Application Note

Self-Powered Solar Tracking Sensor

AN-CM-252

Abstract

The application note will present the design of a simple self-powered solar tracking sensor circuit based upon the Dialog Semiconductors products, i.e. the Dialog Semiconductors operational amplifier. The circuitry uses only the energy obtained from the photodetectors, i.e. the sensors. This application note comes complete with design files which can be found in the References section.

Contents

Figures

1   Terms and Definitions

OP, OpAmp   Operational Amplifier
PD   Photodiode

2   References

For related documents and software, please visit:

https://www.dialog-semiconductor.com/configurable-mixed-signal.

Download our free GreenPAK Designer software [1] to view the proposed circuit design. Use the GreenPAK development tools [2] to freeze the design into your own customized IC in a matter of minutes. Dialog Semiconductor provides a complete library of application notes [3] featuring design examples as well as explanations of features and blocks within the Dialog IC.

[1]   GreenPAK Designer Software, Software Download and User Guide, Dialog Semiconductor

[2]   GreenPAK Development Tools, GreenPAK Development Tools Webpage, Dialog Semiconductor

[3]   GreenPAK Application Notes, GreenPAK Application Notes Webpage, Dialog Semiconductor

[4]   SLG88103/4 Rail to Rail I/O 375 nA/Amp Dual/Quad CMOS Op Amps with Power Down, Datasheet, Dialog Semiconductor

[5]   BPW 34 B Silicon PIN Photodiode with Enhanced Blue Sensitivity; in SMT Version 1.6, Datasheet, OSRAM Opto Semiconductors

3 Introduction

This application note will present the possibility of designing a simple self-powered solar tracking sensor circuit using a Dialog Semiconductor SLG88103 operational amplifier. The complete circuitry is self-powered, since it uses only the power obtained from the photodetectors. There is no need for an additional external power supply. The photodetectors are arranged so that they can sense the direction of solar irradiance. Based upon the signal processing circuitry at the outputs, two highly sensitive voltage signals are generated. These signals correspond to the pitch and roll angles of the sun with respect to the photodiodes. The circuitry has an inherent automatic gain control. Therefore, the output signals are only proportional to these angles and not to the solar irradiation level.

4 The Sensor Circuitry

The schematic of the proposed simple self-powered solar tracking sensor circuitry is presented in Figure 1. Processing the signals from the photodetectors requires only two operational amplifiers and several resistors. Additionally, as the photodetectors (photodiodes PDYU1, PDYU2, PDYD1, PDYD2, PDXR1, PDXR2, PDXL1, and PDXL2) work in the photovoltaic mode the generated power is significant enough to power the op-amps. Both the X and Y direction use four photodiodes (PDYU1, PDYU2, PDYD1, and PDYD2) connected in series to power on the operational amplifiers OP1 and OP2. The corresponding voltages, obtained at the photodiodes when in photovoltaic mode, are given by:

$$V_i = V_T \ln\left(\frac{\Re P_i}{I_S}\right) \quad (1)$$

where V_i is the corresponding i-th (i = YU1, YU2, YD1, YD2, XR1, XR2, XL1, and XL2) photodiode voltage, V_T is the thermal voltage given by $V_T = k_B T/q$ where k_B = 1.38×10-23 J/K is the Boltzmann constant, T is the absolute temperature, q = 1.602×10-19 C is the elementary charge, $\Re$ is the photodiode responsivity, P_i is the i-th photodiode captured optical power, and I_S is the photodiode saturation current.

