

LED Selection Guidelines for Human-Machine Interface (HMI) Applications

1. Abstract & Scope

Human-Machine Interface (HMI) across industrial control panels, automotive cockpits, medical equipment, and premium home appliances rely heavily on surface-mount LED illumination for status indication, icon backlighting, and dynamic user feedback. Selecting the wrong LED package or optical parameter often results in visual non-uniformity, unacceptable hotspots, color shifts across adjacent keys, optical crosstalk, or accelerated thermal degradation. This Application Note provides practical engineering guidelines for selecting LED packages, beam angles, luminous intensity ranges, and wavelength tolerances tailored to specific HMI physical architectures

2. Key HMI Architectural Structures & Optical Requirements

The optical and mechanical footprint of the HMI housing governs LED selection. The diagram below contrasts the primary direct backlighting and edge-lit structures:

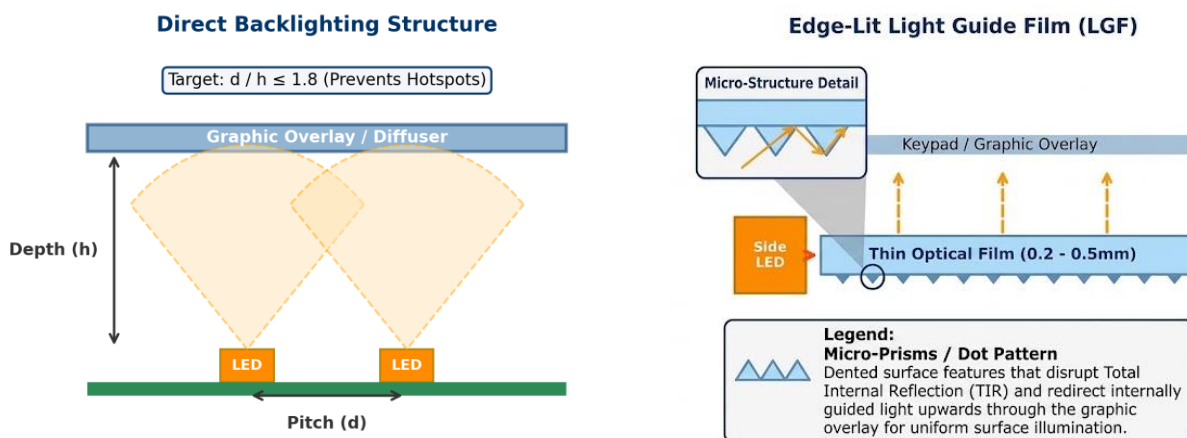


Figure 1: Cross-sectional schematics of Direct Backlighting (left) vs Edge-Lit LGF (right) configurations.

A. Direct Backlighting (Diffused Membrane / Graphic Overlay)

- Structure: The LED sits directly below a translucent graphic layer separated by an air gap or diffuser plate.
- Primary Challenge: Hotspots directly over the LED die.

- Selection Strategy:

For wide-angle ($\geq 120^\circ$) LEDs used with a diffusive overlay, a pitch-to-depth ratio approximately $d/h \leq 1.8$ may be used as an initial design guideline, where d is the distance between adjacent LEDs and h is the cavity depth from the LED emission plane to the optical diffuser surface.

Final LED spacing should be verified through optical simulation or prototype evaluation.

DESIGN RULE: Pitch-to-Depth Ratio

$d / h \leq 1.8$ (Rule of thumb for smooth luminance distribution without visible grid patterns)

B. Edge-Lit Light Guide Film (LGF) & Light Pipes

- Structure: Light is injected laterally into a thin (0.125 mm – 0.5 mm) optical polycarbonate/PMMA film or rigid acrylic light pipe. Micro-dots or surface textures redirect light vertically toward the overlay.
- Primary Challenge: High coupling efficiency into thin light-entry apertures.
- Selection Strategy: Low-profile Side-View SMD LEDs (0.6 mm to 1.0 mm package height) with high luminance density and tight spatial alignment tolerances to minimize optical coupling losses at the film boundary.

