Making LED Screens Look Great!
Methods for LED Video Screen Correction
CONTENTS

Introduction ............................................................................................................. 3

System Description ............................................................................................. 4

Theory of Operation ............................................................................................ 5

Correction Software ............................................................................................ 12

PM Series™ Imaging Colorimeters .................................................................... 17

Control Interface ................................................................................................ 20

Integration and Training ..................................................................................... 22

Contact Information ........................................................................................... 24
INTRODUCTION

Radiant Imaging’s VisionCAL System is an integrated hardware and software solution for measuring and correcting the brightness and color of each pixel in an LED video screen. The use of the VisionCAL System eliminates LED-to-LED performance variations and produces a uniform appearance. A combination of precision pixel-by-pixel brightness and color measurement technology, sophisticated image analysis tools, and over 5 years of experience correcting tens of thousands of LED screens and modules, makes the VisionCAL System the most capable, accurate, and powerful LED screen correction system available.

VisionCAL uses a ProMetric Series imaging colorimeter to precisely and simultaneously measure the luminance and chromaticity of each LED in a target module or screen. This data is then used to calculate correction factors for each pixel or module that will allow it to achieve user defined targets for color and brightness uniformity. These correction factors are uploaded to the panel video control board and applied to the incoming video signal.

The result is an LED panel that uniformly displays the proper luminance and color throughout the entire screen. The boundary between modules is seamless. Screen brightness is optimized.

The entire process is fast and simple, whether for a full screen or just a module, as the VisionCAL software controls the entire process from measurement to uploading the correction coefficients. The system can be used to calibrate an LED screen in as little as six minutes, depending on the speed at which correction factors can be uploaded to the video control electronics.

Figure 1 – Appearance of an LED screen before and after correction.
SYSTEM DESCRIPTION

The VisionCAL System consists of three components:

- An **imaging colorimeter** to collect detailed, pixel-level, data on screen appearance for various test patterns.
- **Application software** controls the measurement process, performs automated analysis of screen performance and calculates the optimal correction coefficients.
- A **control interface** to the module or screen controller provides automated control of the module or screen during testing and automates correction coefficient transfer to the controller to complete the correction process.

VisionCAL can be used to calibrate any size LED screen ranging from a small module to the biggest stadium screen.

VisionCAL has the following features:

- **Fast single-image analysis** enables the software to measure up to 40,000 LEDs in a single screen simultaneously.
- **Auto-centering** locates the center of each LED, even if the module or panel is rotated or improperly registered.
- **Flexible geometry definitions** accommodate modules with any number or arrangement of LEDs per pixel.
- **Edge-effect controls** eliminate lines between panels
- **Tilted module controls** eliminate gradients in modules with tilted louvers or LEDs
- **Statistical analysis tools** record and display the outliers, central tendency, deviation and gradient statistics for luminance and chromaticity.
- **Data graphing tools** show luminance uniformity, chromaticity scatter, and coefficient performance.
- **User-specified pass/fail criteria** for luminance and chromaticity of each LED support production quality control.
- **Complete data records** store before/after data, pass/fail data and correction factors data for each pixel and also test date, operator, panel serial number, and test conditions for each module or panel.
- **Precision correction** with module-to-module luminance corrected to +/-3% and module-to-module color corrected to +/- .003 delta u’v’. Pixel to pixel level variations will be corrected to be imperceptible to the human eye.
THEORY OF OPERATION

LED video screens are an amazing display technology. They are bright enough to see in broad daylight, withstand severe weather conditions, last almost forever, and consume far less power than traditional display technologies. However, variations in individual LED performance and in the design of LED video screens too frequently results in pixel-to-pixel or module-to-module luminance and color non-uniformity that is clearly perceivable by viewers and that is seen as a quality failure. Understanding the causes of luminance and color non-uniformity in LED screens is important to understanding what screen manufacturers can do to fix these problems.

Source of Non-uniformity in LED Screens

The root cause of luminance and color uniformity problems in LED screens is the brightness and color variations of the LEDs themselves. Modern manufacturing processes for LEDs produce LEDs that can vary greatly in both brightness and color.

For example, when applying the same electrical current to two green LEDs produced as part of the same batch the brightness may vary by as much as 50% and the wavelength may vary by as much as 15-20 nanometers. These differences are easily noticeable to the human eye.

