



Enhancing Display Component Characterization for Color Quality Control

Introduction

In today's digital world, display screens are not just visual interfaces, they are experiential canvases for consumers. Whether it's a smartphone OLED, a laptop LCD, or an automotive dashboard display, users expect vivid, accurate, and consistent color across devices and environments. Color fidelity has become a hallmark of quality in the electronics industry, directly influencing user satisfaction and brand perception. To achieve this consistency, manufacturers must tightly control the color characteristics of display components during production. This technical white paper explores the needs, challenges, and solutions involved in display component characterization for color quality control. It emphasizes how spectrophotometers - particularly the HunterLab UltraScan PRO - can enhance the measurement and management of display component color performance.

Overview: Market Scope and Applications

The global display market is vast and rapidly growing, reflecting the ubiquity of screens in modern life. In 2024 the market was estimated around \$182 billion and is projected to reach \$370+ billion by 2034, fueled by demand in consumer electronics, automotive, healthcare, and other sectors. Consumer electronics (smartphones, tablets, laptops, TVs) account for the largest share of this market, with smartphones alone expected to exceed \$125 billion by the early 2030s. Automotive displays are another high-growth segment, as vehicles incorporate more and larger screens for



instrument clusters, infotainment, and head-up displays. The automotive display market is forecast to triple in size from 2024 to 2034, reaching an estimated \$48.9 billion.

Across these applications, color performance is a critical differentiator. Consumers increasingly demand lifelike color, high contrast, and uniform brightness in every environment. For example, in automotive use, TFT-LCD screens have dominated due to their excellent color accuracy and reliability. Similarly, smartphone and TV manufacturers promote wide color gamut and calibrated screens as selling points. Achieving these qualities consistently at high production volumes requires rigorous color quality control of the display components from the backlight or OLED emitters to the optical films, glass covers, and coatings that make up a display assembly.

Importance of Color Measurement in Displays

Color measurement is essential at every stage of display component manufacturing for several reasons:

- **Brand Consistency and User Experience:** Leading device makers have defined target color profiles (such as sRGB or DCI-P3 gamut's and white points) to ensure a uniform look and feel. Measuring color ensures each display meets the brand's standard, so that a phone or dashboard from one batch doesn't look noticeably different from another. This consistency strengthens brand quality and optimizes the user experience under varying conditions. For instance, a smartphone's interface should appear the same warm or cool tone regardless of which factory produced its screen. Instrumental color checks enable this repeatability.
- **Meeting Performance Standards:** Displays must meet strict specifications for brightness, contrast, and clarity. Color measurement ties directly into these



metrics. Brightness and contrast relate to luminance (Y value) and black level, which can be verified by measuring transmitted and reflected light. Clarity is quantified by haze measurements. By quantifying these parameters, manufacturers ensure each unit meets industry and safety standards (for example, automotive regulations for minimum luminance and maximum haze for instrument panels). Color accuracy itself is often specified in terms of allowable ΔE (color difference) in CIELAB units, requiring precise instrument measurement to enforce. In short, quantitative color data is needed to prove compliance with both internal quality targets and external standards.

- **Adaptive Performance in Various Lighting:** Displays are viewed in environments ranging from dark rooms to bright sunlight. Human vision adapts, but a display's design must account for these extremes via features like adaptive white balance or night mode. Measuring color and luminance under standardized lighting conditions (e.g. standard illuminant D65 daylight vs. Illuminant A incandescent) allows engineers to understand how the display's appearance shifts with ambient light. This supports development of compensation algorithms (such as automatic brightness or gamma adjustment) to maintain image fidelity in any environment. In manufacturing, sample displays may be measured under multiple illuminants to validate that color and contrast remain within acceptable ranges for, say, daylight vs. dim indoor lighting.
- **Integration of Embedded Technologies:** Modern displays often incorporate sensors and other technologies beneath or around the screen (e.g. cameras for facial recognition, ambient light sensors, in-display fingerprint sensors). These impose optical requirements on display components. For example, a near-infrared facial recognition sensor behind a phone screen requires the cover glass and OLED stack to transmit sufficient IR light. Precise spectrophotometric measurements in the IR range are needed to ensure the display materials have



the required transmission at the sensor's wavelength. Another example is touch screens, which add layers that must not introduce color tint or haze that would degrade the image quality. By measuring the color and clarity of these layers, engineers can guarantee that added functionality does not come at the expense of visual performance.

Ultimately, color is a key indicator of quality, and only through objective measurement can manufacturers manage it effectively. Relying on subjective visual inspection alone is insufficient to catch subtle color variations or haze that can compromise the product. Therefore, integrating spectrophotometric color control into display component production is critical for optimizing yield, reducing rework, and delivering the high-quality visual experience that customers expect.

What Color Reveals About Display Component Quality

Careful color analysis of display components can reveal a great deal about product quality and process control. Color and appearance are often proxies for underlying material or manufacturing issues. Key insights that color measurements provide include:

- **Material Composition and Coating Efficacy:** Many functional coatings and films have a characteristic color or tint that correlates with their performance. A clear example is the UV-blocking coatings used on camera lenses or display covers. A properly applied UV filter coating will impart a slight amber tint to the glass; if the glass appears nearly colorless, it may indicate the coating is too thin or absent, meaning UV light will not be adequately blocked. In one case, manufacturers found that filters which were supposed to block UV appeared too clear - spectrophotometer readings showed low absorbance in the UV range, confirming insufficient coating and prompting a process fix. Similarly,



anti-reflective (AR) coatings on display glass often produce a faint residual color (often a pale blue or violet reflection). Measuring the reflectance spectrum and color of AR-coated glass lets manufacturers verify that the coating thickness is on target – a significant color shift could mean the coating is out of spec, affecting reflectivity.

- **Presence of Contaminants or Degradation:** Unwanted color shifts can signal contamination or aging of materials. For instance, yellowing of a normally colorless adhesive or polycarbonate lens indicates oxidation or UV damage. By measuring the b^* (blue-yellow) value or a Yellowness Index over time, engineers can quantify even slight yellowing and determine if a component has been degraded by environmental exposure. An increase in yellowness beyond acceptable limits would reveal that a batch of material or a curing process is causing premature aging. Likewise, haze measurements (percent scattering of transmitted light) can uncover the presence of microscopic particles or improper curing in optical films. A higher haze % than expected means the material is less clear, possibly due to residual solvents, particles, or an uneven surface finish. In production, a spike in haze readings for a batch of polarizer film, for example, would immediately flag a quality issue (such as contamination or a processing error) that could reduce display contrast if left unaddressed.
- **Thickness or Uniformity Variations:** Many display components are multi-layered or coated, and slight variations in thickness can manifest as color differences. A polarizing film, for example, might develop a slightly greenish or bluish cast if its dye concentration or thickness drifts from the norm. By measuring the transmitted color (in CIELAB or spectral terms) of incoming polarizer rolls, quality control can detect such shifts before they affect assembled panels. Color uniformity measurements across a large glass panel can also indicate coating uniformity – e.g. if one side of a large LCD glass shows a different L^* or a^* value than the other, it may mean a coating was applied unevenly. In essence, color



serves as a “fingerprint” of the process: any deviation in the process (different temperature, mix ratio, etc.) often leaves a detectable color difference that instruments can pick up even if the human eye cannot.

