



CDS TECHNICAL GUIDE

The Science of Sunlight Readability

Introduction

Sunlight readability is a critical performance requirement for industrial, commercial, and outdoor display systems. Engineers designing products for transportation, marine, military, medical, kiosk, or field-service environments must ensure that visual interfaces remain legible under high ambient illumination, including direct sunlight exposure exceeding 100,000 lux.

This technical manual provides a comprehensive engineering perspective on the science of sunlight-readable display technologies, detailing optical principles, performance metrics, enhancement techniques, application scenarios, and integration guidelines. It is intended to support product designers and technical decision-makers evaluating CDS's sunlight-readable display solutions.

Technology Overview

When a display is exposed to intense ambient light, particularly sunlight, two primary phenomena reduce visibility: ambient light reflection and insufficient display luminance.

1. Ambient Reflection

Ambient reflection originates from:

- Surface reflections (specular)
- Scattering within the cover lens
- Internal reflections between LCD layers
- Diffuse reflections from backlight or internal mechanical surfaces

If reflections exceed the display's emitted luminance, contrast washes out, rendering the image illegible.

2. Inadequate Luminance

A display's perceived brightness is relative to ambient illumination. Typical indoor displays operate at 250–350 cd/m², insufficient for outdoor readability. Sunlight-readable displays generally require 800–3000 cd/m² depending on the environment.

Core Principles of Sunlight Readability

Three primary variables determine display visibility under sunlight:

- Luminance (cd/m²)
- Contrast ratio (including ambient contrast ratio)
- Surface reflectance (measured in %)

The key engineering goal is maximising the Ambient Contrast Ratio (ACR), defined as:

$$ACR = (L_{display} + L_{ambient} \times R) / (L_{black} + L_{ambient} \times R)$$

Where R is the average reflectance.

CDS designs displays to optimise ACR through optical bonding, high-brightness backlighting, anti-reflective coatings, and high-TNI liquid crystal formulations.

High-Brightness Backlight Systems

High-brightness (HB) LCD modules incorporate LED arrays with increased density and optimised thermal management to achieve luminance levels up to 3000 cd/m².

Engineering Characteristics:

- LED binning ensures chromatic consistency
- Custom light guides reduce hotspot formation
- Enhanced driver circuitry maintains constant-current operation
- Heatsinks and thermal vias dissipate waste heat

For detailed HB display specifications, visit www.crystal-display.com.

Optical Bonding Technology

Optical bonding is one of the most effective methods for improving outdoor visibility. It eliminates the air gap between the LCD and cover glass, reducing internal reflection by up to 65%.

Benefits:

- Higher contrast in sunlight
- Reduced parallax
- Increased mechanical strength
- Improved resistance to moisture and dust
- Elimination of condensation within the air gap

Types of Optical Bonding

1. Silicone Bonding – Flexible, reworkable, wide temperature tolerance.
2. Epoxy Bonding – Permanent, robust, ideal for rugged environments.
3. OCA (Optically Clear Adhesive) Bonding – Common in consumer devices; can be used in industrial applications with proper environmental sealing.

CDS provides complete optical bonding services, including custom cover glass, touch integration, and impact-resistant materials.

<https://crystal-display.com/enhancing-tft-display-performance-with-optical-bonding/>

Anti-Reflective and Anti-Glare Coatings

Surface treatments further enhance sunlight readability by controlling reflection and scattering:

- Anti-Reflective (AR) Coatings: Reduce surface reflectance to <1%.
- Anti-Glare (AG) Coatings: Micro-etch surface to diffuse reflected light, reducing glare.
- Anti-Fingerprint (AF) Coatings: Improve visibility under fingerprint contamination.

CDS offers custom AR/AG/AF configurations tailored to the deployment environment.

High-TNI Liquid Crystal for No-Blackening Performance

Standard liquid crystal materials exhibit temporary blackening when exposed to elevated temperatures ($>70^{\circ}\text{C}$), especially under direct sunlight. High-TNI LC prevents this defect.

Applications requiring high-TNI:

- Automotive dashboards
- Outdoor ticketing kiosks
- Marine navigation systems
- Defence vehicle displays

For high-TNI product options, visit www.crystal-display.com.