This is in contrast to CRT displays which rely on phosphors to produce brightness and color. In a CRT, the phosphors in each pixel produce nearly the same brightness and color when exposed to the same amount of energy from the cathode ray gun. Since the pixel response in CRT devices is very repeatable, the uniformity of CRTs is very high. This is illustrated in Line 1 of Figure 3.

LED pixels are more variable than CRT pixels. First, the brightness of each LED varies widely even when they are driven by the same voltage and current (see Figure 3, Line 2; the brightness of each LED is indicated by dot size). Second, the colors of the LEDs are variable (see Figure 3, Line 3). When the effects of variations in LED
brightness and color are combined the objective of achieving uniformity across a LED screen becomes very difficult (see Figure 3, Line 4).

Another cause of non-uniformity in LED screens is an aging effect: LEDs get progressively dimmer as they are used. Blue LEDs dim the fastest over time and the red LEDs dim the slowest. This divergence in performance degradation results in color migration over time for individual LED screen pixels. Therefore, even if an LED screen were perfectly uniform when it left the factory, after about one year of continuous usage the LED screen will be noticeably less uniform.

Therefore LED screen correction is required to achieve brightness and color uniformity both when the screen is initially built and as a regular maintenance activity.

Methods for Addressing LED Non-Uniformity

There are several methods screen manufacturers may use to address non-uniformity issues. The first method focuses on low cost manufacture – LED variability and its effects on LED screen performance is taken a given. The second method is to buy the LEDs from manufacturers in binned lots with reduced variability and to build modules and screens using LEDs from matched bins. Third, the electrical current to the LEDs can be controlled to produce luminance, but not color, uniformity. Finally, they can use PWM (pulse width modulations) correction to control both LED luminance and color.

To evaluate these methods, it is important to understand the sensitivity of the human eye to color and luminance differences. The human visual system is much more adept to distinguish edges than it is to distinguishing slowly changing light levels. Therefore module-to-module differences are easier to distinguish than pixel-to-pixel differences because the straight boundary between modules is easier to detect.

The human eye can distinguish a module-to-module difference of 1-2% in luminance and a 1-2 nm difference in color. Pixel-to-pixel thresholds are on the order of 4-5% in luminance and 3-4 nm in color.

Do Nothing. This is the lowest cost approach to the problem. Instead of improving uniformity of the LED screen, some manufacturers focus on increasing LED brightness and lowering price. The shortcomings of this approach are readily seen by setting the screen to display a single, uniform color – the lack of uniformity will be readily apparent. Manufacturers often show fast moving video clips to avoid revealing this flaw. Non-uniformity will be readily apparent in static images such as when an advertiser’s logo, product name, and contact information are shown; this is a significant shortcoming in viewer perceived display quality.

Bin LEDs by Performance. To address inconsistency in LED performance, LED manufacturers can measure and sort LEDs into groups (referred to as “bins”) of roughly similar luminance and color. LED screen manufacturers then will use only LEDs from a single bin to build all of the modules that are used to construct a specific LED screen. Binning is a costly, time consuming process that reduces but does not eliminate LED performance variation.
Industry standards for bin sizes as published by LED manufacturers are set to approximately 25% to 40% variation in luminance and 5nm in color wavelength. These variations are detectable by the human eye.

More precise binning criteria can be applied, but this increases the expense of measurement, selection, and storage of the LEDs. Binning to variation levels undetectable to the human eye may be prohibitively expensive. Even if binning can be done into indistinguishable collections of LEDs, the LED screen manufacturer must still deal with the complexity of segregating modules during production and also post production if needed for replacement.

While extreme binning will result in uniform LED screens there are further issues that must be addressed. First, the more precisely the LEDs are binned, the more likely it becomes that there are noticeable LED screen to LED screen variation. Second, different colored LEDs in these screens still age at different rates so the screens become less uniform over time.

**Current Adjustment of LED Luminance.** The brightness of LEDs is determined by the amount of DC current that flows through the P/N junction. More current produces a brighter LED. Changing the current will also change the color of the LEDs. Brightness and color cannot be simultaneously be controlled by this method.

