The Effect of Spot Size on Linearity Improvement of Tetra-lateral Position Sensitive Detector

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***Abstract*—Linearity improvement of tetra-lateral position sensitive detector (PSD) is highly desired in many applications where accurate measurements of the PSD are required. The effect of beam size on our newly proposed linearity improvement scheme is discussed in this paper. Theoretical studies are presented to simplify the numerical calculation when the beam size is considered. Simulation results show that our new formula can still give a nearly perfect linearity and measurement accuracy even if the spot has a considerable beam size.**

I. Introduction

Tetra-lateral position sensitive detector (PSD) is capable of providing the spot position measurement in two dimensions when the light spot is projected on its surface. It consists of a square semiconductor substrate with a resistive surface layer. When there is a light spot projected on its surface, photocurrents can be measured from electrodes and they are used to estimate the spot position in two dimensions [1]. The tetra-lateral PSD has the advantage of low dark currents, easy bias application, fast response, low cost and high resolution [2]. Because of these advantages, the tetra-lateral PSD is deployed in many research and industry applications.

However, the inherent nonlinearity of the tetra-lateral PSD introduces measurement errors. And the measurement error will be more and more significant if the light spot is towards the boundary of the PSD. This bottlenecks many potential applications of the tetra-lateral PSD as certain measurement accuracy is required. The challenge for the linearity improvement of the tetra-lateral PSD is that the nonlinear relationship between the incident position of the light spot and its estimate is implicit and we are not able to deduce the real position. Recently, we have proposed a new calculating formula to achieve a nearly perfect linearity for tetra-lateral PSD [3]. Our new formula is simple and it is derived based on a theoretically proved method. All our analysis, simulations and experiments are based on the assumption that the light spot has a negligible beam size. This assumption is not always true as the light spot has a considerable beam size in many applications and it is difficult to measure and control the beam size in practice. Thus, there is a strong need to analyze and simulate the effect of the beam size on our linearity improvement method.

But it is difficult to compute and simulate the effect of the beam size because it is complicate and time consuming to calculate the electrical potential when considering the beam size. In this paper, we give a theoretical analysis to simplify the numerical calculation when the intensity of the light spot is Gaussian distributed. Then, simulations are carried out to estimate the light beam center when different beam sizes are considered.

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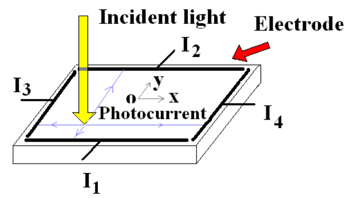

Fig. 1. The schematic of tetra-lateral PSD

II. Theoretical analysis

The tetra-lateral PSD has a square semiconductor substrate with four electrodes on each side (Fig. 1). When the light spot is projected on the surface layer and the PSD is reversely biased, the electrical potential can be calculated from the following equation [4]:

$$\nabla^2 U(x,y) = -\frac{\rho_d}{w_d} I_s(x,y) \tag{1}$$

where $U(x,y)$ is the electrical potential at the position (x,y), ∇^2 is the laplace operator, ρ_d is resistivity, w_d is the thickness of the substrate and $I_s(x,y)$ is the generated photocurrent. Electrical currents collected from electrodes can be calculated from the following equation:

$$I_i = \frac{\omega_d}{\rho_d} \int_{l_i} \frac{\partial U}{\partial p}|_{p=p_i} dl_i, \quad i = 1,2,3,4 \tag{2}$$

where p_i is the normal to each electrode and l_1 to l_4 refer to the lengths of the four electrodes. To calculate the position of the light spot, a conventional formula based on four photocurrents is given below:

$$\hat{X} = k_1 \frac{I_4 - I_3}{I_4 + I_3}, \quad \hat{Y} = k_1 \frac{I_2 - I_1}{I_2 + I_1} \tag{3}$$

where k_1 is the linearity constant, $\hat{X}$ and $\hat{Y}$ are position estimates in the x and y directions. To improve the linearity and accuracy of the position measurement, we proposed a new estimation formula based on the assumption that the light spot has a negligible beam size [3]:

$$\hat{X} = \frac{k_2(I_4 - I_3)(0.7(I_1 + I_2) + I_{sum})}{(I_{sum} - 1.02(I_2 - I_1))(I_{sum} + 1.02(I_2 - I_1))}$$
$$\hat{Y} = \frac{k_2(I_2 - I_1)(0.7(I_3 + I_4) + I_{sum})}{(I_{sum} - 1.02(I_4 - I_3))(I_{sum} + 1.02(I_4 - I_3))} \quad (4)$$

