RADIANT VISION SYSTEMS

Display Test & Correction of OLED, MicroLED, and Other Emissive Displays

Charles Skinner | October 9, 2025

Agenda

RADIANT VISION SYSTEMS

- The Rise of OLED & MicroLED in Displays
- Emissive Displays Present New Inspection Challenges
- Pixel-Level Measurement of Emitter Displays
- Pixel-Level Correction (Demura)

Today's Speaker

Charles Skinner, International Sales Engineer

Charles supports global partners and customers in applying imaging colorimetry solutions to next-generation display technologies. He works with developers and manufacturers of OLED, microLED, and AR/VR devices, providing technical guidance and pre- and post-sales support to ensure accurate measurement, correction, and optimization of display performance. Charles brings a background in applications engineering, with experience training international teams on optical test systems, automating analysis workflows, and validating designs against industry standards. His work spans automotive, aerospace, and consumer electronics, where he has helped organizations solve challenges in display quality, luminance, and color uniformity. He earned dual Bachelor of Science degrees in Physics and Astronomy from the University of Washington.

RADIANT
VISION SYSTEMS

A Konica Minolta Company

Light & Color

Automated Visual Inspection

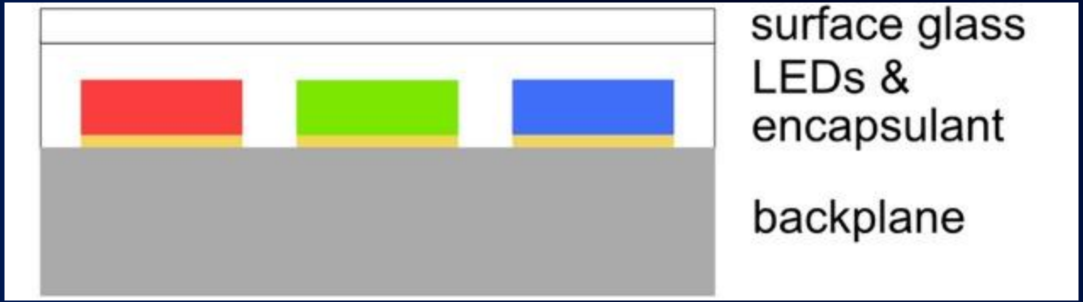
Global Support

Rise of OLED, MicroLED & MicroOLED in Displays

Increasing Adoption of Emissive Display Types in Consumer Electronics, Automotive, AR/VR and Beyond

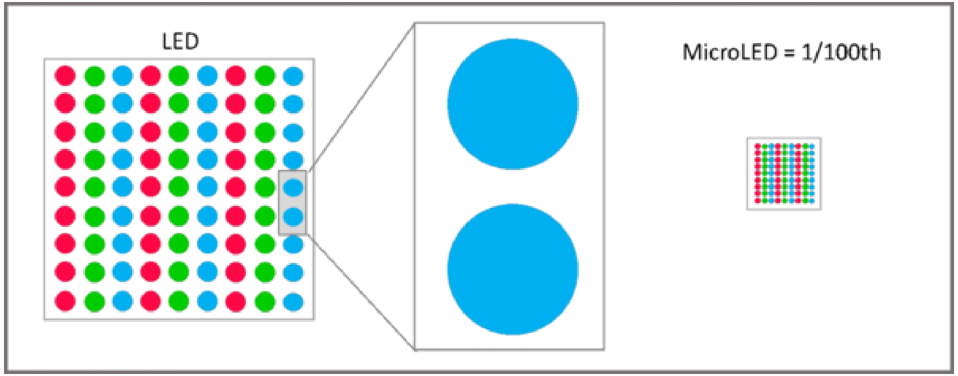
What are Emissive Displays?

- Emissive displays
  - Source of illumination: each pixel emits light and is controlled independently
  - A pixel is typically made a red, blue, and green (or RGBW) sub-pixels



Types of Emissive Displays

- OLED
- MicroLED
- MicroOLED
- Also
  - Quantum Dot
  - Plasma
  - Field Emissive
  - Thin-film electroluminescent



Size Definitions (Roughly):

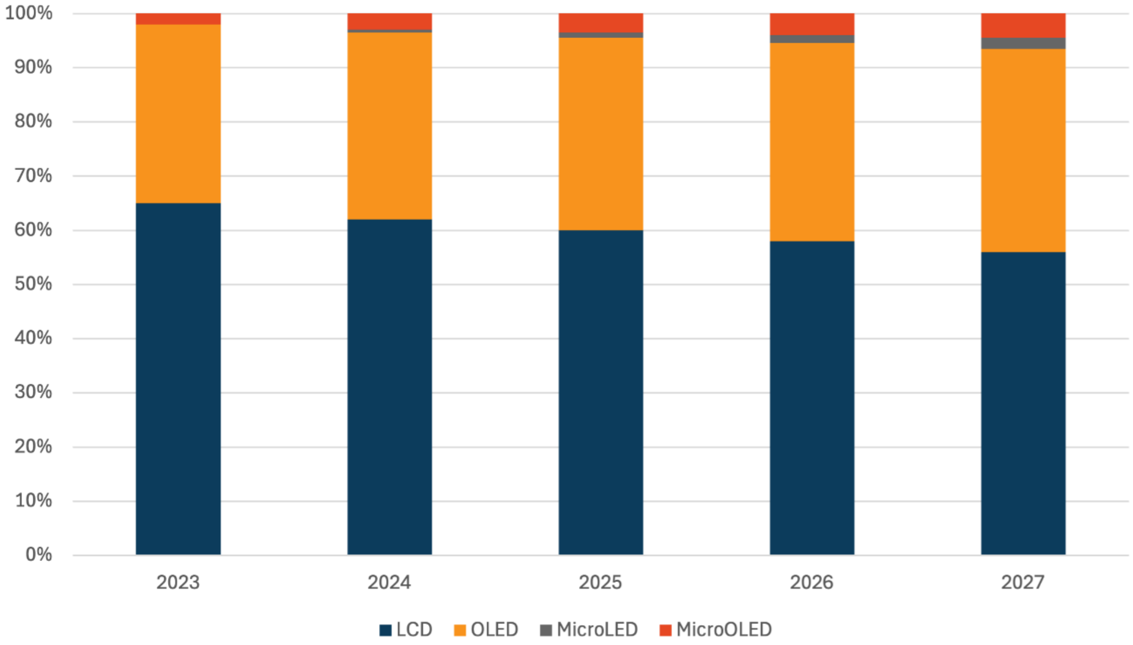
MicroLED <50 µm

MiniLED 50 µm – 100/150 µm

LED 150 µm – 1 mm +

Adoption of MicroLED & OLED

- Rising demand especially in premium display segment
- OLED, MicroLED, and MicroOLED predicted to reach 45% of display market share by 2027



Emissive Display Characteristics

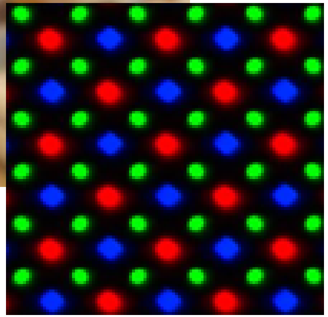
- **Performance Advantages:**
  - High luminance
  - High contrast
  - High pixel density
  - Wide color gamut
  - Flexibility (for curved or folding displays)
  - Lower power usage
  - Stable at wide range of operating temperatures
  - Higher resolution (microLED)
  - Longer lifespan (microLED)

Improved visibility, contrast and legibility in all ambient light conditions

Quality Challenges of Emissive Displays

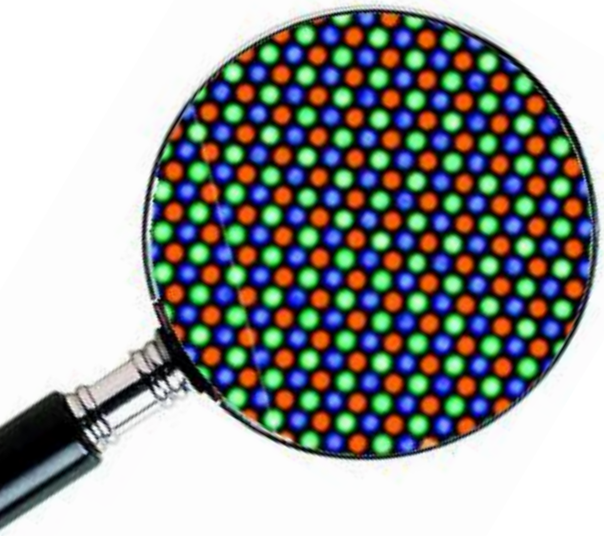
- Display defects
- Non-uniformity across a display, individual emitters vary in output

MicroLED
Display



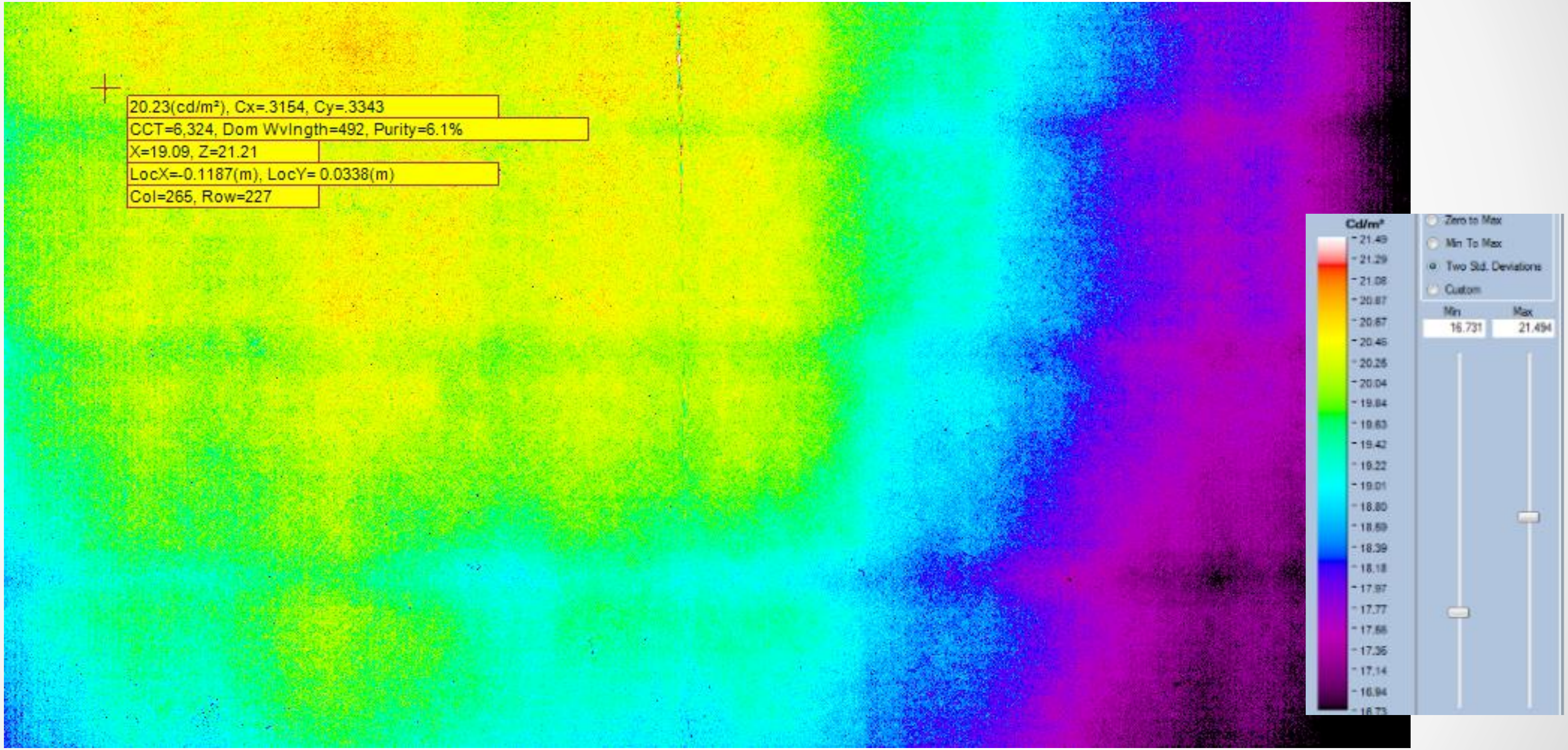
OLED
Display

New Challenges

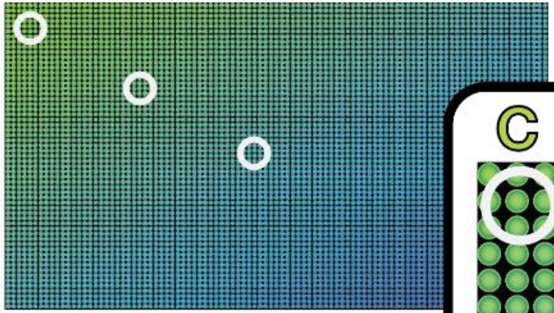


- Emitters are extremely small and densely populated in various patterns.
- Displays exhibit pixel-level variation from individual emitter state.
- The color of each pixel depends on brightness.
- Display may have regional non-uniformity (mura) at low grey levels.