LED manufacturers can adjust the current applied to each module by adjusting a set of three – one each for red, green, and blue colored LEDs – variable resistors on the
power supply or on the module itself. This method can be used to make sure that the
modules all have the same brightness, but it cannot be used to adjust the color
differences. If two modules were the same color before adjusting the current to
balance brightness, they are unlikely to exhibit the same color after the adjustment.
This method is only practical for correcting module-to-module brightness differences.
Correcting pixel-to-pixel brightness differences is prohibitively expensive because of
cost of the electronics required to individually address the very large number of pixels
on a screen.

**Pulse Width Modulation (PWM) Correction**

Pulse Width Modulation (PWM) is a widely used technique for controlling the
brightness of individual LEDs. PWM is preferred to current modulation as PWM
does not cause the LED color to change. PWM pulses the LEDs either full on or full
off at a very high rate - so fast that the human eye cannot detect them – with the
duration of the individual flashes (pulse width) determining the perceived brightness.

PWM is illustrated in Figure 4. The amplitude of the pulse (current applied) is always
either full on or full off. The applied current is either zero (off) or maximum (on).
The brightness of the display is determined solely by the temporal duration of the
pulses. A bright display at 90% brightness will have pulses that are 9 times longer than
a dim display at 10% brightness. Since the maximum current is a constant value, the
brightness of the LED is controlled only by percentage of time that the LED is in the
“on” state.

![Figure 4](image)

**Figure 4** – Illustration of pulse width modulation for various brightness levels; the
signal is modulated so that the “on” time is equal to the percent brightness desired.

PWM uniformity correction works by modifying the pulse widths to compensate for
LEDs that are naturally brighter or dimmer. By controlling the brightness of the
individual LEDs – usually some combination of red, green and blue LEDs – in an LED
screen pixel, the color of the LED pixel can be selectively adjusted to a target color. In
an uncorrected system, the video signal is turned into pulse widths by the video
controller and then sent to the LED drivers to flash the LEDs. In a corrected system,
the pulse widths are multiplied by correction coefficients before being sent to the LED drivers\(^1\).

The PWM brightness and color correction process as applied to a single LED screen pixel is as follows:

**Establish Design Objectives.** For this example, let us assume that we wish to design a video screen where the LED screen pixel should have:

- Target luminance: 1000 nits
- Target color coordinates: \(C_x=0.32\), \(C_y=0.64\) (green)
- Input video signal: 50% GREEN.

**Select LEDs.** For this example, we will assume that the LED pixel consists of 3 LEDs: one each of Red, Green, and Blue. These LEDs should be selected to have a maximum output of 2000 nits, and the Green LED should have a wavelength of about 556 nm. The Red and Blue LEDs should similarly be close to their respective target wavelengths.

**Determine Errors Due LED Variation.** However, due to LED performance variation, when the 50% GREEN video signal is applied the actual luminance and color is likely to be somewhat different than the target values. These values must be measured. An example is shown in the upper drawing in Figure 5. The error values are calculated with reference to the target luminance and color coordinates.

**Determine Pixel-specific Correction Coefficients.** PWM correction coefficients are computed for this LED screen pixel in such a way as to correct the luminance and the color coordinates. The key is that color and luminance are corrected by adding some amount of Red and Blue to the Green signal. Luminance is additive and the final color is achieved by mixing Green, Red and Blue. The correction coefficients computed for each LED screen pixel.

**Apply the Correction Coefficients.** In the example portrayed in Figure 5, the Green signal will be reduced by a factor of 0.923 and some Red and Blue signal will be added to achieve the desired targets. The result is that both the luminance and the color will be very close to the target values when a 50% GREEN video signal is applied.

This sequence corrects one color in one pixel of the LED screen. To correct the complete LED screen, this process must be applied to each color – Red, Green, and Blue – for each pixel in the LED screen. The final correction matrix for each pixel includes 9 correction coefficients as shown in Figure 6 below. Note that the “Video Out” value for green is a bit higher than the previous example; this is because the green correction values for the red and blue color have been added.

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\(^1\) See the following United States Patents for more information on PWM color correction: 6,150,774, 6,323,832, 6,127,783, 6,016,038, 6,150,774, 7,088,059, 6,618,031, 6,313,816, 6,583,791.
The video signal (50% gray in the example shown in Figure 6) is multiplied by the 3x3 correction matrix to determine the pulse widths of each color channel for the pixel. As the video progresses, the video signal will change, but the coefficients will not, they remain the same for each pixel regardless of the video signal.

