Preliminary investigation on performance of a low-cost OPT101 sensitive element for digital pyramidal solar sensor

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Abstract: Optical Photodiode Transistor (OPT101) is a monolithic photodiode and single-supply operational amplifier integrated into a single package, designed for accurate light-to-voltage conversion. In this work, several tests were conducted to ensure the reliability and performance of the sensitive element and its associated electronic components before integration into a digital pyramidal solar sensor for space application. These tests include measurements in total darkness, controlled light source, and drift evaluation to assess stability over time. To make the sensor work in different incidence angle conditions, an optical F-100 lens is adopted. Additionally, a digital filtering algorithm is proposed to process the signals measured by the OPT101 sensor. Compared to other digital filtering algorithms, the verification results demonstrate that the suggested rounded average method improves the quality and the stability of the sensor's output signal. Four Printed Circuit Boards (PCBs) were manufactured, which can be utilized in the future for the calibration of the digital pyramidal solar sensor.

Keywords: Satellite, OPT101 Sensitive Element, Digital Pyramidal Solar Sensor, Rounded Average Filtering Algorithm

1. INTRODUCTION

The determination and estimation of satellite attitude are essential for ensuring the successful operation of space missions, whether focused on earth observation, telecommunications, or space exploration [1-4]. Among the various sensors used to accomplish this task, solar sensors play a fundamental role thanks to their simplicity, reliability and low energy cost. These devices exploit the apparent position of the sun relative to the satellite to provide information on its orientation [5]. Solar sensors come in several types, each adapted to specific requirements in terms of accuracy, angular resolution, and robustness against hostile space environments. Analog solar sensors, for example, are widely used for applications where moderate accuracy is sufficient [6]. They measure the light intensity received by photodiodes or photovoltaic cells to estimate the angle of incidence of the sun. On the other hand, digital sensors offer better resolution and increased accuracy thanks to signal processing algorithms.

Light-sensitive sensor, such as OPT101, plays a crucial role in a multitude of industrial, domestic and scientific applications [1, 7-9]. This device converts light into an electrical signal, enabling accurate measurements of light intensity. In [8], and OPT 101 is used as a light detector for fiber optic sensor for monitoring and early warning of Soil Shift on IoT-based System. In [10], OPT-101 sensor is used to detect sensor value variations for wearable four channel near-infrared spectroscopy system. In [1], a photodiode sensor OPT101 for Texas Instruments was employed to detect light intensity variations in optical systems [11]. In this research, light-dependent resistors LDRs were utilized for automatic brightness adjustment, while phototransistors were applied to enhance the detection accuracy of security systems. Besides, two optical sensors, OPT101 and SFH-3310, have been used for non-invasive hemoglobin measurement [12]. The OPT101 sensor is intended to yield a relation factor in terms of voltage for mass of hemoglobin through a specified body part for each cardiac cycle.

In spacecraft attitude application, multi-axis solar sensors, such as pyramid sensors allow to simultaneously measure the position of the sun on several planes, thus offering a wider angular coverage [13, 14]. These sensors,

often equipped with sensitive elements, are particularly suitable for small satellites and CubeSats, where space and weight constraints are critical. In addition, the integration of advanced techniques such as digital filtering based the significantly improves their performance. This study is part of this context and explores an approach based on the use of digital pyramid sensors equipped with the OPT101, highlighting their design, calibration and experimental validation.

Inspired by the above discussions, a novel application of OPT101 light detector is investigated for spacecraft attitude determination. Several tests were performed to validate the reliability and performance of the sensitive element along with its associated electronic components prior to integration. The tests comprised measurements in complete darkness, under a controlled light source, and drift analysis to evaluate stability over time. The reminder of this paper is outlined as follows. In Section 2, the test bench of OPT101 validation is presented. In Section 3, the design of the printed circuit board of OPT101 is provided. In Section 4, unit testing of the OPT101 sensing element is derived and analyzed. Finally, the conclusion is outlined in Section 5.

2. TEST BENCH OF OPT101

A test bench was designed to perform unit tests on the OPT101 analog light detector, developed within the optoelectronics laboratory of Satellite Development Center (CDS). These tests aim to optimize the performance of the component to guarantee its optimal use in the pyramid solar collector. Figure 1 illustrates the block diagram describing all the tools used in the test bench.

