

Position-Sensing Detectors Characteristics

POSITION SENSING DETECTORS

Semiconductor photodetectors are commonly used for light power measurements in a wide range of applications, such as:

- Bar-code readers
- Laser printers
- Medical imaging
- Spectroscopy

However, another function utilizes photodetectors as optical position sensors, widely called Position Sensing Detectors (PSDs). PSDs are used in applications ranging from human eye movement monitoring and 3-D modeling of human motion to laser, light source, and mirror alignment. They are also widely used in ultra-fast, accurate autofocusing schemes for various optical systems, such as microscopes, machine tool alignment, and vibration analysis. PSDs can obtain the position of a beam within fractions of microns. They are divided into two families: segmented PSDs and lateral effect PSDs.

SEGMENTED PSDS

Segmented PSDs are common substrate photodiodes divided into two or four segments (for one or two-dimensional measurements, respectively), separated by a gap or dead region. A symmetrical optical beam generates equal photocurrents in all segments if positioned at the center. The relative position is obtained by measuring the output current of each segment. Segmented PSDs offer position resolution better than 0.1 μm and accuracy higher than lateral effect PSDs for low light intensity applications. They exhibit excellent stability over time, temperature, and fast response times necessary for pulsed applications. However, they are confined to certain limitations, such as the light spot having to overlap all segments at all times and not being smaller than the gap between the segments. They are excellent devices for applications like nulling and beam centering.

LATERAL EFFECT PSDS

Lateral effect PSDs are continuous single-element planar diffused photodiodes with no gaps or dead areas. These types of PSDs provide a direct readout of a light spot displacement across the entire active area. This is achieved by providing an analog output directly proportional to the position and intensity of a light spot on the detector's active area. A light spot present on the active area will generate a photocurrent, which flows from the point of incidence through the resistive layer to the contacts. This photocurrent is inversely proportional to the resistance between the incident light spot and the contact. When the input light spot is precisely at the device center, equal current signals are generated. By moving the light spot over the active area, the amount of current generated at the contacts will determine the exact light spot position at each instant of time. These electrical signals are proportionately related to the light spot position from the center.

ADVANTAGES

The main advantage of lateral-effect diodes is their wide dynamic range and independence from the light spot size and shape. They can measure the light spot position to the edge of the sensor and are independent of the light spot profile and intensity distribution that affects the position reading in segmented diodes. The input light beam may be any size and shape since the position of the centroid of the light spot is indicated and provides electrical output signals proportional to the displacement from the center. The devices can resolve positions better than 0.5 μm , but the best achievable position for lateral effect PSDs is usually lower than for segmented PSDs. The resolution is detector/circuit signal-to-noise ratio dependent.

TETRA-LATERAL PSDS

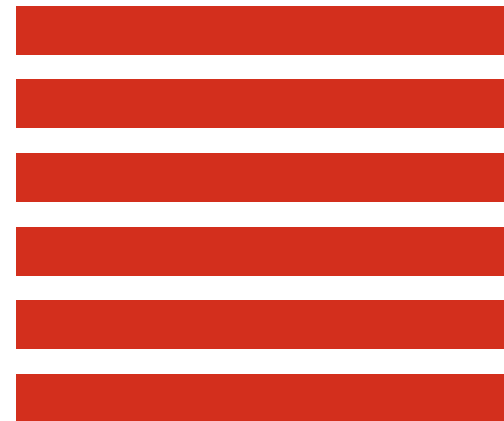
The tetra-lateral PSDs have a single resistive layer, in which the photocurrent is divided into two or four parts for one or two-dimensional sensing, respectively. These devices exhibit more position non-linearity at distances far from the center due to the so-called pincushion effect and larger position detection errors compared to the duo-lateral types. However, the repeatability of position detection is the same as that of the duo-lateral PSDs.

TWO TYPES OF LATERAL EFFECT PSDS

OSI Optoelectronics manufactures lateral effect PSDs in one-dimensional and two-dimensional configurations. Two-dimensional configuration is available in Duo-Lateral and Tetra-Lateral structures.