In order to implement PWM uniformity correction for an LED screen, a screen manufacturer or screen owner must be able to do the following:

- **Measure the luminance and color of each pixel** displayed with fully saturated red, green, and blue.
- **Compute a 3x3 matrix of correction coefficients** (or 3x1 coefficients if only luminance is being corrected) for each pixel.
- **Store the coefficients** in the video controller.
- Use FPGA electronics to **multiply the video signal stream by the PWM correction coefficients** when video is being displayed on the screen.

Implementation of the electronics to support LED screen correction can be developed in-house by the LED screen manufacturer, or LED device drivers and module controllers can be obtained from specialized suppliers. Given the electronics, the VisionCAL Screen Correction System will be able to automate the measurement process, the calculation of the correction coefficients, and their transfer to the video controller.
PWM Uniformity Correction Performance

PWM uniformity correction has proven to be the best method for correcting uniformity problems in LED screens. When a screen has been calibrated using PWM correction methods, it is not possible to see any change in color or brightness at the module and panel boundaries. The LED screen image is crisp and clear.

When an LED screen correction is properly performed, the modules vary in luminance by less than 1% and in chromaticity by less than 0.003. This level of quality is expected today for top venues such as major sports stadiums, event centers, and advertising spectaculars.

The PWM based LED screen correction method is the only LED screen correction approach that uses information from every LED screen pixel and optimizes corrections for every pixel, making generally applicable to many different screen sizes and pixel configurations.

Further Considerations

The discussion above addresses the basic issues in LED module and screen correction. For simplicity in explanation, several significant factors were mentioned only briefly, but they are worth considering more deeply.

White Balance. By displaying a White field (with Red, Green, and Blue full on), capturing a color image, and determining the luminance and chromaticity of each pixel, the VisionCAL System can further refine the correction coefficients so that a pure white display exhibits a very high degree of uniformity.

LED Luminance Degradation. It is well understood that the luminance of LEDs degrades over time, and that red, green and blue LEDs degrade at different rates. This means that screens will noticeably drift out of calibration after as little as 6 months of operation. The effect will be an overall decrease in brightness – which cannot be avoided – but also a drift in the color of each LED
screen pixel because the correction coefficients will no longer mix colors in the correct proportions to optimize Red, Green, and Blue.

**Environmental Effects.** LED luminance and color are known to vary with environmental conditions including temperature and humidity. LEDs that are matched or corrected on one day may not match those corrected at another time. Generally this is not an issue for screens that are assembled from modules corrected or matched at the same time. However, LED aging or environmental variations during manufacturing will lead to significant and visible lack of uniformity if a new module is inserted into a screen without performing a calibration. This is true of both modules that are corrected to match a prescribed color gamut, and modules that are assembled from tightly binned LEDs.

**Simultaneous Correction of Multiple LED Modules.** The VisionCAL System can take full advantage of the resolution of the PM Series Imaging Colorimeter to either correct a full screen or to correct multiple stand-alone modules simultaneously. The later capability is particularly useful in high throughput manufacturing environments.

**Field Correction of LED Screens.** Field correction of LED screens introduces many environmental, test set-up, and geometric issues that must be dealt with. We will not cover these here except to note that the VisionCAL System has carefully thought out, integrated, functionality specifically designed to support these applications.

### CORRECTION SOFTWARE

The VisionCAL System employs a ProMetric Series Imaging Colorimeter to measure the luminance and chromaticity of each LED. The PM Series camera operation is controlled by the VisionCAL software to implement the correction process. VisionCAL software also interfaces with the video controller to display test patterns and to upload correction coefficients to the LED panel. The general process is shown in Figure 7.

The VisionCAL System operates by placing the LED screen or module being corrected in several different display states, capturing images of the DUT (device under test), determining brightness and color values for each LED, establishing a target color gamut and luminosity, generating optimal correction coefficients to meet the targets, and then uploading the correction coefficients to the panel video controller. After the correction coefficients are implemented, the brightness and color uniformity of the LED screen or module may optionally be verified. The process is as follows.
Determine the physical location of each LED in the panel. Upon initialization of the LED screen correction process, a registration image of the LED module or screen is captured and then searched to locate a predetermined key LED in each LED screen pixel. The VisionCAL software uses both the registration image and the known geometry of the module to establish a grid across the screen with the location of each LED device identified. This registration process is able to locate each LED even if the module or panel has been rotated or poorly aligned. This is particularly important in a high-throughput manufacturing environment. While physical registration is typically used to align the module under test relative to the imaging colorimeter, VisionCAL is readily able to adapt to small, but significant, changes in module position.