To keep photodiodes in the photovoltaic mode they must be connected to the high impedance nodes, thus requiring high values of the resistance RL. The corresponding photodiode-captured optical power depends upon the shadow position within the enclosure, i.e. it depends on the shadow distribution over the active photodiode surface. This is presented in Figure 1. The actively-illuminated area on the photodiodes' surface depends upon the pitch and roll angles of the sun with respect to the photodiodes, as presented in Figure 2. This is, naturally, valid only for the photodiodes that are shadowed by the enclosure. For example, if the Sun illuminates the sensor from the first quadrant, shown in Figure 2, only photodiodes PDYU2 and PDXR2 will be in the shadow and their corresponding illuminated area will be:

$$A_{XR2} = A - K\xi \qquad (2.1)$$

$$A_{YU2} = A - K\psi \qquad (2.2)$$

where small pitch ξ and roll ψ angles were assumed (ξ, ψ ≪ 1) thus giving, in the first approximation, the linear dependence of the illuminated photodiode area with respect to the corresponding angles, where A is the area of the photodiode active surface, K is the positive proportionality constant that depends on the sensor geometry, and where A ≫ Kξ, Kψ is also valid.

Self-Powered Solar Tracking Sensor
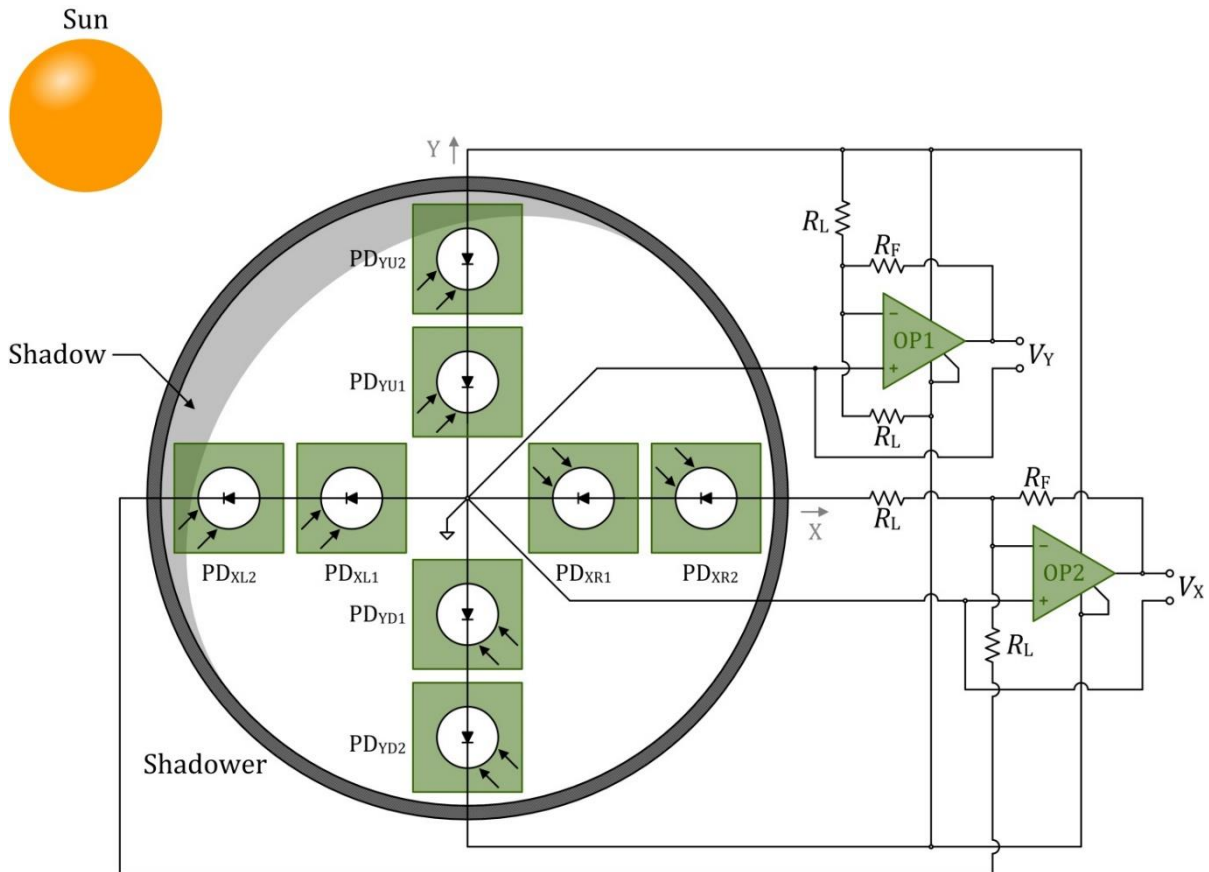
Figure 1: Schematic of the Simple Self-Powered Solar Tracking Sensor Circuitry

