MACHINE VISION & INDUSTRIAL INSPECTION

Designing Optical Subsystems for Machine Vision and Industrial Inspection

A practical guide to *LED and photodiode selection* for design engineers, system architects, and integrators specifying optoelectronics for automated inspection lines.

WHAT YOU'LL LEARN

- How matched LED–photodiode pairs determine SNR
- Which wavelengths reveal which defects
- How to specify for the factory environment
- Common failure modes and how to engineer them out

WHO IT'S FOR

- Vision system designers and OEM integrators
- Optomechanical and electrical engineers
- Process engineers upgrading inspection lines
- R&D teams specifying new platforms

01 Why the Optical Subsystem Determines Inspection Outcomes

> In machine vision, the camera and the algorithm get most of the credit. The **optical subsystem**—the matched pair of emitter and detector—does most of the work. Get the optics right, and inspection becomes deterministic.

Machine vision failures rarely originate in software. They originate upstream, at the moment a photon either reaches the detector cleanly or does not. Three failure categories dominate field returns:

- **False rejects under lighting drift.** An LED whose output power drops 8% over an hour pulls thresholded vision systems out of calibration. Lines stop, operators retune, throughput suffers.
- **Missed defects on low-contrast targets.** When the illumination wavelength sits in the wrong part of the target's reflectance curve, real defects produce less signal than the surrounding noise floor.
- **Ambient interference.** Overhead fluorescents, sunlight through skylights, and adjacent stations leaking IR into the field of view all corrupt signal if the detector cannot reject what the emitter did not produce.

All three are addressable in the optical subsystem before they reach a single line of code. The decisions that prevent them are made when the LED part number and the photodiode part number are chosen—not after.

02 The Physics of a Matched LED–Photodiode Pair

Every photodiode has a **spectral responsivity curve**—amps generated per watt of incident light at each wavelength. Every LED has an **emission spectrum**, typically 30–50 nm wide centered on its peak. The signal a system actually produces is the integral of the product of those two curves, weighted by the optical path.

> **DESIGN PRINCIPLE**
>
> A 22 mW LED matched to a peak-aligned detector can outperform a 50 mW LED feeding a poorly matched one. **Raw output power is a misleading single-figure metric**—pair selection drives signal strength as much as LED power.

Two photodiode families cover most of the visible-to-NIR machine vision range: **blue-enhanced** silicon detectors optimized for 400–700 nm, and **red-enhanced** silicon detectors optimized for 600–1000 nm. The naming refers to which side of the spectrum has been enhanced beyond a standard silicon photodiode's flatter response.

03 Choosing the Right Wavelength for the Inspection Task

Wavelength selection is where most engineering value gets created. Different wavelengths reveal different defects on different materials. Use this table to map the inspection task to a starting wavelength and matched detector type.

λ	Best For	Why It Works	Matched Detector
450 nm BLUE	Surface defects, scratches on plastics, cosmetic inspection	Short wavelengths scatter strongly off micron-scale surface features; high contrast on light substrates	Blue-enhanced Si photodiode
630 nm RED	Color discrimination, label inspection, pharma blister packs	Strong contrast on printed marks; good penetration through thin clear films	Red-enhanced Si photodiode
685 nm DEEP RED	Vision-guided robotics, fluorescent ambient suppression	Sits beyond peak fluorescent emission; less affected by overhead lighting flicker	Red-enhanced Si photodiode
850 nm NIR	General-purpose conveyor vision, part counting, edge detection	Outside human visible range, doesn't disturb operators; strong silicon response; high-power LEDs available	Red-enhanced Si (NIR-optimized)
940 nm NIR	Outdoor or sun-exposed lines, agricultural sorting	Solar irradiance has a relative dip near 940 nm (water absorption); improved daylight rejection	Red-enhanced Si (NIR-optimized)

BANDWIDTH NOTE

Specifying a wavelength is only half the job. LEDs vary in spectral width (FWHM); photodiodes vary in how steeply responsivity rolls off. For high-speed inspection, also confirm the detector's **rise time and capacitance** match your bandwidth budget.

04 Designing for the Industrial Environment

Lab benchtop performance does not predict factory-floor performance. Four environmental factors do most of the damage to inspection systems and should be specified explicitly.

THERMAL STABILITY

LED peak wavelength shifts roughly **0.2 to 0.3 nm per °C**. A line running from a 25 °C cold start to 60 °C steady state will see emission drift 7–10 nm—enough to walk partially off a narrowband detector or filter. Specify LEDs in hermetic TO-can packaging rated for the full operating range, not the typical-condition range.

MECHANICAL DURABILITY

Conveyor vibration, robotic arm shock, and washdown cycles all stress optoelectronic packages. Plastic-encapsulated emitters can develop micro-cracks under thermal cycling that admit moisture and degrade output. **Hermetic metal-can packages** (TO-5, TO-46, TO-18) eliminate this failure mode.

OPTICAL ALIGNMENT TOLERANCE

An LED with a tightly controlled beam angle simplifies fixture design. Wide-angle emitters illuminate broadly but waste optical power; narrow-angle concentrate flux but demand tighter mechanical tolerances. Match the half-angle (typically 10°–60°) to working distance and target size early in optomechanical design.