Next, the VisionCAL software instructs the LED screen to sequentially display red, green and blue patterns and captures a color image of each. Using these images and the previously recorded locations of each LED, the software determines each LED’s luminance and chromaticity (Cx, and Cy) and records this information in the measurement database.

The software computes the correction coefficients for each pixel or module based on the target values set by the user. The correction coefficients are then uploaded to the DUT. At this point the panel has been corrected and the process can stop. However, there are several optional steps that the user may choose to implement.

It is also possible to perform a white balance for the DUT. Further refinement of the correction coefficients results in improved uniformity for an all white display. Large areas of white are common in many images and displaying this areas uniformly white presents the greatest challenge for an LED screen. When displaying a pure white screen, a lack of uniformity is easily apparent for uncorrected LED screens.
Further improvements are possible by performing module level correction for an array of modules. This step is similar to the previous steps except that the images integrate the luminance and color data of an entire module and adjust the correction coefficients of each pixel by the same value. This step can be applied to module arrays or an entire screen. It ensures that any module boundary artifacts are removed.

The final optional operation is to capture images of the corrected LED screen or module. This data is used to determine if the LED screen performance meets any predefined pass/fail criteria. This data should also be recorded in a results database referenced by the modules serial number and retained for future analysis or reference. Since this step takes extra time on the production line, it is optional and may be skipped.

VisionCAL Correction Software Design

The VisionCAL Software is simple enough that a factory floor operator can use it with confidence, yet also flexible enough for an experienced engineer to modify it to accommodate a new type of module or panel. This dual capability is achieved by providing basic capabilities to an operator and providing full control capability to an administrator - usually an experienced engineer - by using password protection.

Also, by placing all of the control parameters for the program into a table and giving the system engineer full access to these parameters, it is possible to accommodate any type of LED module or screen layout without modifying the program.

The VisionCAL Software is can be run in a number of modes depending on user objectives:

Operator Mode. In this mode, a factory floor operator has access to a full set of basic system controls. The operator can choose the type of LED module or screen to be corrected, make the physical control connections, and start the correction process. The VisionCAL Software will automatically gather measurement data, compute correction coefficients, and upload them to the video controller if desired.

Upon completion of the correction process, the test results clearly indicate whether the module or panel was successfully corrected. The operator can choose to view the graphical output of the test results. All test results are stored in the Test Results database for future review for auditing or quality purposes.

In Operator Mode all of the parameters used to correct the LED screen can be viewed, but cannot be reset or altered.

Administrator Mode. In Administrator Mode, an engineer has full access to all of the parameters and tests used to measure, analyze and correct a module. Various tests are available that can be used to check the system and the parameter setup.
Working in Administrator Mode enables the engineer to test LED screens, to develop test sequences, to set test objectives and targets, and to access and analyze LED screen correction data.

**Panel Parameters.** VisionCAL requires screen parameters to be entered by an engineer in Administrator Mode. All of the parameters necessary to define the unique geometry of an LED screen or module and how it is to be measured are stored in this database. The engineer or Administrator is responsible for determining the correct parameters for each type of LED screen or module to be corrected.

VisionCAL Software functions include:

- Measurement Set-up (Figure 8)
- Correction Target Computation (Figure 9)
- Manual and Automated Correction (Figure 10)
- Module and Screen Performance Description (Figure 11)
- Data Analysis Tools, including Pass/Fail (Figure 12)
The Chromaticity Color Calculator is used to evaluate the color gamut that can be achieved by the LEDs used in the screen and to set a target gamut for the screen uniformity correction.

Auto registration allows accurate measurement of LED performance independent of screen alignment to the imaging colorimeter. The correction process can be run automatically or step-by-step under user control.

Figure 9 – VisionCAL Chromaticity Color Calculator

Figure 10 – VisionCAL Pixel Measurement and Correction
The synthetic bitmap function summarizes spatial variations and provides the user with an easy visual description of the screen performance.

Figure 11 – LED screen analysis tools show spatial variation in luminance and color.

Analysis tools summarize performance information by LED, pixel and module against user defined acceptance criteria before and after correction.

