Optical Position and Angular Sensing With the K857 4-Quadrant Photodiode Series

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Many industrial, consumer, and automotive applications require precise position or angular sensing. Our K857 series 4-quadrant photodetectors feature four independent photodiode zones that enable accurate position and angular sensing within a single SMD package. Unlike standard one-zone photodiodes, which lack positional information, the K857 series delivers separate output signals from each quadrant to sense positions or angulars. The advanced chip and package design enables the position-sensitive detector (PSD) to detect slight changes in illumination on the device to provide you with high precision positional information for your application. With short rise and fall times, this detector is ideal for real-time feedback and control systems for centering, alignment, or position sensing, and can be further used for angular sensing tasks.

APPLICATION POSSIBILITIES



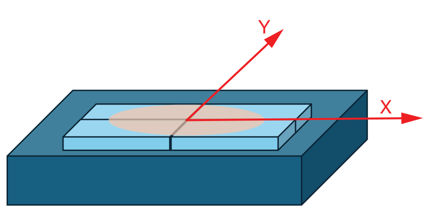
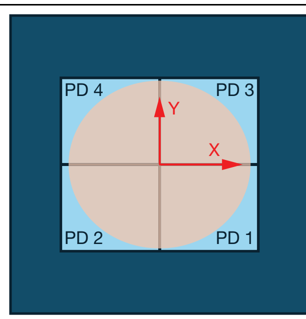
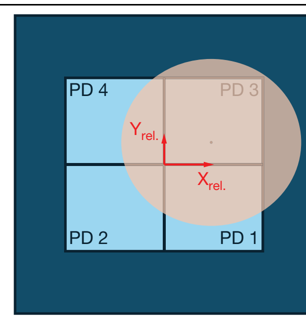

The typical applications for 4-quadrant photodiodes include:

- High precision positioning sensing
- Automatic alignment and centering processes

PRINCIPLE OF POSITION AND ANGULAR SENSING

The measurement principle of optical positioning and angular sensing is based on the detection of the light spot position within the four separate photodiode quadrants. The photocurrent of each quadrant is generated proportional to the are illuminated by the light spot. Analyzing the ratio of the photocurrents from each of the individual quadrants allows a precise determination of the spot's position, which provides information about the position or angle depending on the implementation.

PRINCIPLE OF POSITION DETECTION

3-Dimensional View	Front View With a Centered Light Spot	Front View With a Shifted Light Spot in X- and Y-Direction
		

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DESIGN CHALLENGES

The primary design task in position and angular sensing is to shape the light spot. Several considerations have to be addressed to ensure proper light spot characteristics for the position and angular sensing to work with the 4-quadrant photodiode.

Position Detection - Light Spot Design

In addition to general design considerations for optoelectronic devices, the main focus for position sensing applications must be laid on the light spot design. Key elements for the light spot design are:

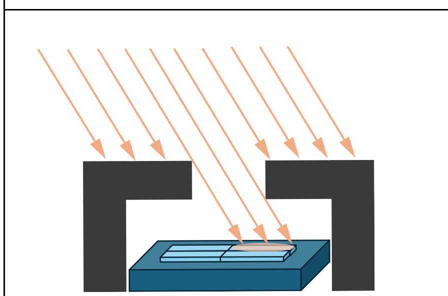
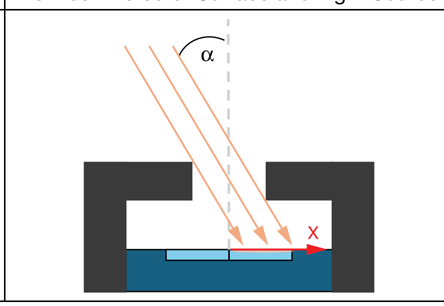
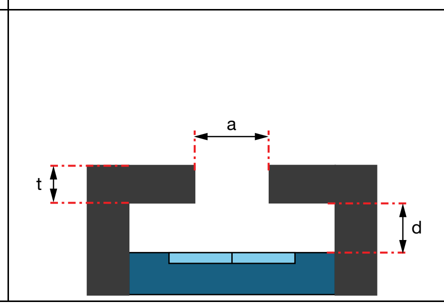
- A symmetrical and homogeneous light spot
- The light spot size must not be smaller than the area of one quadrant or bigger than the total detector surface area
- The wavelength range of the light source must match the sensitivity range of the photodiode
- Sufficient output power of the light source

