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A self-powered single-axis maximum power direction tracking system with an on-chip sensor

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Abstract

This paper demonstrates a self-powered Maximum Power Direction Tracking (MPDT) system capable of maximizing the energy harvesting by automatically adjusting the angle of the solar panel. The whole system is powered by a solar panel so no extra power supply is needed. The entire system consists of a solar panel, a motor, and a CMOS chip. A novel light direction sensor and the needed circuit are integrated in a single chip which is fabricated by a standard 0.5 μm CMOS process. So it is small-size and low-cost. The system was tested to verify performance with different light direction and intensity. The results show that the system has good sensitivity to the incident angle and achieve tracking accuracy of ±1.8° over a optical power range of 30–110 mW/cm^2. The presented system obtains an average output power gain of 18.4% over the fixed southwards mounted system under real weather conditions.

Keywords: Self-powered; Maximum power direction tracking; Light direction detection; On-chip sensor

1. Introduction

In a variety of applications, we usually need a tracking system to get maximum solar panel output power. For example, it is used in the spacecraft power system to improve the energy harvesting efficiency and also used for the spacecraft attitude determination (Liebe and Mobasser, 2001; Deans et al., 2005; Delgado et al., 2012). Many of these applications require low power, low cost, small size, and light weight. Miniaturized on-chip sensor is an attractive choice to meet these requirements. That make it easy to integrate complex circuits in a same chip, to improve the reliability, and to cut down the cost. In this case, it is necessary to have an on-chip light direction sensor for this system. Many techniques have been developed to detect sun or light direction, such as the shading device method (Quero et al., 2001), the tilted surface method (Karimov et al., 2005; Koyuncu and Balasubramanian, 1991), and the collimator tube method (Mousazadeh et al., 2009). However, for the shading method, not only the achieved accuracy of ±10° is lower than the tilted surface method and collimator tube method, but also its light sensitivity is low compared with the other two methods. For the tilted surface method, it requires special off-chip optical components, for example, light dependent resistors (LDR). Which make it impossible to realize it on a chip. Although the accuracy of the collimator tube method is

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high, the detection range is relative small i.e. 1 degree and its size is large. It is also difficult to make this sort of sensor small-volume and light-weight.

In this paper, we present a self-powered maximum power direction tracking system, which consists of a motor, a solar panel, and a CMOS chip with a light direction sensors and the signal processing circuits. Most of the circuits are integrated on the same chip to process the sensing signal and control the motor. Because batteries are expensive, bulky and require replacement and disposal, many ways to recharge or replace them are being researched (Sarkar and Chakrabartty, 2013; Guan and Liao, 2005; Dong et al., 2007). To overcome this problem, a solar panel is used to power the sensor chip and the motor driver, which means this system is completely self-powered.

2. Sensor design

In this paper, an on-chip CMOS sensor is designed to detect the incident light direction so as to know the strongest light direction. Fig. 1 shows a basic cell of the sensor. The whole sensor is formed by a number of the basic cells. A metal wall created by stacking all metal layers, contacts, and vias available in the process is used to generate on-chip micro-scale shadow. The height of the metal wall is h. We should optimize the dimensions of the metal wall for the sensor's good performance. In this design, we choose 4.6 μm as the height of the metal wall.

In this design, diffraction has been considered. As we all know, the bandgap voltage of silicon is about 1.12 V. So the longest wavelength of the absorbed light is about 1.1 μm. Actually, the absorption peak is around 0.7 μm. However, in this design the distance between two adjacent metal walls is 20 μm, and the height of the mental wall is 4.6 μm. The physical dimensions are much larger than the wavelength of the absorbed light. So the diffraction has little influence on the sensors performance (Wang et al., 2014, 2013).

Two identical photodiodes are located on opposite sides of the metal wall. D_L is the left side diode and D_R the right side diode. They have same width w and same length, l. The schematic current sources shown beside each diodes indicate the photocurrents generated by the corresponding photodiodes. The angle between the metal wall and the light direction is θ. When the light comes from directly above of the wall, namely $\theta = 0$, the two photodiodes are illuminated equally and produce same currents. When the light comes from one side above the wall, namely $\theta > 0$ or $\theta < 0$, the wall blocks part of the light to the opposite photodiode which therefore produces less current than the other photodiode. So the relationship between of I_{DL} and I_{DR} is relative to angle of the incident light. We can get more details by deriving the expressions of I_{DL} and I_{DR} as flowing.

As we known, the photocurrent generated by a photodiode is proportional to the optical power the photodiode receives. The short-circuit photocurrent can be written as

$$I_{DIO} = kP_T = kP_0A_{EFF} = kP_0wL_{EFF} \tag{1}$$

where k is a constant coefficient, P_T is the total optical power the diode receives, P_0 is the optical power per unity sectional area of the light, A_{EFF} is the sectional area of the incident light, and L_{EFF} is the length of the sectional area.

Here, we analyze the case of $\theta > 0$. That means the left diode is fully illuminated and the right diode is partly shadowed by the metal wall. The case of zero incident light on any diode is not considered for brevity. In this case, the total photocurrent generated by the left diode D_L can be divided into three parts. The first part is the current generated by the light which directly illuminates the diode. According to Eq. (1) and the geometrical structure, this part of current can be described as

$$I_{LD} = kP_0wl\sin\theta \tag{2}$$

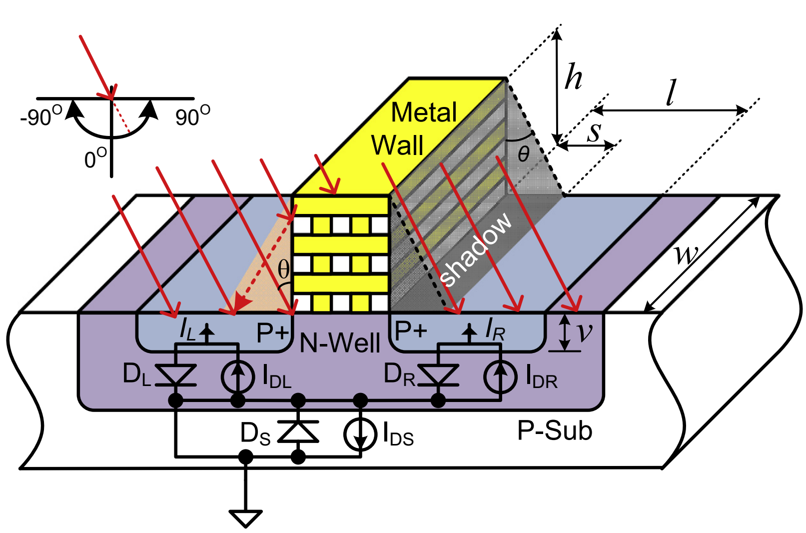

Fig. 1. Structure of the proposed CMOS light direction sensor.