Achieve Accurate Critical Display Performance
With Professional and Consumer Level Displays

Display Accuracy to Industry Standards
Reference quality monitors are able to very accurately reproduce video, film, and graphics content in color-critical content creation and editing applications, but aren’t cost-effective in many applications. Professional or consumer level displays are more affordable, but often don’t provide the level of accuracy for reproduction to industry standards that is needed in these critical applications.

An ideal solution for this problem meets these requirements:

- Provides color reproduction accuracy to industry standards with professional or consumer level displays.
- Versatile solution easily incorporates into current content creation and editing workflows.
- Provides higher accuracy than traditional display profiling methods.
- Fast display calibration method doesn’t require overnight display measurement process.
- Automatically provides measured verification of calibration accuracy.
- Convenient process automates all hardware interfaces.

CalMAN AutoCube™ is a unique solution that has been specifically designed to meet these requirements.

The 3D color space calibration engine behind CalMAN AutoCube 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 AutoCube process uses Dynamic Profiling™ to measure, write, verify, and optimize the most accurate display correction data possible in a 3D cube LUT.

This allows CalMAN AutoCube to produce more accurate calibration for professional and consumer level displays than legacy static profiling products, with faster calibration time.
Accurate, Affordable Monitors are Crucial

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

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.

The lower cost of professional and consumer level 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 picture reproduction and poor conformance to industry standards, which can lead to poor content interchange and client dissatisfaction.

The adjustments available within these affordable displays usually aren’t sufficient to produce the required image accuracy to industry standards.

3D LUTs Correct All Color Space Points

A number of methods are available to calibrate a display’s performance to a desired performance standard. Among these, 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.

To better visualize the range of colors that a video signal is able to represent or the range of colors that a display is able to reproduce, we often use a three dimensional color space representation. We typically use an RGB color cube to visually represent an RGB video signal’s color space (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 65,536 color points on each face of the cube (256x256), and 16,777,216 total color points in the RGB
cube, corresponding to the 16.7 million possible colors in an 8-bit digital image (1,073,741,824 values in a 10-bit system).

Each of these 16.7 million or 1 billion different colors has a unique combination of hue, saturation, and brightness, and each color is uniquely important for realistically reproducing photographic images.

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.

![RGB Color Space Diagram](image)

**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 change any color to a lower luminance color, we would move within the RGB cube to a color point closer to black. To change any color to a lower saturation color, we would move to a color point closer to white.

A three dimensional lookup table (3D LUT) of correction values can be placed anywhere in a display’s video signal input path to control the conversion of individual pixel input values into more desirable pixel output values. A 3D LUT can correct a display’s luminance, saturation and hue reproduction errors (but it can’t decrease the display’s black luminance, increase the white luminance, or increase the gamut volume). For every video signal tristimulus input (e.g. R=146, G=92, B=241), the lookup table provides a corrected tristimulus output signal (e.g. R=139, G=95, B=247) to correct the display’s color reproduction 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 16.7 million or 1 billion values is impractical, the 3D lookup table holds a smaller number of color control points (e.g. 17 or 33 points each for R, G, and B), distributed across the digital signal range. Correction values for other color points that fall between the LUT control points (sometimes called nodes) are calculated on the fly by the signal processor by interpolating (estimating) between the adjacent LUT control point correction values.

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.
3D LUT Calibration Alternatives

Rather than include a comprehensive 3D lookup table to correct their color inaccuracy, many displays use a 1D LUT and a 3x3 color correction matrix to improve the display’s color reproduction accuracy. These require less display memory for the 1D lookup table and color matrix correction values but do not provide the color correction accuracy of a 3D lookup table.

1D LUT – Gamma and White Balance Correction

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).

![Figure 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.](image)

A display with grayscale gamma errors causes points on the line to be shifted along the line, away from their intended luminance point, closer to either the white point or black point. Grayscale white balance errors (also called white point errors) cause points that are normally 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.

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

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

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 values.

Note that a 3D cube LUT corrects the same 256 or 1024 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. 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.

3x3 Color Matrix – Primary Linear Color 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. Most displays contain a 3x3 matrix to allow modification of the display’s native primary colors. A display’s color space selection or CMS color gamut controls change the values in the display’s 3x3 matrix.

The display’s signal processor uses the values in the 3x3 color correction matrix (Figure 4) to perform a linear color transform on each pixel in the incoming signal. The supplied correction values are applied to fully saturated primary colors, and linear interpolated correction values 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 values 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 values, nonlinear luminance errors and nonlinear saturation errors are not corrected. A 3D cube LUT corrects these nonlinear errors for all 16.7 million or 1 billion colors in the display’s color space.

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 reproduction, 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 signal reproduction. 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 BT.709 standard. Note that a 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 reproduction 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 previsualization 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.

Look LUT

A look LUT, also called a viewing 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, 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 signal reproduction.

Traditional 3D LUT Calibration
Traditional 3D LUT calibration systems use 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 control points for each of the three primary colors (e.g. 17x17x17 = 4,913 colors) is usually considered the minimum number of points required to obtain sufficient accuracy with the traditional method of LUT calculation. Measuring 4,913 displayed colors takes from 4 to 20 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 values** – 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 values are calculated in a single pass through the measured display values. With traditional static profiling, individual LUT correction values are not validated or optimized.

