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Sun Tracking Sensor with Current Loop Output

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Abstract –**The paper is presented the technical solution of simultaneous measurement of the angle of the sun elevation and the create radiation. The sensor is based on three photodiodes. The diodes are arranged at different angles, three amplifier circuits and three transmitters for the current loop 4÷20 mA. The relation between the signals from each photodiode depends of the sun altitude. The PSpice simulation results for the amplifier ant the current converter circuit are shown.**

Keywords – **Sun altitude sensor, photodiode, Optoelectronic device, PSpice optoelectronic circuit simulation**

I. INTRODUCTION

The sun light absorbing technologies are among the priorities in the world energetical economy development. Increasing the efficiency of photovoltaic systems is possible, through their continuous panel orientation perpendicular to the solar radiation. Sun-tracking photovoltaic systems provide 40% more energy compared to static ones [1, 2, 6]. For the implementation of such system a sensor measuring sun angular placement is needed. This is the ascent to the horizon, respectively the angle of the solar radiation when the sensor is placed horizontally. Another option is a sensor that generates a signal proportional to the angular deviation between the sun and solar system direction. In this case the sensor can be moved together with the solar system.

The proposed solution is an optoelectronic sensor, used for setting-up on the moving part of the solar system (mirror or photovoltaic) and for generating current proportional to the solar radiation. The sensor consists of three identical channels. Solar radiation measurement is based on the photodiode in a photovoltaic mode. The generated voltage is further gained, filtered and converted into a current loop 4÷20 mA [3].

The algorithm for tracking the sun's angular deviation is implemented in the computing unit by using information about the incident solar radiation. It is calculated according to the voltage generated by the photodiode, which depends logarithmically of the incident solar radiation [4, 5].

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II. PRINCIPLE OF OPERATION

A. Block Diagram

The basic requirements that must be satisfied by the angular sun deviation sensor are: Firstly normal operation in a wide dynamic range of sun light; Secondly changing the luminance of the Earth's surface is in the range 500-150000 Lux or the entire spectral range - irradiance in the range up to 1300 W/m^2; High accuracy of the conversion and measurement of solar radiation; Multiple channels of photosensitive elements availability in order to accurately calculate the angular deviation; Last but not least is the sensor implementation in the minimum size and weight.

To satisfy the variety of requirements we propose that the sensor is composed of three photodiodes, arranged at different angles, three amplifier circuits and three drivers for the current loop 4÷20 mA. A block diagram for one channel is shown on Fig.1 as the other two are identical to the shown one. The generated by photodiodes voltage is amplified by non-inverting amplifier with amplification gain 6. On the input of the voltage to current convertor is fed the maximum value of 4.2 V. This voltage value is selected to be the maximum value and is being converted into 20 mA current. There is a constant voltage of 5V in the driver's current circuit for supplying the analog part. To establish an initial value of radiance transmitted in the circuit, a source is switched on the input of the convertor.

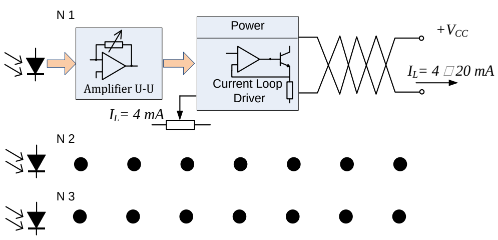

Fig. 1. Sensor Block Diagram

The geometric positioning of the photodiodes is shown on Fig. 2. The first one is mounted horizontally, and the other two photodiodes symmetrically on both sides in a 40 degrees angle. Thanks to such positioning, when the sensor is precisely directed towards the sun, the optical flow falling on the photodiode side will be cos (40 °), or 0.76 of the photodiode Ph1's one.

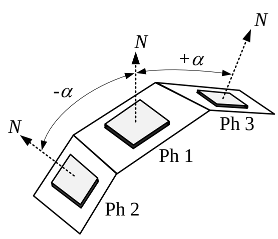

Fig. 2. Geometric positioning of the photodiodes.

Horizontally set-up photodiode is calibrated such that the output current is functionally dependent on the incident solar radiation in units of W/m^2.