Angular Detection - Aperture Design

For angular detection, an aperture on top of the photodiode is needed to limit the light spot size on the photodiode. The correlation between the position of the light spot relative to the four quadrants and the angle of illumination makes it possible to detect the angle of incident. Several design properties of the aperture have to be addressed:

- The aperture material has to be non-transmissive for the sensitive wavelenghts of the detector
- The aperture diameter “a” has to match the size of the individual quadrant of the photodiode
- Distance “d” between the aperture and photodiode active surface
- Wall thickness “t” of the aperture

PRINCIPLE OF ANGULAR DETECTION

3-Dimensional View	Angle of Incident α Between Detector Surface and Light Source	Aperture Design Parameters
		

K857 SERIES: 4-QUADRANT PHOTODIODES FOR POSITION AND ANGULAR SENSING APPLICATIONS

The K857 series (K857PE and K857PH) consists of 4-quadrant photodetectors in small surface-mount packages. Each quadrant photodiode has an active area of 1.6 mm^2. The photodiode is AEC-Q101 qualified, which makes it suitable for automotive applications. With a small package and high output signal, the component can be used for a wide range of positioning, centering, and alignment tasks. Combined with an aperture, these detectors will also allow you to design angular sensing solutions.

KEY BENEFITS: K857PE

Package dimensions	4.72 mm x 4.72 mm x 0.75 mm	
Reverse light current (1)	8.5 μA typical	
Operating temperature range	-40 °C to +110 °C	
Range of spectral bandwidth	$\lambda_{0.1}$ = 690 nm to 1050 nm	
Low crosstalk (2)	0.1 %	

Notes

(1) Test condition for reverse light current I_{ra} (E_e = 1.0 mW/cm^2, λ = 850 nm, V_R = 5 V)

(2) Based on crosstalk specification; laser illumination (850 nm, 65 μm spot diameter, radiant power 0.7 mW) of center of PD quadrant 1 (q = 1), V_R, q = 5 V applied to all quadrants

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RELATIVE LIGHT SPOT DISPLACEMENT CALCULATION

The 4-quadrant detector allows a comparison between four quadrants, enabling the detection of position or angular displacement. Since the output signal is proportional to illumination, the signal on each quadrant is related to the position of the light spot on the photodiode. The following calculation yields to the relative X- and Y-position of the light spot to the optical center and allows for two-dimensional sensing:

$$X_{rel.} = \frac{(PD1 + PD3) - (PD2 + PD4)}{PD1 + PD2 + PD3 + PD4}$$

$$Y_{rel.} = \frac{(PD1 + PD2) - (PD3 + PD4)}{PD1 + PD2 + PD3 + PD4}$$

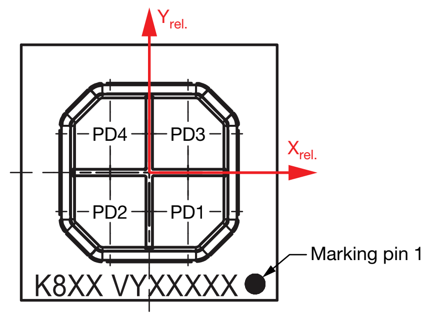

Fig. 1

Note

- PD1: photocurrent from quadrant PD1; PD2: photocurrent from quadrant PD2; PD3: photocurrent from quadrant PD3; PD4: photocurrent from quadrant PD4

SIGNAL INTERPRETATION

The following diagrams show that the photodetector responses of the quadrants are related to the position of the light spot, regardless if the light spot is moving due to an angular or translative displacement of the light source. Using the above formula, the following graphs discuss the signal results for position and angular sensing, as well as the M-shape response using the K857 series photodetectors.

