# PHOTODIODE BASED PYRANOMETER

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**Abstract**—Accurate measurement of solar irradiance is necessary for the successful implementation of solar power systems, both photovoltaic and solar thermal. This paper presents the idea and design of a new photodiode-based pyranometer for the measurement of solar irradiance in the visible spectral range (approx. 400 to 750 nm).The principal characteristics of the proposed design are: accuracy, ease of connection, immunity to noise, remote programming and operation, interior temperature regulation, cosine error minimization and all this at a very low cost, tens of times lower than that of commercial thermopile-based devices. This new photodiode-based pyranometer overcomes traditional problems in this type of device and offers similar characteristics to those of thermopile-based pyranometers and, therefore, can be used in any installation where reliable measurement of solar irradiance is necessary, especially in those where cost is a deciding factor in the choice of a meter.

## I. INTRODUCTION

A large number of solar power systems, large and small, are now being installed worldwide. By measuring solar radiation one can find an optimal solar prospecting location which will maximize the operating efficiency and also help in making investment decisions. As a result, there is a growing demand for inexpensive devices for accurately monitoring the solar irradiance. For most system applications, reasonable accuracy at low cost is usually preferred over high accuracy at high cost. The pyranometers that gave accurate readings were quite expensive and hence not used extensively. This paper presents the design and construction of a new pyranometer for measuring solar irradiance (W=m2) or solar radiation flux density within the visible spectral range (approx. 400 to 750 nm). Although the sensing element is a silicon photodiode, the developed pyranometer presents some characteristics and features similar to those of pyranometers based on thermopiles [1] at a price which is tens of times lower.

The presented pyranometer can be used in any installation where reliable measurement of solar irradiance is necessary, especially in those where cost may be a deciding factor. Generically, a pyranometer is a device for measuring solar radiation on a normally flat surface, in a field of 180 degrees. Measurement of solar radiation per unit of surface (W=m2) is termed irradiance. Irradiance measurement requires, by definition, that the pyranometers sensors response to radiation varies with the cosine of the angle of incidence from a line vertical to the surface of the sensor. The difference between the pyranometers real response and the ideal cosine response is termed cosine error. Pyranometers are widely used in passive solar systems analysis[2], meteorology studies, climatology, agriculture[3], irrigation scheduling, solar energy studies and building physics. In spite of the interest in measuring solar radiation, the use of pyranometers is still not very widespread outside the field of research, probably due to their high cost.

## II. COMPARISON BETWEEN REFERENCES CELL AND PYRANOMETER

Reference cells show similar properties to PV panels, but even after the process of calibration, they have similar shortcomings in temperature and spectrum range. Therefore, they will not be able to give an accurate measurement of the available solar radiation under all conditions. A pyranometer has the following advantages over reference cell:

1) The pyranometer gives an independent, ac-curate reading of the total available solar radiation.
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3) The pyranometer are classified and calibrated to ISO standards.
4) The response time of the pyranometer is longer than a PV cell.
5) The pyranometer is PV cell type independent.
6) A pyranometer can have a very small temperature coefficient.
7) PV cells are specified at STC (Standard Test Conditions).
8) Reference cells (and PV panels) suffer more from pollution than pyranometers.
9) Performance Ratio or Performance Index calculations are more accurate using a pyranometer.

## III. CHARACTERISTICS OF PYRANOMETER

The element that characterizes a pyranometer is the sensor it uses, which may be thermal (thermopile) or photovoltaic. Photovoltaic sensors are a cheap alternative, whose only advantage in principle over thermopiles in measuring radiation, aside from their price, is their response speed. Thus, while photodiode-based pyranometers have a response time of around 10μs, in those based on thermopiles, response time ranges between 1 and 10s[4] making them less suitable for measuring very rapid changes in radiation. The influence of temperature on pyranometer 0s measurement is also well known. Although this influence exists, it is lower in thermopile pyranometers[1,5-7] than in photodiode devices[8-11]. With regard to integrating a pyranometer into an instrumentation system (generally into any measuring device), there is a series of very important factors to take into consideration, namely:

- Ease of connection
- Signal degradation due to the transmission process

## IV. FEATURES OF THE PROPOSED PHOTODIODE BASED PYRANOMETER

In order to achieve the objective proposed in this work, designing and building a photodiode-based pyranometer with similar characteristics to those of a thermopile-based device, also incorporating significant connection, measuring and programming utilities, the authors have analyzed and corrected both the defects mentioned in literature and those observed during the testing of various commercial units. That is, the pyranometer developed has the following original features:

- Excellent cosine response guaranteed by both the level gauge (to guarantee horizontality), which is incorporated, and by the specifically designed solar radiation diffuser. Insensitivity in measuring variations in ambient temperature. A control circuit keeps temperature constant in the interior of the device.
- Its interior incorporates all necessary electronics for both conditioning and controlling which minimizes noise and the need for auxiliary electronics.
- Connection features in the proposed pyranometer are significant, both in terms of their quality (ease, robustness, immunity to noise, etc.) and the cost-saving involved in not having to transmit and condition analogue signals outside the device.
- In order to avoid internal condensation due to the temperature and air-tightness of the device which may degrade its electronic circuitry and steam up the lens of the photodiode sensor the proposed pyranometer must be equipped with a hygroscopic-salts container.
- The cost will be tens of times cheaper than that of a thermopile-based pyranometer of similar quality (including all signal conditioning).

## V. SOLAR ANGLE OF INCIDENCE

The irradiance sensors response to the direct (beam) irradiance component is influenced by the cosine of the solar angle-of-incidence (AOI), and by the optical characteristics of its front surface. The response of the sensor to diffuse irradiance can be assumed to have no dependence on angle-of-incidence. The optical influence of the front surface could be a flat- or domed-glass cover or a translucent diffuser. To make a measurement of irradiance, it is required by definition that the response to beam radiation varies with the cosine of the angle of incidence, so that there will be a full response when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 degrees angle of incidence), zero response when the sun is at the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and 0.5 at 60 degrees angle of incidence. Therefore, it can be deduced from the definition that a pyranometer must have a directional response or, as it is usually termed, a co-sine response to emphasize the fact that its response must ideally be analogous to the cosine function. Fig. illustrates the relative response of the irradiance sensors versus the solar angle-of-incidence. The sensors with a planar glass front surface have a stronger sensitivity to AOI, for angles greater than 60 degrees. To some degree, the stronger sensitivity is offset by the observation that the planar devices have more repeatable behavior, device to device, than many commercial pyranometers. Users should recognize that all pyranometers are subject to significant measurement errors at high AOI due to mechanical misalignment. For instance at AOI=70 degrees, mounting a pyranometer only 1 degree different from the plane of a photovoltaic array will result in a 5% error in measured irradiance.