B. Relation between the Sun Radiation and the Voltage over the Photodiode

Silicon photodiode type BPW34 is selected for the sensor. BPW34's spectral sensitivity is in the range of 0.4 to 1.1 micrometers, whereas the maximum sensitivity is 0.6 A/W [7, 8]. The luminance created from the sun light is in a range of tens lx to 150 000 lx, or expressed in energy units from approximately zero to 1300 W/m^2. A wide dynamic range of the photodiode-generated voltage according to a logarithmic dependence can only be implemented in photovoltaic mode [4, 9]:

$$V_{OC} = \frac{kT}{q} \ln\left(\frac{E_e A_{ph}.R_{ph}}{I_S} + 1\right), [V] \qquad (1)$$

Where: kT / q is the temperature potential equal to 25 mV, I_S is the saturation current in the opposite direction; A_{ph} - the photosensitive area; Rph - integral sensitivity of photodiodes according to the source generating irradiance Ee, W/m^2 over the photodiode. For the used photodiode the current I_S is equal to 2 nA, which is the dark current from the data sheet, A_{ph} is equal to 7.5 m (from the data sheet). After conversion and calculating the relation of irradiation, created by the sun, is:

$$E_e = \frac{\left(e^{\left(\frac{qV_{OC}}{kT}\right)} - 1\right).I_S}{A_{ph}.R_{ph}}, \qquad (2)$$

The measured voltage is V_{OC}, other variables in the equation are constants. The equation (2) for the sun irradiation includes the integral sensitivity of photodiodes R_{ph}. For its calculation is used mathematical package MATHCAD. On Fig. 3 are shown the spectral characteristics in relative units: curve 1 - the solar radiation; curve 2 – the spectral response of the photodiode; dotted curve 3 - the sensitivity of the human eye and 4 – the product of curve 1 and curve 2. These characteristics are necessary for determining the coefficient of radiant flux from the sun as the source, by the set spectral characteristics of the photo detector.

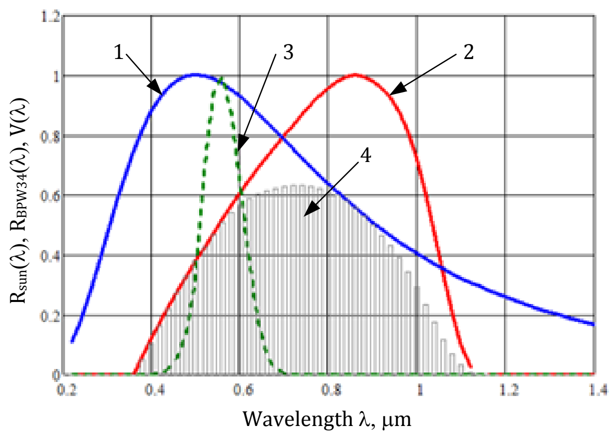

Fig. 3. Spectral characteristics.

After calculating and substituting the numerical values for the sensitivity the transfer characteristic of photodiode's relative to the solar radiation is obtained. This characteristic is, shown on Fig. 4.

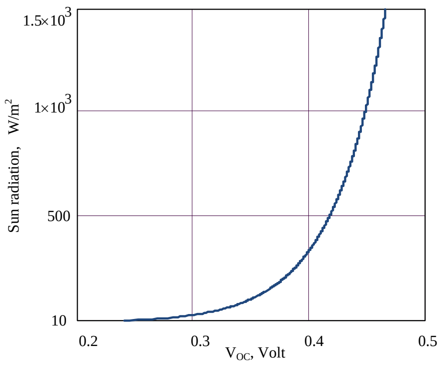

Fig. 4. Transfer characteristic of photodiode's relative to the solar radiation.

III. Hardware Realization

The sensor's circuit is functionally composed of two parts. First part is an amplifier for the photodiode voltage and the second is a current-loop transmitter in the range of 4÷20 mA. This part of the circuit can be realized using the precision current output converter XTR117 of TI Inc. [3]. Fig. 5 shows the circuit diagram as the converter is replaced with representative simplified input circuitry enclosed by the solid line because there is no Spice model for this circuit.