DUO-LATERAL PSDS

In duo-lateral PSDs, there are two resistive layers, one at the top and the other at the bottom of the photodiode chip. The photocurrent is divided into two parts in each layer. This structure type can resolve light spot movements of less than 0.5 μm and has a very small position detection error, almost to the edge of the active area. It also exhibits excellent position linearity over the entire active area.



Glossary

POSITION DETECTION ERROR (PDE)

Position Detection Error (PDE) is the geometric variation between the actual and measured positions of the incident light spot. In most cases, it is measured over 80% of the sensing length for single-dimensional PSDs and 64% of the sensing area for two-dimensional PSDs. For all calculations, the zero point is defined as the electrical center. At this point, the photocurrents collected from two opposite electrodes at the end of the detector resistive layer are equal, $I_1 = I_2$.

In the ideal case, Position Detection Error in X-direction is calculated using the following Equation (1):

$$\text{PDE } [\mu\text{m}] = \left(\frac{I_2 - I_1}{I_2 + I_1} \right) L - X \quad (1)$$

I_1 and I_2 are the photocurrents at the ends of the PSD, L is the sensing area half-length in μm , and X is the actual (“mechanical”) displacement of the light spot from the electrical center in μm . A similar equation can calculate PDE in the Y direction for two-dimensional PSDs. The calculated PDE value depends on the alignment accuracy of the detector with respect to “mechanical” axes and the light spot quality. It also depends on the equation used to calculate the measured displacement. Equation (1) is the simplest equation that allows us to estimate the measured position accuracy vs the actual “mechanical” position. Multiple publications proposed corrected equations that account, e.g., for the pincushion effect, allowing for minimized PDE value even for tetra-lateral PSDs.

POSITION RESOLUTION

Position Resolution is defined as the minimum detectable displacement of a spot of light on the detector’s active area. The system’s signal-to-noise ratio limits it and depends on the light intensity, detector noise, inter-element resistance, and electronics bandwidth. OSI Optoelectronics lateral effect PSDs have achieved position resolutions above one part in ten million.

POSITION DETECTION THERMAL DRIFT

Position Detection Thermal Drift is the position that drifts with a change of temperature. It is the change in position divided by the total length. Two-dimensional PSDs are defined within 80% of the length or 64% of the area.

PERCENTAGE POSITION NON-LINEARITY

Position non-linearity is determined by dividing the position detection error by the total length of the sensing area. Similarly to PDE, the position nonlinearity depends on the accuracy of the detector alignment with respect to the mechanical axes and on SNR. In the best cases, the position nonlinearity is typically better than 0.05% for the single-axis PSD and better than 0.3% for the 2D duo-lateral PSDs. The position nonlinearity is usually higher for tetra-lateral PSDs due to the pincushion effect.

INTERELECTRODE RESISTANCE

Interelectrode Resistance (IER) is the resistance between the two end contacts in one axis, measured with or without illumination. IER is one of the main parameters determining PSD sensitivity and position resolution.