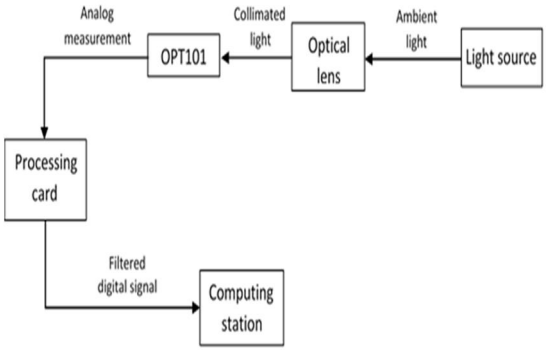


Fig. 1 Block diagram of the test bench.

2.1. OPT101 analog light detector

OPT101 is a low-cost analog light sensing element that integrates a photodiode and a specially optimized op-amp (see Fig. 2). The integrated combination of photodiode and amplifier on a single chip eliminates problems commonly encountered in discrete designs such as leakage current errors, noise detection, and gain peaking due to parasitic capacitance.

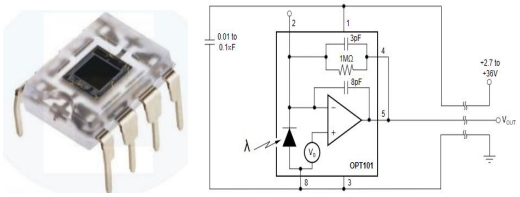


Fig. 2 Internal components and connections of OPT101 circuit [15].

The output voltage of the photosensor increases linearly with light intensity. The amplifier is designed for single or dual supply operation, making it ideal for battery-operated equipment such as satellites.

2.2. Electronic circuit for data acquisition and processing

An electronic circuit was realized to set up the architecture allowing to perfectly exploit the OPT101. The circuit contains the following elements: processing card based on the ATMEGA microcontroller, OPT101 sensor, and other passive components. The analog signal output of the OPT101 is transformed into a digital value, processed by a proposed filtering algorithm, which is implemented on the processing card. Finally, the filtered signal is subsequently sent to a computing station via the serial port with a speed of 115200 bauds for the purpose of signal analysis (see Fig. 3).

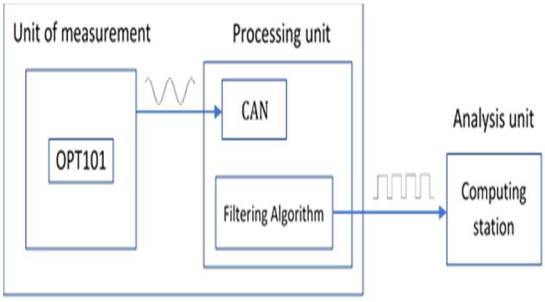


Fig. 3 Block diagram of the electronic assembly.

2.3. Filtering algorithm

The major problem of the sensitive element is the noise that can influence the reliability and robustness of the device. To reduce this noise $V_D(j)$, a filtering algorithm has been developed based on the calculation of the rounded average of the surrounding values as described in Fig. 4.