C. Dead-Front (Hidden-Until-Lit) Indicators

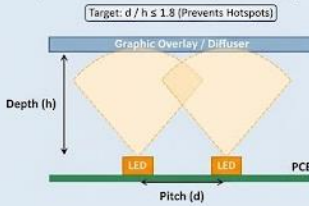
- Structure: Icons remain completely invisible against a dark, opaque-appearing housing surface until backlit by the LED.
- Primary Challenge: Penetrating low-transmittance (15%–30%) neutral-density filters or semi-transparent specular coatings while keeping dark-state light bleed at zero.
- Selection Strategy: Medium-to-high intensity Chip LEDs (100–500 mcd at low drive currents like 5–10 mA) with narrow dominant wavelength (λ_d) tolerance to avoid color shifts caused by non-linear transmission spectra of tint coatings

D. Capacitive Touch Rings & Halo Switches

- Structure: Annular illuminated rings surrounding tactile touch sensors or rotary knobs.
- Primary Challenge: Uniform perimeter illumination with zero backlight bleed into adjacent status icons.
- Selection Strategy: Ultra-compact Chip LEDs (0402 / 0603 footprint) arrayed in radial symmetry, or reverse-mount LEDs firing upward through PCB cutouts.

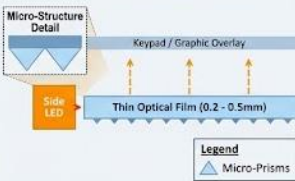
DESIGN GUIDELINES FOR ILLUMINATED HMI STRUCTURES & LED SELECTION

A. Direct Backlighting (Diffused Membrane / Graphic Overlay)



- **Structure:** LED below translucent layer.
- **Primary Challenge:** Hotspots.
- **Primary Challenge:** Hotspots.
- **Selection Strategy:** Use pitch-to-depth ratio $d/h \leq 1.8$ (initial guideline) with wide-angle LEDs ($\geq 120^\circ$). Spacing verification recommended.

B. Edge-Lit Light Guide Film (LGF) & Light Pipes



- **Structure:** Light injected laterally into a 0.125mm - 0.5mm optical film (Polycarbonate/PMMA) with micro-textures.
- **Primary Challenge:** High coupling efficiency.
- **Selection Strategy:** Select low-profile Side-View SMD LEDs (0.6mm - 1.0mm) with high luminance and tight alignment tolerances.

C. Dead-Front (Hidden-Until-Lit) Indicators



- **Structure:** Icons invisible against a dark surface until backlit.
- **Primary Challenge:** Penetrating low-transmittance (15%-30%) neutral-density filters. Zero light bleed in dark state.
- **Selection Strategy:** Select medium-to-high intensity Chip LEDs (100-500 mcd at 5-10 mA) with narrow wavelength (λ_d) tolerance.

D. Capacitive Touch Rings & Halo Switches

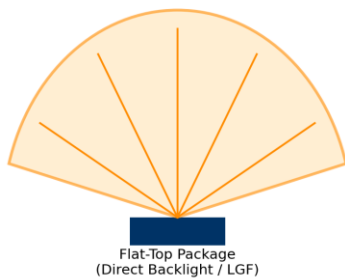


- **Structure:** Illuminated rings surrounding tactile/touch sensors.
- **Primary Challenge:** Uniform perimeter illumination with zero bleed into adjacent icons.
- **Selection Strategy:** Select ultra-compact Chip LEDs (0402 / 0603) or reverse-mount LEDs, arranged in radial symmetry.

3. Optical Characterization & Selection Parameters

3.1 Radiation Angle (2θ½) vs. Package Lens Profile

Wide Lambertian Emission (120° - 150°)



Narrow Directional Emission (30° - 60°)

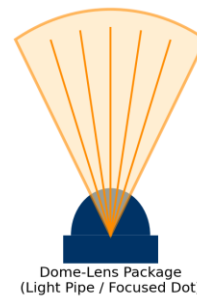


Figure 2: Beam pattern comparison: Wide Lambertian (flat top) vs Directional (Dome Lens).

- Wide-Angle Top-View LEDs (120°–150° Lambertian) are typically preferred for direct backlighting applications. For edge-lit structures, Side-View LEDs with emission patterns matched to the light-guide entrance geometry are generally preferred.
- Dome-Lens LEDs (30°–60° Directional): Ideal for deep light pipes, localized status dot indicators, or long throw distances without intermediate light guides.

3.2 Luminous Intensity (Iv) & Current Scaling

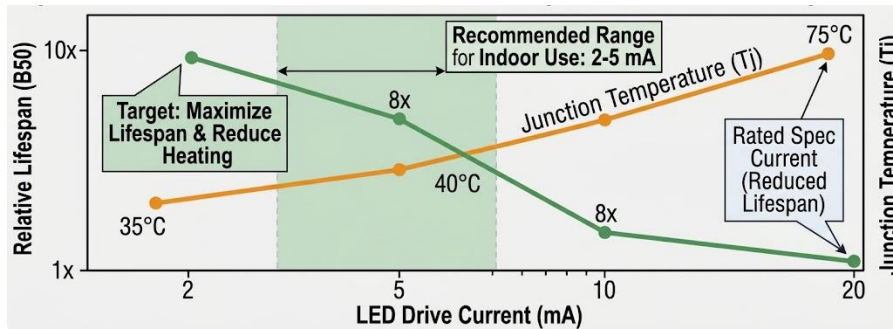
Target Surface Luminance:

- Industrial / Indoor Control Panels: 50 – 150 cd/m²
- High Ambient / Outdoor Direct Sunlight: > 1,000 cd/m²

Drive Current Tuning: Use the datasheet test current as the reference for optical comparison, then determine the actual operating current based on brightness, thermal margin, and lifetime requirements.