Technical Specifications Relevant to Sunlight Readability

Key performance parameters include:

Brightness

- Standard: $300\text{--}500\text{ cd/m}^2$
- Sunlight readable: $800\text{--}3000\text{ cd/m}^2$

Contrast Ratio

- IPS displays achieve 800:1 to 1500:1
- Optical bonding improves perceived contrast in bright conditions

Viewing Angle

- IPS: $80^{\circ}/80^{\circ}/80^{\circ}/80^{\circ}$
- VA: High contrast but narrower vertical viewing

Surface Reflectance

- Typical air-gap LCD: 4.5–7% reflectance
- Optically bonded LCD: $<1.5\%$ possible with AR coatings

Operating Temperature

- Industrial: -20°C to $+70^{\circ}\text{C}$
- Extended: -30°C to $+85^{\circ}\text{C}$
- High-TNI recommended for direct sunlight exposure

Power Consumption

Higher brightness requires increased electrical power:

- 1000 cd/m^2 display: typically 8–12 W
- 2500 cd/m^2 display: 15–25 W depending on efficiency

Medical and Laboratory Equipment

Optical bonding improves durability and ease of cleaning. It also enhances precision for touch interfaces used in analytical instruments.

<https://crystal-display.com/products/medical-displays/>

Consumer and Light Commercial Devices

Air-gap displays may be preferred for cost-sensitive designs that do not require high optical performance.

Applications Scenarios for Sunlight-Readable Displays

Outdoor Kiosks and Digital Signage

Requirements:

- High brightness (≥ 1500 cd/m²)
- AR/AG-coated cover glass
- Temperature management with fans or heat exchangers
- Optional optical bonding to prevent condensation

Transportation and Automotive Systems

Use cases:

- Bus display systems
- Train door signage
- In-vehicle operator terminals

Key considerations:

- Vibration-resistant assembly
- Extended temperature range
- High-TNI LCD modules

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<https://crystal-display.com/products/medical-displays/>

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Marine and Military Applications

Challenges include:

- High ambient light
- Salt spray and corrosion
- Shock and vibration
- Wide temperature swings

CDS offers ruggedised sunlight-readable marine-grade displays with IP-rated enclosures.

<https://crystal-display.com/products/marine-ip65-waterproof-monitors/>

Medical and Laboratory Equipment

Although not exposed to sunlight, high-illumination surgical lighting replicates similar high-ambient-brightness conditions. Optical bonding improves clarity and eliminates internal reflections.

Industrial Outdoor HMIs

Features required:

- Impact-resistant cover glass
- Optically bonded PCAP touch
- UV-resistant materials

Integration Guidelines

Backlight Driving and Thermal Management

High-brightness LEDs generate significant heat. Engineers must:

1. Select efficient LED drivers with constant-current regulation.
2. Integrate thermal pads or heat spreaders into the enclosure.
3. Allow for airflow or conductive cooling paths.

Failure to manage temperature leads to:

- LED colour shift
- Reduced lifetime
- Panel mura effects

Touchscreen Integration

PCAP performance can degrade under high light due to reflections and optical interference.

Integration tips:

- Use low-iron glass for improved clarity
- Apply AR coating to the cover lens front surface
- Ensure correct grounding of the touch controller
- Avoid stacking excessive layers that increase reflections

<https://crystal-display.com/how-are-touchscreens-manufactured/>

Mechanical Integration

- Maintain uniform bracket pressure around LCD to avoid mechanical stress
- Avoid direct sunlight on internal components through enclosure openings
- Consider shading visors or recessed mounting when possible

Environmental Protection Ratings

For outdoor systems:

- IP65 or IP67 front glass protection
- Sealed bonding to prevent moisture ingress
- UV-stable materials for long-term exposure

Electrical Interface Compatibility

Sunlight-readable displays typically support:

- LVDS
- eDP (preferred for high-resolution HB panels)
- HDMI (for open-frame monitors)
- MIPI DSI (for compact embedded systems)

Engineers should verify timing profiles against LCD datasheets. Download technical datasheets at www.crystal-display.com/resources.

Troubleshooting Considerations

Issue: Display washed out in sunlight

- Check ACR values
- Verify AR/AG coating presence
- Evaluate if brightness is sufficient for the application

Issue: Image non-uniformity at high temperature

- Inspect panel for heat imbalances
- Validate thermal path design

Issue: Touch misregistration outdoors

- Recalibrate touch controller
- Verify optical bonding performance

Issue: Excessive power consumption

- Reduce brightness via ambient-light sensor
- Optimise driver efficiency

Conclusion

Sunlight-readable display design requires a holistic approach that combines optical enhancements, high-brightness engineering, thermal control, and ruggedisation. Crystal Display Systems Limited provides a comprehensive range of industrial-grade sunlight-readable displays, optical bonding services, and customisation capabilities to meet the demands of outdoor and high-illumination environments.

For further consultation, detailed datasheets, or engineering support, visit www.crystal-display.com or contact the CDS technical team.



Want More Information? Contact Us Now

Need any additional information?

If you need any assistance with pricing information, technical support or require any additional information our team would be more than happy to assist



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Note: Monitor images are for marketing purposes only and you should refer to the mechanical diagrams for accurate dimensions and designs