The corresponding photodiode voltages V_i according to equation (1) are given by:

$$V_{\text{XR2}} = V_T \ln\left(\frac{\Re E A_{\text{XR2}}}{I_\text{S}}\right) \qquad (3.1)$$

$$V_{\text{XR1}} = V_{\text{XL1}} = V_{\text{XL2}} = V_T \ln\left(\frac{\Re E A}{I_\text{S}}\right) \qquad (3.2)$$

$$V_{\text{YU2}} = V_T \ln\left(\frac{\Re E A_{\text{YU2}}}{I_\text{S}}\right) \qquad (3.3)$$

$$V_{\text{YU1}} = V_{\text{YD1}} = V_{\text{YD2}} = V_T \ln\left(\frac{\Re E A}{I_\text{S}}\right) \qquad (3.4)$$

where E is the solar irradiance. The output voltages V_X and V_Y are given as:

$$V_\text{X} = -\frac{R_\text{F}}{R_\text{L}}(V_{\text{XR2}} + V_{\text{XR1}} - V_{\text{XL2}} - V_{\text{XL1}}) \qquad (4.1)$$

$$V_\text{Y} = -\frac{R_\text{F}}{R_\text{L}}(V_{\text{YU2}} + V_{\text{YU1}} - V_{\text{YD2}} - V_{\text{YD1}}) \qquad (4.2)$$

where R_F is the feedback resistor resistance. Equations (2), (3), and (4) give:

$$V_\text{X} = -\frac{R_\text{F}}{R_\text{L}}V_T \ln\left(1 - \frac{K\xi}{A}\right) \approx \frac{R_\text{F}}{R_\text{L}}\frac{K}{A}V_T\xi = S\xi \quad (5.1)$$

$$V_\text{Y} = -\frac{R_\text{F}}{R_\text{L}}V_T \ln\left(1 - \frac{K\psi}{A}\right) \approx \frac{R_\text{F}}{R_\text{L}}\frac{K}{A}V_T\psi = S\psi \quad (5.2)$$

In the first approximation the output voltage signals V_X and V_Y are directly proportional to the pitch and roll angles with sensor sensitivity S. As the output signals are independent of the solar irradiance the circuitry has an inherent automatic gain control.
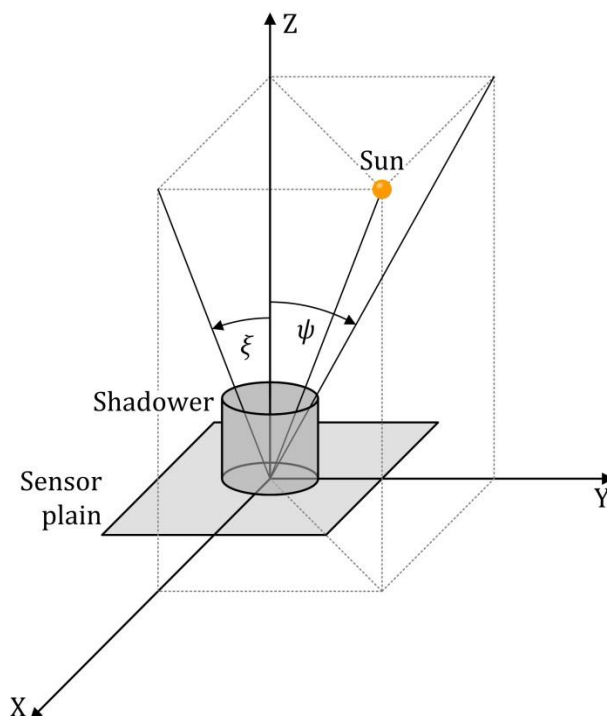
Figure 2: Measurement of the Position of the Sun with Respect to the Sensor