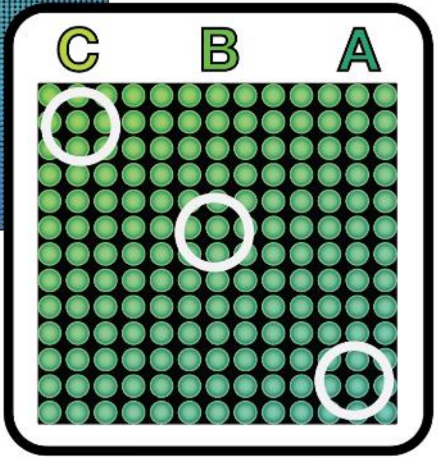
White OLED Display



Emissive Display Characteristic: Variability

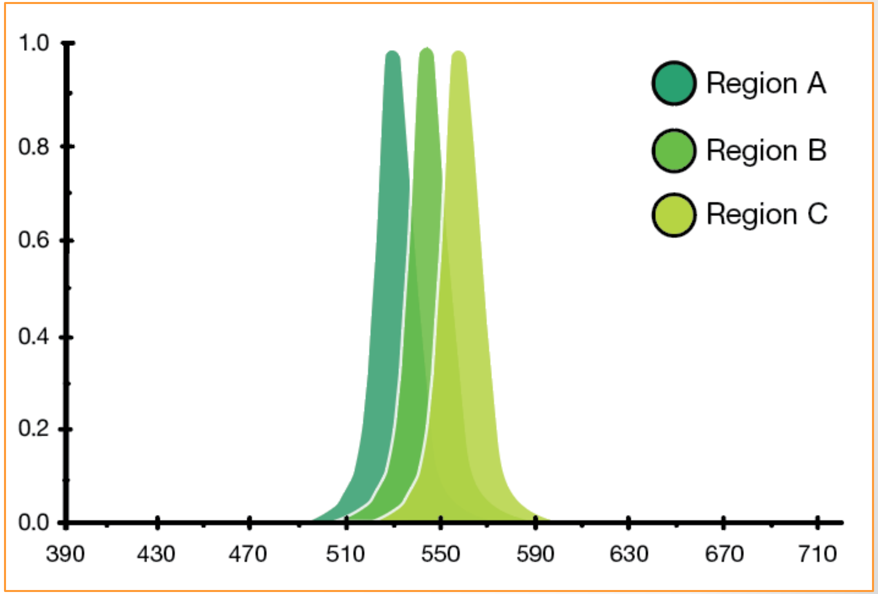


Example of an emissive OLED display



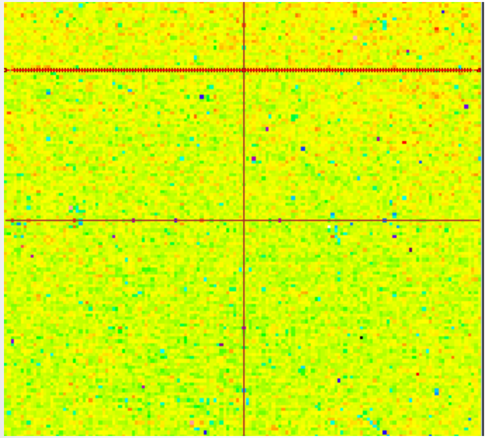
Magnification of display pixels A, B, C

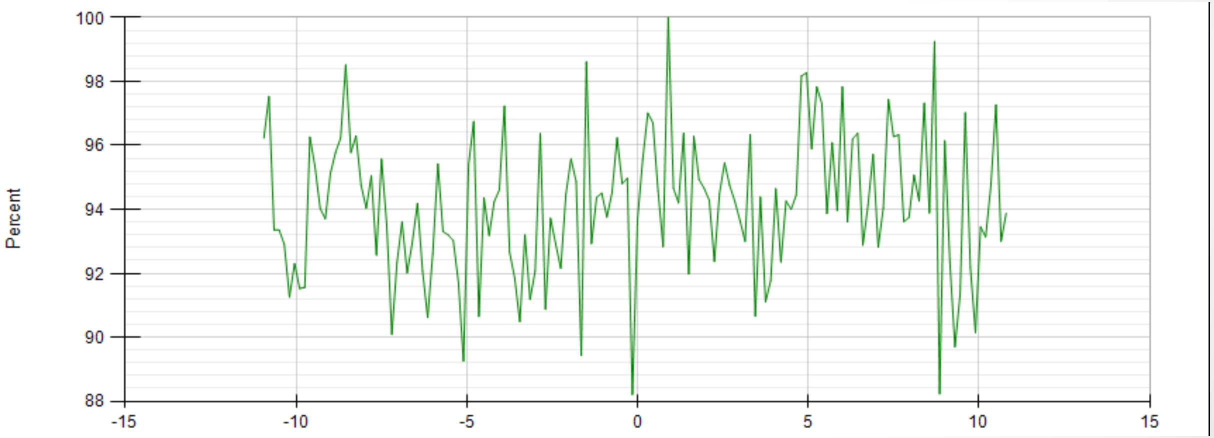
Spectral data for display pixels A, B, C



Pixel-level Variation

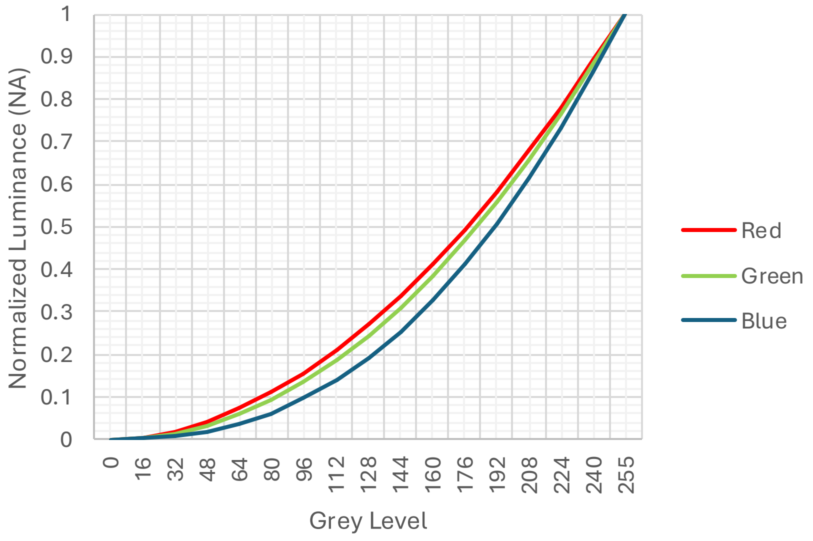
At high grey levels (bright display), there is strong pixel-level variation, which is noticeable to the observer.





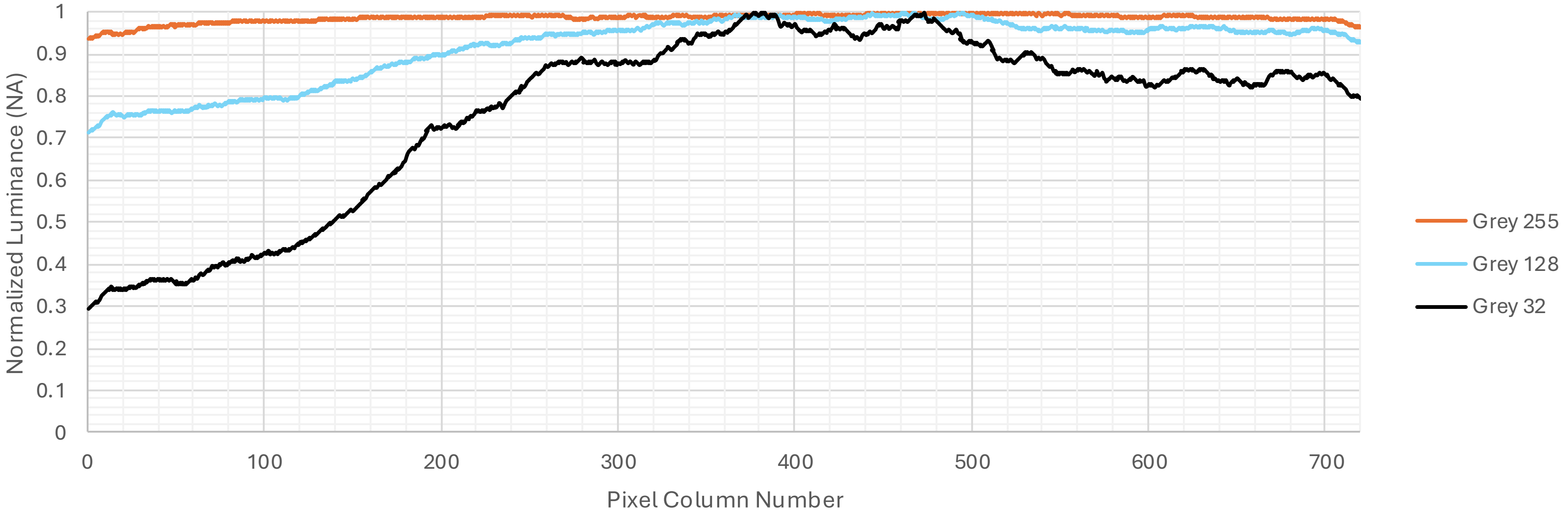
Color Dependence on Grey Level

- Response over grey level is different for the red, green, and blue emitters for the same pixel within an OLED display.
- This response can lead to an overall white point change of the display over grey level, as well as on the pixel level.