- **Optical Performance Metrics:** Ultimately, the goal of controlling component color is to ensure the final assembled display meets its performance targets. Color measurements allow calculation of derived metrics that speak to real-world performance. For example, measuring the total transmission (Y%) and the haze % of a display stack (polarizer + LCD + cover glass) enables computation of the display’s contrast in bright light. A high haze in any layer will lower contrast by washing out blacks with stray light, and a low Y transmittance will make the display dimmer. By quantifying these, engineers can predict the readability of a display in sunlight and ensure it meets requirements for automotive or outdoor use. Additionally, measuring reflected color with specular included vs. excluded geometries can quantify the gloss level of a screen or cover. Excessive reflectance (glare) can be identified by a higher specular reflectance value, prompting the use of better anti-glare treatments. In summary, instrumental color data reveal whether each component is doing its job - scattering the right amount of light, transmitting the required spectrum, and not introducing unintended tints - all of which translates to the quality of the user’s viewing experience.

By interpreting these color measurements, manufacturers can diagnose issues early. For instance, if a batch of diffuser film shows an unusual color shift, it might indicate a resin formulation error, preventing a potential image uniformity problem down the line. In this way, spectrophotometric characterization of color is a powerful diagnostic tool to maintain display component quality.



Display Component Color Measurement Applications

To control and improve display quality, manufacturers employ spectrophotometers in a range of display component measurement applications. Some important applications include:

- **Transmission Color and Haze of Optical Films:** Display assemblies contain multiple transparent or translucent films - examples include diffuser sheets, brightness enhancement films, liquid crystal layers, polarizers, and adhesive interlayers. Each of these can affect the color and clarity of light passing through. Spectrophotometers with transmission fixtures are used to measure the spectral transmittance of these films, ensuring they meet design specs. For example, a diffuser film may need a certain haze percentage to spread light uniformly; too little haze and the backlight's LED hotspots might be visible, too much haze and the image looks hazy. Using an integrating-sphere spectrophotometer, engineers can quantify the transmission haze (ASTM D1003) of diffuser films and adjust processing to hit the target haze%. They also measure transmitted color (CIELAB or transmission % at specific wavelengths) to verify that films intended to be neutral do not introduce an unwanted color cast. If a brightness enhancement film slightly tints the white backlight (shifting it toward blue, for instance), this will show up as a deviation in transmitted a^*/b^* values and can be corrected. In summary, measuring transmission color and haze of films is critical for maximizing display brightness and maintaining neutral white and accurate colors.
- **Reflectance and Appearance of Display Glass and Coatings:** The front surface of a display (cover glass or touch panel) often has coatings for anti-reflection, anti-fingerprint, or other purposes. Spectrophotometers in reflectance mode (using diffuse/8° geometry) allow manufacturers to measure the *reflectance color* (L, a, b^*)** of glass coatings, as well as the percentage of light reflected. A



low reflectance across the visible spectrum is desired for anti-reflective coatings; using a spectrophotometer, one can measure reflectance with specular component included, etc., but more commonly a sphere instrument will capture diffuse reflectance and allow specular-excluded measurement to evaluate just the gloss vs. diffuse reflection. This helps quantify how effective the AR coating is in reducing glare. Likewise, any decorative coatings or tints on display glass (for example, the black frit around the edges of smartphone glass or the slight gray tint on some automotive display covers) are measured for consistency. A spectrophotometer can ensure the *black border L value** is within tolerance for a uniform look, or that the tint of a heads-up display combiner glass is exactly as specified so that the projected image color is correct. Even emissive displays (OLED or microLED) have an appearance when off – often a mirror-like black – which can be characterized by measuring reflectance; controlling this reflectance is important for contrast. By measuring and controlling reflectance properties of display surfaces, manufacturers improve contrast and aesthetic uniformity.

- **Y Transmission and Luminous Efficacy of Assemblies:** Often the overall luminous transmission (Y%) of the entire display stack is measured to gauge efficiency. For example, an automotive display or a phone display with several layers can be placed in the spectrophotometer's transmission compartment (if the sample is small enough or using a reduced sample of the assembly) to measure how much light gets through. The instrument provides the tristimulus Y value in transmission, which corresponds to photopic transmission. This is a critical metric – if Y transmission is, say, 5% lower than expected, the display will appear dimmer, or the backlight power must be increased to compensate. By measuring Y%, manufacturers can compare different configurations (such as glass with different anti-glare etches, or one vs. two diffuser layers) quantitatively to choose the design with higher efficiency. Many quality control



labs will monitor the Y Transmission of cover glass batches: for instance, if a batch of chemically strengthened glass has higher iron content, it may look slightly green and transmit a few percent less light (lower Y%). The spectrophotometer would catch this difference, and that batch might be flagged as out-of-spec for top-tier devices that demand crystal-clear glass. Maintaining high and consistent Y transmission is especially important for high-brightness displays (outdoor-readable screens, vehicle displays).

- **Absorbance and UV/IR Characteristics:** Beyond the visible range, display components can be characterized for UV and IR absorption. The UltraScan PRO and similar spectrophotometers often cover near-UV (down to 350 nm) and near-IR (up to 1050 nm) ranges. This capability is used, for example, to measure how much UV a polycarbonate lens or film absorbs – relevant for outdoor displays which must resist UV yellowing (materials with UV-blockers will show high absorbance below 400 nm). It’s also used to ensure that IR transmissive windows (for IR sensors or emitters under the display) are performing: a piece of “IR passthrough” glass might be measured at 850 nm and 940 nm to confirm it has high transmittance there while perhaps blocking visible light (to remain visibly dark). The instrument can report an absorbance spectrum (optical density) which is useful for quantifying blocking performance of filters. For instance, an OLED smartphone may have a notch filter film to reduce specific blue light wavelengths – by measuring the film’s absorbance curve, engineers verify that it indeed attenuates the intended band (say around 450 nm) to the required degree. Spectrophotometers enable this level of analysis, and the results can be converted into metrics like % transmission at X nm or optical density, which are often part of specifications. The availability of full spectral data is a major advantage, as it allows simultaneous evaluation of color (visible range) and other functional optical properties (UV/IR) in display components.



In all of these applications, using a calibrated spectrophotometer removes guesswork and subjectivity, replacing it with numerical targets and pass/fail criteria.

Manufacturers can set tolerances on CIELAB values, haze %, Y transmission, etc., and reliably catch any component that falls outside those limits. This ensures that only components which will collectively produce a high-quality display are sent to assembly. As a result, color measurement has become a cornerstone of display component quality control, supporting everything from routine incoming material QC to advanced R&D of new display technologies.