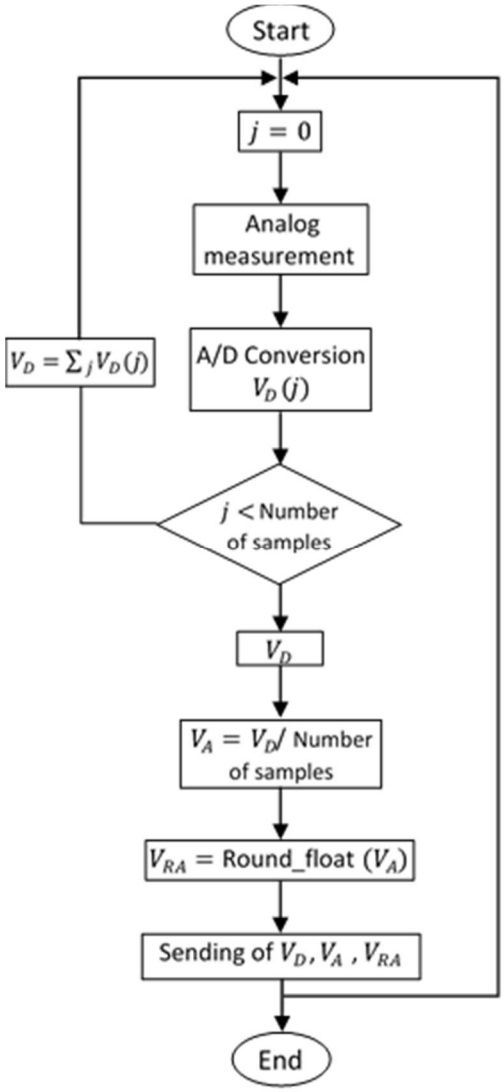


Fig. 4 Flowchart of operation of the rounded average filtering algorithm.

It is interesting to note that the process time of the algorithm T_P must be greater than the averaging time T_A = Number of samples $*$ (Sampling time: T_S). The process of the digital filtering algorithm is illustrated in Fig. 5.

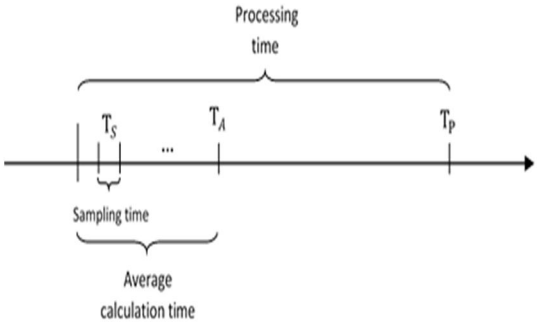


Fig. 5 Periods of signal processing from OPT101.

3. TEST BENCH OF OPT101

The design of a printed circuit board (PCB) is completed following the unit test of the OPT101 sensitive element. The 40x20 mm PCB, shown in Fig. 6, provides an overview of its expected appearance.

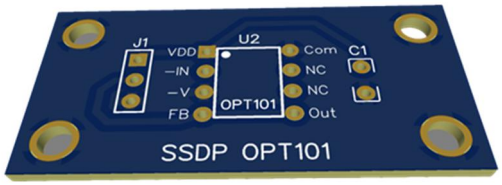


Fig. 6 Printed circuit board of the OPT101 sensitive element.

A design of a pyramidal support for the solar collector is carried out and then manufactured in the mechanical laboratory of the assembly, integration and testing department, as depicted in Fig. 7.

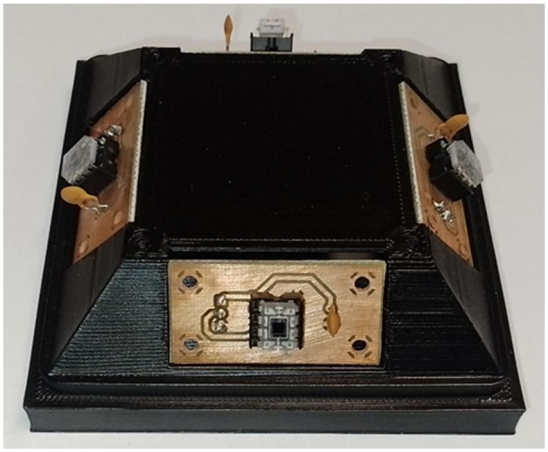


Fig. 7 OPT101 in the pyramidal support of the solar sensor.

4. UNIT TESTING OF THE OPT101 SENSING ELEMENT

A set of tests are performed to verify the unit operation of the OPT101 before its integration into the solar sensor (see Fig. 8). It is noted that it is necessary to properly determine the distance between the light source and the sensing element, to study the need to add an optical lens inside and to filter the raw signal measured by the OPT101, based on several experimental tests.

