Journal of Physics: Conference Series

PAPER • OPEN ACCESS

A development of a low-cost pyranometer for measuring broadband solar radiation

To cite this article: K Tohsing *et al* 2019 *J. Phys.: Conf. Ser.* **1380** 012045

A development of a low-cost pyranometer for measuring broadband solar radiation

K Tohsing, D Phaisathit, S Pattarapanitchai, I Masiri, S Buntoung, O Aumporn and R Wattan

Laboratory of Tropical Atmospheric Physics, Department of Physics, Faculty of Science, Silpakorn University, Muang, Nakhon Pathom, 73000, Thailand

Email: korntip.tohsing@gmail.com

Abstract. In this work, the design of an inexpensive and reliable pyranometer used for measuring broadband solar irradiance is proposed. A BPX43 – 4 phototransistor is used as a light detector, which has the spectral response in the range approximately 450 to 1100 nm. This system is controlled by an Arduino pro mini ATmega328P (5 V, 16 MHz) microcontroller and all components are located inside a FB05 black box. Due to a high level of solar radiation in the different environmental conditions, the pyranometer encountered the voltage saturation. Therefore, a 0.25 mm thick of Teflon is selected for attenuating the sunlight. After investigating against a reference sensor, the transmittance of this attenuator is found to be about 12.5%. Finally, the experimental results from the system are compared with a standard pyranometer performed at Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC, 46.80 °N, 9.83 °E and 1,610 meters above sea level), Switzerland. The results demonstrate a satisfactory agreement between the global irradiance obtained from our proposed pyranometer and the standard pyranometer.

1. Introduction

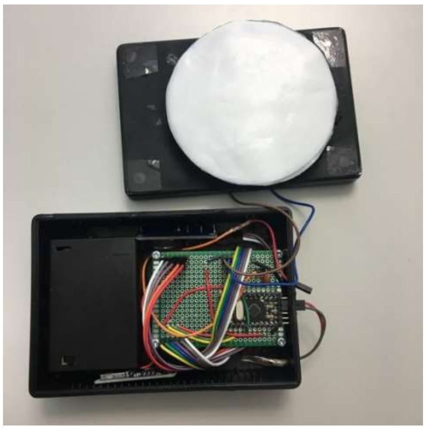
Broadband solar radiation or global irradiance is an electromagnetic wave in the wavelength of 300 – 3000 nm consisting of three segments, namely ultraviolet radiation (280 – 420 nm), visible light (400 – 700 nm) and infrared radiation (700 – 3000 nm). Information of broadband solar radiation incident on the Earth's surface is essential for many solar energy applications for example designing of energy conversion systems such as solar photovoltaic (PV) [1] or studying of the variation of solar radiation [2]. In order to utilize these applications, it has to know the global irradiance data at that location, which can be measured by using a pyranometer. The output of the pyranometer is voltage, which can be converted into global irradiance in W/m^2 by using a sensitivity of the pyranometer provided by the manufacturer. Normally, pyranometes use different kinds of detectors to measure global irradiance. For commercial instruments with a high accuracy, a solid state or thermopile sensor has been widely used, whereas the devices such as a photodiode, light dependent resistor (LDR) or phototransistor were applied for non-profit proposes [3]. This leads to a budget problem for using commercial pyranometers and inaccurate data by using photodiodes or LDR. Therefore, the aim of this work is to develop and design a reliable pyranometer for measuring global irradiance from inexpensive and easy to find components. This device should also be used as a mobile pyranometer, which can collect the global irradiance everywhere for further solar applications.

2. Design of the pyranometer

In this work, the BPX43-4 phototransistor was selected as a light sensitive detector because its spectral response lies in the wide range from 450 nm to 1100 nm corresponding to the visible and infrared spectrum compared with LDR or other types of phototransistor. This device made of a silicon NPN semiconductor, which can generate high current value and no current amplifier needs. Furthermore, it can be easily found in a local market and very cheap. Other electronic components of this pyranometer composed of a micro SD card applied as a data logger for collecting the data, real time clock module (DS1302) and power supply. This system is controlled by an Arduino pro mini ATmega328P (5 V, 16 MHz) microcontroller, which has a compact size with very thin board and easies to program. All components are located inside a FB05 black box for protecting the electronic components from severe environment such as moisture, dust and temperature variations. The black box needs to be allowed us easily for mounting, changing or modifying all parts inside the box.

