

## Introduction

The quality control of flat panel displays (FPDs) during manufacture, can either be assessed whilst in-line, or individually using portable instrumentation. This may depend on whether every single panel is to be selected for a particular test, or simply a representative random sample. Panels that undergo one test may be typically categorised as pass, rework, or scrap. Other tests may grade the panel into different quality 'bins' or classes, depending on the requirements of the purchaser, such as a particularly tight specification. There are a surprisingly large variety of tests that an FPD might undergo during its assembly. Whilst some of these are related to quality assurance, other tests concern basic functionality. Many of the construction stages involve dealing with very small items that need to be precisely aligned in order for the panel to perform properly. Clearly, it is impossible for a factory worker to do this repeatably over an extended period – some form of automation or visual assistance is likely to be required. Other procedures generate results that need to be assessed objectively. Given the extremely wide variety of tests, a selection of high-performance cameras, coupled with smart software, would seem to be essential for this purpose. Some tests may require very sensitive cameras, whilst others will benefit from cameras capable of a high data throughput.

## Common types of display panel

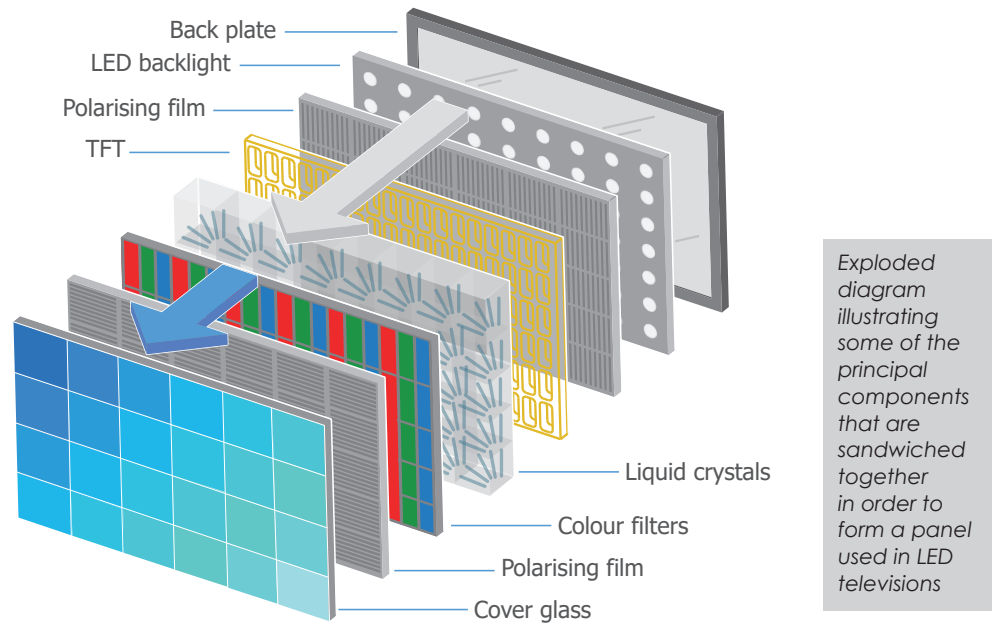
Flat Panel Displays are currently employed in all manner of consumer devices. For example, televisions, computer monitors, tablets, smartphones, and more recently, automotive displays.

For a long period, the principle technology was TFT LCD, which was essentially a development of that used in calculator displays. The way that these displays were backlit, evolved from fluorescent cathode tubes, to electroluminescent phosphor panels, and onto arrays of LEDs. These LEDs can be variably edge-lit or backlit in an effort to improve the dynamic range of the image. In particular, dark portions of the image can now appear truly black, rather than dark grey. Other benefits of LED illumination are a significant reduction in power consumption, and a much improved MTBF of the backlight assembly.

At one time plasma displays were popular for larger televisions. However, their high-power consumption was unattractive, and so eventually fell out of favour due to environmental concerns. As they are now obsolete, they will not be discussed here.

