the red, green and blue primary colors at the three corners directly adjacent to the black point (Figure 2).

White is at the corner opposite from black, with the cyan, magenta, and yellow secondary colors at the three corners directly adjacent to the white point.



Fig, 2: On an RGB color cube, the primary colors are at the three corners nearest the black point and the secondary colors are at the three corners nearest the white point.

To move from any color to a lower luminance version of that color, we would move within the RGB cube to a color point closer to black.

To move from any color to a lower saturation version of that color, we would move to a color point closer to white.

Display Calibration Methods

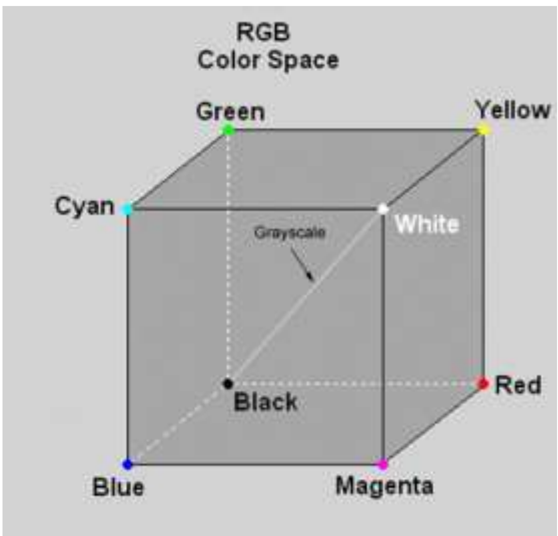
A number of methods are available to calibrate a display's performance to a desired rendering standard; a 1D LUT, a 3x3 color matrix, and a 3D LUT.

Among these, a three dimensional lookup table (3D LUT) is the ultimate display calibration method. However, most less-than-reference quality monitors use a combination of a 1D

LUT and a 3x3 color correction matrix to adjust the display's image rendering performance.

Gamma and White Balance Errors

A straight line through the center of an RGB color cube, connecting the black point to the white point, runs along the line of neutral gray image tones that we term the grayscale (Figure 3).



Fig, 3: Neutral gray tones lie on the grayscale line that runs through the center of the RGB cube, between the black point and the white point.

Gamma errors in a display cause points on the grayscale line to be shifted along the line, away from their intended luminance point, closer to either the white point or black point.

White balance errors (also called white point errors) cause points that should be on this line of neutral gray tones to be shifted off the neutral line, to one side or another, adding a color cast to neutral gray image areas.

1D LUT – Gamma and White Balance Correction

A one dimensional lookup table of correction data can be placed in the video signal path at a display's input to correct the display's gamma and white balance rendering errors.

With an 8-bit RGB signal, there are 256 points along the internal grayscale line (1024 points for 10-bit). For every input signal grayscale value (e.g. R=146, G=146, B=146), the 1D lookup table produces a replacement output signal (e.g. R=142, G=147, B=153) to correct the display's gamma and white balance inaccuracies.

1D LUT – Gamma and Grayscale Correction

Most displays contain a 1D LUT to control the display's gamma and white balance, but the display may provide only very limited user controls to accurately adjust the 256 values in the LUT. A display's white balance Gain and Offset controls, or possibly multipoint controls, adjust the display's 1D LUT data.

While a 1D LUT can correct color hue and saturation errors caused by gamma or white balance errors, it cannot correct the major hue and saturation errors caused by display non-linearity, color decoder errors, or non-additive color primaries.

Color Matrix – Color Gamut Correction

Fully saturated primary colors define the outside edges of a display's three dimensional color space. A 3x3 color correction matrix can be placed in the video signal path at a display's input to correct inaccuracies in the fully saturated primary colors that the display produces, compared to the desired standard colors.

3x3 Color Matrix Controls

Most displays contain a 3x3 matrix to allow modification of the display's native primary colors. A display's color space selection and/or CMS color gamut controls change the transform values in the 3x3 matrix.

The display's signal processor uses the data in the 3x3 color correction matrix (Figure 4) to perform a linear color transform on each pixel in the incoming signal. The supplied correction data are applied to fully saturated primary colors, and linear interpolated correction data are applied to all other colors.