Besides these electronic components inside the box, a Teflon sheet used as an attenuator of solar radiation is also a very important part. After testing under an artificial light source, the BPX43 – 4 phototransistor saturated when received the light intensity of about 200 W/m^2 but the average solar irradiance at the surface can reach to 800 W/m^2. To avoid the saturation of the phototransistor, the 0.25 mm thickness of Teflon sheet, which allows the solar radiation passed through it about 12.5% was chosen. In order to measure such a high intensity of the sunlight, four layers of Teflon sheet with 1.00 mm thick is suitable for our purpose. The outlook of BPX43 – 4 phototransistor and the prototype pyranometer are shown in figure 1.

(a)



(b)

Figure 1. Side view of the BPX43 – 4 phototransistor (a) and the purposed pyranometer (b).

As mentioned above, the global irradiance measured by the pyranometer can be derived from the voltage signal and the sensitivity. To obtain the correct and precise irradiance data, the field pyranometer has to be annually calibrated. The calibration standard method according to the standard ISO 9847: 1992 [4] states that sensitivity S (in μV/ W.m^{-2}) of a field pyranometer is the ratio between its voltage output V (in μV) and the global irradiance from the reference pyranometer I (in W.m^{-2}). Therefore, the sensitivity S is equal to V/I. In this work, the outdoor calibration method according to the ISO 9847 under stable cloudless sky conditions was performed and evaluated the sensitivity of our prototype pyranometer.

After the development of the low-cost pyranometer, its calibration and validation need to be performed. Our purposed pyranometer and reference pyranometer (Kipp&Zonen, Model: CM21) were installed at Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC, 46.80 °N, 9.83 °E and 1,610 meters above sea level), Switzerland during 11 March – 25

April, 2019. The global irradiance from a reference pyranometer called CM21 and the voltage signal from the designed sensor was collected every 2 minutes under different sky conditions.

3. Results and discussion

The data obtained from the two pyranometers under clear sky condition were analysed for estimating the sensitivity of the proposed pyranomer and under other sky conditions such as partly cloudy and overcast sky for validating our pyranometer. The results were separately described as follows.

3.1. Sensitivity of pyranometer

The data corresponding to 0 – 5 Vdc variations, which are represented by 0 – 1023 counts measured by the pyranometer under cloudless condition on 23 – 24 March, 2019 were plotted against the global irradiance from CM21 as shown in figure 2. A slope of the graph deliveries the sensitivity of our pyranometer, which is found to be 1.65 mV/W.m^2. A slightly curved line at the beginning of this graph might originate from the misalignment of the BPX 43 – 4 phototransistor in the box during the experiment.

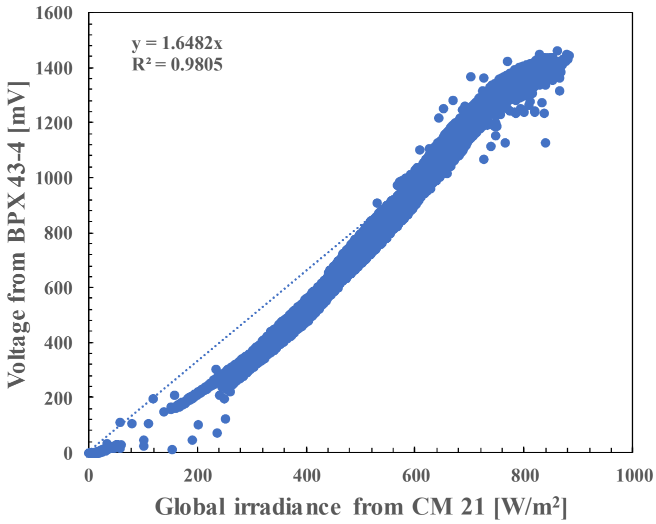


Figure 2. Voltage signal from the purposed pyranometer and the global irradiance from CM21 under clear sky condition on 23 – 24 March, 2019.