Position Calculations

SEGMENTED PSDS

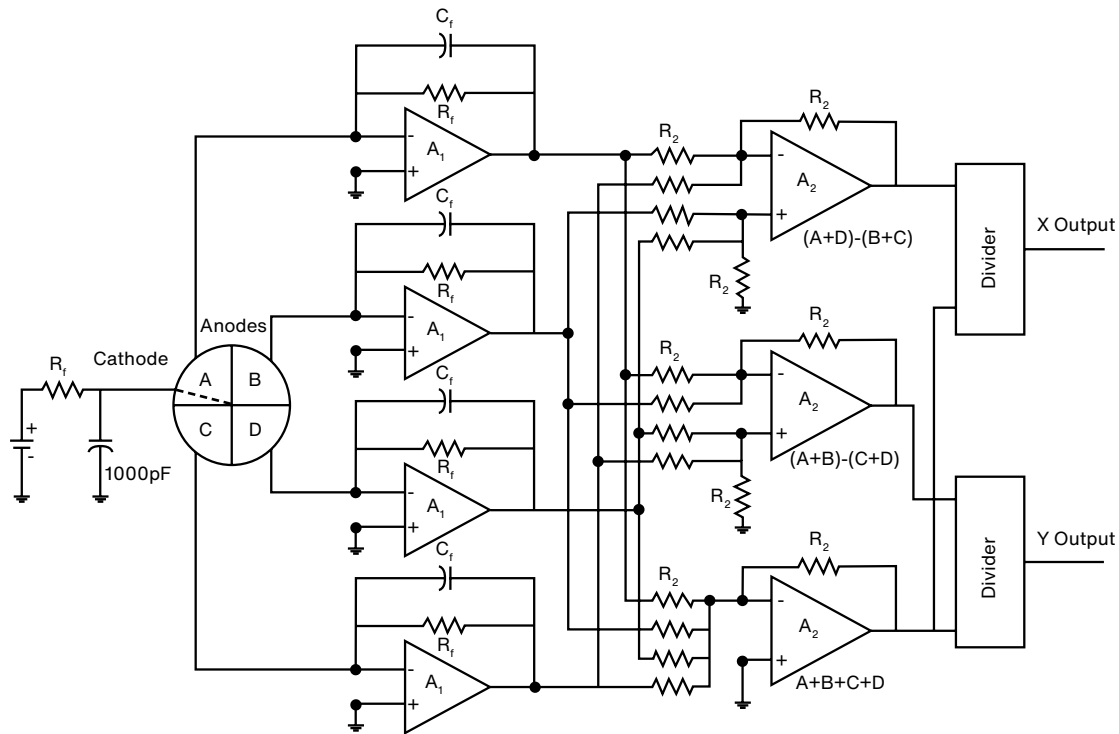


Figure 1. A typical circuit used with OSI Optoelectronics segmented photodiodes.

The X & Y positions of the light spot with respect to the center on a quadrant photodiode are found by:

$$X = \frac{(A+D) - (B+C)}{A+B+C+D} \quad Y = \frac{(A+B) - (C+D)}{A+B+C+D} \quad (2)$$

Where A, B, C, and D are the photocurrents measured by each sector. The recommended components for this circuit are application-specific. However, the following components are widely used in most applications:

Amplifiers A₁ & A₂	OPA-37 or similar
Divider	AD-534 or similar
R_f & R₂	10kΩ to 10MΩ
C_f	1/(2πR _f f)

The same circuit can be used for one-dimensional (bi-cell) measurements

LATERAL EFFECT PSDS

The one-dimensional lateral effect measurements are the same for duo-lateral and tetra-lateral structures since they have two contacts at the top and a common contact at the bottom. In tetra-lateral devices, however, the bottom common contact can be either an anode or cathode with two opposite

polarity contacts (cathodes or anodes) on top, thus making them a positive (or negative) current generator. In duo-lateral devices proposed by OSIO for one-dimensional lateral effect measurements, there are two anodes on top with a common cathode at the bottom.