Challenges in Applying Color Measurement (Visual vs. Instrumental)

Historically, color quality in displays was often evaluated visually – workers would inspect screens or components and compare them to reference samples. However, human visual evaluation is subjective and approximate, prone to inconsistency across different observers and conditions. For example, one inspector might perceive a slight color tint that another does not, or ambient lighting in one factory area could mask a subtle non-uniformity that would be visible under different lighting. Human eyes also fatigue and vary in color perception (and a significant portion of the population has some form of color vision deficiency). In contrast, instrumental measurement provides objective and precise results that correlate with standardized human perception models.

The fundamental challenge in visual vs. instrumental assessment is that color perception can be influenced by many factors – lighting, surrounding colors, observer experience, even physiological differences or fatigue. In one striking example, what one person considers “barely yellowish white” might be judged as neutral by another; an instrument, however, might measure that the sample’s b^* is +2.0 (a quantification of the yellow tint) and thus clearly identify the deviation. In short, a color’s visual evaluation is subjective, while its measured color values are objective.



Spectrophotometers are designed to emulate how the average human observer would perceive color (through CIE standard observer functions and illuminants), but with the benefit of absolute consistency. The readings do not vary from day to day or person to person, which is critical for tight quality control.

Another challenge is detecting subtle differences or faint defects that the human eye might miss. For instance, a very slight haziness in a film might not be noticed until it's assembled and the display looks a bit dull. A spectrophotometer measuring haze % or clarity will pick up that subtle increase in scattered light and flag the material as out-of-spec long before a person could notice the difference. Instruments can often detect color differences on the order of ΔE 0.5 or less, far below what an untrained eye can reliably discern (the just noticeable color difference for humans is often cited around $\Delta E \sim 2$ under ideal conditions). This sensitivity helps maintain higher quality—proactive corrections can be made before differences become large enough to be visible to customers.

There are also practical challenges, especially with the complex structure of displays:

- **Extremely High-Resolution Components:** Modern displays contain millions of pixels or subpixels, each potentially a slightly different color. It is infeasible for a spectrophotometer to measure each pixel on a high-resolution screen one-by-one - not only would it be time-prohibitive, but conventional bench instruments have a measurement spot size (several millimeters) much larger than an individual pixel. Specialized imaging colorimeters are used for mapping pixel-level uniformity (a process known as *demura* or pixel calibration and correction). These camera-based systems can quickly capture luminance and chromaticity of every pixel and identify non-uniform areas (*mura*). However, even these systems rely on spectroradiometers or spectrophotometers for calibration and reference - the imaging device is first calibrated against a spectrophotometric measurement to ensure its color readings are accurate. This underscores that



while imaging systems address spatial challenge; the spectrophotometer remains the authority for color accuracy. The two work together: the spectrophotometer provides the absolute color reference, and the imaging system extends that across millions of pixels. Without the instrument's reference, the camera's output could drift or misjudge colors.

- **Subjective Visual Evaluation of Uniformity:** Certain defects like mura (cloudy or patchy areas on an LCD) historically have been evaluated by human inspectors because they are low-contrast and context-dependent. As the industry notes, mura can be “extremely difficult” to quantify objectively and visual judgments tend to be subjective. This is a case where neither a single-point spectrophotometer nor an unassisted human is ideal. The solution has been to use advanced machine vision (as mentioned) or to improve manufacturing to prevent mura altogether. From the color measurement perspective, one can use an imaging colorimeter to quantify luminance or ΔE uniformity across an entire screen (effectively giving a map of color differences). Standards are emerging to define acceptability of these maps. The key point is that instrumentation is evolving to tackle even those challenges that were once considered purely in the realm of subjective evaluation. By moving to instrument-based assessment, even for uniformity defects, manufacturers gain consistency – each display is judged against the same quantitative criteria rather than a possibly inconsistent human judgment.
- **Environmental and Observer Metamerism:** A display might appear color-matched to a reference under one light source but not another – a phenomenon known as metamerism. Humans could be fooled if they only compare two displays under fluorescent lighting, for example, only to find they differ under daylight. A spectrophotometer can calculate color coordinates under multiple illuminants (D65 daylight, D50, Illuminant A, etc.) quickly from the measured spectrum. This capability helps predict metamerism issues.



Instruments can also apply the 2° or 10° observer functions (which simulate human color perception differences at foveal vs. wider field). By measuring and computing across these conditions, one ensures the color will be acceptable in all intended viewing situations - something a single-condition visual check might miss.

In summary, instrumental color measurement overcomes the limitations of human vision by providing objective, repeatable, and standardized data. It eliminates guesswork and interpersonal variation in judging color. The result is a more reliable quality control process: decisions are based on data (e.g. " $\Delta E = 3$, which exceeds our tolerance of 2, so reject this component") rather than subjective impressions ("looks a bit off-color to me"). This is especially critical as display technologies push the envelope of performance - with narrower tolerances and more complex optical behaviors, only instruments can ensure those tight requirements are consistently met. Human inspectors remain important for certain aesthetic checks, but the heavy lifting of color and appearance quality control is now firmly in the domain of spectrophotometric instruments.

Global Color Measurement Methods and Standards

When implementing color quality control for displays, it is essential to use globally recognized color measurement methods and standards. This ensures that measurements are meaningful, reproducible, and in line with industry expectations. Key concepts and standards include:

- **CIE L*a*b* (CIELAB) Color Space:** The CIELAB color space is the international standard color space for quantifying object colors and color differences. It was recommended by the CIE in 1976 and has since become the most widely used method for measuring and ordering color in industries ranging from textiles



and plastics to electronics. CIELAB is a perceptually oriented 3D color model: L^* represents lightness, a^* the red-green axis, and b^* the yellow-blue axis. In quality control, a target color for a component might be specified in CIE L^* , a^* , b^* coordinates under a given illuminant/observer (e.g. " $L^* 95.0, a^* 0.0, b^* -2.0$ under D65/10°"). The difference between a measured color and the target is expressed as ΔE (delta E) in the CIELAB space. A ΔE of 1-2 is roughly the minimum just noticeable difference for humans, so tolerances are often set accordingly. Because CIELAB is device-independent and correlates reasonably well with human vision, it allows companies around the world to speak the same "color language." For instance, if a polarizer film's spec says $L^* \geq 90$ and b^* between -1 and +1 (neutral gray), any lab with a calibrated spectrophotometer can measure in CIELAB and check compliance - the results will be directly comparable across different facilities or instruments, if they follow CIE standard methods. CIELAB and its associated ΔE formulas (ΔE^*76 , $\Delta E00$, etc.) are central to global color quality standards.

- **Haze % (ASTM D1003):** Haze is a measure of the diffuse scatter of light as it passes through a transparent material, reported as a percentage of total transmitted light that is scattered more than a certain angle (usually 2.5°). In simple terms, it quantifies the cloudiness or milkiness of a transparent sample. The international test method ASTM D1003 (and equivalent ISO 13468/14782) defines how to measure haze using a spectrophotometer with an integrating sphere. In display components, haze is critical for elements like diffusers (which intentionally have high haze) and clear protective layers (which should have haze as low as possible). A low haze value (close to 0%) means the material is highly transparent/clear, whereas a high haze value means a material is translucent or cloudy. For example, an automotive instrument cluster lens might require haze $< 1\%$ so that the display behind it remains sharp, while a diffuser film in a backlight might be designed for 30% haze to spread light - these



numbers are determined by design and verified by measurement. Instruments such as the HunterLab UltraScan PRO directly output Haze % by performing two measurements (with and without a light trap) and applying the ASTM formula. Many spectrophotometers (including HunterLab models) support haze measurement in transmission mode, and the results are reported per the global standard, so they are comparable across labs. By adhering to ASTM D1003, manufacturers ensure that their haze measurements of display films or glass are accurate and recognized industry wide.