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Fig, 4: A 3x3 matrix of color correction data controls the linear conversion of RGB color input values to corrected R'G'B' color output values.

Since a 3x3 matrix produces linear calculated correction data, nonlinear luminance errors and nonlinear saturation errors are not corrected.

3D LUT – Total Color Space Correction

A three dimensional lookup table (3D LUT) is the ultimate display calibration method. This table of correction data provides fast, real-time substitution of corrected color values for all the color points in a display's three dimensional color space.

A 1D lookup table and 3x3 color matrix provide correction data only for a display's grayscale points and for its RGB primary color points. The remaining points in the display's color space are corrected with linear interpolation, which doesn't account for the display's nonlinear luminance errors or nonlinear saturation errors.

Nonlinear Luminance and Saturation Correction Throughout Color Space

The 1D LUT and color matrix require less display memory, but do not provide the color correction accuracy of a 3D lookup table. A 3D lookup table of calibration data provides fast, real-time substitution of corrected color values, correcting nonlinear luminance and saturation errors for all the 16.7 million or 1 billion color points in the display's three dimensional color space.

A 3D cube LUT corrects the same grayscale values that a 1D LUT corrects, but the 3D LUT also corrects the other 16,776,960 or 1,073,740,800 remaining color values in a display's 3D color space.

A 3D LUT corrects gamma, grayscale tracking, color gamut, and color encoder display errors. This includes nonlinear luminance errors and nonlinear saturation errors for all colors in the display's color space.

Replacement Pixel Values

A three dimensional lookup table of correction data (3D LUT) can be placed anywhere in a display's video signal input path to control the replacement of individual pixel input values to more desirable pixel output values. A 3D LUT can correct a display's luminance, saturation and hue rendering errors (but it can't decrease the display's black luminance, increase the white luminance, or increase the gamut volume).

For every RGB triplet video input signal (e.g. R=146, G=92, B=241), the lookup table provides a replacement RGB triplet output signal (e.g. R=139, G=95, B=247) to correct the display's image rendering errors. Theoretically, a video LUT could contain a replacement output value for every one of the possible 16.7 million RGB color input values in an 8-bit system (1 billion values in a 10-bit system). As each pixel's RGB input values arrive at the LUT processor, it would check the lookup table for the desired replacement RGB output values.

However, since using a LUT with 256x256x256 or 1024x1024x1024 values is impractical, the 3D lookup table holds correction data for a smaller number of color points (e.g. 17, 33, or 65 points each for R, G, and B), distributed across the digital signal range. Correction data for other color points that fall between the LUT data points are calculated on the fly by a correction data renderer in the LUT processor, by interpolating (estimating) between the adjacent LUT data.

3D LUT Purposes

In a creative environment, such as broadcast or motion picture production or post-production facilities, 3D LUTs are used for a number of different purposes. A LUT might be used as a calibration LUT to improve the accuracy of a display's color and luminance rendering, but it might also be used as an emulation LUT or as a creative LUT.

Calibration LUT

A calibration LUT is used to correct a video signal being applied to a display, to correct inaccuracies in the display's image rendering. A calibration 3D LUT is most often used to match a display's gamma, grayscale, and color gamut performance, as closely as possible, to the selected standard (BT.709, BT.601, DCI P3, etc.). Note that a 3D LUT cannot decrease a display's native black luminance level, increase its white luminance level, or increase its color gamut volume.

A calibration LUT is created with a display calibration system, using a light meter to measure a display's image rendering characteristics with reference test images.

Emulation LUT

An emulation LUT, also called a transform LUT or technical LUT, is used to transform a display's calibrated color space to emulate, as closely as possible, an entirely different color space. A 3D transform LUT may be used to transform the color gamut of a BT.709 monitor to emulate, as closely as possible, the color gamut of a particular film stock print or a digital cinema projector, to allow digital film scan content or digital camera output destined for film or DCI output to be viewed more closely to what its final output will look like.

This allows pre-visualization of how an image being color graded on a BT.709 monitor will look when printed to a particular film stock, for example. This type of 3D emulation LUT may be produced in-house, or may be supplied by an outside vendor.