Signal Interpretation - Position Sensing

The following diagram shows the output signals for a change of position between the detector and the light spot along the X-axis using the formula for $X_{rel.}$.

When the light spot is centered with the component, each photodiode quadrant is illuminated equally, resulting in a relative detector signal of 0.5. By changing the position between light source and detector, the light spot moves away from the optical center, and the illumination on each quadrant changes. The diagram shows an increase in the signal for positive translatory movements in the X-axis, and a decrease for negative translatory movements of the light spot. The same approach can be used with the $Y_{rel.}$ formula for position sensing in the Y-direction. The sensing width is limited by the design of the light spot and the outline dimensions of the component.

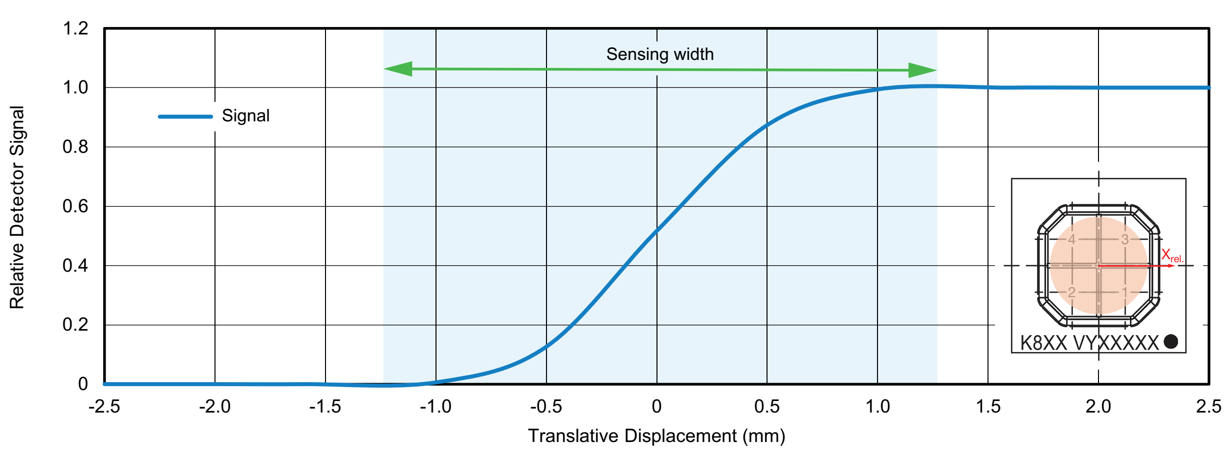

Fig. 2 - Relative Output Signal X-Translative Displacements
(Light Spot Diameter: b = 1.5 mm)

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Signal Interpretation - Angular Sensing

The following diagram shows the output signals for a change in angular between the detector and the light source. As an angular displacement leads to a light spot translative movement, formula $X_{rel.}$ can be used for a rotation along the Y-axis.

When the light source is orthogonal to the detector's surface, each quadrant of the photodiode is illuminated equally, resulting in a relative detector signal of 0.5. By changing the angle of incidence between the light source and the detector, the light spot moves away from the optical center, altering the illumination on each quadrant. The diagram shows an increase in the signal for positive rotational movements of the detector and a decrease for negative rotational movements. Angular sensing for rotations around the X-axis can be approached by using the $Y_{rel.}$ formula. The sensing width is limited by the design of the aperature and the outline dimensions of the component.