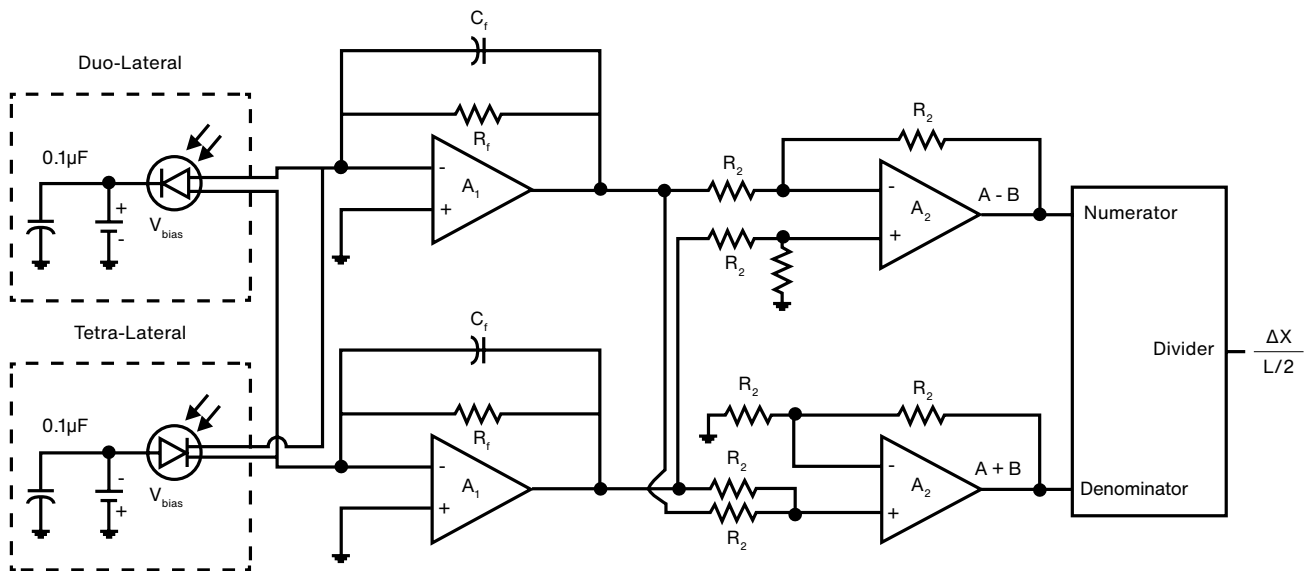


Figure 2. A typical circuit used with one-dimensional lateral effect PSDs.

In this configuration, the outputs from the first stage are summed and subtracted in the second stage and divided by the divider in the final stage. The summation, subtraction, and division can also be performed by software. The position is given as:

$$X = \frac{A - B}{A + B} \quad (3)$$

A typical electric circuit with one-dimensional lateral effect PSDs (Figure 2) may use the same components as the segmented photodiodes of the schematics shown in Figure 1, with R2 varying from e.g. 1 kΩ to 100 kΩ.

The photodiode P-N junctions can be reverse-biased for high-speed applications with a small gain (small feedback resistor Rf of a trans-impedance amplifier). However, the photodiode can be left unbiased for low-frequency applications, and the gain (Rf) can be as high as 100 MΩ. The feedback capacitor stabilizes the frequency dependence of the gain and can vary from 1 pF to 10 µF. The gain in the first stage amplifier is IP x Rf (with IP being the photocurrent), and the gain in the second stage is typically below 10.