Creative LUT

A creative LUT, also called a look LUT or on-set LUT, is often used to preview digitally captured images on a motion picture shoot location to give a good idea of what the final look for each scene might be. This allows us to approximate the look that log-C digital camera images will have after conversion to a standard video color space such as ITU-R BT.709, possibly with a global creative color grade. This type of creative LUT is typically produced in-house, by exporting either a 1D or 3D LUT from a desired grade, and the LUT is then applied to on-set monitors and to a display used to view digital dailies.

LUT Containers

A LUT can be stored in a number of different "containers" along the signal path leading to an electronic video display. This LUT container can be a dedicated block of memory in the display itself, a LUT processor in the display's signal input path, or a block of memory accessed by an image editing system used to create or play back a video image file.

Display LUTs

Professional displays often include an internal 3D LUT in their signal input path. This allows a calibration LUT to be loaded directly into the display, to apply color correction across the display's entire color space. This allows the display to always produce calibrated images, without depending on external correction devices and no matter the input signal source.

Processor LUTs

A number of available image processors contain one or more 3D lookup tables, including the SpectraCal ColorBox, Fujifilm IS-mini, Cine-tal DAVIO, Blackmagic Design HDLink Pro, Pandora Pluto, and Lumagen Radiance.

All these LUT processors have 16-bit signal processing pipelines. The processors perform internal calculations and color space conversions (YCC to RGB, color value interpolation, RGB to YCC) at 16-bit accuracy to avoid luminance and color contouring (posterization) in gradient images. Color space calculations performed with lower bit-depth signals, particularly 8-bit or 10-bit signals, often create image artifacts, due to accumulated rounding errors with repeated math operations.

Image Editing System LUTs

Many software and hardware image editing systems are able to import 3D lookup table data in the form of an electronic file and use the LUT correction data to modify the color output values from the image editing system. This imported LUT can be a calibration LUT to correct the video signal being applied to a display, to correct inaccuracies in the display's image rendering.

Traditional 3D LUT Calibration

The earliest method of creating 3D LUT correction data is a static "display profile" process consisting of multiple steps, using multiple software packages.

1. **Profile display** – The first step that traditional systems use to create a 3D display calibration LUT is to measure a subset of the total number of colors that the display is capable of producing (16.7 million colors for an 8-bit display). With traditional static profiling, measuring 17 luminance and saturation points for each of the three primary colors (e.g. 17x17x17 = 4,913 colors) is usually considered the minimum data required to obtain sufficient accuracy with the traditional method of LUT calculation. Measuring 4,913 displayed colors takes up to 4 hours, depending on the speed of the meter being used.

   The measurement data is then exported as a display profile data file.

2. **Calculate LUT correction data** – Next, the display profile data file is imported to another software tool, where the measured display values (display profile) are compared to the desired target values for each color. Correction data are calculated in a single pass through the measured display values. With traditional static profiling, individual LUT correction data are not validated or optimized.

3. **Export 3D LUT file** – The LUT correction data are then written to a LUT file with a particular selected format.

4. **Load 3D LUT** – The display calibration LUT file is then loaded into the image editing tool that is being used (e.g. Resolve, SpeedGrade, Avid, Final Cut Pro, etc.) or into a LUT processor. Loading the calibration LUT into a LUT processor requires the use of a file utility supplied by the processor manufacturer.

   The LUT file modifies the output signal values from the creative software or LUT processor to correct the attached display.

5. **Test the LUT** – Finally, the display is tested with the calibration LUT in place. This can be a visual test, viewing one or more familiar reference images to make a visual judgment. Or, it can be a measured test, measuring a series of calibration test patches with a metered calibration system, such as CalMAN, that provides delta E metrics to indicate the quality of the display performance with the calibration LUT in place.

This multi-step process of creating and implementing a 3D calibration LUT with a traditional LUT calibration system is not a convenient or intuitive process.

The major problem with static 3D LUT profiling systems is that they measure a static set of profile points. This places more points than are needed in linear areas of a display's color gamut and not enough points in the nonlinear areas. This allows any display nonlinearities to skew the accuracy of the calculated and linear interpolated LUT data.

