WHITE PAPER
How to Use Imaging Colorimeters to Improve OLED Display Production Testing Efficiency and Yields
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Introduction

OLEDs (Organic Light-Emitting Diodes) are emerging as the next wave of technology in the flat-panel display market. This is exciting because OLED displays promise improved display appearance for both smartphones and large-format TVs at lower cost and power than other display technologies. OLEDs have superior contrast ratios and sharper images with deeper blacks and more vibrant colors. They require no backlight, resulting in a thinner, lighter-weight display that uses less power. OLEDs also bring a dramatic boost in responsiveness, about 1,000 times faster than existing technologies, virtually eliminating blur on fast-moving and 3D video.

As OLED manufacturers work to launch commercially viable OLED based products, high costs due to manufacturing yield issues have hindered widespread OLED technology adoption, most dramatically in large-format implementations, as they drive up end-customer prices. The smartphone market has been the most successful segment for OLED technology to date and will likely be the catalyst that drives long-term adoption of OLEDs for other applications. Lux Research analysts predict that by 2017 more than one-third of all smartphones will have an OLED screen [source: http://www.luxresearchinc.com/blog/2012/06/smartphone-market-will-ring-up-largest-share-of-the-oled-display-market-through-2017/]. This growth will require improvements in manufacturing efficiency.

Figure 1 - Smartphone market leads the way for OLED adoption.

OLEDs have superior contrast ratios and sharper images with deeper blacks and more vibrant colors. They require no backlight, resulting in a thinner, lighter-weight display that uses less power.
For the large-format OLED TVs, although the short-term market size is small, analysts at NPD DisplaySearch forecast that shipments will exceed 3% penetration in the TV market by 2016 [source: http://www.dolcera.com/wiki/index.php?title=OLED_Mobile_Phones_Market_Research_and_Analysis_Report]. Manufacturers have found it difficult to achieve consistent picture quality on large-format OLED displays creating low production yields. This impacts the timing of viable market entry, and drives up retail price for OLED large-screen TVs. Current large screen OLED TVs are priced upwards of $10K, making them only of interest to affluent early adopters; the price point for volume market adoption and replacement of current technologies will be significantly lower.

**OLED Manufacturing Challenges**

OLED technology faces several unique challenges to the manufacturing process, regardless of the size of display.

**Line Mura**

In the OLED manufacturing process, material is deposited that forms the individual sub-pixels. If this process is not completely uniform, the end result may be line mura which will have well-defined horizontal and/or vertical orientation in the OLED display.

![Figure 2 - OLED display with uncorrected line mura.](image)

**Sub-Pixel Luminance Performance**

OLEDs use organic semiconductor material that is emissive, meaning it lights up when electric current is applied. Because of this, OLED displays do not require a backlight. OLED display pixels are composed of red, green, and blue sub-pixels. The output of each sub-pixel is individually controlled. Brightness (luminance) and color are determined at a pixel level by the combination of the sub-pixel outputs. Due to production variations, there may be variations in luminance for the same electrical signal input throughout the population of same colored sub-pixels on the display. This results in variations in brightness from pixel to pixel.
This sub-pixel-level variability in OLED displays results in different performance issues than in LCDs. In LCD panels, adjacent pixels generally have the same luminance because LCDs use a common backlight that ensures the brightness of adjacent pixels will be fairly uniform.

**Display Color Non-Uniformity**

A second impact of inconsistent brightness levels of the OLED display sub-pixels is reduced color accuracy and color non-uniformity across the display. To achieve accurate and uniform colors, the brightness of each individual sub-pixel must be within tight bounds. The reality is that even with a well-controlled manufacturing process, sub-pixels in OLED displays will have significant variations in brightness levels. When these variations are not compensated for, there is a lack of color uniformity across the display, reducing picture quality to potentially unacceptable levels and so reducing production yields.

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**Figure 3** - Sub-pixels combine to create pixels with various colors and brightness.

To achieve accurate and uniform colors, the brightness of each individual sub-pixel must be within tight bounds.

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**Figure 4** - Incorrect brightness levels create non-uniformity across an OLED display.
Imaging Colorimeter Applications to OLED Display Manufacturing

Imaging colorimetry-based testing systems have demonstrated success in improving quality and reducing production costs for LCD displays and LED display screens. Testing applications span smartphones, tablets, laptops, monitors, TVs, and digital billboards. These proven techniques can be readily adapted to OLED display production testing.

The two key components of these systems are:

1. **Imaging Colorimeters**, which provide accurate measurement of display visual performance that matches human perception of brightness, color, and spatial (or angular) relationships. High-performance imaging colorimeters can accurately measure the luminance (brightness) of individual sub-pixels in an OLED display as well as overall display uniformity.

2. **Test Execution and Analysis Software** – production-line software for image analysis to identify defects and quality issues, quantify their magnitude, and assess the measurements to make pass/fail determinations. This software can also include display performance correction methods that can be adapted to identify and correct variations that are unique to OLED displays.

Improving Delivered Quality to Enhance Customer Experience

In a typical manufacturing process, display visual performance is tested by human inspectors, resulting in high variability in the quality of delivered product. With the improved image quality of OLED displays, this is becoming an even more significant issue. Human inspectors are not able to consistently and repeatedly evaluate display quality on high-contrast, high-resolution displays.