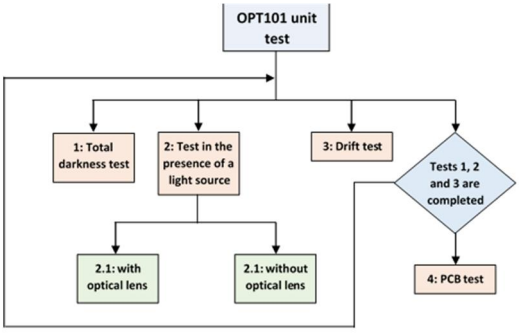
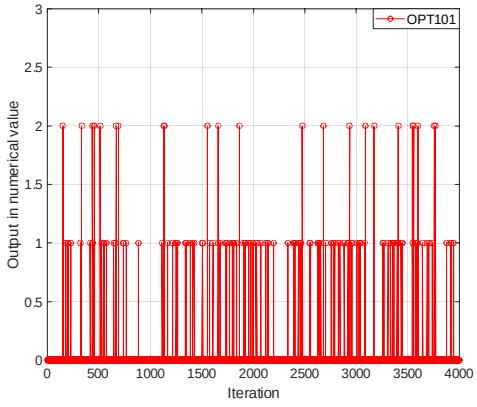


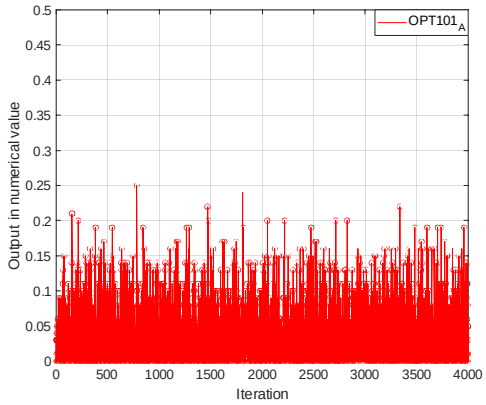
Fig. 8 Unit test procedure of the OPT101 sensitive element.

4.1. OPT101 in the complete darkness of the environment

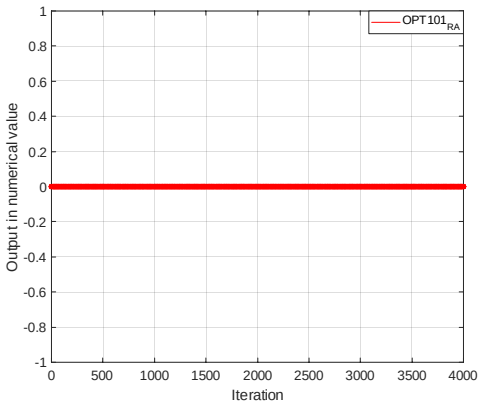
Figure 9 shows the response of the raw OPT101 measured signal filtered by a filtering algorithm called “rounded average filtering” under total darkness in the test environment. First, the raw signal received by the card is converted into a digital value. This signal varies in digital value between 0, 1 and 2 in total darkness causing an uncertainty in the measurement during the test period (see Fig. 9 (a)).



(a)



(b)



(c)

Fig. 9 Acquisition of OPT101 measurements in total darkness of the test environment: (a) raw measurement, (b) measurement filtered by the mean, (c) measurement filtered by the rounded mean.

Then, this noise is reduced by applying a digital filtering algorithm by calculating the average of 80 samples (measurements), as shown in Fig. 9 (b). It is clear from Fig. 9 (c), that the filtered digital signal gives the value zero during the entire test period of the OPT101 sensitive element in total darkness of the environment, thereby demonstrating its superior efficiency.

4.2. OPT101 with a light source

The purpose of this experiment is to test the OPT101 by exposing it to a fixed amount of light using a light source under the reference LED 10W HEXAPOWER. In order to extract the correct use of the source, several factors were varied such as: the angle of incidence (0 deg, 20 deg, 40 deg, … etc.), the type of lens (100-, 100+, 500+, … etc.), the distance between the OPT101 and the lens (20 cm, 40 cm, …, etc.). the number of measurements is set to 400 iterations.

4.2.1. OPT101 without using the optical lens

In this test, the OPT101 is exposed directly to the light source with an incidence angle of 0 deg. Figure 10 shows the signals obtained by the sensing element. The raw measured signal obtained by the OPT101 has a variation of ∓ 4. Through the application of the proposed digital filter, the signal has stabilized at a fixed value of $\mathrm{OPT101_{RA}} = 862$.