where $I_{sum} = \sum_{i=1}^{4} I_i$ and k_2 is the linearity constant for our proposed formula. In most applications, a single mode laser is used as the light source where the generated photocurrent on PSD is Gaussian distributed:

$$I_s(x, y) = I_0 \exp\left(\frac{-((x - x_0)^2 + (y - y_0)^2)}{w^2}\right) \quad (5)$$

where I_0 is the current density at the spot center (x_0, y_0) and w is the spot radius. In our paper, the PSD center is the origin of the coordinate $(0, 0)$ and side length of the PSD is assumed to be 1 unit. The electrical potential is zero at electrodes. The solution to Eq. (1) can be obtained as:

$$U(x, y) = \frac{\rho_d}{w_d} \sum_{m=-\infty}^{+\infty} \sum_{n=-\infty}^{+\infty} \left[\int_{D_1}\int (I_s(x_1, y_1) \times \frac{\sin(m\pi x)\sin(n\pi y)\sin(m\pi x_1)\sin(n\pi y_1)}{(n^2 + m^2)\pi^2}) dx_1 dy_1\right] \quad (6)$$

where D_1 is the effective area of the PSD. It is difficult and time consuming to compute the electrical potential directly so we have derived a simplified expression for the electrical potential in theory:

$$U(x, y) = \frac{2\pi I_0 \rho_d}{w_d} \sum_{m=-\infty}^{+\infty} \sum_{n=-\infty}^{+\infty} \left(\frac{\sin(m\pi x)\sin(n\pi y)}{(n^2 + m^2)\pi^2} \times \sin(m\pi x_0)\sin(n\pi y_0)\exp\left(\frac{-(m^2 + n^2)\pi^2 w^2}{4}\right)\frac{w^2}{2}\right). \quad (7)$$

With specified spot size w, we are able to compute the electrical potential, collected photocurrents and estimates of the light spot center from different estimation formulae efficiently.

III. Simulation Results

In the simulation, the light spot is moved from the center in steps of 0.05 in both directions inside the central square of (0.8×0.8) when the spot size is $w = 0.01$ and $w = 0.05$. Then position estimates are plotted in Fig. 2 and Fig. 3 respectively. If the estimation is perfect without inaccuracy, they will form a regular grid pattern. It has been shown that a nearly perfect linearity of the tetra-lateral is achieved when the beam size is considered. In some PSD applications, the light spot may have an extremely large beam size. Thus we simulate a light beam with a large beam size $(w = 0.2)$ moving from the center in steps of 0.05 in both directions inside the central square of (0.4×0.4). The area of the movement is reduced because a considerable amount of the light will not be projected on the PSD if the light beam is outside the central square of (0.4×0.4) which will introduce significant errors in the position estimates. The simulation result shows that the linearity improvement is not affected under this scenario. Thus, our linearity improvement scheme for the tetra-lateral PSD is robust to the beam size and our linearity improvement scheme will be effective to a broad range of PSD applications where the light spot projected on the PSD has a considerable beam size.

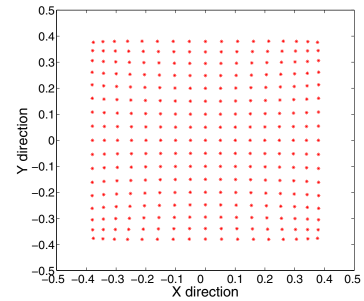

Fig. 2. Estimation result of 2-D tetra-lateral PSD using our new formula when $w = 0.01$.

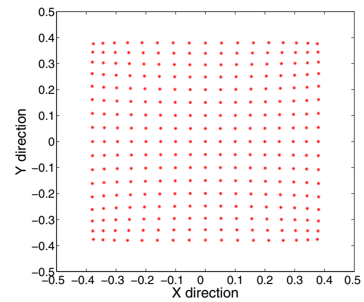

Fig. 3. Estimation result of 2-D tetra-lateral PSD using our new formula when $w = 0.05$.

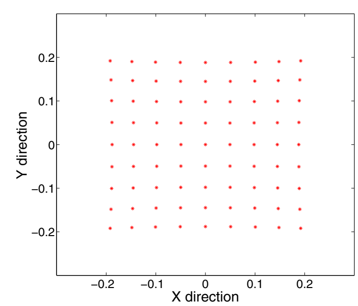

Fig. 4. Estimation result of 2-D tetra-lateral PSD using our new formula when $w = 0.2$.

References

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