Automated visual inspection (AVI) using imaging colorimeters has multiple quality benefits, all of which improve the end-customer experience:

- Improved consistency in test application, from line to line and location to location, as all systems share the same calibration and test definitions
- Quantitative assessment of defects, with precise filtering of good from bad
- Increased testing speed, which allows more tests to be run in the same time interval, ensuring a more careful assessment and a better delivered product
- Simultaneous assessment of full display quality – e.g., uniformity and color accuracy – and fine scale – e.g., pixel and sub-pixel level – defects

When applied to OLED display testing, imaging colorimeter-based AVI simplifies testing while improving delivered product quality.
Correcting OLED Displays to Improve Yield

As the OLED display size scales, yields decline drastically and the cost of each component is much higher. At this point it becomes viable for manufacturers to perform correction, or electronic compensation, to improve display image quality. The concept is simple: by modifying the inputs to individual sub-pixels, known dim sub-pixels can be brightened resulting in improved luminance uniformity and correct color across the OLED display.

Performing electronic compensation for OLED displays requires, first, having in-display electronics that can accurately control brightness of the individual sub-pixels and that can adjust this based on a set of pixel-specific correction factors. Second, a system is required to accurately measure individual sub-pixel brightness and color, and compute specific correction factors for each of them. This method has been widely used for LED display screens made up of individual LEDs, and Radiant Vision Systems has adapted this technique to OLED flat-panel displays.

Figure 5 - An imaging colorimeter measures brightness and color of each sub-pixel on the OLED display.

When the OLED display is completely assembled, test images are displayed. These images enable measurements and calibration values to be computed. For example, a “green screen” with all green sub-pixels turned on can be used as a sample image and the imaging colorimeter can measure and record the brightness of each individual green sub-pixel. This is repeated for all the primary colors and, usually, white. This data can be gathered in the course of ordinary quality testing of the OLED display.

Once these values are known, unique correction factors can be computed and applied to the electrical input of each individual sub-pixel, so that brightness will be accurate and uniform across the entire display. When this correction map is applied to the finished OLED display, there is a significant improvement in color and brightness accuracy and uniformity. The net effect is that OLED displays that would have failed quality inspection without electronic compensation will now be able to pass, thereby increasing production yield.
Radiant Vision Systems Solutions

OLED technology is very promising as the next generation for flat-panel displays, but technical issues related to image quality and production yields need to be resolved before it can be considered commercially viable beyond the smartphone market. The issues facing OLED manufacturers, although unique, are similar to technical issues that have already been solved by Radiant Vision Systems in LCD production and by LED screen manufacturers.

ProMetric Imaging Colorimeters

Radiant Vision Systems ProMetric Imaging Colorimeters are high-sensitivity, high-accuracy, CCD-based imaging systems calibrated to match human visual perception of spatial and angular distributions of brightness (luminance) and color. Radiant Vision Systems offers 10 different models of imaging colorimeters – more than twice as many as anyone else in the industry – with multiple options for resolution and sensitivity. The appropriate system for specific OLED display testing scenarios will depend on your measurement accuracy and resolution requirements.

TrueTest AVI Software

Accurate measurement of OLED display performance is important, but equally so is the analysis of the measurement data. Radiant Vision Systems TrueTest AVI (automated visual inspection) software completes the solution and makes the data actionable by implementing test sequences against user-defined pass/fail criteria. TrueTest is a software test suite and sequencer with built-in tests available for OLED uniformity testing, line defect detection, pixel defect detection, contrast measurement, and more. TrueTest allows the user to select from this test library and to order the tests in any sequence. The user can also specify test parameters and pass/fail criteria.

TrueMura is an add-on to TrueTest that adds JND (just noticeable difference) mura analysis and blob analysis techniques.

TrueTest incorporates software alignment and Moiré pattern removal functions to simplify test setup. On the production line it runs in Operator mode where access to test parameters is locked, preventing changes. TrueTest also stores configuration information, test parameters, and pass/fail criteria for multiple models of displays; the correct data file can be applied or changed on-the-fly during real-time production.
Integration and Support
Practical implementation of the Radiant Vision Systems ProMetric + TrueTest solution requires both physical and software integration in the production line. Radiant Vision Systems is highly experienced in working with customer selected fixture providers, and in providing full turnkey solutions that include fixtures. Radiant Vision Systems TrueTest software can operate in a standalone mode, but more typically it is integrated with the Production Control System (PCS). This integration can provide fully-automated testing, wherein the Radiant Vision Systems software is triggered by the PCS, or simply provides a reporting interface for pass/fail results (and potentially testing data). TrueTest can also be set up to work with video pattern generators and barcode readers (or the equivalent).

Radiant Vision Systems provides global support for our ProMetric + TrueTest solutions. Our support staff provides engineering, installation, training, maintenance, and calibration services. Radiant Vision Systems has support staff in the US, China, Korea, and the UK, supporting thousands of imaging colorimeters currently deployed on production lines worldwide.
Imaging colorimetry-based testing systems have demonstrated success in improving quality and reducing production costs for LCD displays and LED display screens. Radiant Vision Systems has extended these proven techniques to OLED display production testing. Contact us to learn more about OLED display correction and how it can be used with your OLED design.

Contact Us Today

Worldwide
Radiant Vision Systems, LLC
22908 NE Alder Crest Drive, Suite 100
Redmond, WA 98053 USA

T. +1 425 844-0152
F. +1 425 844-0153

info@radiantvs.com
RadiantVisionSystems.com