ELECTRICAL NOISE ENVIRONMENT

Industrial environments are electrically loud. Variable-frequency drives, contactors, and adjacent solenoids inject noise that masquerades as optical signal. Low-capacitance photodiodes paired with TIAs configured for actual signal bandwidth—not the maximum the part can support—recover SNR without exotic shielding.

05 Common Failure Modes and How to Engineer Them Out

Failure Mode	Root Cause	Design Response
Saturation on bright targets	Detector signal exceeds linear range; output flattens before brightest pixel resolves	Specify detectors with broad linear range; reduce optical gain or LED drive rather than sacrificing dynamic range in software
Drift across temperature	Dark current rises with temp; LED output decays; combined effect erodes thresholds	Choose low-dark-current detectors; specify LEDs with rated stable output across full operating range
Ambient & strobe interference	Overhead lighting, sunlight, or adjacent stations contribute uncontrolled signal	Modulate LED illumination at known frequency; lock-in detect; combine with bandpass detector and optical filter
Wavelength-mismatch SNR loss	LED bin shift across lots moves emission peak off detector responsivity peak	Specify tight LED wavelength binning; or use detectors with broad enough response to tolerate normal bin variation
Beam non-uniformity across FOV	Single-emitter point source produces hot center, dark edges; calibration becomes position-dependent	Use multi-die LED arrays, diffusers, or line-source geometries; calibrate per-pixel rather than globally

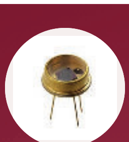
06 Selection Framework: From Application to Component

Working through this sequence in order, before specifying any part numbers, prevents most downstream design loops:

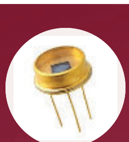
- **Define the inspection task.** What feature, defect, or measurement is the system detecting? At what resolution and throughput?
- **Choose the wavelength.** Use the wavelength selection table in Section 3. Where two options exist, prefer the one with the larger commercial selection of matched detectors.
- **Set the optical power budget.** Calculate required illumination at target given working distance, beam angle, and detector responsivity. Build in 30–50% margin for end-of-life LED degradation and contamination.
- **Specify the speed envelope.** Determine required detector bandwidth (rise time, junction capacitance) from line speed and feature size. Underspecifying here is a common source of motion blur and false rejects.
- **Define the environment.** Operating temperature range, vibration class, contamination exposure. This drives package selection.
- **Choose matched parts.** Apply the building blocks in Section 7. Where standard parts don't fit, move to custom design.

07 Opto Diode Building Blocks

Standard products span the visible to NIR range used in 95% of industrial inspection systems. Manufactured in Camarillo, California—single supplier for both emitter and detector.



ODD-12WB
BLUE ENHANCED



ODD-12W
RED ENHANCED

OD-110W
850 NM LED

OD-110WISOLHT
880 NM HIGH TEMP

PHOTODIODES FOR MACHINE VISION

Part Number	Active Area	Spectral Optimization	Typical Inspection Use
ODD-5WB	5 mm²	Blue-enhanced, 0.28 A/W @ 450 nm	Surface inspection, blue-LED systems
ODD-12WB	12 mm²	Blue-enhanced, 0.28 A/W @ 450 nm	Larger field-of-view blue inspection, edge detection
ODD-5WISOL	5 mm²	Red-enhanced, 0.35 A/W @ 632 nm	Red and NIR inspection, label and barcode reading
ODD-12W	12 mm²	Red-enhanced, 0.35 A/W @ 632 nm	Conveyor vision, larger-area NIR detection
NXIR Series	Various	NIR-enhanced, 700–1100 nm	850 / 940 nm systems, back-facet laser monitoring

LEDS AND IR EMITTERS FOR MACHINE VISION

Part Number	Peak λ	Typ. Power	Beam	Typical Use
OD-850LHT	850 nm	22 mW	Narrow	Focused NIR illumination, high-temp environments
OD-850WHT	850 nm	26 mW	Wide	Broad-area NIR illumination on conveyor lines
OD-110W	850 nm	140 mW	Wide	High-power NIR for long working distances
OD-110WISOLHT	880 nm	120 mW	Wide	High-temperature, wide-area illumination

08 When Standard Parts Don't Fit

Standard catalog parts cover most inspection scenarios. A meaningful minority do not. Opto Diode's **vertically integrated manufacturing** in Camarillo supports custom design across:

- Wavelength binning and selection beyond standard tolerances
- Custom active area shapes (elongated, segmented, multi-element arrays)
- Integrated photodiode plus amplifier hybrids tuned to specific bandwidth and gain
- Packaged optical filter assemblies and daylight-rejection filters
- Custom LED beam shaping, multi-die arrays, and emitter packaging
- Optoelectronic subsystems combining emitter, detector, optics, and electronics

Custom programs typically begin with a one-page requirements specification and prototype within **8 to 12 weeks**.

NEXT STEPS — TALK TO APPLICATIONS ENGINEERING

To discuss an upcoming machine vision design, request samples of any standard part, or scope a custom program, contact our team in Camarillo, California.

WEB
www.optodiode.com

EMAIL
sales@optodiode.com

PHONE
(805) 465-8700

ADDRESS
1260 Calle Suerte, Camarillo, CA 93012