TWO DIMENSIONAL DUO-LATERAL PSDS

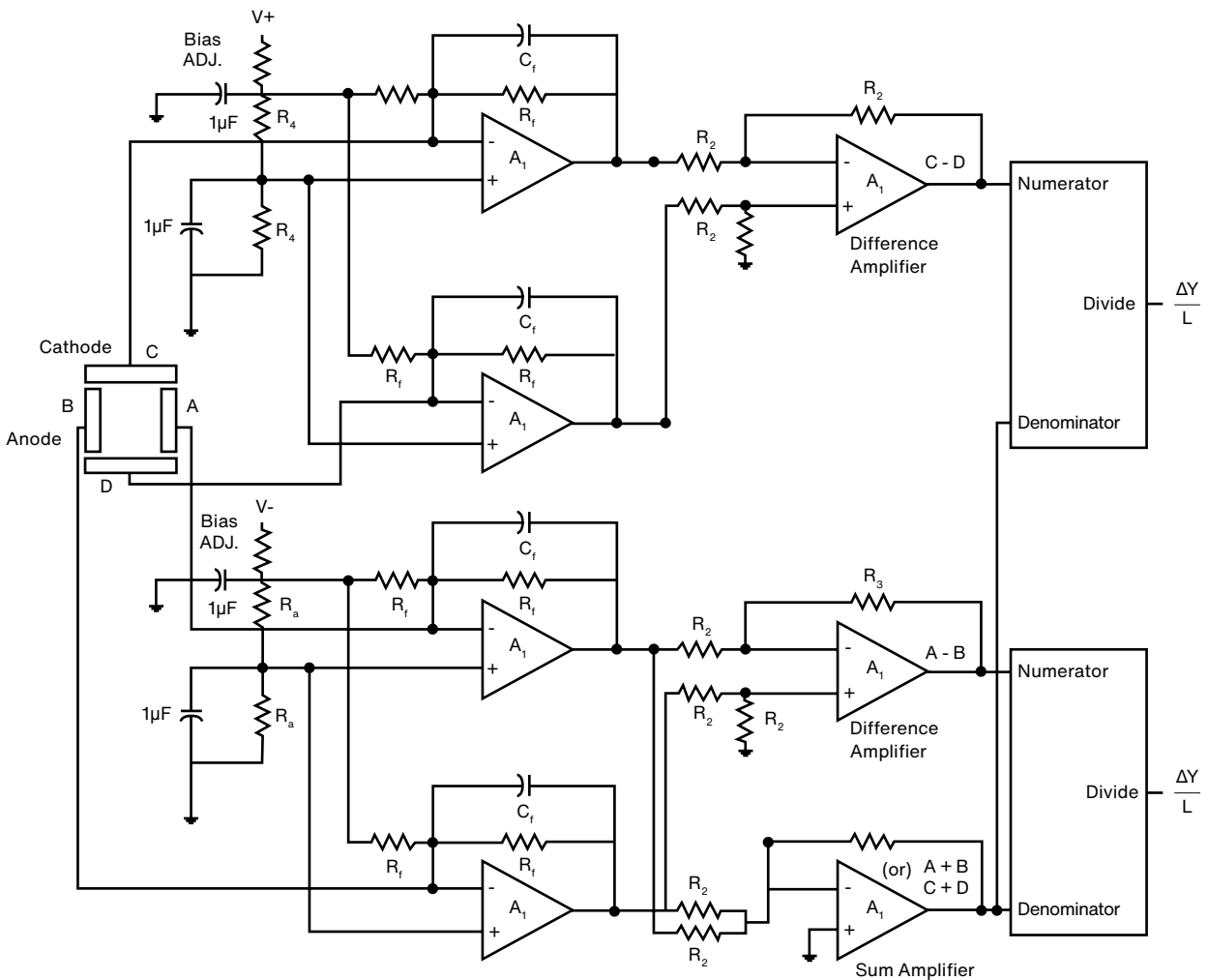


Figure 3. A typical circuit for two-dimensional duo-lateral PSDs.

The two-dimensional duo-lateral PSDs, with two anodes on top and two cathodes on the back surface of the photodiode, measure positions in two different directions, respectively. They provide a continuous position reading over the entire active area, with an accuracy higher than the tetra-lateral PSDs.

The cathodes are usually forward-biased for high-speed applications, while the anodes are reverse-biased. This extends the bias range usually limited by the maximum reverse voltage. The same components as the one-dimensional PSDs are recommended. The output is as follows:

$$X = \frac{A - B}{A + B} \qquad Y = \frac{C - D}{C + D} \qquad (4)$$

TETRA-LATERAL PSDS

In a two-dimensional tetra-lateral PSD, four cathodes or anodes are located on one side of a semiconductor chip and one common anode or cathode on the opposite side. They provide a continuous position reading over the entire active area, with accuracy comparable to or lower than the duo-lateral PSD. Figure 3 shows a typical circuit for two-dimensional duo-lateral PSDs. Figure 4 shows a typical circuit for two-dimensional tetra-lateral PSDs. Similar to other PSDs, the signals from the detector are converted to voltage in the first stage, then

summed and subtracted in the second stage, and then divided into the final stage.

Similarly to duo-lateral PSDs, the anode is reverse biased for high-speed applications of tetra-lateral PSDs, and the feedback resistor (R_f) shall be chosen small. Additional amplification stages can achieve additional gain. The recommended components and output are similar to those of two-dimensional duo-lateral devices.