- **Y Total Transmission (Luminous Transmittance): Y Transmission** refers to the transmittance of a material weighted by the CIE standard photopic response (the human eye's sensitivity). In practice, it is the Y tristimulus value (the luminance component) of the transmitted light, expressed as a percentage of the Y value for a completely open aperture. This metric indicates how much visible light passes through a sample, which directly relates to brightness or light losses in an optical stack. Many standards and regulations use luminous transmittance. For example, automotive safety standards require a minimum luminous transmittance for windshields (often around 70–75% Y transmittance). In display terms, a cover glass with AR coating might transmit, say, 95% of light (so Y Trans \approx 95%), whereas an untreated glass might only transmit 91% - that difference can be critical for a display's brightness efficiency. Spectrophotometers calculate Y transmission by integrating the spectral transmittance with the CIE Y curve and illuminant (typically CIE Illuminant A or D65, depending on context). The HunterLab software, for instance, includes "Y Total Transmission" as one of the reported indices. Using this standard metric allows engineers to quantitatively compare how different materials or coatings impact display brightness. It is often reported alongside haze, because together they describe a material's transparency (clear vs. cloudy and how much light gets through).



- **Spectral Transmission and Absorbance:** Beyond single metrics, the full spectral data in transmission or reflectance is often used to derive various color indices and to analyze optical filters. Absorbance (sometimes called optical density, OD) is another way to express how much light is blocked by a material. Absorbance is useful when dealing with very low transmittance (e.g., a neutral density filter or a polarizer at its extinction orientation) because absorbance adds linearly for stacked filters. Many spectrophotometers can report both %T and absorbance across the spectrum. For display components, absorbance spectra can help in filter design – for example, a blue-light-blocking screen protector might have an absorbance peak in the blue wavelengths; by measuring it, one can quantify how much blue light is reduced. Likewise, polarizer films are sometimes characterized by their spectral absorbance for each polarization state. Global standards like ASTM E308 outline how to compute color values (XYZ, etc.) from spectral data, and spectrophotometer software follows these standards to ensure consistency. HunterLab’s EasyMatch software, for instance, can display spectral transmittance and also convert it to color values under any standard illuminant/observer, as well as compute absorbance or other indices. In summary, having traceable spectral measurement capabilities allows manufacturers to comply with international norms (CIE, ASTM, ISO) when reporting color characteristics, ensuring that results are accepted and understood across the industry.
- **Standard Observation Conditions:** It’s worth noting that global standards also define the conditions under which color is measured – typically Illuminant D65 (simulating daylight) and a 10° observer for many product color evaluations, or Illuminant C/2° for some legacy tests. Organizations like the CIE and ISO have published guidelines (e.g. CIE 15, ISO 11664) that detail these conditions. Display component colors are often evaluated under D65/2° if the goal is to simulate daylight viewing. If a measurement is done under different conditions



(say Illuminant A to simulate indoor tungsten light), it should be explicitly stated. By conforming to these standardized conditions, the measurement data remains comparable and meaningful globally. HunterLab instruments adhere to CIE and ASTM specifications in their design and calibration - for example, ensuring the integrating sphere geometry meets standards and the photometric linearity is maintained, etc., which underpins the trust in the data they produce.

In practice, a comprehensive color quality program for display components will utilize these methods: using a spectrophotometer to gather spectral data, then computing CIELAB values, haze, Y%, and other needed indices via standard formulas. Results might be documented in reports showing ΔE from a standard, percent haze, etc., all traceable to international standards. This gives both suppliers and customers confidence - a given ΔE or haze value has the same meaning no matter where it is measured. Such standardization is vital when, for example, a phone company sources components from multiple vendors worldwide; they can require "CIELAB within tolerances and haze per ASTM < X%" and trust the numbers provided. The use of CIELAB, haze %, Y trans, and absorbance in this manner thus forms the backbone of global color and appearance quality control for display materials.

HunterLab UltraScan PRO Solution - Optimal for Display Components

To address the demanding color measurement needs of display component characterization, the HunterLab UltraScan PRO spectrophotometer is a highly recommended solution. The UltraScan PRO is a research-grade, reference spectrophotometer designed to deliver the precision, versatility, and consistency required for challenging applications like those in display manufacturing. Below, we outline why the UltraScan PRO is optimally suited for enhancing display component color quality control:



- **Broad Spectral Range with High Precision:** The UltraScan PRO measures across an extended wavelength range from 350 nm to 1050 nm (near-ultraviolet through the full visible spectrum and into the near-infrared). This broad range is crucial for modern display components – it means the instrument can characterize not only visible color but also UV-blocking properties and IR transmission. For example, the PRO can evaluate how a coated glass blocks UV (350–400 nm) or how a phone display cover transmits at 850 nm for facial recognition sensors. Many conventional spectrophotometers only cover 400–700 nm, but UltraScan PRO's extended range provides a more complete optical profile. Additionally, it offers fine spectral resolution (5 nm reporting interval), ensuring it can capture sharp spectral features and slight color differences accurately. This high spectral precision allows detection of subtle shifts in colorant cutoff or film spectra that simpler devices might miss. The instrument's dual-beam xenon flash design and dense sampling (measurements every 2 nm, reported every 5 nm) yield exceptionally low noise data and excellent agreement between instruments. For the user, this means confidence that a ΔE of 0.5 reported by one UltraScan PRO will match that measured on another unit elsewhere – a testament to its inter-instrument agreement and stability which is best-in-class.
- **Measures Reflectance, Transmittance and Haze (Diffuse/8° Sphere):** The UltraScan PRO uses an integrating sphere geometry (d/8°) with automated specular-included and specular-excluded modes. This design is extremely versatile for display applications because it can handle both reflectance and transmission measurements in one device, and it conforms to CIE and ASTM geometry standards. In reflectance mode, one can measure the color of opaque parts (e.g. painted bezels or filter glass coatings) including or excluding surface gloss as needed. In transmission mode, the UltraScan PRO not only measures total transmittance and color but also computes transmission haze by



the ASTM D1003 method (it has an internal programmable light trap). This means a single instrument can quantify the clarity of a film (haze%), the brightness (Y% transmittance), and the color (L^* , a^* , b^*) all in one go – a critical capability for evaluating display films and clear polymers. The ability to exclude the specular component is useful when measuring things like anti-glare etchings on glass; one can measure with specular excluded to just get the diffuse transmission (related to haze) or include it to get total transmission. Few instruments in the market offer such comprehensive optical characterization in one package. The diffuse/ 8° geometry also means the UltraScan PRO is insensitive to sample surface texture or directionality, which is beneficial when measuring textured diffusers or slightly roughened surfaces (the measurements remain accurate and representative of visual appearance).