CalMAN Dynamic Profiling™

CalMAN's Dynamic Profiling 3D LUT display calibration system now includes a new display profiling and 3D LUT targeting engine, first available in CalMAN version 5.4.0. The new calibration engine makes it easier than ever to create a corrective 3D LUT for a display. There are four new aspects to the new profiling and targeting engine:

- Intelligent Resolution Profiling™
- Lightning LUT
- 3D LUT Targeting
- 3D LUT Retargeting

Previous static profiling methods took six to ten hours to accurately profile a display, which was inconvenient and error-prone. CalMAN's Intelligent Resolution Profiling creates an extremely accurate profile in just two to three hours, for very nonlinear displays. And, for displays with moderate linearity, CalMAN's Lightning LUT process creates an accurate profile in just five minutes.

The 3D LUT targeting engine also enables 3D LUT retargeting to a new color space target from an existing display profile, in just a couple of minutes.

Intelligent Resolution Profiling™

This newest method of collecting display performance information and creating a 3D lookup table of correction values combines the legacy method of static display profile measurements with the proven Dynamic Linearity Correction algorithm that was previously developed and used with iterative calibration.

Intelligent Resolution Profiling (IRP™) provides two important benefits over previous 3D LUT creation methods.

1. Higher calibration efficiency – the new IRP 3D LUT process requires fewer color measurements than any previous method to achieve a desired level of display calibration accuracy. Typically only 2,000-3,000 measurement points are required to create an extremely accurate display profile, taking only two to three hours.

   The key to this efficiency is that DLC strategically locates most of the measurement points in nonlinear areas of the display's color space that couldn't otherwise be accurately interpolated.

2. Calibration flexibility and user friendliness - a user can select a time limit to devote to a 3D LUT calibration and the IRP process will create a display calibration with the highest accuracy possible within that selected time.

When CalMAN initiates IRP, it first presents a setup dialog to the user to select a desired calibration completion time. CalMAN then measures about 400 display colors to define the structure of the display's rendered color gamut; along the RGB signal cube edges, on the cube faces, and within the cube interior.

From these initial color measurements, the CalMAN Dynamic Linearity Correction algorithm uses linear interpolation to predict the colors that would be produced, by a perfectly linear display, from the next sample set of 300-400 RGB signal values. CalMAN then measures that set of color points and the DLC function compares each point's measured value to its linear predicted value, to detect the degree of nonlinearity at each color point.

At color points that exceed a preset DLC error threshold, CalMAN then adds adjacent measurement points in that color area, repeating the process until each nonlinear area of the display's gamut is fully sampled with measurement points.

Measurement Time Limit

From the initial measurements, CalMAN determines how long each measurement takes (driven by color meter and pattern source variables). From the first set of DLC sample colors, it also projects the total number of linearity correction points that would be dynamically added during a complete profile at the preset error threshold, if there were no time limit.

From the results of this initial sample set, DLC runs a heuristic analysis to evaluate the degree of linearity error that can be corrected within the selected time limit. CalMAN then automatically resets the DLC error threshold to the level that it has calculated will result in the achievable number of calibration points in the given time.

This automatic DLC threshold setting allows CalMAN to add measurement points in the most nonlinear areas of the display gamut, to take optimal advantage of the allocated measurement time.

The IRP process then proceeds to measure the remaining color points and create an optimized 3D table of display correction data. CalMAN writes the final set of color gamut error data to a profile log file, to a 3D LUT software output file, and to a hardware LUT device, if connected.

Intelligent Resolution Profiling™ produces the highest accuracy conversion from the display's native gamma and color gamut to the desired target gamma and gamut, given the available measurement time.

Lightning LUT

CalMAN's new profiling and targeting engine includes the Lightning LUT profiling process. Lightning LUT produces a high quality corrective LUT in five minutes or less for displays with at least moderate linearity, regardless of display technology. For a moderately linear display, Lightning LUT provides the ultimate efficiency. The fast Lightning LUT profile measures just 65 to 73 color points along a display's RGBW ramps, in less than five minutes, depending upon the luminance levels calibrated. The 3D LUT targeting engine then uses an innovative conversion matrix algorithm to exploit the full relational significance of the profile data at adjacent color points while creating a transform to the target color space. Lightning LUT corrects gamma, grayscale balance, RGB crosstalk, moderate color saturation and luminance nonlinearities, and reduces wide gamut volume to a target volume. Lightning LUT rivals the accuracy of CalMAN's previous 2,000 point DLC calibration, on displays with moderate linearity.