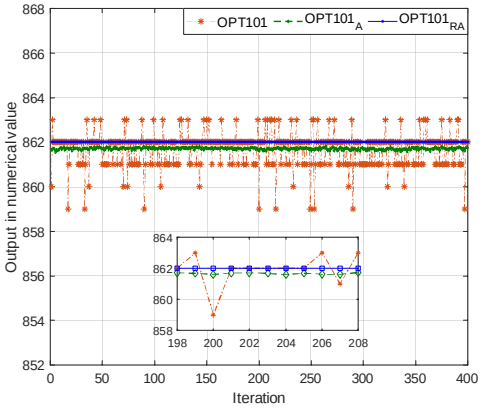


Fig. 10 Acquisition of OPT101 measurements in the presence of the light source and without the use of the optical lens.

Then, we varied the angle of incidence of the light source in order to evaluate the effect of the angle on the OPT101. During this test we observed that the OPT101 sensitive element did not detect a variation in the angle of incidence, which it kept the same response. This prompted us to add a lens between the source and the sensitive element to obtain a variation on the signal measured by the OPT101 when the angle of incidence was varied. Several tests were carried out at each change of lens: (F+100, F+200, F-100, … etc.) and the distance between the OPT101 and the lens (20 cm, 40 cm, …, etc.).

4.2.2. OPT101 with the optical lens

After testing the different lenses available on the optical bench, the F-100 lens gave a better result with a distance between the OPT101 and the lens of 120 cm and 25 cm between the lens and the light source (see Fig. 11).

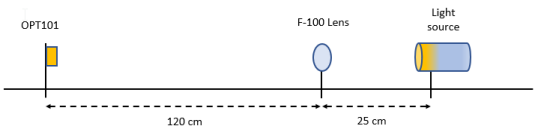


Fig. 11 Appropriate lens and distances for unit testing in the presence of the light source.

- **Test at 0 deg incidence angle**

Figure 12 shows the variation of the measured signal as a function of the incidence angle for the 0 deg incidence angle.

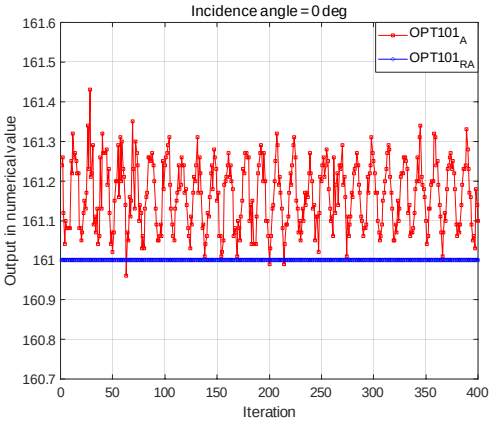
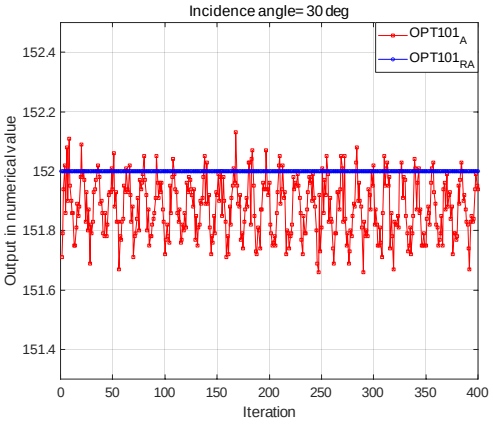


Fig. 12 Acquisition of OPT101 measurements at 0 deg incidence angle using the 100+ lens.

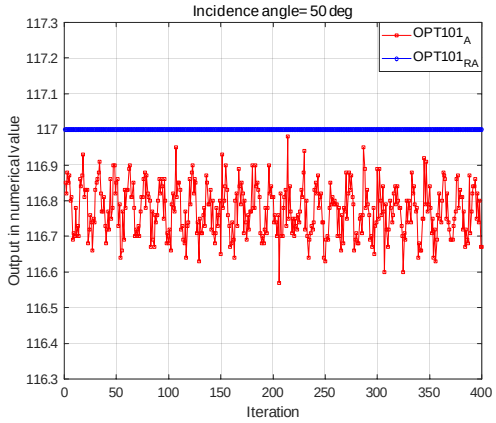
It can be observed that the signal processed by the OPT101_MA rounded mean filter remained stable during the 400 iterations (equivalent to 25 seconds of the test). This shows once again that the filtering algorithm is effective even in the case where the OPT101 is exposed to the light source.