The drive towards ever more realistic image quality has produced in a display type known as OLED<sup>1</sup>. In this case, the pixels are formed from tiny LEDs that utilise organic dyes to generate colour. These LEDs are, by their very nature, self-illuminating – they determine both the colour of the pixel and control its brightness. Therefore, they do not require a separate backlight. Consequently, these devices can be made significantly thinner, and in some other applications can even be foldable (e-paper). These very thin displays are particularly attractive for use in smartphones and digital cameras, where space is at an absolute premium.

Another important recent display technology is QLED, where 'Q' denotes 'Quantum dot'. These dots are nanoparticles that are used to improve the performance of LCD displays. When back illuminated via LEDs, these Quantum dots emit a colour that is determined purely by their physical size. For example, the larger (10nm) dots emit light at the red end of the visible spectrum, whereas smaller ones emit in the green. The end result is an LCD display with an enhanced range of colours that are more intense when compared to existing designs, and thus have the possibility to be used in more challenging environments, such as in outdoor sunlight for billboards and other advertising applications.



### Typical tests during FPD assembly

When assessing the quality of FPDs during manufacture, there are an extremely wide range of parameters that need to be inspected in order to achieve a consistent product. Some of the more common ones include:

- ◆ Bright or dead pixels such as those caused by transistor failure in TFT displays
- ◆ Bad columns or groups of pixels
- ◆ Localised uneven illumination, distortion of clouding- known as 'mura'
- ◆ Scratches or chips in the external surface
- ◆ The appearance of air bubbles when LCD panels are filled
- ◆ Unwanted dust particles that are trapped within the visible area of the assembly
- ◆ Formation of blisters when the component layers are sandwiched together
- ◆ Deformation or misalignment of individual layers during assembly
- ◆ Image distortion
- ◆ Acceptable viewing angle
- ◆ Performance of the external antireflection coating
- ◆ Integrity and alignment of the electrical edge connectors

### Mapping the luminosity over the display panel

It is clearly desirable to produce display panels that produce uniform brightness from edge to edge. Using a dependable inspection camera, you can investigate how adjacent areas across the display panel vary in luminosity (brightness). Using Weber's Law, the principle is to establish a critical ratio that identifies when such an effect is barely perceptible to the human eye.

## Perceptible change $K=\Delta L/L$

By automating this process, it is possible to objectively quantify whether a panel falls within the allowed tolerance in luminosity variation. The procedure is both rapid and repeatable.



*An example of screen Mura – in this case showing noticeable luminosity variation in different areas of the panel*

If an area of the image is identified as being out of specification, then it should be possible to dynamically correct for this by adjusting the voltage of the pixel group concerned.

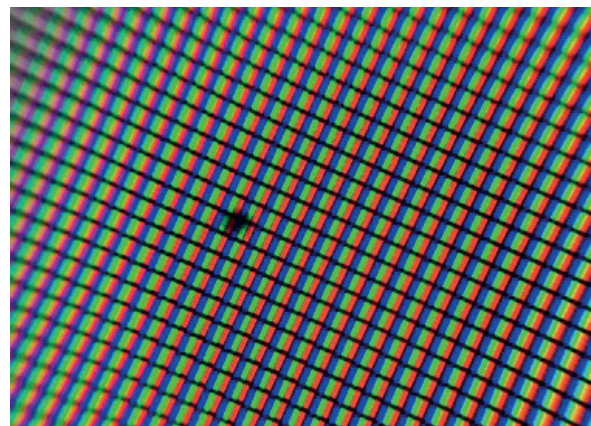
As the areas of the panel under comparison are not particularly small, this procedure does not likely require a camera of particularly high resolution, unless, of course, the whole display is to be imaged in a single pass. In which case a CMOS camera would be preferable as it is able to download large images considerably faster than a CCD, which aids work flow in a fast paced production environment.