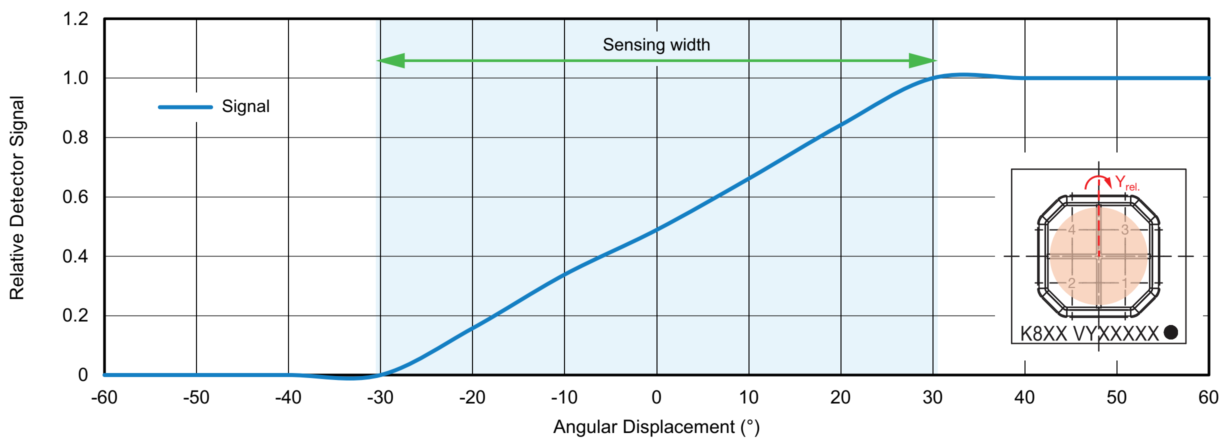

Fig. 3 - Relative Signal Angular Displacement
(Aperture Dimensions: a = 3.0; t = 1.0; d = 1.0)

M-Shape Response Using K857 Series Photodetectors

The M-shape response simplifies the interpretation of detector signals and can be achieved by determining a reference photodiode pair and using the mathematical approach mentioned in the section "Relative Light Spot Displacement Calculation". The sensing width of the signal can be adjusted through the design of the aperture, as discussed in the "Design Challenges" section.

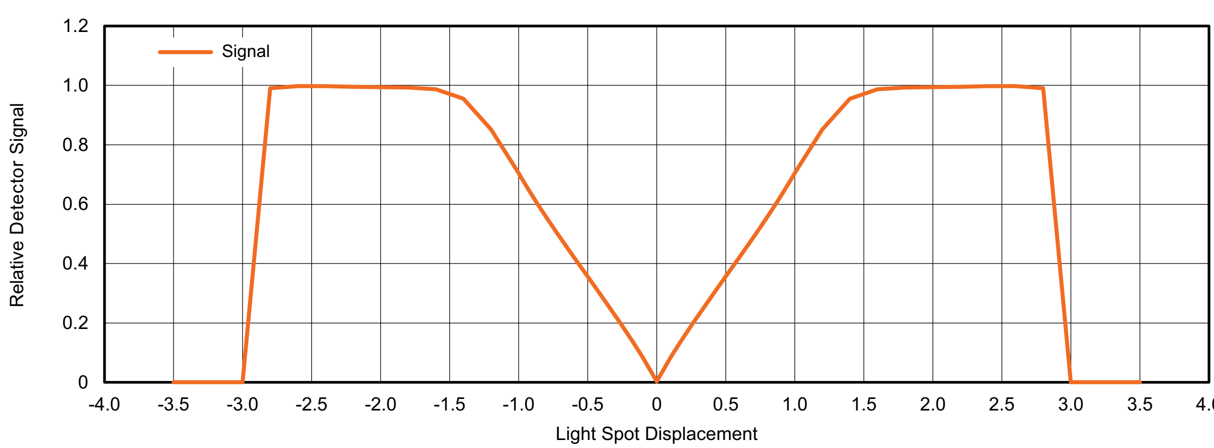

Fig. 4 - M-Shape Signal Response