- **Flexible Sample Handling for Various Sizes and Shapes:** Display components come in different sizes – from small smartphone cover glasses to large automotive display lenses or entire tablet screens. The UltraScan PRO is built with flexibility in sample handling in mind. It features three automatic lens positions (Large, Medium, Small Area View apertures of approx. 25 mm, 13 mm, and 7 mm) to accommodate various sample sizes and measurement areas. The instrument also boasts *the largest transmission compartment in the industry*, open on three sides. This open, spacious compartment allows users to measure oversized or odd-shaped samples with ease – for example, an entire car dashboard display cover or a stretched film sample can be positioned without trimming. A one-touch footswitch or button triggers the measurement, simplifying handling of large pieces. By comparison, many bench spectrophotometers have small, fixed sample ports that can't fit anything larger than a few-inch square. UltraScan PRO's design thus uniquely suits the large format nature of some display parts (e.g., a 17-inch automotive center stack display panel or a full laptop screen can be measured in sections). Even for



small parts, the multiple aperture sizes ensure the measurement area can be optimized: use the largest aperture for uniform samples to get an average, or a smaller aperture to measure small features or avoid edges. This flexibility reduces the need for any custom fixtures and speeds up the QC process for a wide range of components.

- **Advanced UV Control and Xenon Light Source:** The instrument's illumination system uses pulsed xenon flash lamps, which provide several advantages. Xenon closely simulates daylight (approximately D65) and has strong output from UV through NIR. The UltraScan PRO includes automated UV calibration and control, with calibrated D65 UV content. This is especially important when measuring materials that have optical brighteners or UV-sensitive tints (though those are more common in textiles, in displays it's relevant for UV-blocking films). The xenon flash source is high-energy but very short duration, which means virtually no sample heating and no need for lamp warm-up – you get instant measurements in a matter of seconds. Fast measurement speed is beneficial when you might be measuring dozens of points across a large panel or doing spectral scans for many wavelength points. Additionally, the xenon lamp system has a long lifetime and stable output, contributing to the instrument's long-term stability. UV control allows toggling or adjusting the UV portion for compliance with different standards (for instance, some standards require including UV, others excluding it to simulate indoor lighting). These features ensure that the UltraScan PRO can accurately measure samples under standardized conditions and also handle specialized tasks like measuring with UV exclusion if needed for certain tests. For display work, this level of control guarantees that, for example, the slight fluorescence of a coating (if any) or the UV absorption of a film is correctly accounted for in color measurements.
- **Integrated EasyMatch Software:** The UltraScan PRO comes with EasyMatch software, a powerful platform for color data analysis and quality control. The



software provides real-time data display and a rich set of functions tailored for QA/QC and R&D. For instance, EasyMatch can display spectral curves, CIELAB values, color difference (ΔE) with tolerances, and pass/fail judgments instantly after each measurement. It supports all the widely used color scales and indices under various illuminants and observers. In the context of display components, this means a user can easily get, say, a D65/10° L*,a*,b* reading and a D50/2° reading without remeasuring, to see how a film's color would look in different lighting. The software also calculates haze % and total transmission Y automatically, logging them alongside color values for each sample. For production use, EasyMatch QC allows setting up tolerance limits (for example, ΔE tolerances or minimum transmittance thresholds); it will flag any measurement that falls outside these as a failure, which is extremely useful on the line. The data can be archived and trended - over time, one can monitor if a process is drifting as the color values approach a control limit. It also simplifies generating reports and certificates of analysis for customers by outputting the measured indices. Additionally, the UltraScan PRO offers options for FDA 21 CFR Part 11 compliant software for industries that need electronic record-keeping (pharma, etc.), ensuring secure data management. In summary, the integrated software streamlines the workflow: instead of manual calculations or separate tools, everything from measurement to analysis to reporting is handled in one interface, tailored to color quality control needs.

- **Reference-Grade Performance and Reliability:** The UltraScan PRO is considered a benchmark instrument in the color measurement field - it's often used as the lab standard against which other instruments are compared. For the user, this translates to confidence that the instrument's measurements are traceable and repeatable to the highest degree. It meets or exceeds relevant international standards for color measurement accuracy (conforming to CIE, ISO, ASTM methods for both reflectance and transmittance). Its sphere is 152 mm (6 inch)



diameter, which contributes to excellent integrating capability for accurate diffuse measurements. The photometric range (0-150% reflectance) means it can even handle highly transmissive samples or measure reflectance with specular included beyond 100% (perfect reflectors) without error. Inter-instrument agreement for the UltraScan PRO is exceptionally tight (often within 0.15 ΔE or better on calibrated tiles), meaning it's suitable for a multi-site operation where instruments must match. The instrument is also built to be robust - with a solid optical bench and precision alignment that maintains calibration over time. HunterLab provides calibrated standards (white tile, black trap, etc.) that come with the unit for routine verification and calibration. Users in the display industry often require equipment that can run continuously and reliably, as downtime can slow production analytics. The UltraScan PRO's xenon lamps and optical components are designed for heavy use, and the device includes self-diagnostics (like wavelength accuracy checks with internal filters) to ensure everything stays within spec. All these factors contribute to making the UltraScan PRO a "best in class" solution for color measurement - it delivers all the needed capabilities without compromising on the rigor or accuracy.

In essence, the HunterLab UltraScan PRO provides a one-stop solution for the complex color measurement tasks in display component manufacturing. It can measure anything from a small OLED cover glass to a large polycarbonate HUD windshield piece, delivering accurate color, transmission, and haze data. By deploying such an instrument, manufacturers can tackle the challenges outlined earlier - from ensuring multi-layer components meet color specs, to characterizing new materials for AR coatings or quantum dot films - with confidence that the data are precise and globally standardized. This makes UltraScan PRO not just a tool for lab measurements, but a strategic asset for improving color quality control and driving innovation in display technology.



Competitive Landscape and HunterLab's Best-in-Class Advantage

When evaluating solutions for color and appearance measurement in the display industry, several types of instruments and approaches emerge as competitors or alternatives. However, the HunterLab UltraScan PRO distinguishes itself as best-in-class through its unique combination of features and performance. Let's consider the competitive landscape and how HunterLab's technology compares:

- **General-Purpose Colorimeters vs. Spectrophotometers:** Some manufacturers might consider simple tri-stimulus colorimeters or hand-held units for color checks. These devices use fixed filters (often simulating X, Y, Z responses) and can be handy for quick comparisons but lack spectral information and haze measurement capability. They typically measure only reflected color on opaque samples and cannot measure transmission or provide data on specific wavelengths. In contrast, the UltraScan PRO is a full spectrophotometer, capturing the entire spectrum and thus offering vastly more information (e.g., detection of metamerism or identification of where in the spectrum a tint occurs). It also yields higher accuracy and repeatability - spectrophotometers generally provide more precise color values (ΔE) than filter colorimeters. Additionally, a colorimeter cannot measure something like the transparency or haze of a display film. The UltraScan PRO, by measuring both reflectance and transmittance and calculating indices like Y%, haze, etc., covers all the needs that a basic colorimeter would miss. Thus, for critical color quality work (especially on transparent components), spectrophotometers like the UltraScan PRO are the industry standard, and simpler instruments fall short of the required performance.
- **Benchtop Spectrophotometers (Competing Models):** Within the class of bench spectrophotometers, not all are equal. Some competing instruments may only



cover the visible range (400–700 nm) or may not include an integrating sphere (using 0°/45° geometry instead). For example, a 45/0 geometry device is excellent for measuring surface color of matte samples and excluding gloss, but it cannot measure transmission or haze at all. It's also less suited to measuring textured or translucent samples (like diffuser films) because those require an integrating sphere to capture diffuse light. The UltraScan PRO's diffuse/8° sphere with large diameter ensures it can handle translucent and transparent materials accurately, which many competitor instruments cannot. Furthermore, many spectros in the market have smaller spheres (~100 mm or less) and smaller sample compartments, limiting sample size and potentially accuracy for highly scattering samples. UltraScan's 6-inch sphere and large sample compartment provide a practical and accuracy edge. Another differentiator is the wavelength range: some high-end competitors might match the visible range precision, but few extend to 1050 nm like UltraScan PRO does. This extension is critical for applications like IR filter measurement. In essence, when comparing specs, the UltraScan PRO often leads in versatility (reflectance + transmittance + haze in one), spectral range (UV-VIS-NIR), and sample handling capacity.

- **Haze Meters and Separate Instruments:** A notable advantage of HunterLab's solution is that it combines color and haze measurement. In the absence of such an instrument, a lab might use a dedicated haze meter for haze % and a separate spectrophotometer for color. For instance, BYK or Gardner manufacture haze-only meters that give Haze % and Total Transmittance, but they do not provide CIELAB color values. Using separate devices not only increases equipment cost but also complicates workflows (two measurements for the same sample, calibration of multiple devices, etc.). UltraScan PRO performs both functions in one read – simultaneously measuring color in transmission and haze. This streamlines the process and ensures the data (color



and haze) are truly from the same spot on the sample under identical conditions, which is not guaranteed if using separate instruments. Competitors have started to introduce dual-purpose instruments, but UltraScan PRO remains a top-tier reference instrument for this combined capability, with decades of refinement in both color and appearance measurement.

- **Imaging Colorimeters and Camera-Based Systems:** As discussed earlier, for tasks like pixel uniformity (demura), imaging colorimeter systems are used. These are specialized instruments with high-resolution cameras and optical filters, designed to measure luminance and color of each pixel on a lit display. They excel at mapping uniformity and identifying mura, which a bench spectrophotometer cannot do. However, their color accuracy and absolute calibration depend on reference instruments. Typically, an imaging colorimeter is calibrated using a spectroradiometer on a set of color patches displayed on the screen. In this role, the UltraScan PRO (though an object-color spectrophotometer) or its equivalent in radiometric form can serve to calibrate and validate these imaging systems. Moreover, imaging systems do not measure the individual components before assembly – they measure the fully lit display. Issues like a polarizer film’s slight tint or a cover glass reflectance are easier caught at the component level by a spectrophotometer during incoming QC, rather than after assembly by an imaging system. Therefore, HunterLab’s spectrophotometer is complementary to imaging systems: it ensures each component is within spec (preventing compounding errors in the final display), and it can provide the ground truth for color values that imaging devices rely on. When it comes to *speed*, imaging systems are faster for scanning many points, but as noted earlier, their accuracy is limited by their filter system. The UltraScan PRO, while not intended to scan millions of points rapidly, provides the gold standard measurements against which those imaging results are judged. In summary, for spatial uniformity matters, imaging systems are in a



different category (not direct competitors to UltraScan PRO); but for overall color quality and standards, UltraScan PRO is the benchmark instrument that even those systems need for reference.

- **Other High-End Spectrophotometers:** There are a few other high-end spectrophotometers which target similar applications. Many of these, however, might specialize in either reflectance or transmission, or have constraints that the UltraScan PRO addresses. For example, some instruments might require switching accessories to go from reflectance to transmission mode, whereas UltraScan PRO has it integrated and software controlled. Some might not include an internal UV calibration feature - meaning they cannot easily adjust for samples with fluorescence, while UltraScan has built-in UV control. Inter-instrument agreement is another differentiator: the UltraScan PRO, being a reference-grade device, is built for extremely tight agreement across units. This is vital for multi-site operations (common in global manufacturing). HunterLab's long experience (the company founder, Richard Hunter, literally pioneered color measurement scales) also means the algorithms and software (like EasyMatch) are very mature and trusted in the industry. Another example: measurement speed - the UltraScan PRO can measure the entire 350-1050 nm range in about 2 seconds thanks to its xenon flash and simultaneous detection. Some competitor scanning spectros might take longer or require lamp warm-up. These practical differences add up in a production environment. All things considered, when benchmarking across categories like accuracy, functionality, and efficiency, the UltraScan PRO consistently positions itself at the top end.
- **No Compromise on Data Quality:** Perhaps the strongest evidence of UltraScan PRO's best-in-class status is its reputation as *the instrument that other instruments are compared to*. In the coated glass industry, for example, it's described as the "reference color measurement spectrophotometer against which all others are compared". This kind of reputation is hard-earned. It



indicates that UltraScan PRO delivers such reliable and precise data that it's used as the yardstick in round-robin tests and by standards labs. For a display manufacturer, using the best-in-class instrument translates to reduced risk – you can trust the measurements when making decisions about accepting batches or tuning processes. It also can impress customers (if you're a supplier) to know you use the top equipment per industry standard. HunterLab's focus on color science (as opposed to companies that have broader portfolios) means they have deep expertise and support for these applications. This can be an advantage when solving unusual measurement problems; for instance, measuring very low reflectance anti-glare coatings or very high gloss surfaces – the support team can advise on methodology (like specular exclusion, etc.) that leverages the instrument's capabilities fully.

In summary, while there are various tools in the market for color and optical measurements, the HunterLab UltraScan PRO stands out by offering all-in-one capabilities without compromising laboratory-grade accuracy. Its combination of sphere geometry, wide spectral range, simultaneous color plus haze, multiple apertures, and software integration is unmatched by most competitors. Add to that its pedigree as a reference instrument and it becomes clear why it is considered *best in class*. By choosing UltraScan PRO, organizations ensure they are using the highest standard of measurement for their color quality control, which in turn helps them produce best-in-class display products. In a field where slight differences in appearance can separate a premium product from an average one, having the best measurement technology is a crucial competitive advantage.