5 Realization with SLG88103 Operational Amplifiers

The realization of a simple self-powered solar tracking sensor circuitry will be based on the extremely low-power characteristics of the SLG88103 operational amplifiers [4]. To test the proposed circuitry a simulation in LTspice has been performed. The simulated circuitry, only for a single axis, has been presented in Figure 3. The system circuitry consists of two such sub circuitries, each aimed for sensing a single axis position of the sun. As the photodetectors, four BPW34 photodiodes from OSRAM Opto Semiconductors have been used in the simulation due to their relatively large sensing area of 7.45 mm^2 (2.73 mm × 2.73 mm). The spice model of the photodiodes is provided by Opto Semiconductors as well [5].

Self-Powered Solar Tracking Sensor

```
.inc "C:\Program Files\LTC\LTspiceXVII\lib\sub\SLG88103.sub"
.dc VPD2 1mV 100mV 0.01mV dec VPD1 1mV 100mV 10
```
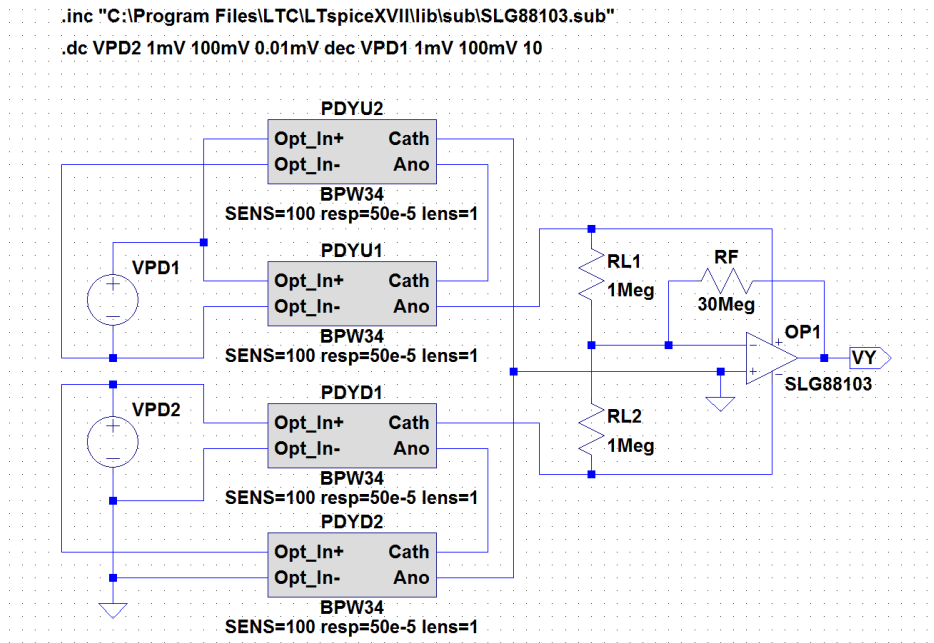

Figure 3: Schematic of the Simulated Circuitry

The solar irradiance has been modeled by two voltage sources VPD1 and VPD2, where the voltage in millivolts (mV) corresponds to the solar irradiance in mW/cm2. The solar irradiance was swept within the range of 1 mW/cm2 (1 mV) and 100 mW/cm2, (100 mV), wherein 100 mW/cm2 also represents the maximal possible value of the solar irradiance. As mentioned above, if the angle between the sensor surface and the Sun is not perpendicular, i.e. the pitch and roll angles are not equal to zero, due to intentional partial-shading of the photodiodes, there will be an unequal distribution of the irradiance at the photodiode surface. The unequal distribution of the solar radiation over the photodiode surfaces has been modeled with the different values of the solar irradiance, i.e. with the different values of the voltage sources VPD1 and VPD2. The corresponding simulation results are presented in Figure 4.