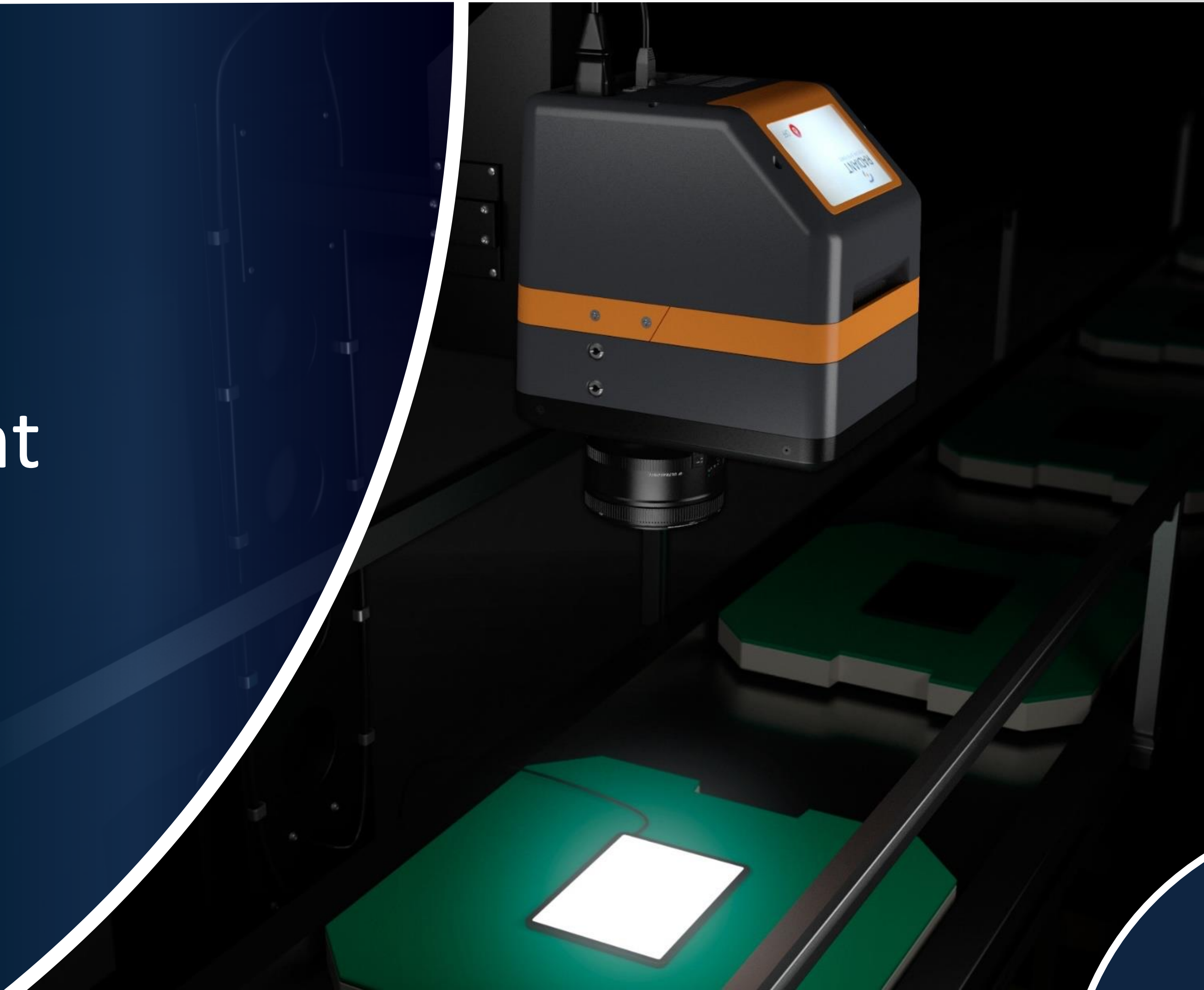


Regional Non-Uniformity

- **Mura** in OLED displays can appear at low grey levels, while the high-grey level can look uniform.



Measurement Challenges



Measurement Considerations

Imaging Precision

Image-based system that optimizes measurement data acquired at each pixel

Measurement Accuracy

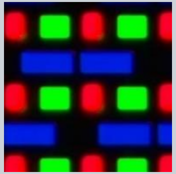
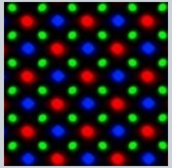
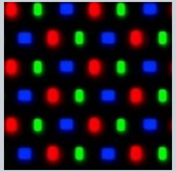
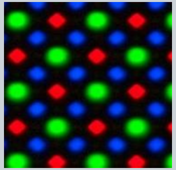
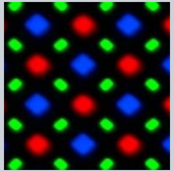
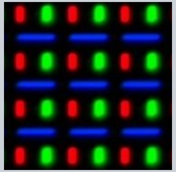
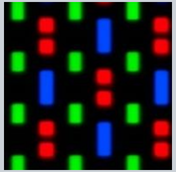
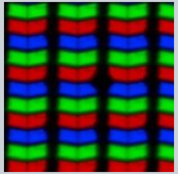
Calibrated, CIE-matched measurement system that measures accurate light and color values

Test & Analysis Tools

To process images and calculate correction factors

Sub-pixel Layout Summary

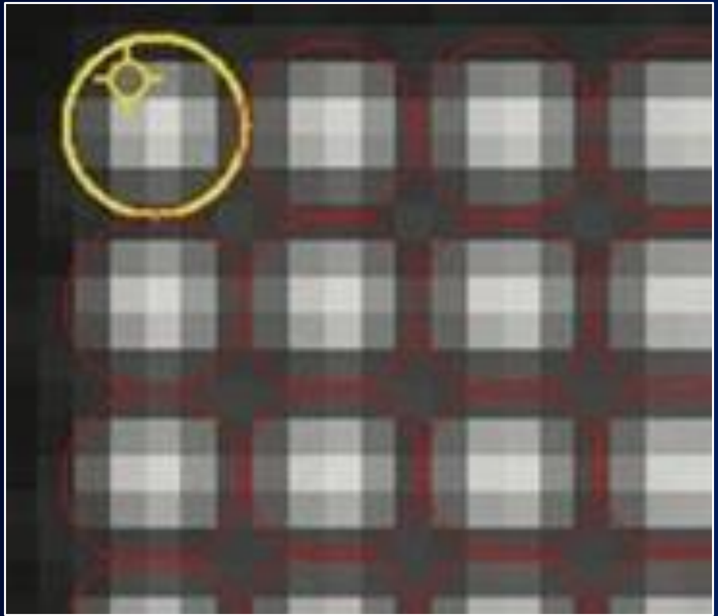
Every OLED device arranges pixels differently, with respect to layout and resolution.

	OLED Laptop	**OLED Phone 1**	**OLED Phone 2**	**OLED Phone 3**	**OLED Phone 4**	**OLED Watch 1**	**OLED Watch 2**	**LCD Phone 1**
FOV: 250um (Full White)								
Resolution	2560 x 1440	1440 x 2560	1080 x 1920	1080 x 1920	1080 x 1920	390 x 312	400 x 400	1080 x 1920
Pixel pitch X	0.12 mm	0.05 mm	0.10 mm	0.13 mm	0.07 mm	0.08 mm	0.09 mm	0.08 mm
Pixel pitch Y	0.12 mm	0.05 mm	0.13 mm	0.13 mm	0.07 mm	0.08 mm	0.09 mm	0.08 mm
RGB primary observations at 20% brightness		R = R+G G = G+R+B	No isolated primaries	R = R+G+B		G = G+R+B		

Measurement: Challenges

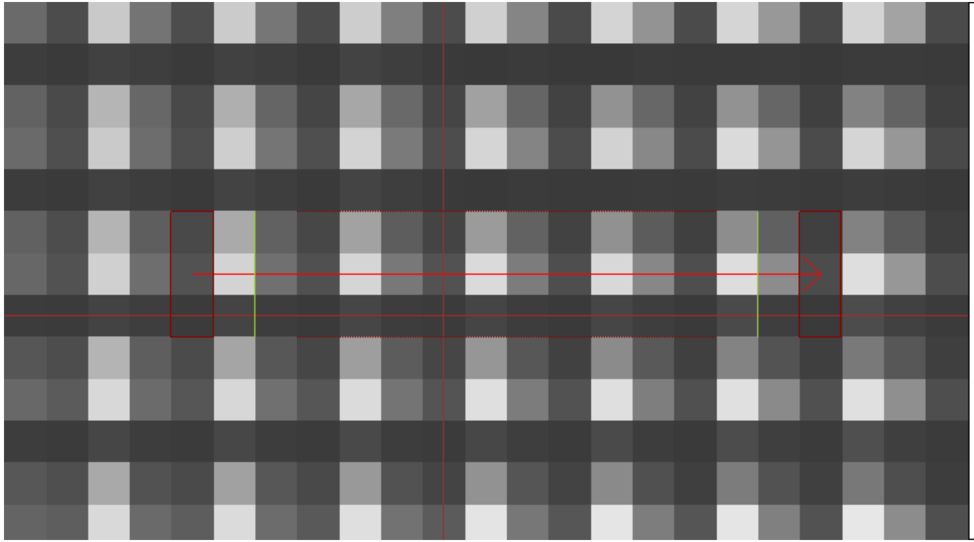
- Limited sensor pixels/display pixel
  - ➢ Sensor pixels can fall *partially* within the ROI, with significant area outside of the ROI
  - ➢ There is no way to use the signal from “whole pixels” to get an accurate measurement

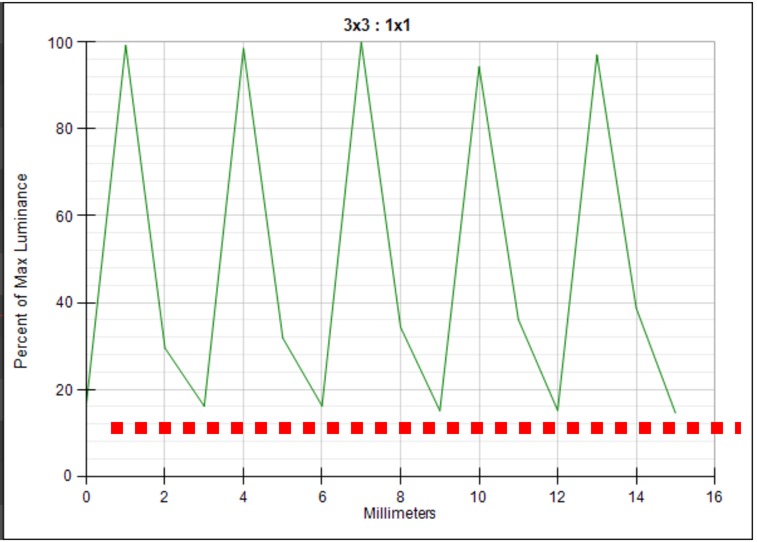
- Pixels in high-PPI displays are very close together
  - ➢ Avoid factoring in luminance of neighboring pixels



Importance of Resolution

What happens if we don't have sufficient imaging resolution?