- **Testing several incidence angles**

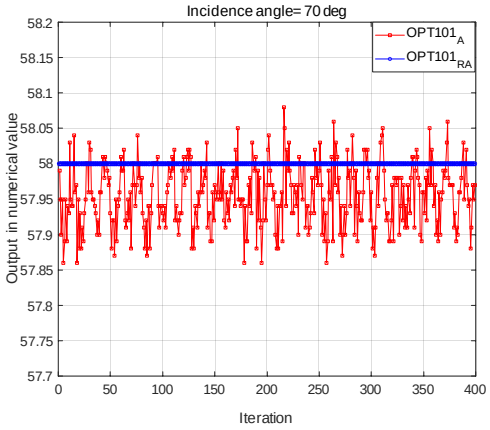
Other incidence angle values: 30 deg, 50 deg, 70 deg and 90 deg, were selected in order to see, on the one hand, the measurement quality obtained by the sensitive element as a function of the variation of the incidence angle and on the other hand to evaluate the efficiency of the proposed filter.



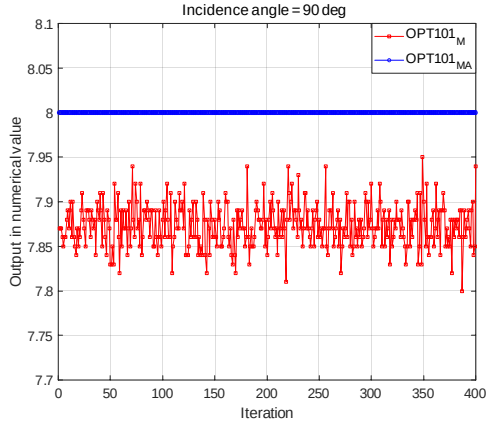
(a)



(b)



(c)



(d)

Fig. 13 Acquisition of OPT101 measurements at 0 deg incidence angle using the F-100 lens.

From Fig. 13, it is observed that the measurement value obtained by the OPT101 varies according to the change of the angle of incidence between 8 to 161 for the angles 0 to 90 deg. This result is obtained thanks to the use of the +100-type lens. In addition, it is important to indicate that the signals obtained remain stabilized around their values during the test period. This is very necessary for a better scanning using the rotary table that carries the solar sensor.

- **OPT101 drift test**

The purpose of this test is to analyze the characteristics of the 10W HEXAPOWER LED light source in terms of drift. The test is carried out for approximately 04 hours, equivalent to 237341 iterations, with the light source fixed at the angle of incidence = 0 deg during the entire period. Figure 14 shows the signal measured by the OPT101 before and after filtering this signal. It can be clearly observed that the rounded filtered signal is almost noise-free but it diverges over time with a significant decrease in the signal measured during the first two hours of the test. This phenomenon occurs because the light source heats up over time and causes a divergence in the amount of light emitted by the inner lamp of the light source.

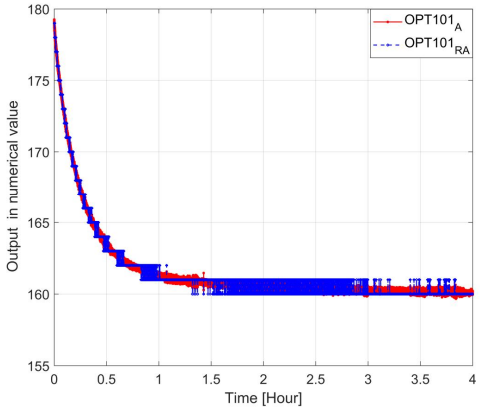


Fig. 14 Acquisition of OPT101 measurements over 4 hours.

After performing this test, it can be concluded that the scanning of the azimuths and elevations of the solar sensor must be performed at least after 03 hours from the ignition of the light source, and for protection it is preferable to perform it after 04 hours. It can be seen from the three tests performed that the signal obtained by the sensitive element OPT101 needs to be filtered and that it is necessary to wait a certain time before using the light source.