The conclusion, which can be drawn from the simulation results, is that the circuitry is highly sensitive to the change in the solar illumination direction, which correlates to the change of the corresponding voltages of the voltage sources VPD1 and VPD2. The important characteristic of the proposed design is that the sensor sensitivity doesn't depend on the overall illumination of the sun, provided the rail-to-rail voltage of the op-amp is greater than 1.71 V. This can be concluded from the same slopes of the sensor response in the logarithmic scale. Therefore, the sensor has inherent gain control, which is a very important feature of this sensor circuitry, especially if it has been used in the control loop where the overall system stability is of the paramount importance. The same sensor sensitivity for a broad range of the solar irradiances leads to the very simple design of the control loop.
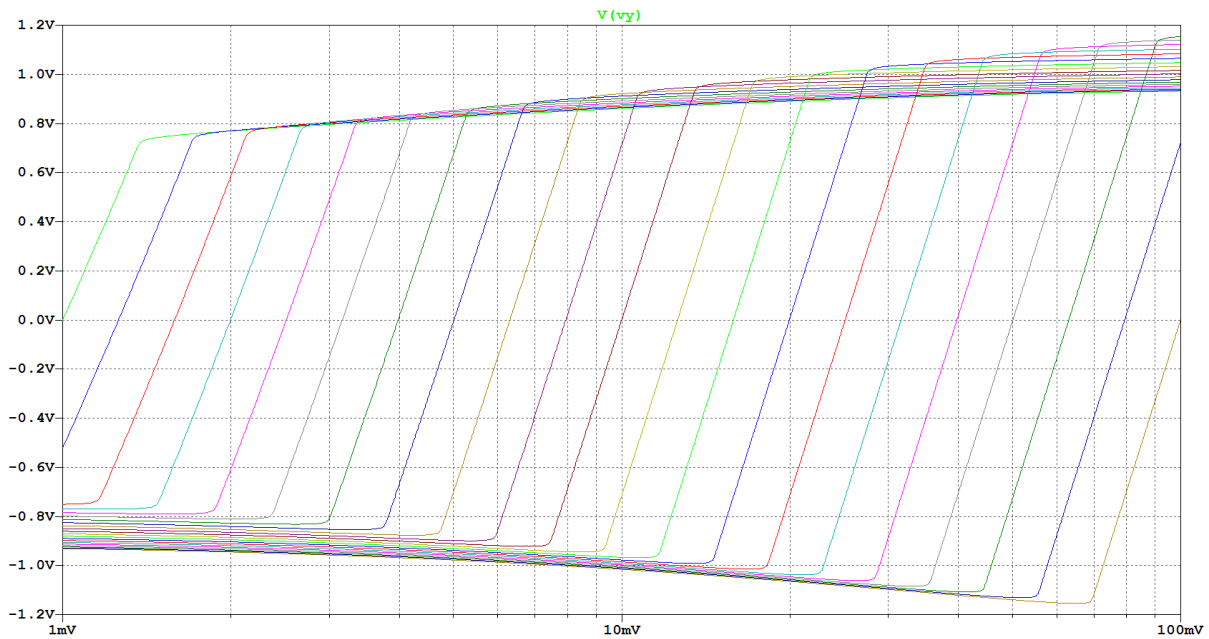
Figure 4: Simulation Results of the Proposed Circuitry

The photodiode shunt resistance RSH is given as:

$$R_{SH} = \frac{V_T}{\Re AE} \qquad (6)$$

which, in the case of the BPW34 photodiode, with $\Re$ = 0.5 A/W, A = 7.45 mm2 and the minimum solar irradiance of E = 1 mW/ cm2, gives the maximum value of the photodiode shunt resistance of $R_{SH} \approx 670\ \Omega$. To operate in the photovoltaic mode the shunt resistance of the photodiode must be much smaller than the load resistance of the photodiode, i.e. must be fulfilled $R_{SH} \ll R_L$. By choosing R_L = 1 MΩ this condition is certainly fulfilled. The value for the feedback resistance R_F can be arbitrarily chosen to obtain the desired sensitivity. In this application the value of R_F = 30 MΩ was chosen.