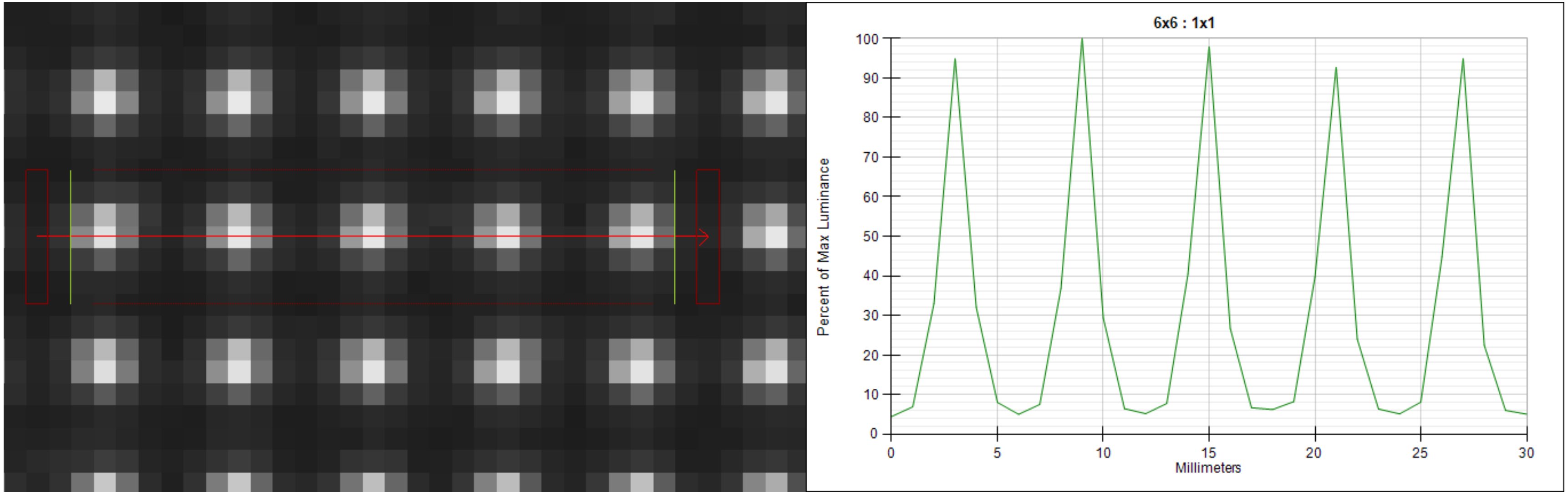




3x3 sensor pixels: 1 display pixel

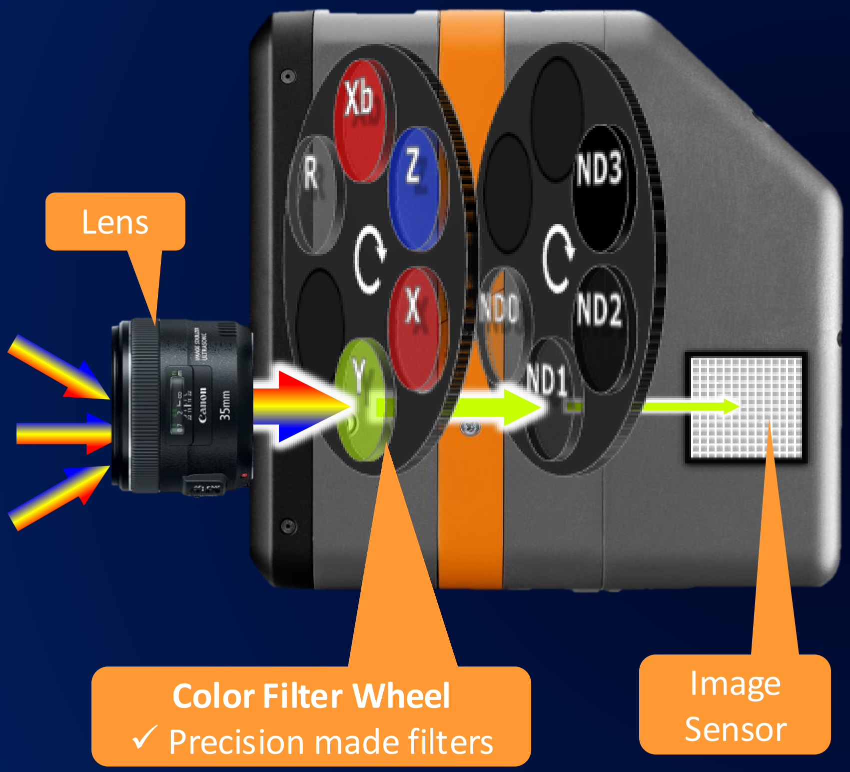
Importance of Resolution

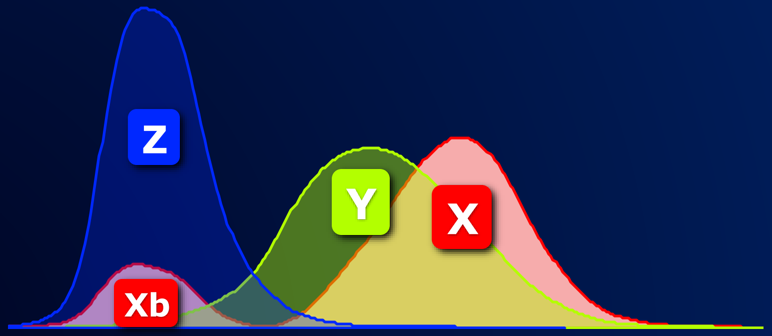
What happens if we don't have sufficient imaging resolution?



6x6 sensor pixels: 1 display pixel

Colorimeter: Tristimulus Filter System



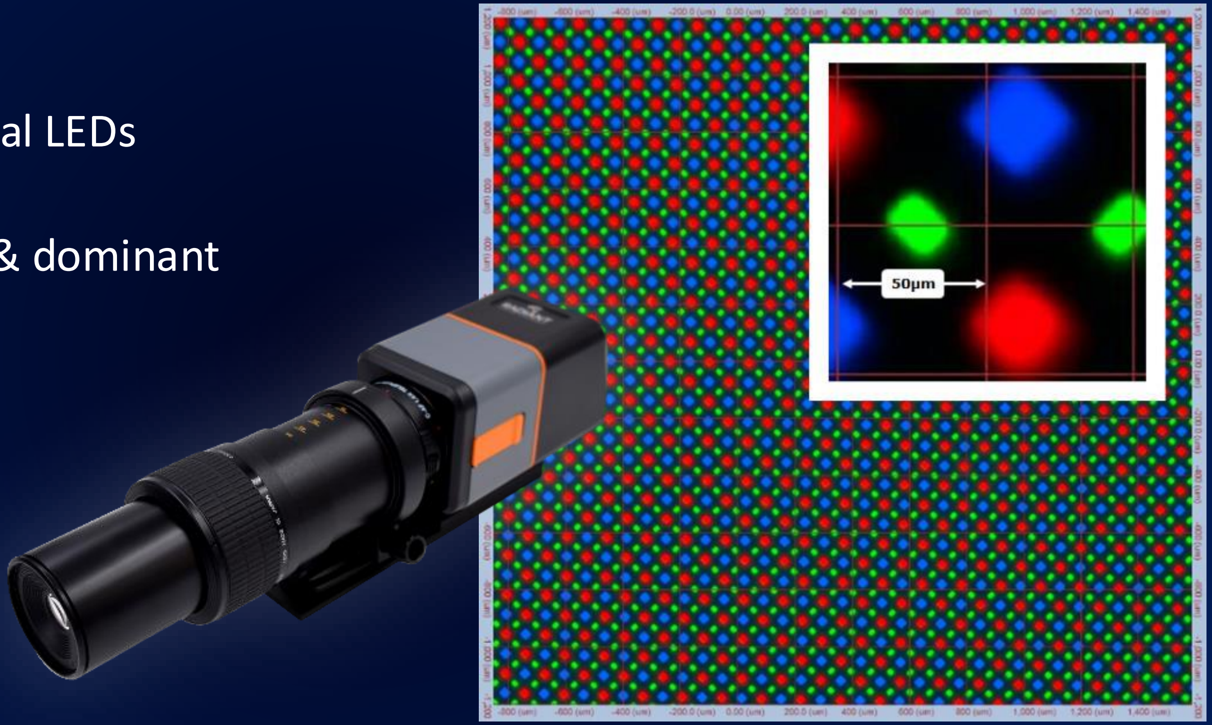


Each proprietary Radiant color filter precisely matches a CIE tristimulus curve; which allows for NIST traceable results.

Color images are a combination of images taken through each filter.