In the circuit of the amplifier a capacitor $C3$, which together with the resistor $R7$ forms an integrated group and narrows the bandwidth. As the movement of the sun in the sky is a slow process, as well as the movement of clouds, which drastically reduce optical flow reaching the ground, the bandwidth of this amplifier does not need to be wide.

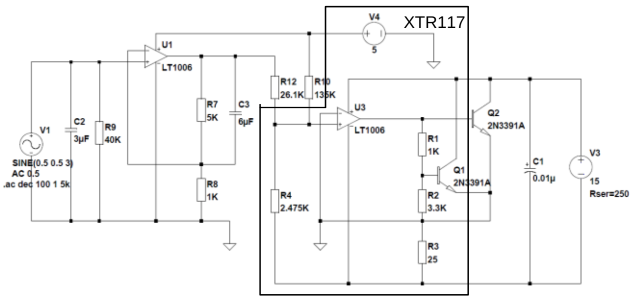

Fig. 5. Circuit diagram.

The precision current output converter designed to transmit analog 4-20mA signals over an industry-standard current loop. It is a two-wire current transmitter. Its input current controls the output current. A portion of the output current flows into the power supply. The remaining current flows in Q2. External input circuitry connected to the XTR117 can be powered from internal voltage regulator. Current drawn from these terminals must be returned to input pin. This pin is a local ground for input circuitry driving the XTR117. The XTR117 is a current-input device with a gain of 100. A voltage input is converted to an input current with an external input resistor, *R12*, as shown in Fig. 5. Typical full-scale input voltages range from 1V and upward. Full-scale inputs greater than 0.5V are recommend to minimize the effects of offset voltage and drift of amplifier.

The power supply of the circuit diagram is unipolar 5V. The selected operational amplifier is LT1006 [10], which is a precise and with low values of polarized voltages and currents.

IV. Simulation Results

The two part of the circuit are simulated separated in order to test their functionality.

The transfer characteristic of the one channel of the amplifier is simulated in case of input from 0 to 0.7V. The simulation result is shown on Fig.6. The circuit amplifies linearly in the range.

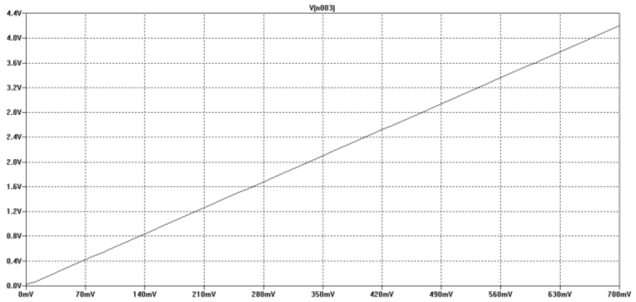

Fig. 6. Transfer characteristic of the amplifier.

The transient analysis of the amplifier is carried out based on a source of sinusoidal voltage with a frequency of 3 Hz. The given amplitude is 0.25V, the average point is also shifted to 0.25 V. The input voltage is only in positive direction. The results of the simulation are shown on Fig. 7.

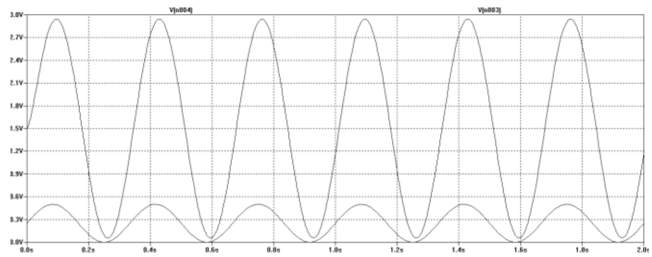

Fig. 7. Simulation results with sinusoidal source.

The results show that the circuit is working normally and without deviations. At the maximum possible input voltage value voltage of 0.5V, the output voltage of the amplifier is approximately 3.0 V. A frequency analysis is made for the amplifying circuit and the results for the gain and the phase are shown on Fig. 8.

The bandwidth is 23 Hz (at -3dB level), which is sufficient for the functions of the sensor.