3. **Export 3D LUT file** – The LUT correction values 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 values 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 biggest problem, though, is that traditional LUT calibration systems produce a LUT with a limited degree of accuracy. Since the LUT is produced in a single-pass calculation of the display profile data, any display nonlinearities skew the accuracy of linear interpolated LUT values.
CalMAN AutoCube™ Calibration with Dynamic Profiling™

SpectraCal CalMAN Display Calibration Software uses its new AutoCube™ one-click calibration process to precisely calibrate a display’s full color space by creating a 3D LUT calibration table. The AutoCube calibration process creates a fully optimized 3D lookup calibration table with its new Dynamic Profiling™ display LUT calibration process (introduced in CalMAN version 5.1.0). Compared to legacy 3D LUT creation methods, the new CalMAN Dynamic Profiling process produces much more accurate display performance, with an automated, faster, more convenient 3D LUT calibration process.

Accurate, Optimized 3D LUT

CalMAN’s Dynamic Profiling uses a software Virtual LUT™ to manage calibration correction values during exclusive LUT verification and optimization processes. The verification and optimization of Virtual LUT values insures the utmost display accuracy from AutoCube 3D LUT calibration. During the 3D LUT AutoCube process, CalMAN measures the current color calibration point, calculates correction data for the measured point and surrounding points, and writes the calibration correction data to its software Virtual LUT™. CalMAN then applies the virtual LUT data to the reference test image to produce a corrected color test patch for the current color calibration point.

CalMAN verifies the calculated correction data by measuring the corrected color test patch on the display. If the measured color is not yet within the selected color or luminance tolerance (often due to display nonlinearity), CalMAN calculates optimized correction data, writes it to the software Virtual LUT, and then verifies the new calibration data with another measurement. CalMAN repeats the optimization process for each color calibration point until each color point is optimized either to within the selected accuracy threshold or to the limit of the display’s native gamut.

CalMAN’s Dynamic Profiling calibration method, requires fewer measurement control points than traditional LUT calibration systems, yet produces higher display accuracy. By adjusting each control point in an interactive process, each new control point that CalMAN measures and adjusts is used to increase the accuracy of the surrounding control points and intermediate color points. This produces a more accurate calibration with fewer measured control points, in much less time than legacy LUT calibration products.

At the end of the AutoCube Dynamic Profiling process, a full set of LUT calibration data is contained in CalMAN’s Virtual LUT, precisely optimized to correct the display’s white point, grayscale tracking, and gamma, and to linearize the display’s hue, saturation, and luminance performance throughout its entire 3D color space.

CalMAN then provides the option to automatically load the fully tested 3D LUT display calibration data into a supported LUT processor. Or, CalMAN can write the 3D LUT data out to a LUT file so you can load the file into your image editing tool, or into the display under test, if it contains a 3D lookup table.

Faster 3D LUT Creation

By using Dynamic Profiling to optimize the accuracy of every 3D LUT calibration point, CalMAN AutoCube can produce higher display accuracy even when measuring fewer color control points. CalMAN offers three choices for calibration speed versus optimization detail – Fast, Standard and Detailed.
For each of these three choices, CalMAN measures and optimizes 17 point luminance ramps for each of the primary and secondaries, plus 17 grayscale points. However, rather than performing a static measurement of 4,913 color points (17x17x17 points) like a traditional calibration system, CalMAN optimizes a subset of the color cube saturation points (color saturation subsampling). With CalMAN’s Dynamic Profiling process, this still results in a more accurate calibration in less time.

The ideal calibration detail depends on the display’s color gamut volume and its color saturation linearity. If the display has a reduced gamut volume, compared to the selected gamut standard, or if the display has nonlinear color saturation, a higher number of color saturation subsample points are optimized to correct the color saturation issues.

- **Fast Calibration:**
  For a display with extended gamut and linear color saturation – CalMAN optimizes a LUT using a low number of color saturation subsample points.

- **Standard Calibration:**
  For a display with extended gamut, but nonlinear color saturation – CalMAN optimizes a LUT using a medium number of color saturation subsample points.

- **Detailed Calibration:**
  For a display with reduced gamut and nonlinear color saturation – CalMAN optimizes a LUT using a high number of color saturation subsample points.

CalMAN gives you the option to measure only enough color saturation subsample points to correct the display’s problems to the selected accuracy threshold, without taking more time than necessary for the calibration.

**Convenient LUT Calibration Process**

CalMAN’s AutoCube™ 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 THX Davio, Pandora Pluto, and Lumagen Radiance.

- **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 values, 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 (.cube, .mga, .3dl, .clt, .csv) 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 professional and consumer 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 5 is a revolutionary new video display calibration tool with a powerful new interactive AutoCube calibration process that accurately calibrates 3D cube lookup tables to correct color reproduction inaccuracies in any video display. CalMAN’s advantage is that it uses Dynamic Profiling™ to measure fewer total points than legacy calibration systems while optimizing each 3D LUT correction value, to calibrate a display faster, with higher accuracy than ever before possible.

CalMAN’s power is harnessed in an easy to use guided workflow that presents the calibrator with easy to use tools and information, while automatically handling all the heavy lifting within the AutoCube™ one-click automated calibration process. CalMAN 5 can help any calibrator produce more accurate color reproduction 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 AutoCube™ 3D LUT technology:

Visit www.spectracal.com or call 877-866-5112 (+1 605 274 6055).