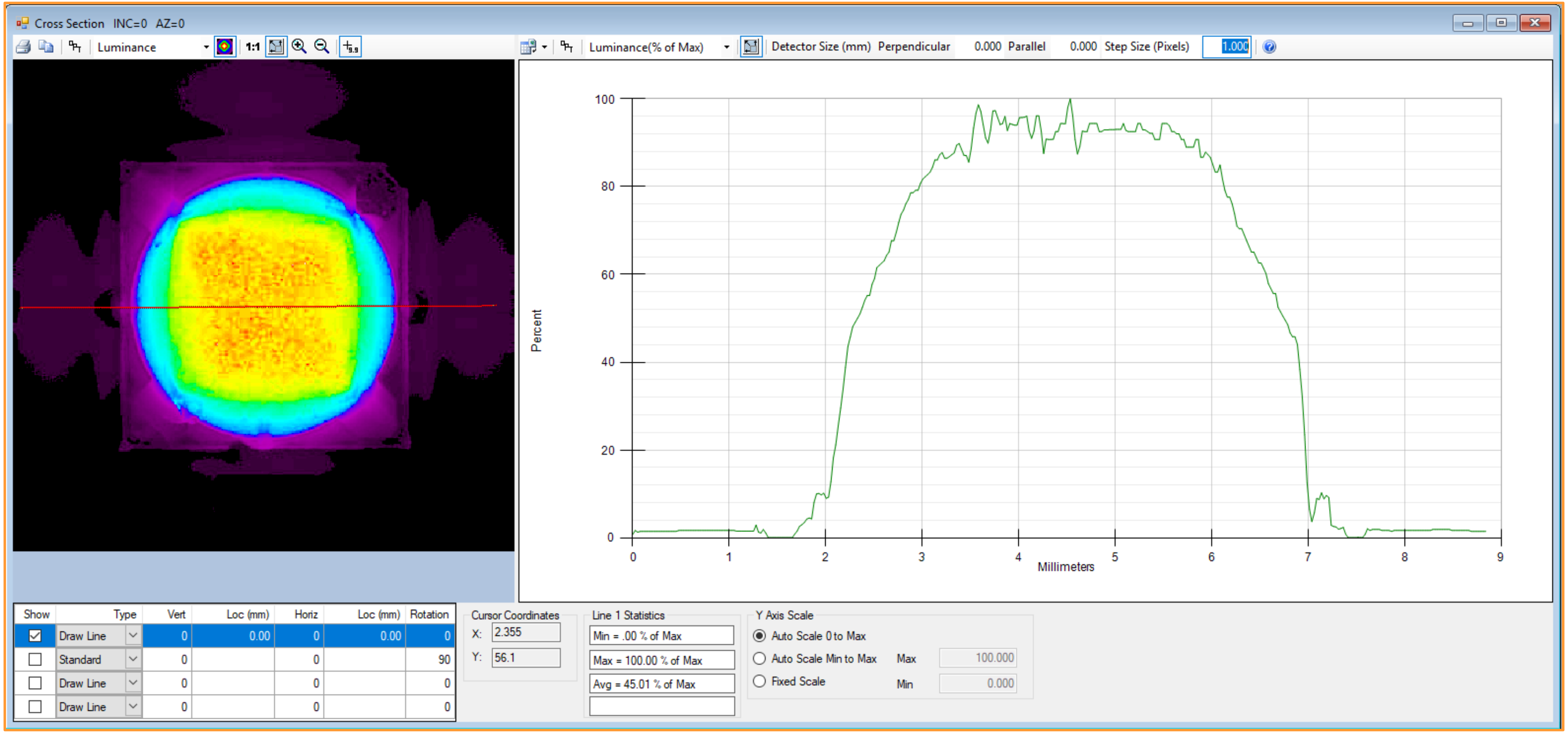
Microscope Lens

- Characterize individual LEDs
- Measure luminance & dominant wavelength

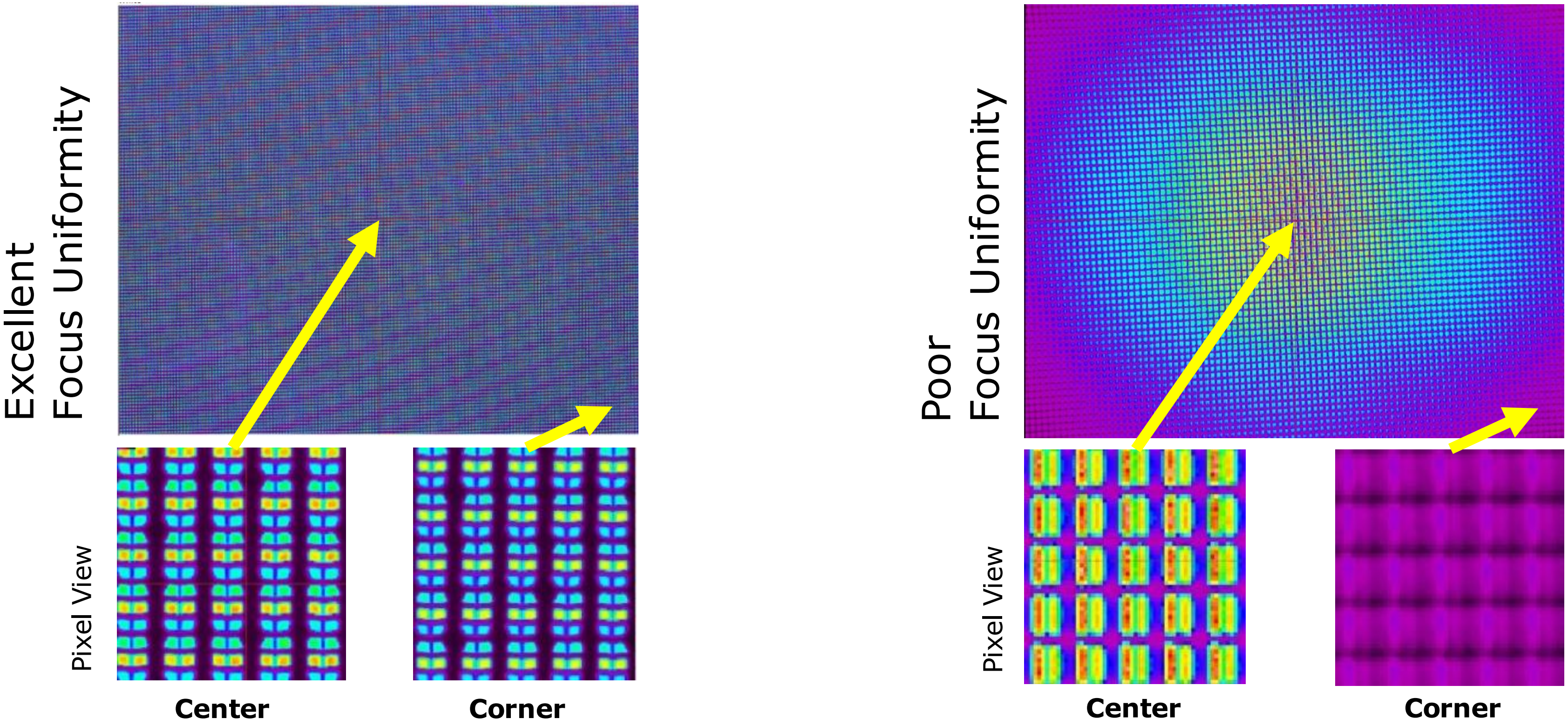


OLED Phone Display
I29 @ ~8x. 2.4mm FOV

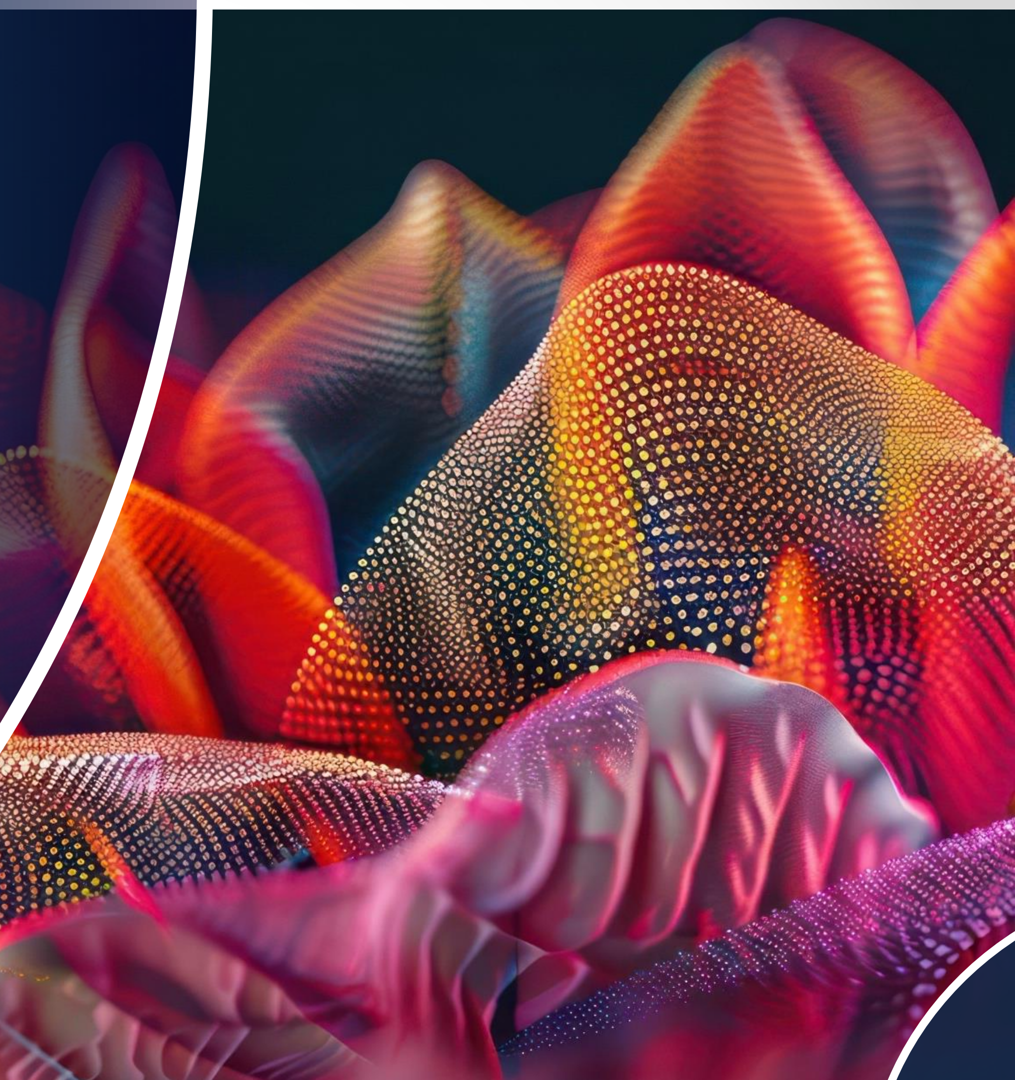
20x Microscope Example Measurement



Uniform Focus

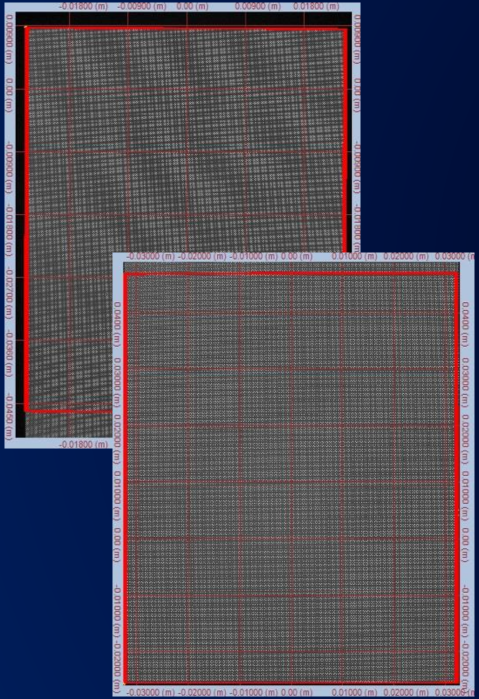


Methods for Testing

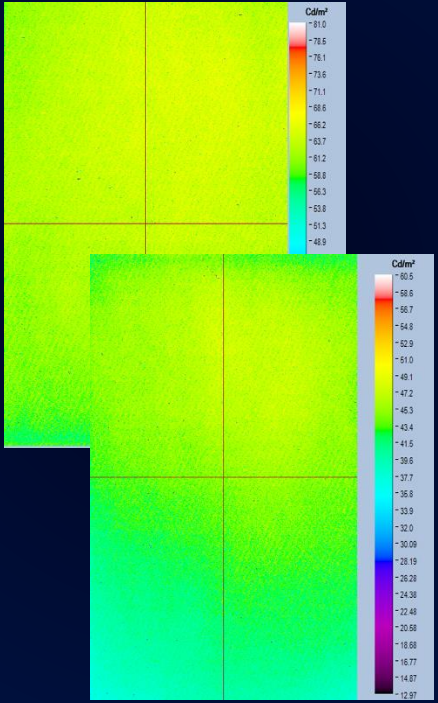


Pixel Measurement Steps

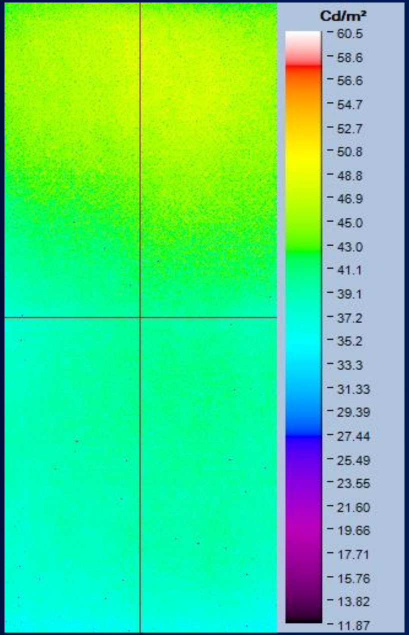
Raw Images



Synthetic Images



Concatenated Image

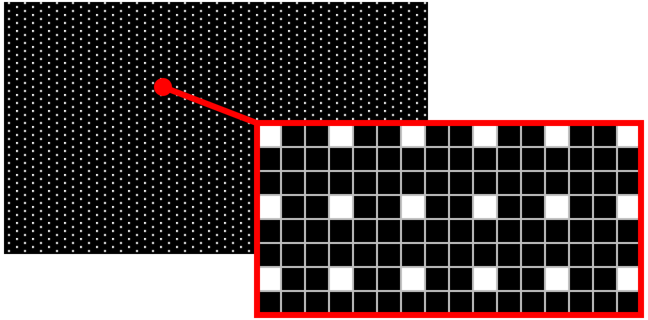


Spaced Pixel Measurement Method

Improving Measurement Accuracy

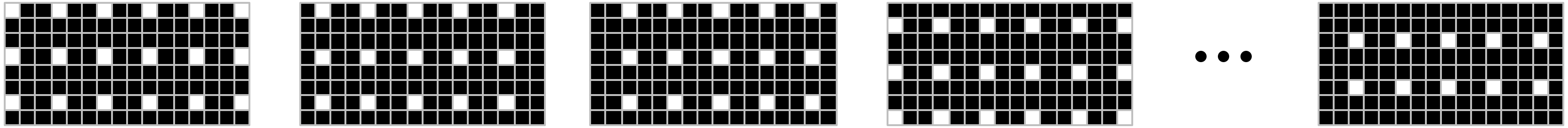
Spaced Pixel Test Patterns

Dot matrix test pattern



- In this method, a series of dot-matrix test patterns will be shown on the display.
- Each pattern has only a small portion of the display pixels turned ON (rest is OFF).
- The other test patterns are similar, but with different display pixels turned ON.
- In this example it will take 9x test patterns to ensure that every display pixels is turned ON one time.