5. CONCLUSION

In this work, preliminary investigation on performance of Low-cost OPT101 sensitive element is addressed in the development of a digital pyramidal solar sensor. First, a set of unit tests on the OPT101 sensitive element are performed to ensure that all the hardware and electronic components used are properly approved before being integrated. Then, the digital pyramid solar sensor is manufactured based on four OPT101 sensitive elements prepared for the extraction of the azimuth and elevation parameters. The verification results reveal that the proposed rounded average

method significantly improves both the quality and stability of the sensor's output signal. Finally, four PCBs were designed for potential use in the future calibration of the digital pyramidal solar, demonstrating its suitability for demanding aerospace applications.

6. ACKNOWLEDGMENT

The authors dedicate this work to the memory of our dear colleague Mr. Abdellatif Bellar, whose contributions and dedication remain a source of inspiration. He will always be remembered with respect and gratitude.

References

[1] L. Baroni, "Attitude determination by unscented Kalman filter and solar panels as sun sensor," The European Physical Journal Special Topics, vol. 229, pp. 1501-1506, 2020.

[2] M. Schmidt, K. Ravandoor, O. Kurz, S. Busch, and K. Schilling, "Attitude determination for the Pico-Satellite UWE-2," IFAC Proceedings Volumes, vol. 41, pp. 14036-14041, 2008.

[3] A. Colagrossi, M. Lavagna, and R. Bertacin, "An Effective Sensor Architecture for Full-Attitude Determination in the HERMES Nano-Satellites," Sensors, vol. 23, p. 2393, 2023.

[4] N. DiGregorio, "Improved Model for Low Cost Sun Sensor Attitude Filtering," 2018.

[5] M. A. Post, J. Li, and R. Lee, "A Low-Cost Photodiode Sun Sensor for CubeSat and Planetary Microrover," International Journal of Aerospace Engineering, vol. 2013, p. 549080, 2013.

[6] J. Yin, J. Liu, and F. Yang, "A yaw attitude determination method based on coarse sun sensor information for the GEO satellite," in Journal of Physics: Conference Series, 2022, p. 012025.

[7] M. Borecki, A. Olejnik, A. Rychlik, M. L. Korwin-Pawlowski, and J. Szmidt, "A passive sensing device for a cloud on the skyline detection," in Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2019, 2019, pp. 972-978.

[8] H. S. Herlin, "Applications of Fiber Optic Sensor for Monitoring and Early Warning of Soil Shift on IoT based System," JOIV: International Journal on Informatics Visualization, vol. 4, pp. 117-122, 2020.

[9] Y. Liu and H. Xu, "Design of an MCU-controlled laser liquid turbidimeter based on OPT101," in 2009 International Conference on Optical Instruments and Technology: Optoelectronic Measurement Technology and Systems, 2009, pp. 291-302.

[10] V. Akila and A. C. John Victor, "Design of Wearable Four Channel Near-Infrared Spectroscopy System," Design of Wearable Four Channel Near-Infrared Spectroscopy System.

[11] R. Faza, S. Chalimah, S. Sudarsono, and G. Yudoyono, "Preliminary Study of Resonance Systems States in Surface Plasmon Resonance Systems," in Journal of Physics: Conference Series, 2024, p. 012037.

[12] B. Desai and U. Chaskar, "Comparison of optical sensors for non-invasive hemoglobin measurement," in 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), 2016, pp. 2211-2214.

[13] J. Wang, X. Wang, and J. Yang, "A Sun Sensor Based on Regular Pyramid Sensor Arrays," in Journal of Physics: Conference Series, 2019, p. 012010.

[14] A. Adnane, M. E.-A. Cheriet, E. Benfriha, A. Bellar, M. A. S. Mohammed, and Y. Kebbati, "Sun sensor design for full field of view coverage," in 2022 5th International Conference on Advanced Systems and Emergent Technologies (IC_ASET), 2022, pp. 85-90.

[15] S.-M. Packages, "Monolithic Photodiode and Single-Supply Transimpedance Amplifier," 1994.London, vol. A247, pp. 529–551, April 1955.