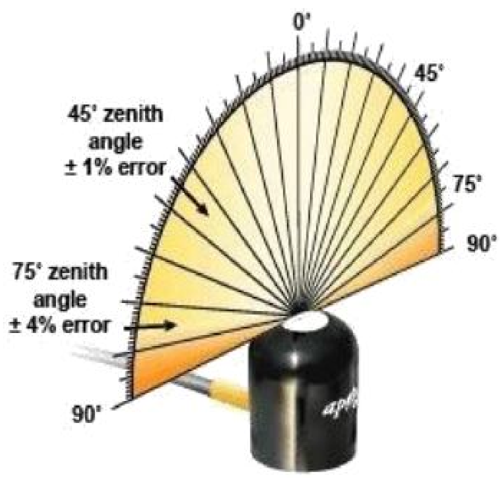


**Fig. 1: Cosine Response of Pyranometer**

## VI. BLOCK DIAGRAM

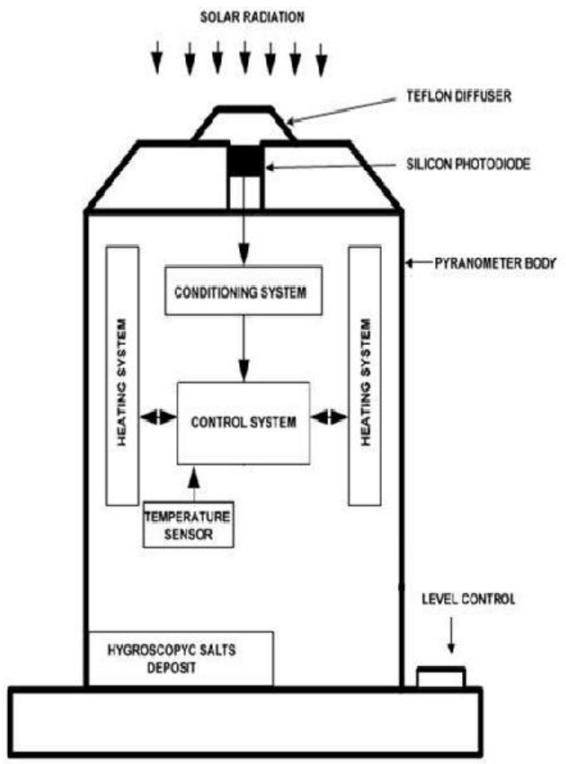


**Fig. 2: Block Diagram**

### A. Teflon Diffuser

The Teflon Diffuser eliminates the cosine error to a large extent. Teflon has been used because it is a good diffuser and is also resistant to the elements and ultra-violet (UV) radiation, given its capability to diffuse transmitting lights nearly perfectly. Moreover, the optical properties of PTFE (TeflonTM ) remain constant over a wide range of wavelengths, from UV up to near infrared.

Most commercial pyranometers use a glass dome which, apart from being more expensive than the TeflonTM diffuser used in this pyranometer, becomes affected by continuous solar radiation and traps higher amounts of dirt [12].

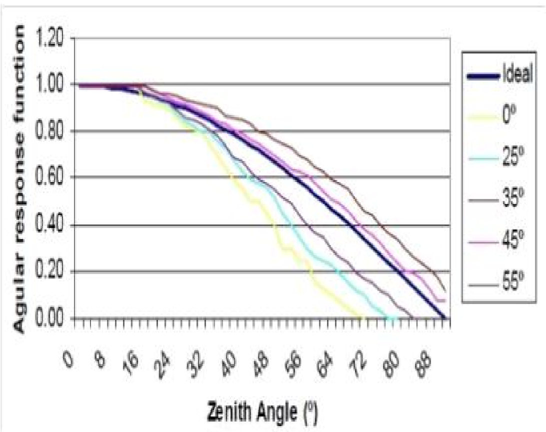


**Fig. 3: Deviation from ideal cosine response for different angles in the machined in the TeflonTM diffuser**

### B. Pyranometer Housing

The pyranometer housing contains the photodiode and all the signal conditioning and distribution electronics. It is manufactured from a single piece of 10 mm thick black polyethylene, since polyethylene is a material which resists the elements very well and also shows excellent characteristics as a thermal insulator.

### C. Hygroscopic Salts Deposit

To avoid condensation inside the pyranometer hygroscopic salts container is used. Use of these hygroscopic salts will ensure moisture levels to a minimum. Because of their affinity for atmospheric moisture, hygroscopic materials necessitate their being stored in sealed containers.

### D. Sensor

The choice of pyranometer sensor element (photodiode) has required an exhaustive study of the commercial devices available, since it constitutes one of the key elements to being able to obtain better performance from the developed pyranometer. A photodiode was required with a response within the visible spectrum, a high value and as linear as possible. Using the characteristics in the datasheets supplied by the manufacturers, the great variety of photodiodes analyzed were classified into two types, namely, those which incorporate the conditioning circuit and those which do not. The former were rejected immediately, as they exhibited problems of saturation at high luminosity. As for the latter, the following were analyzed: BPW21, OSD5-5T, OSD15-5T and S9219-01. In the datasheets for each photodiode the following characteristics were studied:

1) Radiant sensitive area (mm2) and spectral sensitivity (A/W): For a given irradiance (W/m2), these two characteristics allow the level of the signal provided by the photodiode to be known.