## Inspecting for small scale defects

When a defect is in the size regime of one pixel or less, there is the potential for important information to be lost, or obscured, by inadvertently under sampling data in the image. This is governed by the 'Nyquist sampling theorem<sup>2</sup>'. In order to accurately reconstruct an image, it is necessary for the sampling frequency to be at least double that of the frequency of the features in the subject.

As an example, consider that we are wanting to examine a typical 1920 x 1080 pixel (Full HD) display for any errant pixels.

By applying the Nyquist theorem, if we double the number of features (pixels) we get: 3840 x 2160 which leads to a total of about 8.3 million pixels. Therefore, our inspection camera needs have an image sensor with at least 8.3MP resolution in order to avoid the Nyquist limit. If we want to be even more conservative, then tripling the number of features is not out of the question. This would give us a camera with around 18.7MP resolution. So, we can say with some certainty, that a suitable camera for this application ought to have a sensor resolution somewhere in the range 8.3 to 18.7MP. Common camera resolutions in this range that you might choose from are: 9, 12, and 16MP. The display may be imaged in both brightfield and darkfield regimes.



*Typical small-scale pixel defect in a display panel. Even more annoying to the end user, can be the appearance of permanently hot pixels which may need to be disabled during manufacture by laser ablation. High quality panels will usually have strict limits on the permitted number of defective pixels.*

## Cosmetic Flaws

Small scratches or chips, either present in the external glass or its antireflection coating, can be difficult to visualise. This is because they are usually of low contrast when compared to their immediate background. The use of a camera in conjunction with polarising filters, or with the illumination set at an oblique angle, can significantly exaggerate the appearance of these features, making them significantly easier to identify.

Given the low contrast of the subject, it will likely be advantageous to select a camera with a wide number of grey levels – a large bit depth. For example, a camera that utilises a cooled CCD sensor. A mono camera will be preferable for this application as the colour information is unlikely to be useful.



*Varying the illumination angle can make it easier to spot subtle defects where contrast is poor*

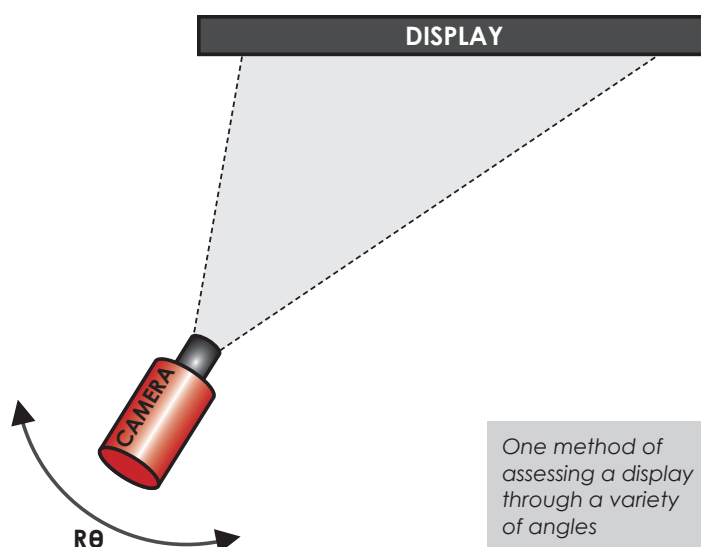
## Viewing Angle and Readability

As domestic televisions have continued the trend to increase in screen size, the importance of a very wide viewing angle is perhaps not quite so critical as it once was. However, for an automotive device, such as a multimedia touch screen placed in the centre of the dashboard, this is still an important consideration. Both driver and passenger will be viewing the display at quite an oblique angle. Therefore, it is necessary to ensure that the readability of the display at these angles is maintained.

*Automotive screens need to be legible through a wide range of viewing angles*



As well as correct assembly, this characteristic will depend on the technology utilised in the construction of the display. They are, most commonly; in-plane switching (IPS), vertical alignment (VA), and twisted nematic (TN). Unless a specialist lens is available, it is likely that this procedure will be performed on a goniometric measurement platform.