3.2. Testing and experimental validation

The sensitivity obtained from previous section has been applied for calculating global irradiance under partly cloudy and compared with that obtained from CM21. The result was shown in figure 3.

From the preliminary comparisons, it was observed that the solar radiation from the pyranometer slightly less than that measured by CM21 but our pyranometer was able to measure closely similar to the CM21 without applying any mathematical algorithms [5, 6]. The discrepancy between both datasets was analysed and presented in terms of mean bias difference (MBD) of -14.4% and root mean square difference (RMSD) of 15.5%. The difference in global irradiance might cause from a limitation of the field of view and the spectral mismatch between both pyranometers.

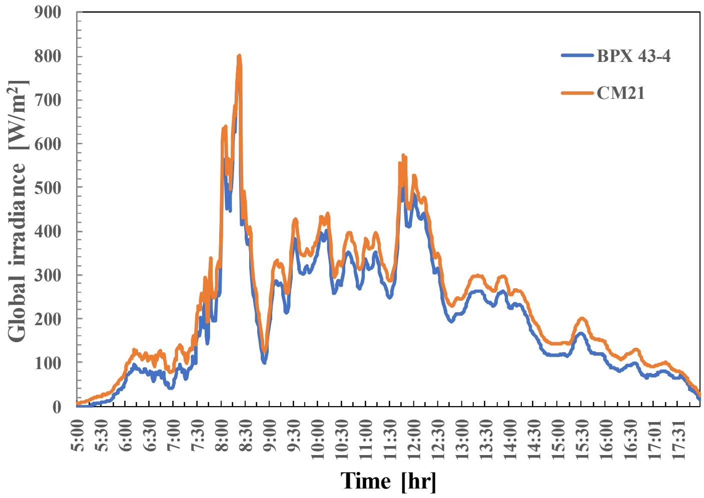


Figure 3. Comparison of global irradiance obtained from the pyranometer and that from CM21 under partly cloudy sky condition on 9 April, 2019.

4. Conclusion

In this work, we proposed a low-cost and reliable pyranometer, which applied a phototransistor as a light detector combined with other electronic elements for measuring broadband solar radiation. This pyranometer was controlled by the microcontroller and all components were located inside the black box. To overcome the saturation of the phototransistor, the Teflon sheet has been used as a solar attenuator. After the development, the sensitivity of the pyranometer has been analysed and then applied this sensitivity to estimate the global irradiance. The comparison of global irradiance from our pyranometer and the standard pyranometer showed the satisfactory performance. However, this prototype pyranometer still needs further development and investigation to get more accuracy of the solar radiation from the measurement.

Acknowledgments

The authors would like to thank Dr. Wolfgang Finsterle from the Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC) in Davos, Switzerland for the support in the measurement and data acquisition of solar radiation.

References

[1] Ubertini S and Desederi U 2003 *Renew. Energy* **28** 1833–50
[2] Janjai S, Laksanaboonsong J, Nunez M and Thongsathiya A 2005 *Sol. Energy* **78** 739–51
[3] Dehghan M, Ghodsirad M H and Taheri S 2015 *Proc. Int. on Energy for Sustainability Multidisciplinaly Conference* (Efs 2015) (Coimbra, Portugal) p 1–5
[4] International Organization for Standardization (ISO) 1972 *Solar Energy - Calibration of Field Pyranometers by Comparison of a Reference Pyranometer* (Geneva, Switzerland)
[5] Hidalgo F G, Martinez R F and Vidal E F 2014 *Ocean Optics XXII Confer* (Portland, USA) p 1–8 online:https://oceanoptics.com/wp-content/uploads/Fernando-Guerra-Hidalgo-Sensors-Design.pdf
[6] Orsetti C *el at* 2016 *Procedia Eng.* **168** 1767–70