Figure 11 – VisionCAL correction results analysis, by LED pixel
The Radiant Imaging PM-14ooF Series is the PM Series Imaging Colorimeter usually used with the VisionCAL System. This system is a CCD-based imaging photometer, radiometer and colorimeter system capable of capturing high resolution, high dynamic range, and highly accurate images.

Several models of the PM-1400F Series Imaging Colorimeter may be used with the VisionCAL System, with the final selection being made based on the LED screen size (number of pixels) and the intended application. For example, is the system to be used for factory or field correction? Is it to be used for correcting individual LED modules, module clusters, or complete screens?

The PM-1400F Series is designed to meet the precision requirements of LED measurement, and is capable of detecting luminance and color variations that cannot be perceived by the human eye. This is accomplished by design innovations and proprietary calibration methods that minimize electrical and optical sources of measurement noise and error.

We are sometimes asked why a commercial digital camera cannot be used instead of a precision colorimeter. The reason is that a commercial digital camera generally does not have a full-frame, high bit depth CCD that allows it to capture all the luminance and color information from the screen with sufficient resolution to determine correction coefficients that will improve the LED screen to the level that the human eye cannot easily detect differences. Nor does a commercial digital camera contain uniform, calibrated color filters that allow accurate color information to be obtained. It is somewhat like using a meter stick without marking to measure the dimensions of a room – it will give you some indication, but will not give you sufficient practical detail when you need to be exact.
## Radiant Imaging PM-1400F Series Specifications

<table>
<thead>
<tr>
<th>2-dimensional Measurement Capabilities</th>
<th>Luminance</th>
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<tbody>
<tr>
<td></td>
<td>Radiance</td>
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<tr>
<td></td>
<td>Irradiance</td>
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<tr>
<td></td>
<td>Luminous Intensity</td>
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<tr>
<td></td>
<td>Radiant Intensity</td>
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<tr>
<td></td>
<td>CIE Chromaticity Coordinates</td>
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<tr>
<td></td>
<td>Correlated Color Temperature (CCT)</td>
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</tbody>
</table>

| Units | Footlambert, Cd/cm², Cd/m², Nit, Mnit, mnit, W/sr/m², W/sr/R², W/sr/cm², mW/sr/m², Footcandles, Lux, mLux, MLux, Lux·Sec, W/m², W/ft², W/cm², mW/m², MW/m², W·Sec/m², Candela W/sr CIE (x,y) and (u’,v’) L*a*b* coordinates Kelvin (for CCT) |

| CCD Resolution | 768x512, 1536x1024, or 3072x2048 pixels (for Models PM-1453F, PM-1423F, and PM-1433F, respectively) |

| CCD Camera A/D Dynamic Range | 14 bits = 16,384 grayscale levels |

| Luminance Range | 0.005 nit minimum 10¹⁰ nit maximum with ND filters |

<table>
<thead>
<tr>
<th>System Accuracy</th>
<th>Illuminance ± 3%</th>
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<tr>
<td></td>
<td>Luminance (Y) ± 3%</td>
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<tr>
<td></td>
<td>Chromaticity Coordinates (x,y) ± 0.003</td>
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</table>

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<tr>
<th>Short Term Repeatability</th>
<th>Illuminance ± 0.5%</th>
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<tbody>
<tr>
<td></td>
<td>Luminance (Y) ± 0.5%</td>
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<tr>
<td></td>
<td>Chromaticity Coordinates (x,y) ± 0.0006</td>
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</tbody>
</table>

| Interface | USB2.0 |

| Neutral Density Filters | Integrated ND0, ND1 and ND2 filters |

| Camera Lenses | Interchangeable lenses from 14mm focal length to 500mm focal length |

<table>
<thead>
<tr>
<th>Minimum Color Measurement Time</th>
<th>For 100 Cd/m² at full resolution:</th>
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<tbody>
<tr>
<td></td>
<td>PM-1453F  5.5 sec</td>
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<tr>
<td></td>
<td>PM-1423F  9 sec</td>
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<td></td>
<td>PM-1433F  20 sec</td>
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<table>
<thead>
<tr>
<th>Camera Field of View (FOV)</th>
<th>PM-1453F  1° to 26°</th>
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<tbody>
<tr>
<td></td>
<td>PM-1423F  3° to 50°</td>
</tr>
<tr>
<td></td>
<td>PM-1433F  5° to 87°</td>
</tr>
</tbody>
</table>

| Dimensions | 242mm (H) x 154mm (W) x 200mm (D) |

| Weight | 4.8 kg |

| Operating Temperature | 0° to 30° C |

| Operating Humidity | 20-70% non-condensing |

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**The PM-1423F-1 is most often used for module correction in factory environments.**

**The PM-1433F-1 is most often used for full screen and on-site correction.**
CONTROL INTERFACE

For the VisionCAL software to correct an LED panel, it must be able to communicate with LED screen or module video controller. The VisionCAL software must be able to initialize the panel; display various colors, patterns and intensities; and read and write the correction coefficient matrices to the panel.