Pattern 1 Pattern 2 Pattern 3 Pattern 4 ... Pattern 9

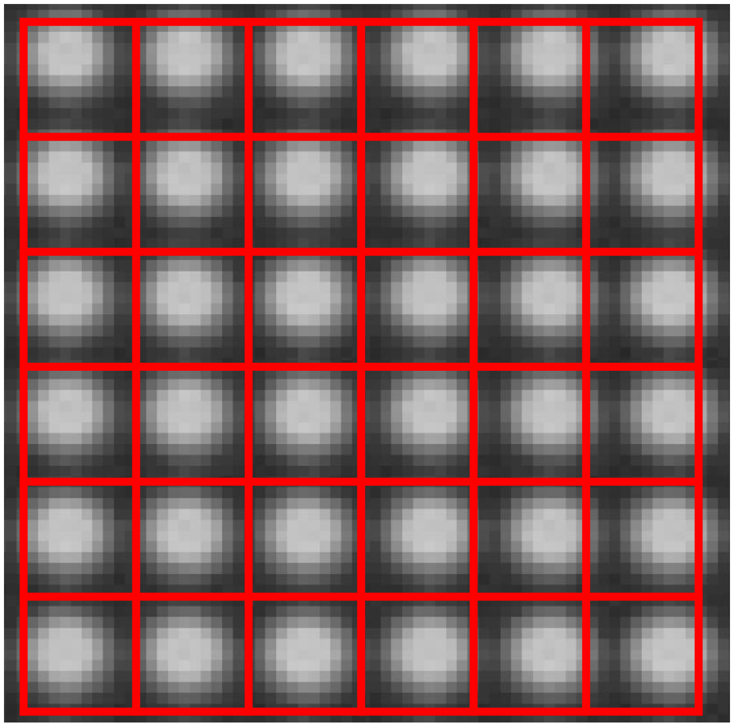


Fixed Grid Method and Active Registration

Improving Measurement Accuracy

Pixel Registration

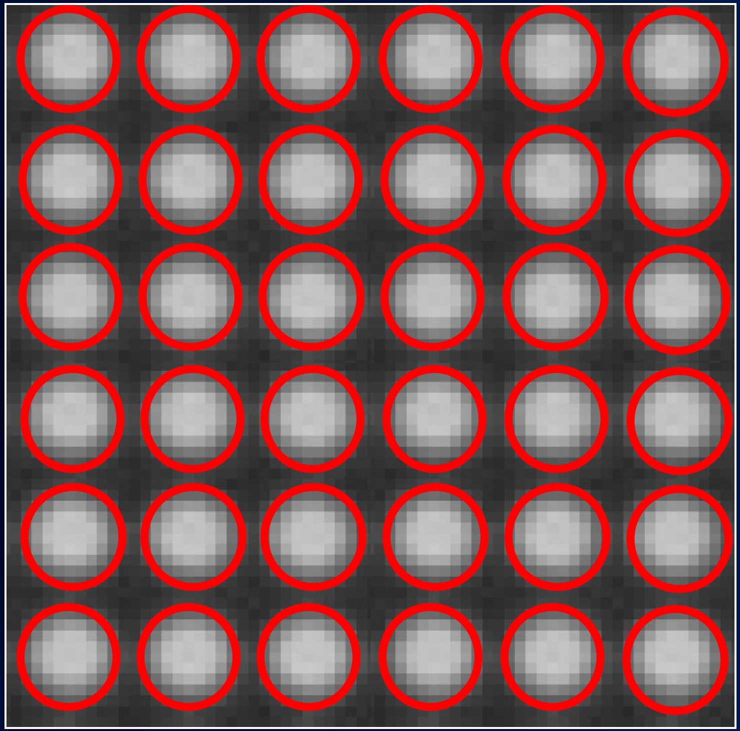
- **Fixed Grid Registration Method**
  Automatically identifies and places virtual detectors across each pixel irrespective of pixel orientation or display shape.
- **Spaced Pixel Display Pattern**
  Takes measurements of every other pixel pattern in one measurement, then takes a second measurement of the remaining patterns.
- **Fractional Pixel Calculation**
  Allows a measurement to capture a percentage of a pixel in a 'cluster' instead of excluding the pixel.



Active Registration

- **Active registration method:**
  - Use image processing to find pixels
  - Create ROI around each pixel

- **Advantages**
  - Improved tolerance for display and imaging system alignment

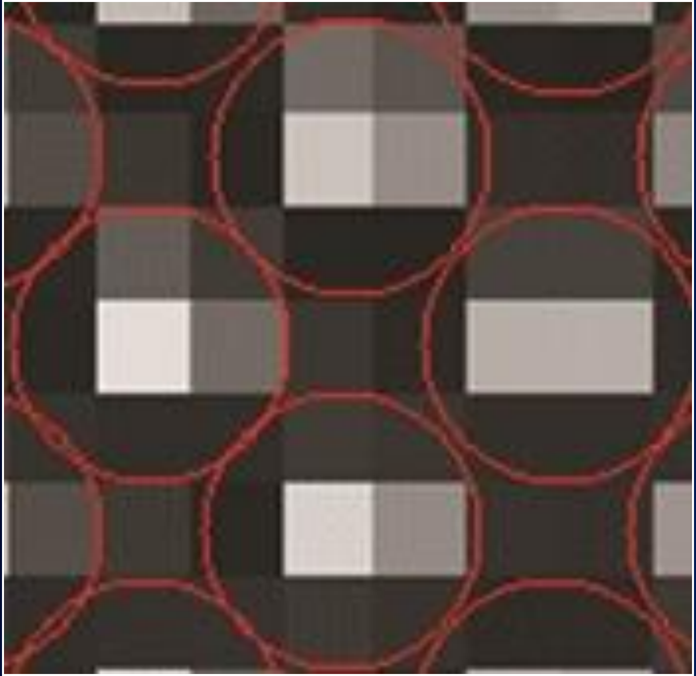


Eliminating Crosstalk

- **Crosstalk -** Light from neighboring pixels that impacts the measurement of a pixel interest.

- **Eliminating crosstalk requires optimizing:**

1. Resolution
2. Focus
3. Stray Light Control

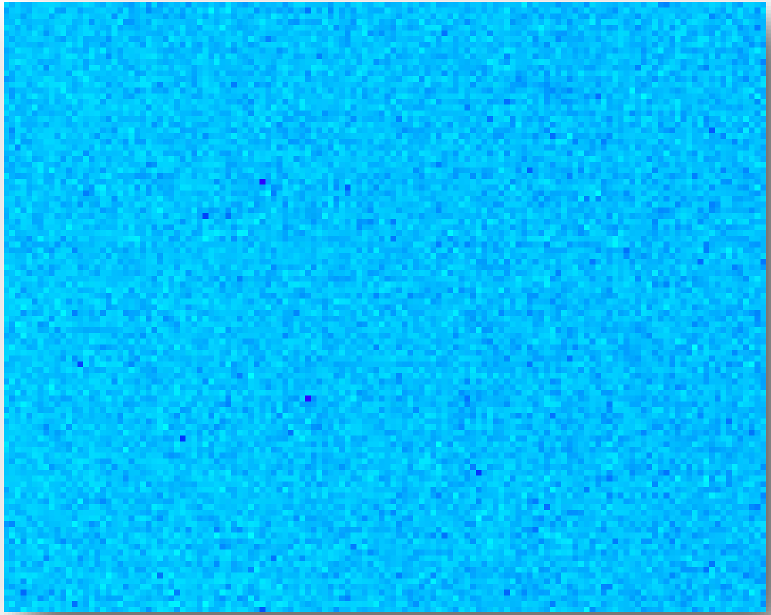


Fractional Pixel Measurement Method

Improving Measurement Accuracy

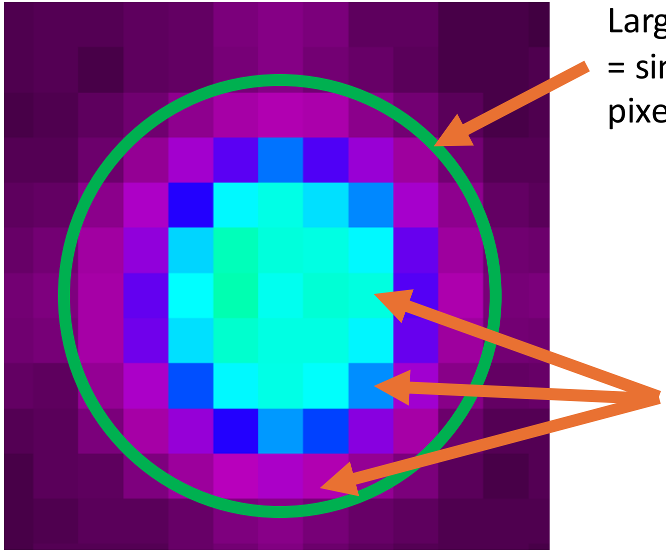
The Importance of Accurate Measurement for LED Correction

- Accurate measurement is a critical prerequisite for the appropriate application of correction coefficients.
- Inaccurate measurement will result in incorrect coefficient that produce persistent non-uniformity.



Non-uniformity is visible to the naked eye (sandy mura)

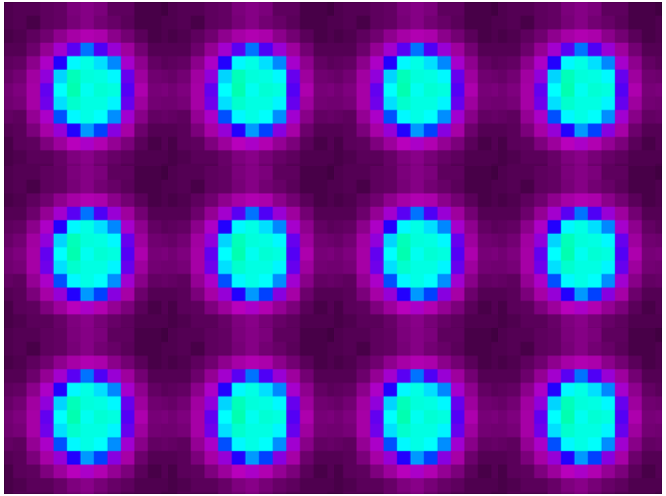
Critical for Accurate Measurement



Large bright area = single display pixel

Small squares = sensor pixels

Sufficiently Isolate Each Display Pixel *(Pixel Registration)*



Capture Accurate Values for Each Pixel *(Pixel Measurement)*

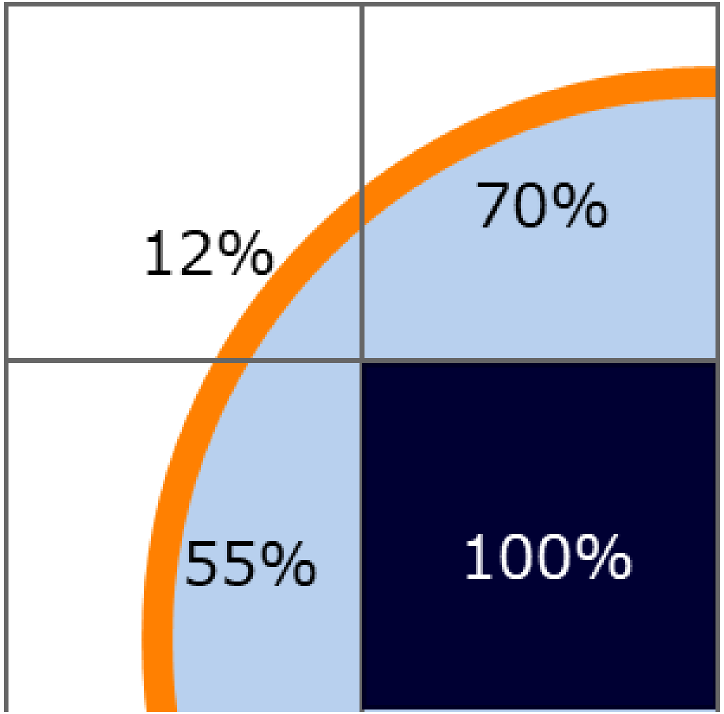
Fractional Pixel Measurement Method

What is the goal?

- Ensure accuracy of pixel-level measurements without requiring extremely high-resolution imaging systems

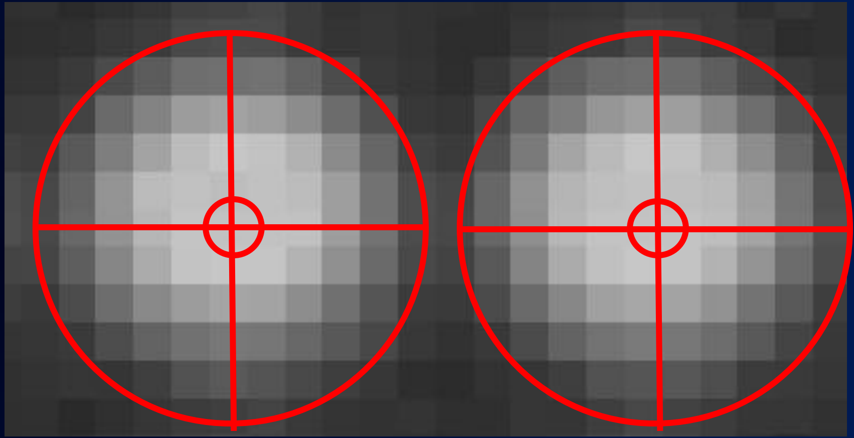
What does it do?