For the current transmitter the efficiency, transfer characteristics and frequency properties are verified. Fig. 10 shows the results of the transfer characteristics simulation. Since the conversion of solar radiation becomes first in voltage ranging from 0 to 4 V, and the current must be within the range 4÷20 mA, is to be added to the input current by means of resistor *R10*.

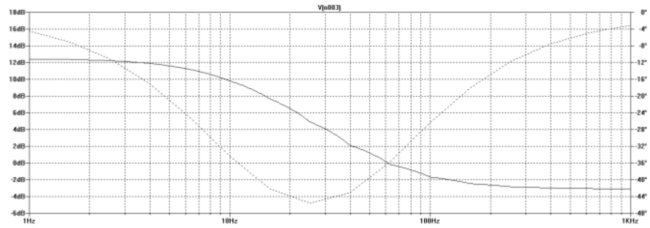

Fig. 8. Frequency response.

The current's value in the output circuit is determined according the following dependence:

$$I_{\text{out}} = \frac{100.\mathrm{V_{inp}}}{\mathrm{R}},$$

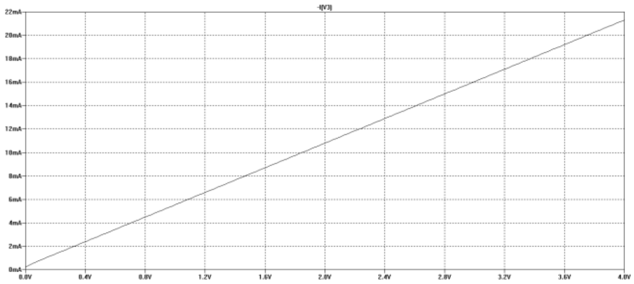

Fig. 10. Result of the transfer characteristic of the converter

Where *R* is the value of the resistor limiting the input current. The resistor *R12* sets the maximum current value in the circuit to 20mA, which must be generated at a maximum output voltage of the amplifier. The value of the resistor *R10*, defines the minimum current value chain - 4mA, when solar radiation is zero.

A frequency analysis is made for the amplifying circuit and the results of the simulations are shown in Fig. 11.

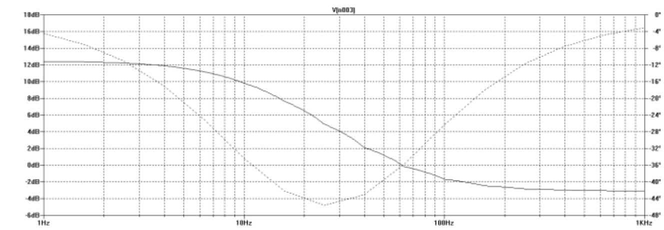

Fig. 11. Frequency analysis of the current output converter.

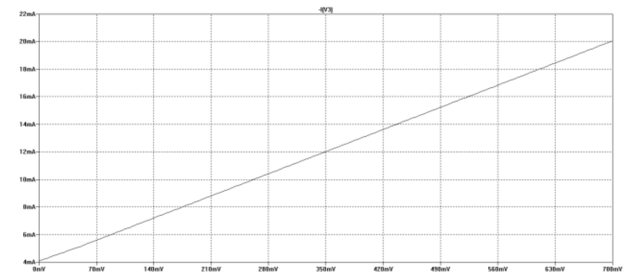

Fig. 12. Simulation results of the transfer characteristic.

The circuits of the amplifier and current output converter are simulated separately, but sensing device transfer characteristic is one. Fig. 12 shows the simulated total transfer characteristic of a measuring channel of the sensor of sun radiation.

V. CONCLUSION

In this paper is proposed a solution of the optoelectronic sensor for simultaneous measurement of the angle of the sun elevation and the create radiation. The theoretical dependencies of the generated voltage value of photodiodes are discussed and the transfer characteristic is represented. The results from the frequency analysis are shown too. Proposed is a block and a circuit diagram of the optoelectronic sensor implemented with minimum components. The circuits are simulated in the PSpice environment. Also the computer simulation results, the performance and the frequency properties of both the amplifier and the current transmitter generating the output current 4÷20 mA, are shown.

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