This interface is usually customized for each manufacturer’s specific video controller during VisionCAL System Integration.

There are currently three separate approaches that can be used to achieve system integration. Radiant Imaging can provide consultation and guidance in implementing the necessary command structures.

.dll Interface. The customer provides a .dll file that contains all of the functions necessary to control the panel and coefficients. Radiant Imaging will then implement the .dll calls into its VisionCAL software.

Customer Provided Serial Interface. The customer provides a serial interface document, which contains commands to send via a serial port that allows VisionCAL to control the panel and coefficients. Radiant Imaging then implements these serial port commands into its VisionCAL software.

Radiant Standard Serial Interface. The customer chooses to use the Standard Serial Interface protocol already built into VisionCAL software when creating the panel communication. This approach provides all the necessary control functions for LED screen and module correction. The Radiant Imaging provided protocol is not intended as a general video controller interface however.

During VisionCAL System Integration several issues may arise. These are caused by communication timing issues between the VisionCAL software and the customer’s hardware and software. It is best if these problems are resolved before a Radiant Imaging engineer comes to the customer’s site for installation and training. Therefore, it is strongly suggested that the customer sends a complete copy of the hardware and software to Radiant Imaging’s laboratories several weeks before the system integration and training is to begin. Radiant Imaging will perform initial system integration at its facility, and, with help from the customer, will solve the most difficult issues before traveling to the customer’s site for installation. This will greatly accelerate the integration process at the customer’s site, leaving more time for training.

It is very helpful for Radiant Imaging to keep the hardware loaned by the customer to use for testing future program changes. Radiant Imaging is extremely respectful of confidentiality. If permanently loaning a set of hardware to Radiant Imaging is not possible or not desired, then Radiant Imaging will return the hardware after the integration phase has been completed.
Panel Requirements for Correction

Not all LED video screens are correctable. For an LED screen to be correctable, the manufacturer must implement the means to receive, store, and use correction coefficients. It is the responsibility of the screen manufacturer to implement each of the capabilities shown below in order for their product to be considered correctable.

Receive Correction Coefficients. The output of the VisionCAL process is a 3x3 matrix of correction coefficients for each pixel on the LED screen. These correction coefficients must be transferred to the user’s video controller automatically through a serial cable, Ethernet cable, or USB cable. These coefficients can also be transferred using removable data storage (such as floppy disk or USB device), but this makes the correction process very slow and laborious as the coefficients have to be hand loaded onto the target system at each iteration of the correction process. Once a transfer protocol is implemented by the LED screen manufacturer or owner, Radiant Imaging will implement the code necessary in its VisionCAL software to send the coefficients over the serial port, or any other port designated.

Store Correction Coefficients. The LED screen manufacturer or owner must also implement a method to store the correction coefficients on the target system. One successful approach is to store the coefficients in flash memory directly on the module or on the video controller. The target system must be able to readily access the correction coefficients in order to modify the video signal in real time. The amount of storage necessary depends on the number of pixels in the LED screen or module and the bit-depth of the correction coefficients. Radiant Imaging suggests using 12-bit correction coefficients.

Apply Correction Coefficients. Electronics must be provided to implement the correction coefficients stored in flash memory on the module or video controller. The video signal must be adjusted by the correction matrix before it is sent to the video output chip. During video replay, the correction coefficients will always be applied to the video signal.

It is also necessary to be able to disable the application of the correction coefficients, as during the correction process it is necessary to measure actual, unmodified LED performance. The correction coefficients should either be turned off or the correction matrix can temporarily be set to the identity matrix.