Conceptual illustration only:

Impact of Drive Current on LED Relative Lifespan & Junction Temperature



- LED luminous intensity: mcd
- HMI surface luminance: cd/m²

LED luminous intensity (mcd) should not be directly equated with final HMI surface luminance (cd/m²). Optical efficiency, diffuser transmission, illuminated area, and cavity geometry must also be considered.

3.3 Color Consistency, Binning, and Chromaticity

Parameter	Recommended Specification for HMI	Failure Mode If Unchecked
Dominant Wavelength (λ_d)	± 2.5 nm single binning for Green/Blue/Red	Visibly different shades across adjacent keys
White Chromaticity (x, y)	3-step MacAdam Ellipse grouping	Cold-blue vs. yellowish white disparity
Intensity Binning (Iv)	1:1.3 maximum ratio per reel	Non-uniform brightness across button arrays

4. HMI LED Selection Flow

- Identify the optical architecture: Direct backlight / Edge-lit / Light pipe / Dead-front
- Define the mechanical geometry: LED pitch, cavity depth, light-guide entrance
- Select the emission pattern: Wide-angle / Directional / Side-view
- Define optical targets: Brightness, color, and uniformity
- Verify thermal and electrical margins
- Validate through prototype testing

5. HMI LED Selection Matrix

Application Structure	Primary Package Type	Beam Angle (2θ½)	Luminous Intensity (Iv)	Key Selection Parameter
Edge-Lit Light Guide Film (LGF)	Side-View SMD (0602 / 1204)	110° - 130°	150 - 400 mcd	Package height < 0.8 mm, narrow spatial footprint
Dead-Front Panel Backlight	Top-View ChipLED (0805 / 1206)	120° - 140°	350 - 1000 mcd	High luminous output at low IF, tight λd binning
Light Pipe Status Indicator	Dome-Lens SMD / PLCC-2	30° - 60°	1000 - 4500 mcd	High axial intensity, low off-axis stray light
Capacitive Touch Ring	Reverse-Mount / 0402 ChipLED	120° - 150°	50 - 200 mcd	Extremely small footprint, uniform wide emission

Inolux LED Recommendation

Application	Recommended Part Number
RGB Status Indicator	IN-PI20TATPRPGPB
Appliance UI Lighting	IN-PI55QATPRGPBPW-60
General Icon Backlight	IN-S126AT5UW
General Single-Color Indicator	IN-S126ATR / ATG / ATB
Compact RGB Indicator	IN-S126TASRGB
Small RGB Pixel HMI	IN-PI10TAT5R5G5B
Dense Button Arrays	IN-PI20TAT5R5G5B

6. Thermal Management & Circuit Reliability Guidelines

[1] Junction Temperature (Tj) Derating: High ambient operational temperatures in industrial or automotive HMIs degrade lumen output over time. Maintain Tj < 105°C using the thermal resistance formula:

THERMAL CALCULATION MODEL

$$T_j = T_a + (R_{th,j-a} \times V_F \times I_F)$$

Where Ta is ambient temperature, Rth,j-a is thermal resistance junction-to-ambient, VF is forward voltage, and IF is forward current.

[2] ESD Protection:

For exposed capacitive touch surfaces or external light pipes subject to human contact, select LEDs with adequate component-level ESD robustness according to the product datasheet. For user-accessible HMI interfaces, system-level ESD protection, such as board-level TVS devices, may also be required.

Engineering Verification Checklist

- ✧ Verify max current derating curve at $T_a = 85^{\circ}\text{C}$.
- ✧ Check solder pad geometry to prevent tombstoning on ultra-small packages (0402/0603).
- ✧ Confirm optical crosstalk barriers (gaskets/baffling) extend to within ≤ 0.1 mm of the top cover overlay.
- ✧ Avoid directly paralleling LEDs without individual current-limiting elements. Use independent series resistors or constant-current channels where uniform current sharing and brightness are required.