- Precisely register display pixels
- Accurately measure display pixels



Registration

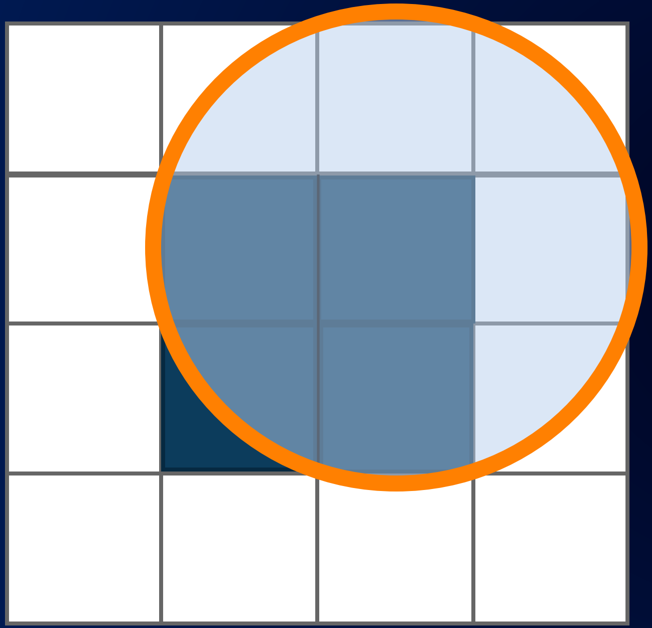
LED Screen



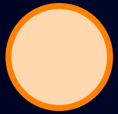
US7907154B2 - Radiant Vision Systems

Method and apparatus for on-site calibration of visual displays

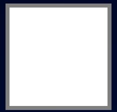
Registration: Traditional Approach



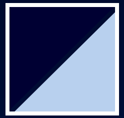
ROI Centered on Image Sensor Pixel: Measurement area excludes significant display pixel area.



ROI

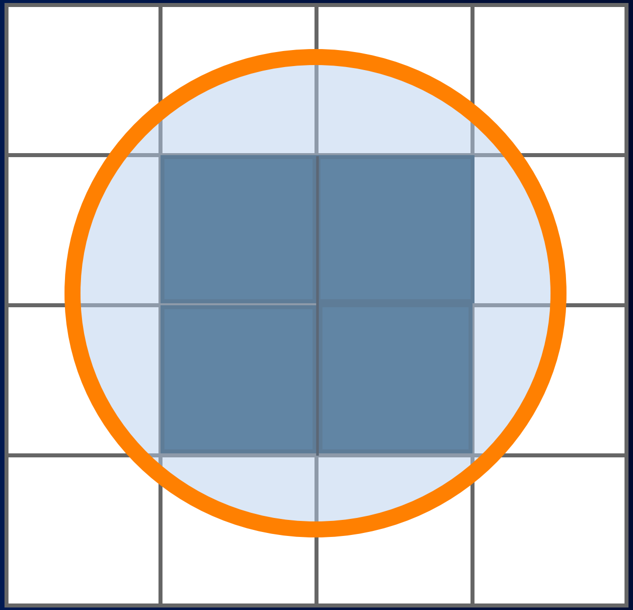


Sensor pixels

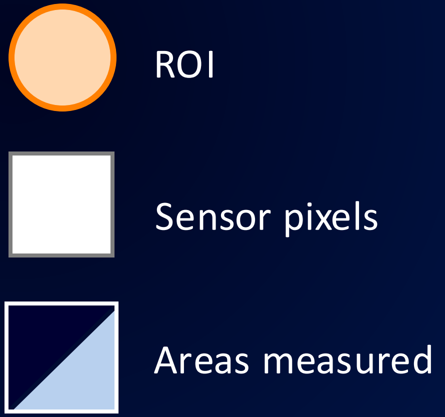


Areas measured

Registration: Fractional Pixel Approach



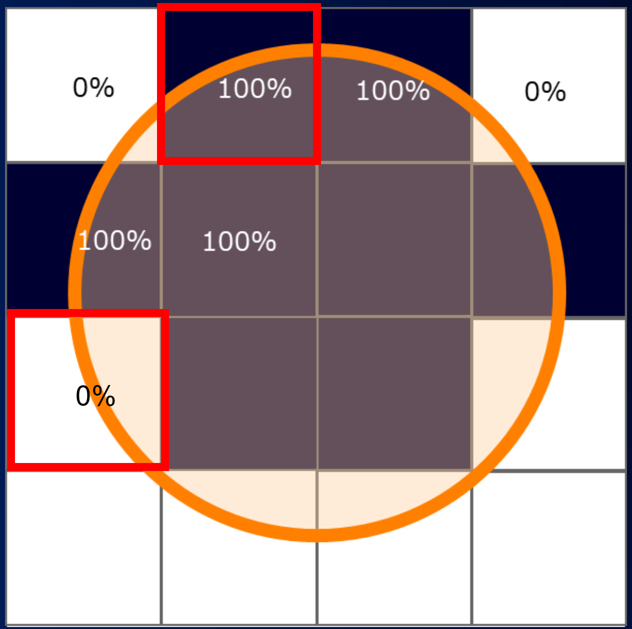
ROI Centered on Display Pixel: Measurement area isolates display pixel area.



Measurement: Fractional Pixel Approach

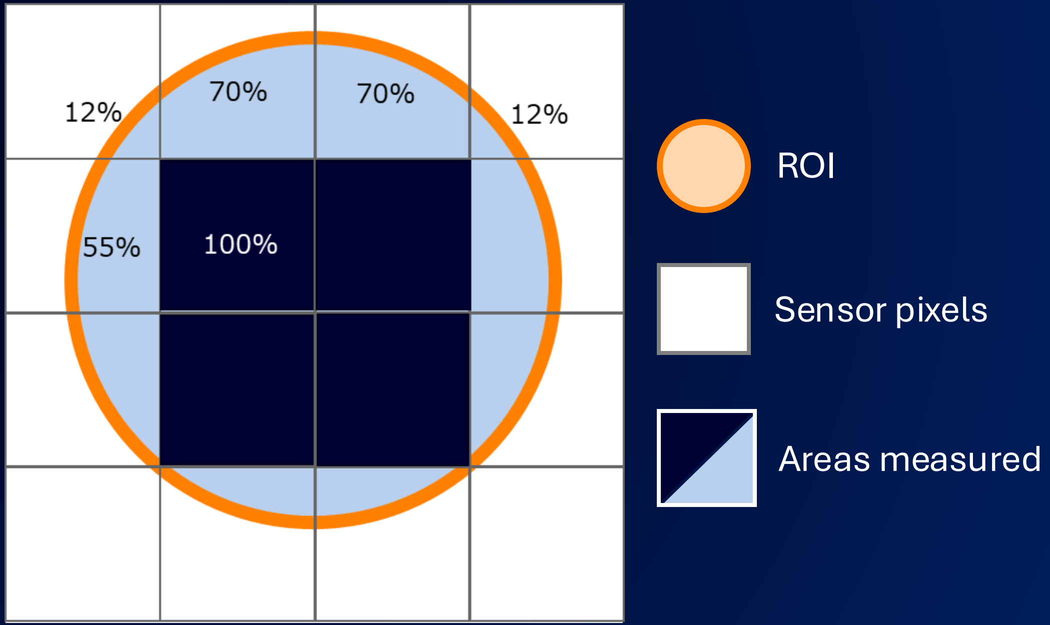
TRADITIONAL METHOD

Pixels with ≥50% fill are measured as 100%
Pixels with <50% fill are measured as 0%



FRACTIONAL PIXEL METHOD

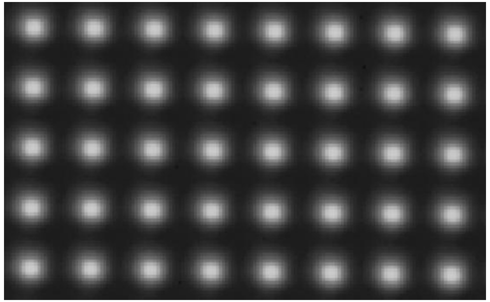
All pixels are weighted by exact fill proportion

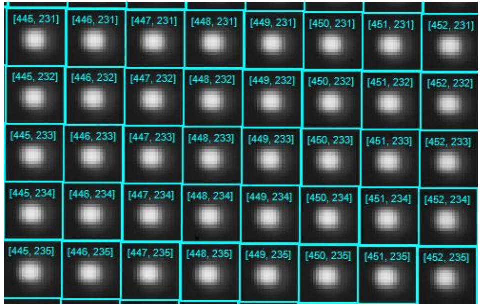


Registration Process

Fixed Grid Registration

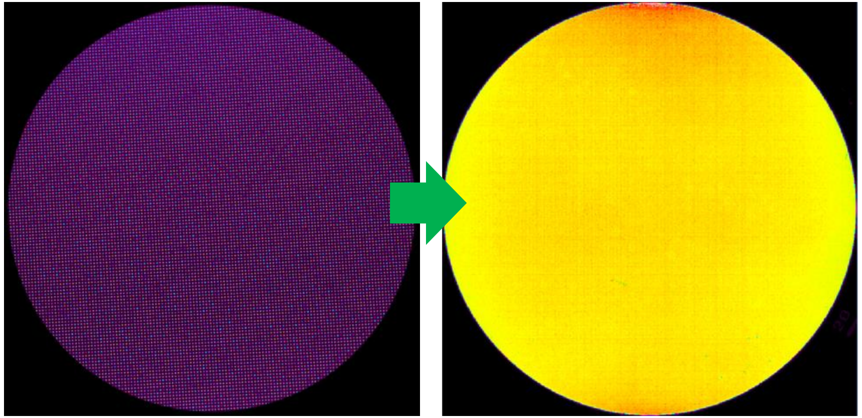
- Finds LED’s at corners/edges ONLY
- Uses known pixel pitch to place grid points over every LED
- Measures every LED’s luminance (Cd/m^2), and color (CxCy/u’v’)

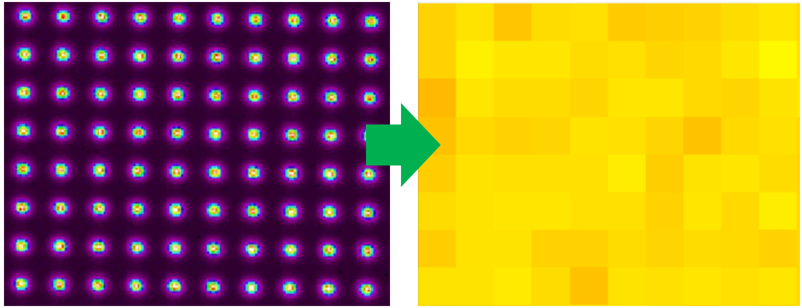




Synthetic Image Created

Once we have the data for every LED, Radiant software makes a "Synthetic Image" of the display, where every "pixel" is the luminance/color average of that LED. Effectively, this removes the black space between LED's, and produces what looks like a standard display.