According to the simulated results in Figure 4, the maximum output voltage is in the range of $V_X, Y_{MAX} \approx 1$ V. Therefore, the current that flows through the feedback resistor and thus through the load resistors is smaller than $IF_{MAX} = V_X, Y_{MAX}/R_F \approx 33$ nA, which is much smaller than the operational amplifier quiescent current of IQ = 375 nA. The operational amplifier quiescent current must fulfill the condition $IQ \ll \Re AE$ to enable the simultaneous work of the photodiode in the photovoltaic mode and proper biasing the operational amplifiers. Since $\Re AE \approx 37$ µA for the minimum solar irradiance of E = 1 mW/ cm2 this condition is also fulfilled.

6   Example Implementation

Using an evaluation board for the SLG88103 operational amplifiers and photodiodes the test circuitry was created. The photo of the proto-board realized circuitry, together with the photodiode-based sensor, is shown in Figure 5. The cylinder, i.e. the shadower, is fixed onto the sensor board in order to form the shadow when illuminated by the Sun. The cylinder dimensions can be chosen with regard to the sensor sensitivity and the required measurement range. The sensor that was used in this application note has a shadower of the cylindrical shape with the inner diameter of the cylinder of 38 mm and the height of the cylinder of 35 mm.
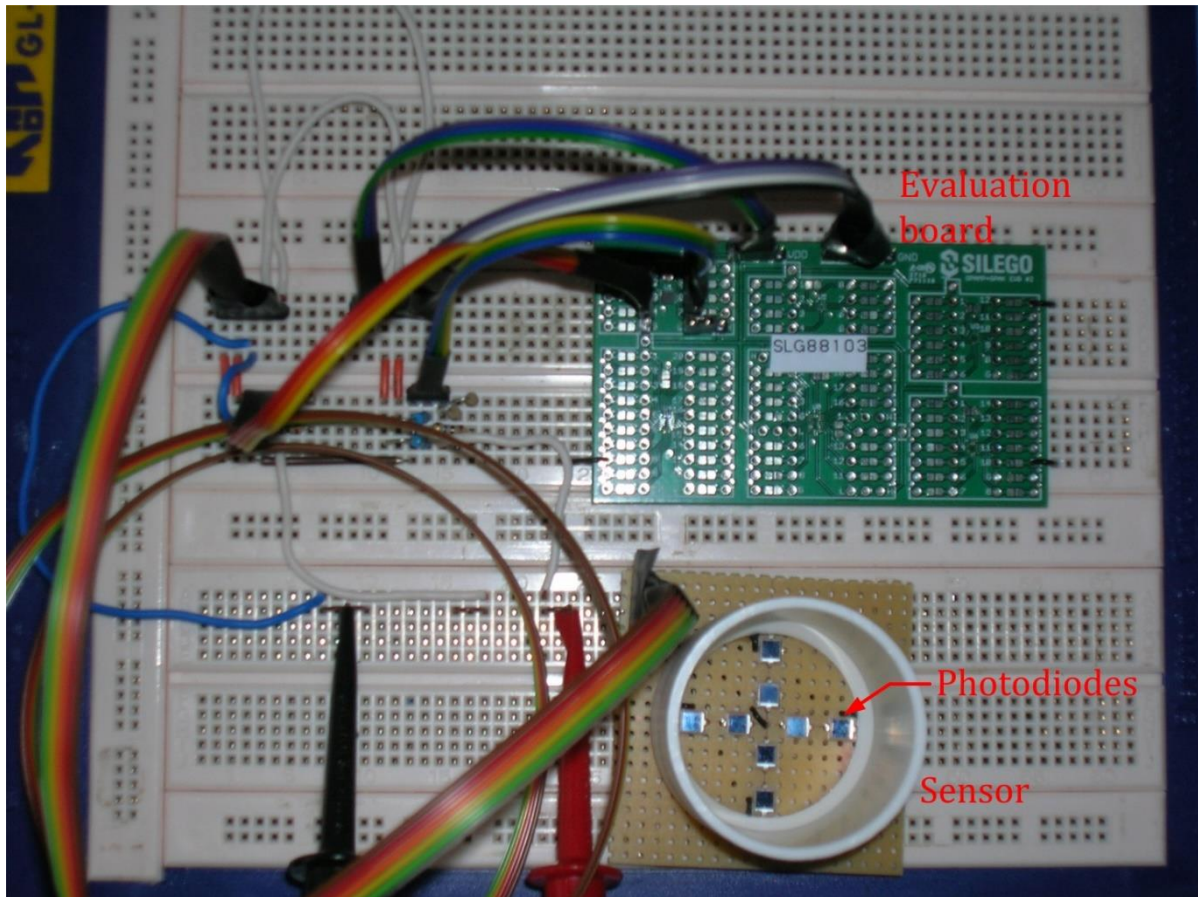
Figure 5: Photo of the Test Board Together with the Sensor