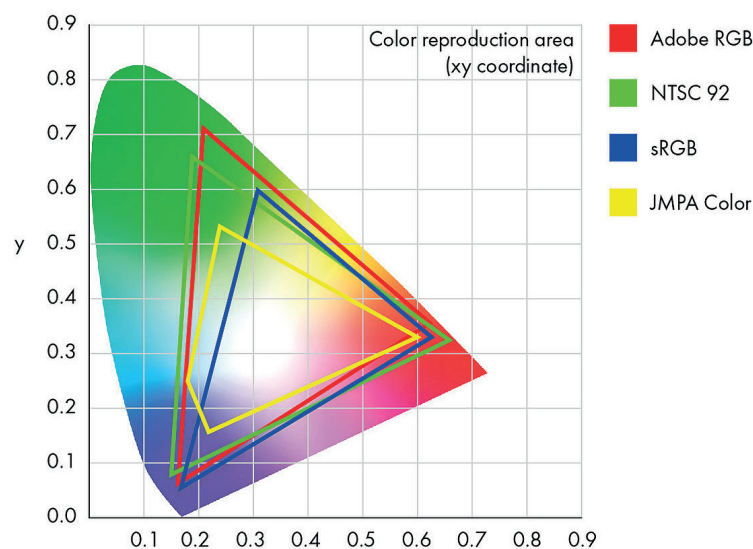


*One method of assessing a display through a variety of angles*

When viewing the subject at an angle, it is effectively compressed into a somewhat smaller physical space. Therefore, it would be beneficial to utilise a high-resolution colour camera so that none of the details are lost and the readability can be rigorously assessed.

## Colour Calibration

In environments where digital images are manipulated before being printed, it may be desirable that they conform to a recognisable colour standard. This is to give an assurance that the images in the final copy appear exactly as the author intended. For example, one instance could be when creating a magazine article featuring various images. Here your preferred choice might be 'Adobe RGB' or 'CMYK'. In other environments, different standards apply. For generic computer displays, the 'sRGB' standard will almost certainly be supported. Whilst in the analogue television industry, the colour profiles within the 'PAL' and 'NTSC' video encoding standards were common, and are still referred to today. These standards, define a colour palette known as a 'gamut' which provides the user with a clear idea, in terms of visible colour balance, of what the device is capable of. Computer monitors that are specifically manufactured to support a wide colour gamut, such as Adobe RGB, command a significant premium in the retail market, particularly in the publishing industry. Select high end FPDs are chosen, then calibrated to one or more of these standards.



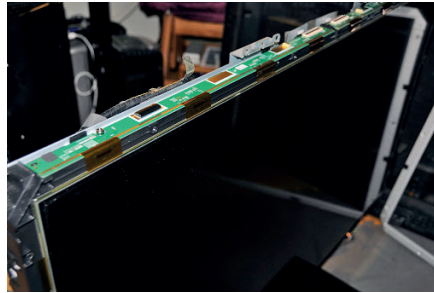
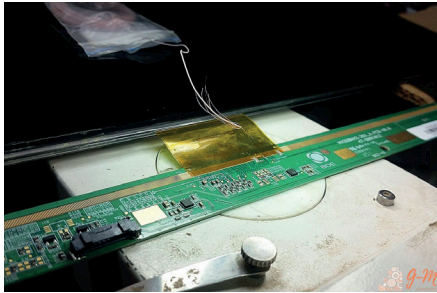
*An example of a colour gamut. Notice that unsaturated colours appear near the centre and can be reproduced by almost any device, whereas vivid colours appear near the edge and are much more challenging. Some display technologies may have to compromise one for the other. A brief examination of the sRGB gamut reveals that it has limited ability to reproduce vivid greens.*