2) Noise equivalent Power (W/Hz1=2): Based on spectral sensitivity, this characteristic allows the noise-signal to be calculated. The signal produced by the photodiode divided by the noise signal is its signal-to-noise ratio (SNR).

3) Price: The prices of the aforementioned photodiodes range from 7 to 20 Euros, with the cheapest being the BPW21. After the previous analysis, a practical test on the four photodiodes mentioned was carried out in the laboratory. For this, the following experiment was prepared to measure the voltage of each photodiode in short-circuit at different levels of irradiance.

## VII. PROPOSED CIRCUIT

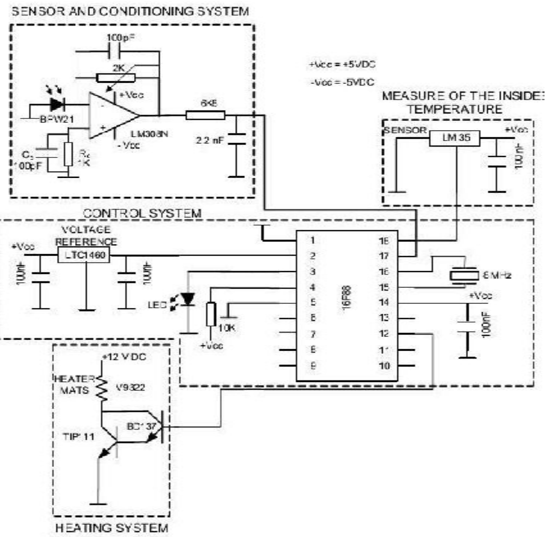


**Fig. 4: Proposed Circuit**

A. Conditioning System

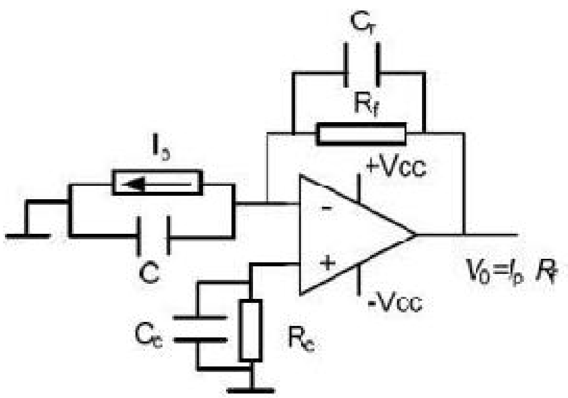


**Fig. 5: Signal Conditioning Circuit**

To calculate the value of Rf a nominal irradiance of 1,000 W/m2 is used. For this, the BPW21 photodiode produces the photocurrent Ip = 2.49 x 10 3 A. Therefore, as the maximum analogue input value accepted by the Analogue-to-Digital Converter (ADC) is 2.5 V, the value of Rf is 1K, which is implemented using a 2 K multi-turn potentiometer to carry out precise adjustment. In order to correct the DC error due to polarization currents, a resistor (Rc) is connected to the non-inverting input of the OPAM. This resistor has a detrimental effect in terms of noise, which is amplified; this is why a 100 pF compensation capacitor Cc is connected in parallel with it. The parasitic capacitor on the photodiode BPW21, C, is 580 pF. This capacitor has to be taken into consideration, as it can influence the stability of the assembly (reducing its phase margin, and therefore, its relative stability). To improve the stability of the amplifier a capacitor Cr is connected in parallel with the feedback resistor Rf. Following the procedure laid down in the bibliography it is calculated that an appropriate value for the capacitor is 100 pF. Finally, a low-pass filter is connected to the amplifier output (see Figure 2) set at the frequency of 10 Hz (R = 6K8 and C = 2.2 F). In this way the possible interference that could affect the ADC input is minimized.