UltraScan PRO Features and Functional Advantages

The table below summarizes key features of the **HunterLab UltraScan PRO** solution and the functional advantages they provide for display component characterization:



Feature	Functional Advantage for Color QC
Full Spectral Range (350-1050 nm)	Captures UV, visible, and NIR in one measurement. This allows evaluation of UV-blocking coatings and IR-transmitting materials (for face ID or optical sensors) in addition to normal visible color. Manufacturers can ensure components meet all optical requirements , not just visible color – e.g. verify a display cover passes IR for an eye-tracker while still appearing color-neutral.
High Resolution & Accuracy (5 nm)	Resolves fine spectral details and small color differences. Yields precise CIE Lab* values and ΔE , enabling tight tolerances. Research-grade optics mean excellent repeatability and inter-instrument agreement, so measurements are reliable across production lines. Subtle shifts (like a slight blue tint from a new film batch) are detected early, preventing quality drift.
Diffuse/8° Sphere Geometry (Reflectance & Transmission, with Specular Control)	Measures reflectance, total transmission, and haze in one device. Versatility to handle opaque, transparent, and translucent samples. Specular inclusion/exclusion enables analysis of gloss effects (e.g. AR coating reflectance vs. true color). This single instrument can characterize every component layer : from reflective anti-glare surfaces to transparent films, following standardized geometry (CIE/ASTM) for trustworthy data.
Multiple Apertures & Large Sample Chamber	Features 25 mm, 13 mm, and 7 mm aperture masks with automated switching, plus an oversized sample compartment open on three sides. Accommodates small parts to large panels . Small aperture measures tiny smartphone lenses or spots on a filter; large aperture averages color over bigger areas (useful for uniformity checks on a tablet screen filter). The expansive chamber allows testing of large automotive display covers or long films without cutting, improving workflow and measurement representativeness.
Pulsed Xenon Light Source with UV Calibration	Instant, consistent illumination simulating D65 daylight. No warm-up needed and minimal heat on samples, enabling fast throughput (entire spectrum measured in ~2 seconds). Automated UV control (with calibrated D65 UV content) ensures accurate measurement of fluorescent or UV-sensitive samples. This feature guarantees that optical brighteners or UV blockers in



Feature	Functional Advantage for Color QC
Comprehensive EasyMatch Software	materials are properly evaluated and that results under different illuminants can be obtained accurately. Integrated software provides real-time color data, pass/fail alerts , and extensive metrics (CIELAB, ΔE , Y%, haze, Gardner, APHA, etc.). Simplifies QC by automatically comparing results to tolerances – e.g. flagging a polarizer film whose $\Delta E > 2$ or haze $<$ specification. Graphical displays (spectral curves, color plots) aid in root cause analysis when something is out of spec. Data can be stored and trended to monitor process stability. The software can also easily switch illuminants/observers or compute color differences under multiple conditions, supporting design evaluations (like how a display looks in store vs. in sunlight). Overall, EasyMatch QC streamlines color management, reducing human error and increasing productivity in the lab or production floor.

(Note: FABS = Features and Benefit Summaries. The advantages listed are directly tied to improving color quality control of display components.)

Hypothetical Case Studies in Display Industries

To illustrate how spectrophotometric color characterization can be applied in practice, let's consider a few hypothetical case studies across different sectors of the display industry: consumer electronics, smartphones, and automotive. Each scenario highlights challenges and solutions using color measurement.

Case Study 1: Ensuring Laptop Display Panel Consistency (Consumer Electronics)

Scenario: A manufacturer of high-end laptop LCD panels was facing occasional customer complaints about slight color non-uniformity – some screens had a subtle warm or cool cast in different areas. The displays passed visual inspection and basic calibration, but a few “mura” patches (uneven color clouds) slipped through. The



company decided to tighten control of incoming components, suspecting that variations in the optical films and polarizer sheets were contributing to the issue.

Application of Spectrophotometer: The quality team introduced a routine where they spectrophotometrically measured each batch of diffuser film and polarizer film used in the LCD stack. Using the UltraScan PRO, they measured the transmitted color (CIELAB) at several points across large film samples and the haze %. They discovered that one supplier's diffuser film had a slight shift toward yellow ($b^* \sim +3$) on one side of the roll and a lower haze near the edges. This would cause parts of the screen to be dimmer and yellower, correlating with the mura reports. With this data, the manufacturer worked with the supplier to improve coating uniformity on the film. They also set strict color uniformity specs: any film roll with $\Delta E > 1$ across its width or haze variation $> \pm 2\%$ would be rejected. The UltraScan PRO's large-area view allowed averaging over big sections, and small-area measurements pinpointed problem zones.

Outcome: By catching non-uniform films early, the incidence of color mura in final panels dropped dramatically. The once sporadic complaints virtually disappeared. Additionally, the manufacturer started using the spectrophotometer to measure assembled panels at various points (in a sampling plan) to ensure uniform output. While an imaging system was used for full pixel-level correction, the spectrophotometer served as an auditing tool – if any panel showed an unexpected ΔE difference corner-to-corner, it signaled an upstream issue. This case underscores how component-level color control translates to better final product uniformity. The investment in the UltraScan PRO paid off by reducing warranty claims and improving the overall reputation of the laptops for having vibrant, consistent displays.

Case Study 2: Optimizing Smartphone Display for Face Recognition and Blue Light Management



Scenario: A smartphone OEM is designing a new model with an under-display infrared facial recognition sensor and an eye-comfort mode that reduces blue light. These features depend on the optical properties of the display stack: the OLED screen and cover glass must transmit IR light effectively to the face ID sensor, and a special film is added to limit blue light emissions for eye comfort. The engineering team needs to verify these properties without compromising visible color performance.

Application of Spectrophotometer: During development, engineers took samples of the OLED stack (OLED on thin glass) and the cover glass with various coatings and measured their spectral transmittance using the UltraScan PRO (which can measure up to 1050 nm). They focused on the 800–940 nm range for IR. Initially, a certain cover glass with an anti-smudge coating was found to transmit only ~50% at 940 nm – likely to interfere with the IR camera. Another coating option transmitted 90% at that wavelength. By measuring these accurately, the team chose the coating that allowed more IR through. They also measured the blue light filter film that was to be laminated above the OLED. The film was supposed to cut 20% of blue light around 450 nm. Spectral absorbance measurements showed one sample was over-performing (cutting ~40% at 450 nm, which made the display too yellow in eye-comfort mode). They iterated the film’s formulation until the spectrophotometer confirmed the target transmission curve – about 80% transmission at blue wavelengths, 100% in red/green, giving the desired balance of reduced blue output but minimal color shift.

Crucially, throughout this process they also measured CIELAB color and luminance (Y%) of the assembled display modules with and without the new films in place. This ensured that adding the film didn’t skew the white point beyond acceptable ΔE and that overall brightness remained within spec. The UltraScan PRO’s data allowed them to tweak the OLED calibration (slightly boosting blue in normal mode to offset the film) with quantitative feedback.



Outcome: The final smartphone launched with a well-optimized display: under normal conditions it achieved the intended wide color gamut and neutral white, and in eye-comfort mode it cut blue light by ~20% with only a minor warm tint that users found comfortable. The face recognition worked flawlessly even in dark conditions, thanks to high IR throughput of the display – a direct result of material choices validated by spectrophotometric measurements. This case highlights how multi-purpose spectrophotometer data (both visible and IR) can guide design decisions for modern display features. By ensuring each component’s spectral properties were understood and tuned, the team avoided after-the-fact fixes and delivered a premium product on schedule.