The calibration procedure is broadly similar to that used for the luminosity assessment discussed earlier, except that a colour camera (or a mono camera equipped with a variety of colour filters) is required. However, in this case the output from the display is being compared against a known standard in order to do this there must be a high degree of confidence in the capabilities of the camera, particularly with regard the reproducibility of the image. The camera may be periodically calibrated in-house by the end user to a known reference. A camera with modest resolution is likely to be sufficient for this task, as the most desirable aspect is sensor linearity - i.e. the output of the sensor increases linearly with increasing illumination. A camera that utilises a sensor with a global shutter would be advantageous, as every pixel is controlled simultaneously. Consequently, there is no ambiguity about the exposure length of individual pixels

Colour calibrations can vary slightly as the display panel ages. This can be especially important if a very large panel is composed of several smaller ones. For this reason, portable camera-based devices exist that enable the end user to correct for this via adjustments in software. This is slightly different to the original factory colour calibration, where the information is stored in hardware.

## Positioning and verification of electrical connections

The interface between the FPD and its control circuitry, is usually comprised of several flexible connectors arranged around the periphery of the display. These provide a conduit that incorporates a large number of tightly packed electrical connections.



*A variety of sub-assemblies of each panel need to be verified during manufacture. This example illustrates the crucial alignment of the flexible connectors that allow communication between the display and the control hardware.*

Unfortunately, owing to the density of these connections and the fragile nature of the display itself, it is impractical to utilise solder to establish permanent electrical joints. The solder would bridge between individual electrodes, and the heat required would stress or damage the panel. One successful alternative to secure these flexible connectors in precisely the correct position, is to use a polymer adhesive. This requires precise alignment as the conducting part of each connector is typically only a few 10s of microns in width. A microscope fitted with a high pixel count CMOS camera can greatly assist the assembly worker during production. This gives both sufficient image detail and smooth focussing, due to its rapid image download. The correct positioning of these crucial parts can also be independently verified by high resolution cameras later on in the process.

## Summary

The process of carefully inspecting an FPD for a wide range of possible defects, subtle flaws, or other problems, is heavily reliant on image capture technology. Some procedures will be automated using image analysis software, whereas others will not test but rather assist the factory worker when performing precise manual tasks. In order to complete the entire suite of tests, a variety of cameras with different characteristics may be required. For example, in order to maintain throughput a CMOS camera with a rapid image download may be preferred. Whatever the choice, camera-based inspection systems, offer the prospect of reproducible, traceable, and objective results, and place less burden on the operator.

## References:

1. Raja Lakshmanan & S.C.G. Kiruba Daniel, Engineered Nanomaterials for Organic Light-Emitting Diodes (OLEDs), in Handbook of Nanomaterials for Industrial Applications, 312-323, 2018, Elsevier
2. NYQUIST, H., Certain Topics in Telegraph Transmission Theory. Transactions of the A. I. E. E., 617-644, Feb. 1928.

## Glossary of Terms:

**Adobe RGB:** a colour profile devised by Adobe Systems Inc, particularly of interest to users of Adobe Photoshop TM

**CCD:** Charge Coupled Device – an image sensor technology formed from an array of capacitive elements

**CMOS:** Complementary Metal Oxide Semiconductor – a type of fabrication technology used in image sensors and many other electronic devices, such as the transistors within microprocessors and memory modules

**CMYK:** a colour profile based around mixing the printing inks cyan, magenta, yellow, and key (black)

**Global Shutter:** a way of controlling the exposure duration, so that every pixel is activated simultaneously. (as opposed to 'Rolling Shutter') This can be significant when recording short exposures and moving subjects.

**Goniometric measurement platform:** used when the property of a system, or device, needs to be measured with respect to a defined angle.

**LCD:** Liquid Crystal Display – a display technology where the variable polarisation of liquid crystals can be used to generate image contrast

**LED:** Light Emitting diode – a type of low voltage, power efficient illumination device

**NTSC:** a video colour encoding system, originally developed for analogue television in North America

**MTBF:** Mean Time before Failure – provides a useful guide to the expected lifespan or the reliability of a device

**PAL:** a video colour encoding system, originally developed for analogue television in Europe, Africa, and parts of Asia.

**TFT:** Thin Film Transistor – used the in operation of individual pixels within an LCD display panel

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