B. Control System

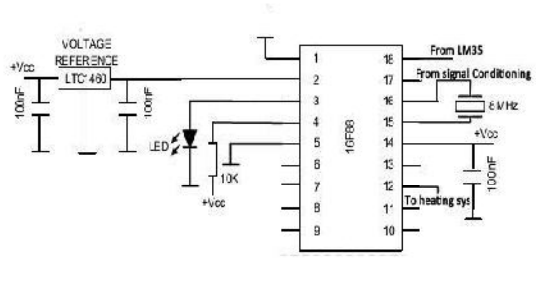


**Fig. 6: Controller Circuit**

A PIC-type microcontroller (manufactured by Microchip Technology Inc., see Figure 2) is used to control the entire pyranometer. The integrated circuit (IC) selected is 16F88, which incorporates an ADC. The ADC in the PIC acquires the conditioned analogue signal from the photodiode and converts it into digital format. The PIC also maintains the inside of the pyranometer at a constant temperature. For this reason, it receives the signal from an analogue temperature sensor: LM35 (chosen for its stability and precision), fitted in the interior of the pyranometer housing.

C. Heating System

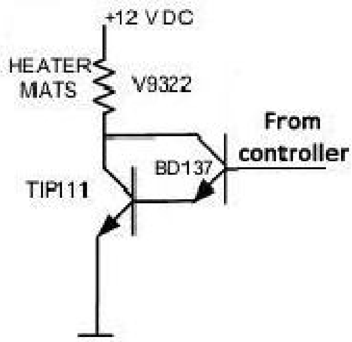


**Fig. 7: Heating Circuit**

Its job is to keep the temperature in the interior of the pyranometer constant at all times. Based on the operating temperature set by the user, the control system sends a signal to the thermostatisation system to activate the heaters until this temperature is reached.

The heaters are heating meshes (circular elements) which run on 12 V with an approximate current consumption of 400 mA. Logically, the control signal from the PIC is not applied directly to the heaters, but to an electronic power stage, made up of BD137 and TIP 111 transistors (see Figure 2). The total power consumption of the device depends on the exterior temperature. However, the system is highly optimised, since the body of the pyranometer, made from 10 mm thick polyethylene, acts as an excellent thermal insulator. From the pyranometer control software, the user can select the minimum level of irradiance for the heating system to operate. This allows, for example, the pyranometer to stop working automatically at night and to start working, also automatically, by day. This utility allows optimisation of energy costs.

## CONCLUSION

This paper presents the design and construction of a photodiode-based pyranometer for the visible spectrum. This device can compete with the traditionally available thermopile based pyranometers at a much lower price. This proposed pyranometer can communicate with a system (typically a PC, weather station, etc) using communication protocols USART, I2C, SPI, RS232, RS485 which can enable remote sensing, data logging applications. Thus the new pyranometer presented in this work brings together features which make it a very competitive alternative to what the market offers at present time.

These features are: Excellent cosine response. Measurement insensitivity to variations in ambient temperature. Incorporation of all necessary electronics in the device itself, both the conditioning and control circuit, which minimizes noise and the need for auxiliary electronics. It allows direct connection to a standard instrumentation system. The connection features included by the developed pyranometer are significant, both in terms of their quality (ease, robustness, immunity to noise, etc.) and cost-saving, since no signals must be transmit-ted and conditioned outside the device. It incorporates a hygroscopic-salt container which prevents internal condensation due to the temperature and air-tightness of the device, which may degrade its electronic circuitry and steam up the lens of the photodiode sensor. Its cost is several tens of times cheaper than a thermopile-based pyranometer of similar quality (including all signal conditioning and transmission circuitry).

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