Case Study 3: Maintaining Automotive Display Clarity and Durability

Scenario: An automotive supplier produces large touch-enabled displays for car dashboards. These displays have a polycarbonate cover lens with anti-reflective hard coating. They must remain clearly viewable in harsh conditions: bright sunlight, high heat, and after years of use (UV exposure). A key requirement from the automaker client is that after 3 years equivalent aging, the cover lens must have haze <2% and no perceptible yellowing ($\Delta b^* < 1$). The supplier needs to validate their materials and process can meet this.

Application of Spectrophotometer: The supplier set up a testing protocol using the UltraScan PRO. First, they measured initial samples of the coated polycarbonate lens: Total transmission Y%, haze%, and CIE b^* . The new parts showed 92% transmission, 1.0% haze, and essentially colorless ($b^* = 0.0$). Next, they subjected samples to accelerated aging – UV exposure, high temperature/humidity cycles – equivalent to 3 years in service. They re-measured these aged samples. The spectrophotometer detected an increase in haze to ~1.8% and a slight yellow tint (b^* shifted to +0.8). These values were within the specification, but close to the limits. Concerned, the



supplier experimented with a couple of alternatives: a different hard coat formulation and a polycarbonate with a UV stabilizer additive. After aging those, one combination yielded haze ~1.0% and Δb^* near 0 (no yellowing). The spectrophotometric data gave concrete evidence that this material set had superior durability.

During production, the UltraScan PRO became a QA tool: from each batch of coated lenses, a sample was measured for haze and transmission. One quarter, the haze values started creeping up to ~1.3% on new parts. Investigating the cause, they found that a subtle change in the curing oven temperature for the hard coat was causing micro-blistering (not visible, but measurable as increased haze). They adjusted the process and brought haze back down around 0.8-1.0%. Without these measurements, the issue might have gone unnoticed until parts began showing visible haziness in the field under sun glare.

Additionally, the supplier used the instrument to measure reflected color of the displays. Automotive specs often require low reflectance to avoid dashboard glare. By measuring reflectance with specular included, they could quantify the effectiveness of the anti-reflective coating. It helped them prove that their coating had <1% reflectance across the visible spectrum, which translated to excellent contrast in the car (they even computed contrast ratio under daylight by measuring a black state reflectance vs. white state transmittance of the display stack, using the spectrophotometer data - it gave a contrast >5:1 in sunlight, meeting the automaker's requirement).

Outcome: Through rigorous use of spectrophotometric characterization, the supplier achieved a highly reliable automotive display lens. They were able to document to the automaker that their parts met clarity and color specs initially and after aging - complete with quantitative data and compliance to ASTM test methods. The automaker was impressed by this data-driven approach, giving the supplier an edge over competitors who might only do subjective checks. In production, the early detection of a haze drift saved potentially thousands of parts from being produced



with suboptimal clarity. In service, vehicles using these displays maintained excellent visibility even after years, contributing to safety and user satisfaction. This case demonstrates how instrumental color and appearance measurement is key for quality and durability in automotive displays, where environmental stresses are high and failure to meet specs can have serious implications.

Each of these case studies, while hypothetical, are grounded in real industry knowledge and demonstrates the value of deep color characterization. Across consumer electronics, smartphones, and automotive sectors, the ability to measure and control the color properties of display components leads to better performance, fewer defects, and innovation in product features. Spectrophotometers like the UltraScan PRO often play a central role in these successes - enabling engineers to see quantitatively what the human eye alone cannot and thereby driving improvements in design and manufacturing.

Conclusion

Color quality control in modern display technology is a multifaceted technical challenge, spanning the precise measurement of visible colors, the management of light transmission and haze, and the need to correlate instrumental data with visual experiences. As this white paper has detailed, spectrophotometers - and specifically the **HunterLab UltraScan PRO** - provide the comprehensive capabilities needed to meet these challenges. By leveraging spectrophotometric analysis, manufacturers can ensure that each optical component, from polarizer films to cover glasses, contributes to the desired overall display performance and meets stringent standards for accuracy and consistency.

We began by recognizing that in today's world of high expectations, displays must deliver perfection: uniform color, high contrast, and clarity under all conditions.



Achieving this requires not only careful design but also rigorous measurement and control of every element that affects the display's visual output. Objective color measurement is the enabler that turns a subjective concept like "image quality" into quantifiable parameters that engineers can monitor and optimize. Through the overview and importance sections, we saw that color measurement ties directly into brand consistency, user experience, and even the functionality of embedded technologies. In "what color reveals," we highlighted that measuring color and appearance gives insight into material health and process fidelity - essentially acting as an early warning system for quality issues.

We then surveyed how global standards (CIELAB, haze %, etc.) provide a common language and method for these measurements, allowing disparate teams and suppliers to align on quality targets. The UltraScan PRO was presented as an ideal solution that not only adheres to these standards but excels in delivering beyond them - with features addressing the full spectrum of needs (literally and figuratively). We compared it against other approaches and found it setting the benchmark in the field. The table of features and advantages succinctly connected its technical specs to real-world benefits, reinforcing why a top-tier instrument is worth the investment for high-stakes applications like display manufacturing.

Crucially, through the case studies, we translated theory into practice. These scenarios demonstrated that whether it's reducing pixel uniformity complaints in laptops, fine-tuning a smartphone's optical stack for new features, or ensuring long-term clarity of an automotive display, the story arc is similar: using data from spectrophotometric measurements to guide decisions, catch problems, and validate solutions. The common outcome is improved quality and reliability - and often a competitive edge in the market. In each case, challenges that would be difficult or impossible to tackle by eye or with basic instruments were resolved with the help of comprehensive color measurement.



Enhancing display component characterization with advanced spectrophotometry is not just a laboratory exercise, but a practical necessity in the modern manufacturing environment. It elevates quality control from a pass/fail exercise to a continuous improvement process grounded in scientific data. By integrating instruments like the UltraScan PRO into their workflows, companies can achieve tighter control over color and appearance than ever before. This results in displays that consistently meet design intent and customer expectations - from the first unit produced to the millionth. Just as importantly, it equips organizations to innovate confidently. When exploring new materials or pushing the boundaries of display performance (higher brightness, new form factors, etc.), having robust measurement capabilities means being able to iterate intelligently and ensure that advances in technology don't come at the cost of quality.

In the competitive landscape of consumer electronics, automotive, and beyond, HunterLab's best-in-class spectrophotometers provide the assurance that color quality will be second to none. The technical rigor and depth of measurement they offer translate into tangible business benefits: reduced rejects and rework, compliance with international standards, and enhanced end-user experience. As display technologies continue to evolve - with trends like mini-LED, microLED, flexible displays, and augmented reality - the role of precise color characterization will only grow more critical. Manufacturers who embrace these tools and techniques position themselves to deliver the next generation of visually stunning, reliable displays, maintaining control over the invisible details that together create a brilliant, flawless picture.

By marrying scientific measurement with manufacturing know-how, we ensure that the art and science of displays - the beautiful images we see and the complex engineering behind them - come together seamlessly. Spectrophotometric color characterization is the bridge between those worlds, and with it, the industry can continue to reach new heights of quality and innovation in display technology.