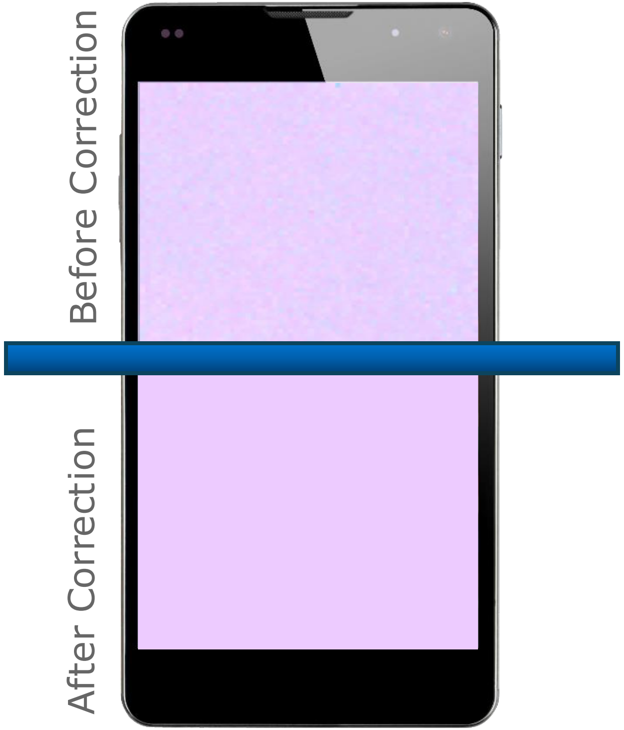
Now we can see trends in luminance & color, and can run standard display tests on the device.
We can also calculate correction coefficients to optimize uniformity across the display.

Pixel-Level Correction (Demura)

Measurement Needs and Challenges

What is “Demura”?

- Even when OLED pixels receive the same electrical signal input, inconsistent luminance and chromaticity can occur from pixel to pixel
- These differences can be resolved using an in-line correction process called “**Demura**”
- Two steps to the Demura process:
  1. Use imaging colorimeters to evaluate and quantify pixel uniformity issues
  2. Apply grey-level passes to resolve uniformity based on precise pixel correction coefficients



Demura Correction Process

The correction process requires:

- Measurement accuracy
- Measurement repeatability
- Careful definition of performance targets
- Compensation for OLED pixel and measurement geometries
- Adjustment for human visual perception

1.Capture Image & Measure Display → 2. Register Pixels → 3. Obtain Individual Pixel Luminance & Color → 4. Generate Synthetic Image to Represent Data → 5. Calculate Correction Coefficients → 6. Transfer to Screen Controller

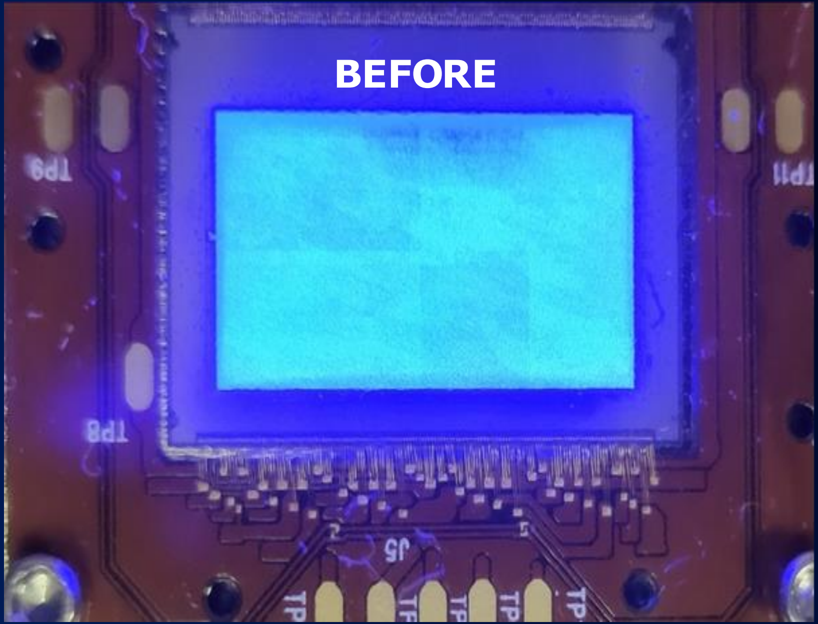
Pixel Correction (Demura) Procedure

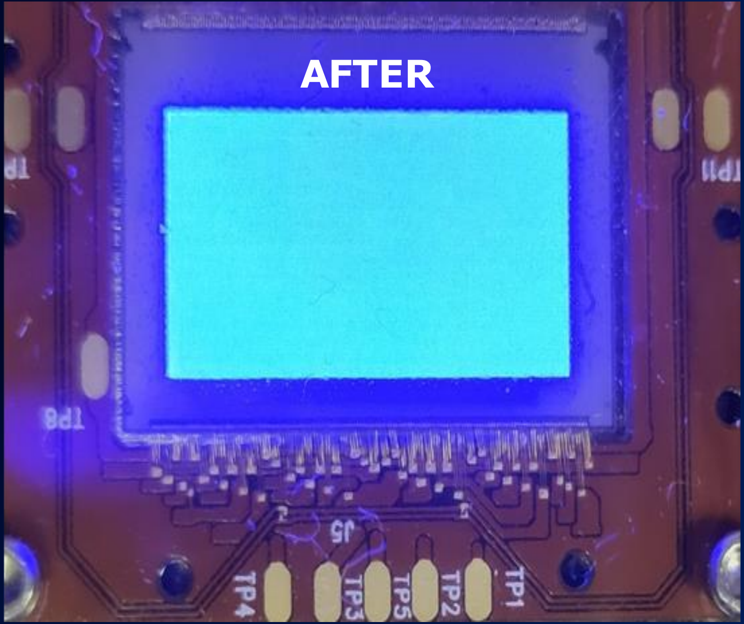
1. Take an image using a **high-resolution** image-based measurement system
2. **Register** or apply a Region of Interest ("ROI") to each pixel or subpixel in the display
3. **Measure** the average signal (luminance) for each pixel or subpixel ROI at different grey levels
4. Compute a **correction factor** that will perform a pixel uniformity correction for all grey levels

Above: ProMetric® 61MP I-series Imaging Colorimeter

RESULT: Uniform Display Appearance

MicroLED Correction using Radiant solution and methods



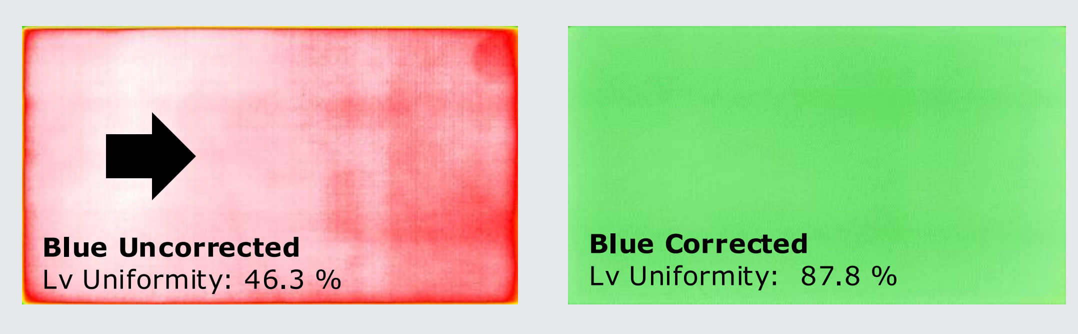


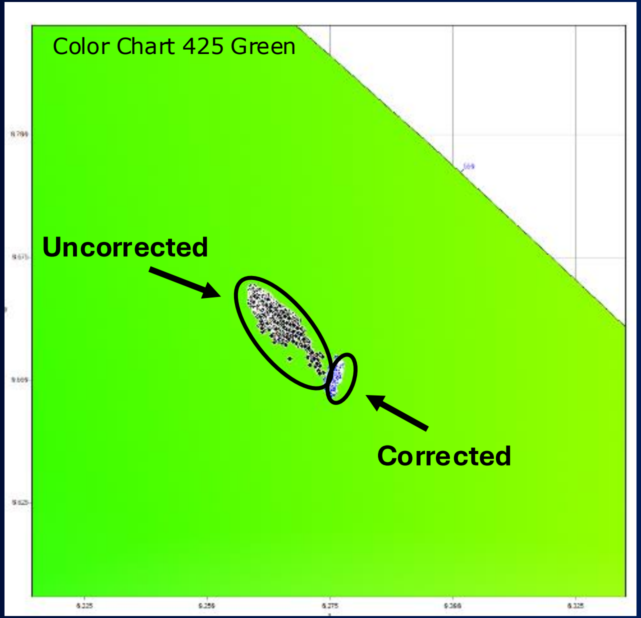
Images © Jasper Display Corporation

RESULT: Uniform Display Appearance

BEFORE **AFTER**

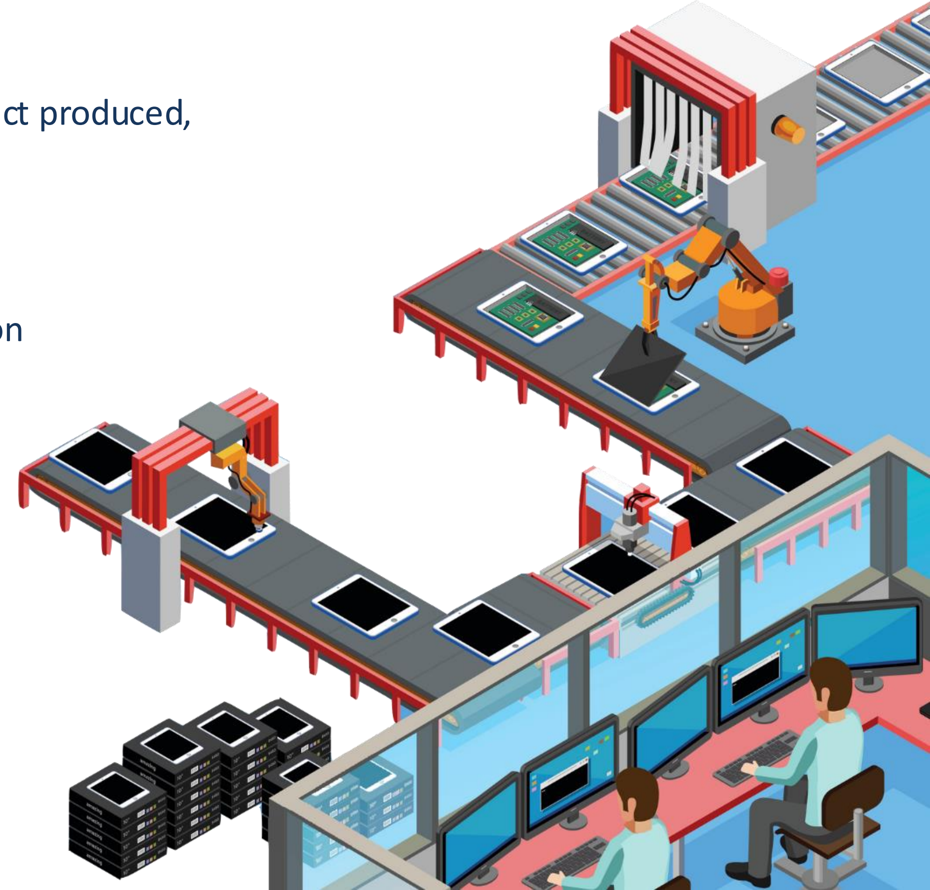
FALD
(MiniLED)
Display





Why Correct Emissive Displays?

- **Improve yield**
  - The more displays that are corrected, the more product produced, the greater a supplier’s competitive advantage
- **Limit waste due to inevitable quality issues**
  - All MicroLED/OLED displays exhibit pixel-level variation
  - Some displays can be corrected, reducing scrapped materials
- **Safeguard efficiency**
  - Automated, in-line MicroLED/OLED correction solutions keep manufacturing processes moving despite quality issues



Why Choose Radiant?

Superior Hardware

High-resolution photometric imaging for rapid and repeatable luminance measurement at all light levels

Software

Dynamic registration, pre-programmed test parameters, and multiple analyses performed from a single image

Color Accuracy

CIE-matched tristimulus (x,y) filters for precise chromaticity measurement, NVLAP-accredited ISO-17025 calibration lab

Experience

30+ years improving quality inspection and product yields for major global brands in consumer electronics, automotive, and aerospace industries

Service & Support

Worldwide application engineering staff for support when and where you need it

Customization

Collaborative approach to tailor solution and reporting for your needs

RADIANT
VISION SYSTEMS

Thank you!

Questions? Contact Info@RadiantVS.com