Note: For displays with higher linearity errors, CalMAN's IRP process provides unmatched accuracy of display linearity correction, in as little as 30 minutes.

3D LUT Targeting

The CalMAN 3D LUT targeting engine accepts an arbitrary number of profiled color points from either the IRP™ or Lightning LUT process. The targeting engine uses superior nearest neighbor interpolation to accurately transform a lower resolution display profile to a higher resolution 3D LUT, at the target color space. The nearest neighbor formula gives excellent accuracy, with low artifacts and good gamut bounds resolution, when interpolating from the sparse grid IRP or Lightning profile to an ordered grid 3D LUT (5x5x5 up to 65x65x65).

3D LUT Retargeting

The CalMAN 3D LUT targeting engine also allows you to retarget a display profile to a new 3D LUT. This allows you to retarget the profile to a different color space, without performing additional display measurements. The targeting engine simply accesses the original saved profile data, re-computes the 3D LUT interpolation to the new color space, and writes a new LUT file. In just a couple of minutes, you can have a new LUT to retarget your display to a new color space.

Convenient LUT Calibration Process

CalMAN's Dynamic Profiling™ 3D LUT calibration process is extremely convenient compared to traditional 3D LUT calibration systems.

- **Automated test pattern control** – CalMAN automatically controls the application of a reference test image to the display under test. CalMAN controls the internal test pattern generator in the Dolby, Eizo, and HP DreamColor displays, plus the Davio, Pluto, IS-mini, and Radiance processors.
- **Automated LUT Processor Support** – If you have connected one of CalMAN's supported LUT processors, CalMAN automatically writes its optimized 3D LUT data out to the LUT processor.

  CalMAN writes to all supported LUTs with 10-bit calibration data, padded to 16 bits, to allow the processors to maintain their full bit level resolution.
- **Monitor Built-in LUT Support** - CalMAN can write its optimized 3D LUT data out to one of its supported LUT file formats (.3dl, .cube, .mga, .m3d, .clt, .csv, .itx, .txt, .dat, etc.) so you can load the LUT file into the display under test, if it contains a 3D lookup table.
- **Image Editing System LUT Support** - CalMAN can write its optimized 3D LUT data out to one of its supported file formats so you can load the LUT file into your image editing software or hardware tool (e.g. Resolve, Scratch, Nuke, Smoke, etc.).

Conclusion

Calibrating your more affordable professional and commercial displays with 3D LUTs allows them to achieve industry standard accuracy throughout their 3D color space. This allows you to produce higher quality video and graphics output and a higher ROI with all your current and future displays. You can literally “do more with less.”

CalMAN’s Dynamic Profiling™ 3D LUT display calibration system, with a new display profiling and 3D LUT targeting engine, more effectively corrects display rendering errors than any other available system. Plus, the Dynamic Profiling system is now more efficient and user friendly. You press a single AutoCube calibration button and come back shortly to a highly accurate, fully optimized 3D corrective LUT.

CalMAN can help any calibrator produce more accurate image rendering from any display than was ever before possible.

About SpectraCal:

SpectraCal specializes in the tools and training necessary to achieve images representative of the content creator's intent for environments from low to high ambient light while achieving the colorimetry, contrast, and dynamic range necessary for the image to have the proper impact on the viewer.

SpectraCal CalMAN software was developed to support the display calibrator in the step by step process of screen optimization. The foundation of screen optimization through display calibration is to understand the elements in a display that require adjustment and how each element inter-relates to the others. From its inception, CalMAN has earned rave reviews and has become the preeminent display calibration software package on the market, compatible with virtually all color meters available today. As display technology evolves, CalMAN will continue to provide the first choice for display calibration solutions.

More Information:

For more information on how you can benefit with CalMAN 3D LUT display calibration, or, to arrange for a full evaluation version of CalMAN 5 Display Calibration Software with Dynamic Profiling™ 3D LUT technology:

Visit www.spectracal.com or call +1 206 420 7514.