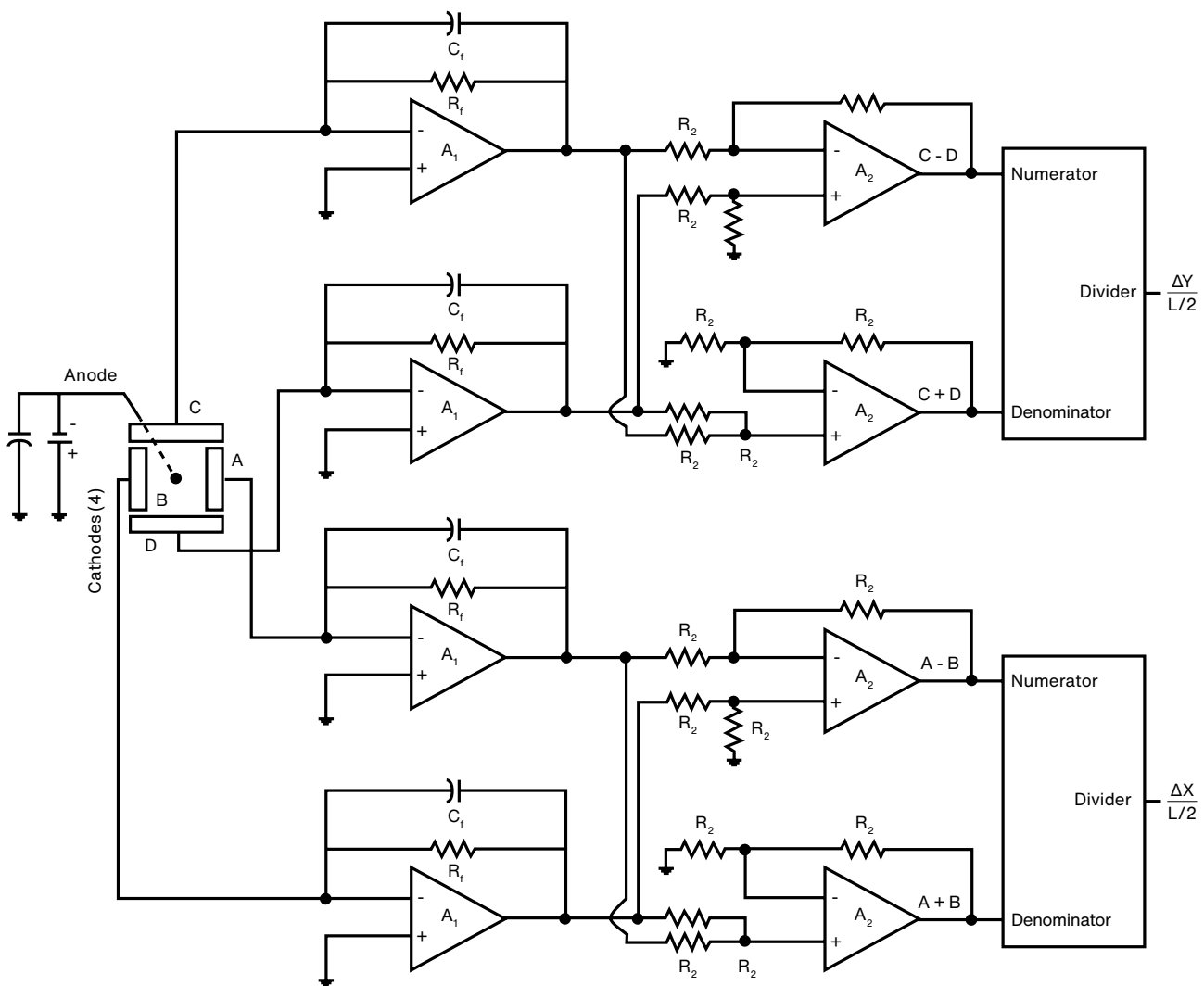


Figure 4. A typical circuit used with two-dimensional tetra-lateral PSDs.