In order to determine the overall sensor circuitry transfer function, the sensor was mounted on a platform, whose tilt angles can be varied. The sensor was directed toward the Sun and by controlling the tilt angles, i.e. the pitch and roll angles of the platform, both voltages VX and VY were adjusted to be as close as possible to zero. Then, by changing the corresponding tilt angles of the platform, the pitch and roll angles of the sensor were changed with respect to the Sun in the range from - 5° to + 5° while simultaneously measuring the output voltages. The transfer function of the sensor circuitry is presented in Figure 6. Based on the measured data set it was estimated that the sensor sensitivity is approximately S ≈ 56 mV/°.
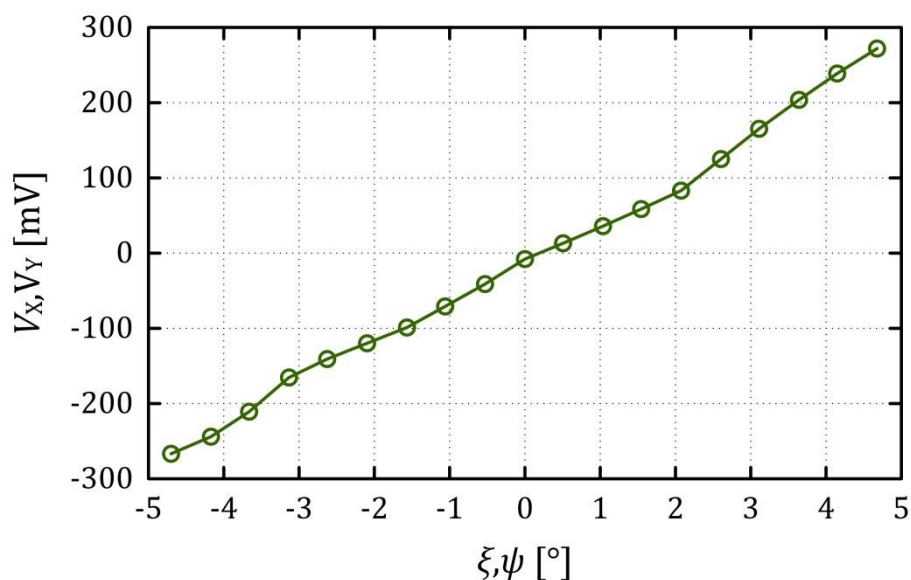
Figure 6: Transfer Function of the Sensor Circuitry

7   Conclusion

Solar tracking sensor has a very important role in many solar power systems (photovoltaic systems) to increase the overall system efficiency. In order to direct the solar panels toward the Sun a control loop, using the signals obtained from the solar tracking sensor, rotates the panels toward the Sun. Therefore, a simple, reliable (without additional power supply), and cost-effective sensor, as presented in this application, will improve the characteristics of the solar power system.

The presented self-powered solar tracking sensor circuitry can be tested with different combinations of photodetectors and shadowing geometries to achieve characteristics that can better fit into the end user requirements.

Revision History

Revision	Date	Description
1.0	16-Aug-2018	Initial Version

Status Definitions

Status	Definition
DRAFT	The content of this document is under review and subject to formal approval, which may result in modifications or additions.
APPROVED or unmarked	The content of this document has been approved for publication.

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