The formula for adjusting the video signal to each LED screen pixel is shown below. The coefficient $C_{RR}$ stands for Video R(ed) LED R(ed); the other coefficients have similar definitions.

\[
\begin{align*}
Red_{out} &= Red_{in} \cdot C_{RR} + Green_{in} \cdot C_{GR} + Blue_{in} \cdot C_{BR} \\
Green_{out} &= Red_{in} \cdot C_{RG} + Green_{in} \cdot C_{GG} + Blue_{in} \cdot C_{BG} \\
Blue_{out} &= Red_{in} \cdot C_{RB} + Green_{in} \cdot C_{GB} + Blue_{in} \cdot C_{BB}
\end{align*}
\]
**Accept Display Commands.** In order to automate the correction process, the VisionCAL software sends display commands to the LED screen or module being corrected. These commands set the color, intensity, pattern, and correction state (use coefficients or don’t use coefficients). These commands are usually sent via a serial cable or Ethernet cable. It is the responsibility of the LED screen or video controller manufacturer to provide a method to automatically set the display state of the panel. Radiant Imaging will modify the VisionCAL software interface to send the appropriate signals to the controller.

If the target system provides the functionality above, then it is considered to be a fully correctable system, and the VisionCAL System can automatically measure the modules, create the correction coefficient matrices, and send them to the panel for storage and implementation. If the target system does not provide this functionality, then correction capability must be added before the VisionCAL System can be used.

**INTEGRATION AND TRAINING**

Radiant Imaging recognizes that the successful implementation of the VisionCAL System is not only a function of system itself, but also of the understanding and training of the operators. Therefore Radiant Imaging offers a multi-level training program that provides basic training for factory floor implementation, individual LED module correction methods, and expert methods for on-site LED screen correction.

**Level 1 Integration and Training**

*Level 1 integration and training* is for module and panel level correction performed at a factory in a darkroom. After this integration and training are complete, you will be able to use VisionCAL to correct all module types used by your company and panels composed of a small array of these modules. Preparatory work for the integration process must be accomplished by your engineers before the Radiant Imaging engineer arrives. *Time: 5 days*

During **Level 1 integration** all of the following capabilities will be programmed into the VisionCAL software and tested on your panel. Engineers from your company will work with Radiant engineers to enable VisionCAL to perform the following tasks.

1) Display Control for LED Module or Screen
2) PWM Correction Coefficient Management
3) Video Controller Interface Functions
4) Serial Interface Error Handling (if applicable)
During **Level 1 training** operators and engineers will learn how to use the ProMetric imaging system and VisionCAL software to correct any type of module used by your company. Training will focus on a few types of modules and engineers will learn the necessary skills to setup up the program for other types of modules plus future modules that you will correct.

**Level 2 Training and Integration**

**Level 2 integration and training** is for whole screen correction performed at the screen site. After this integration and training are complete, you will be able to use the VisionCAL to correct screens of any size and configuration. Preparatory work for the integration process must be accomplished by your engineers before the Radiant Imaging engineer arrives.

This integration and training takes place either outside or in a large warehouse at the factory site. All techniques necessary to perform an on-site correction will be taught, but the integration portion requires access to various company engineers that are readily available at the factory site.

**Level 2 integration and training** requires that **Level 1 integration and training** has already been completed. Those attending the Level 2 training must have skills commensurate with completing Level 1 training. **Time: 1 to 2 days**

During **Level 2 integration**, VisionCAL software will be modified to control an entire screen and send coefficients to the proper module and video controller for any portion of the screen. Engineers from your company will work with Radiant engineers to enable the VisionCAL software to perform the following tasks.

1) Set Display of a Screen Section  
2) PWM Coefficient Management  
3) Standard Options

During **Level 2 training** your operators and engineers will learn how to use the ProMetric imaging colorimeter, a Uniform Light Source (ULS) for camera calibration, variable focal length lens, a spectroradiometer for color calibration, and VisionCAL software to correct a screen of any size. After training is complete, your engineers should be able to go on-site to any screen and perform both pixel-level and global module-level correction.

**Level 3 Training for On-site Correction (optional)**

**Level 3 training** takes place on-site at an LED screen that is to be corrected. A Radiant Imaging engineer will assist your engineers in using your company’s equipment to correct a screen on-site. **Level 3 training** is optional, it can be used to solidify the concepts taught in level 2 training, or it can be used to assist you with a particularly difficult screen. **Level 2 integration and training** is a prerequisite to **Level 3 training**. **Standard Time: 2 nights**
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