Wireless Sensor System for Measuring Parameters of UV Radiation

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***Abstract* – Development of our own mobile wireless sensor networks for tracking the critical parameters of environmental protection (gas emissions, ionizing and non-ionizing radiation, noise and various meteorological parameters) in the specific area has led to the development of different detecting measuring devices. This paper presents a two-channel wireless measuring system for measuring the intensity of UV radiation and UV index. The system can perform on-line tracking of these parameters on maximum distance of 300m from the recepting unit in case of RF transmission, while the distance is not a critical parameter for GSM/GPRS module.**

***Keywords* – UV radiation, UV photodiode, Wireless sensor system, RF transmission.**

I. INTRODUCTION

Solar radiation is an important factor which creates the climate on Earth and therefore it formes the whole environment of the biosphere. The spectrum of electromagnetic radiation includes radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation and also *x* and γ radiation. Radiation that reaches sea level, where the most part of the biosphere is, includes part of the spectrum with wavelengths between 290nm and 3000nm. Energy disposition in this range is as follows (see Fig. 1a):

- ultraviolet radiation – UV (λ=290-490nm), makes 5% of radiation spectrum;
- visible radiation – VIS (λ=400-780nm), makes 39% of radiation spectrum;
- infrared radiation – IR (λ=780-3000nm), makes 56% of radiation spectrum.

The ultraviolet part of the solar spectrum has an important role in many processes in the biosphere. However, despite the large number of beneficial effects, some of the effects of ultraviolet radiation can be very harmful if they exceed a certain level of radiation safety. Because of increased energy, a photons of ultraviolet radiation can produce biological activities relevant for human health. If the amount of UV radiation is high enough, the ability of self-protection of certain biological organisms and humans becomes insufficient so they may suffer significant damage. In the human body that damage is primarily related to organs such as skin (causes burns) and eyes (a cataract is formed), and in some cases can cause degradation of DNA molecules [1].

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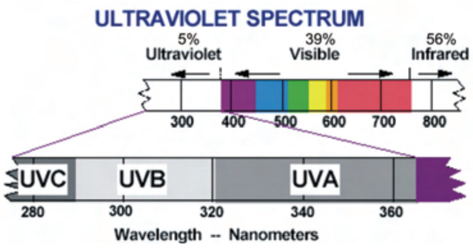
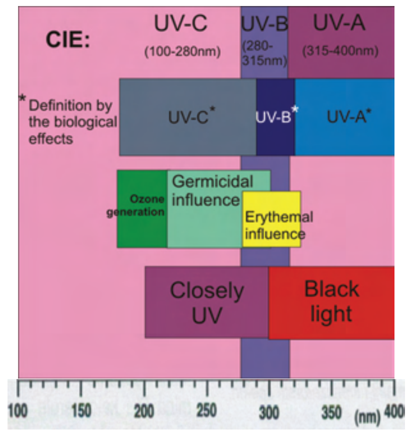
In order to avoid harmful exposure to UV radiation a international unit is defined, so called UV index, which quantitatively characterizes erythemal effects and which should warn people on the level of harmful UV radiation. The most important factors which affect on the intensity of UV radiation are: ozone layer, position of Sun, mean sea level, dispersing in the atmosphere, clouds, atmospheric visibility and reflection on the ground [2].

The division of UV radiation defined by CIE (*Commission Internationale de l'Eclairage, Publication No. 69, 1985*) is shown in Fig. 1b. Definition by the biological effects, the chemical effects, as well as the division from the standpoint of spectroscopy.



(a)



(b)

Fig. 1. UV radiation: (a) energy disposition; (b) radiation division

UV index is measured in relation to the horizontal surface at different centers in the world who are either responsible for providing daily weather forecast or do some research work. However, as people expose their bodies to radiation in all directions and because of continuous apparent motion of the Sun in the sky it is necessary to know levels of UV index in different directions in order to reliably reconstruct solar incidence throughout the human body. In cases with particularly high UVI values, such as in the Antarctic due to high reflection, on construction sites where workers are exposed to sun for several hours, or in regions where the atmosphere filters out UV radiation significantly less due to reduction or absence of the ozone layer, it is necessary to perform several measurements in different directions. This issue has been discussed in several papers from different aspects, paper [3] uses five UV sensors for measuring along different directions.

In this paper, the goal was to design and develop a prototype of sensor node suitable for measuring UVI values which will become the basis for future establishment of a wireless sensor network for measuring UVI in previously mentioned special conditions.

II. UV SENSORS AND INTERFACES

Measuring the intensity of UV radiation in different bands requires the use of modern UV sensors and adequate measuring systems. In principle, depending on to the mechanisms of detection that they use sensors of UV radiation can be classified into two main groups, as a photon or thermal sensors. The basic classification of UV sensors is shown in Fig. 2.

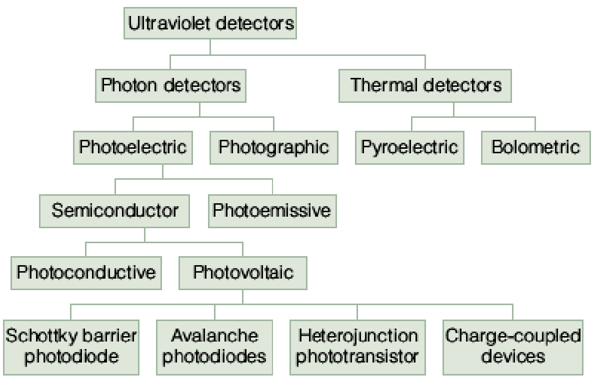


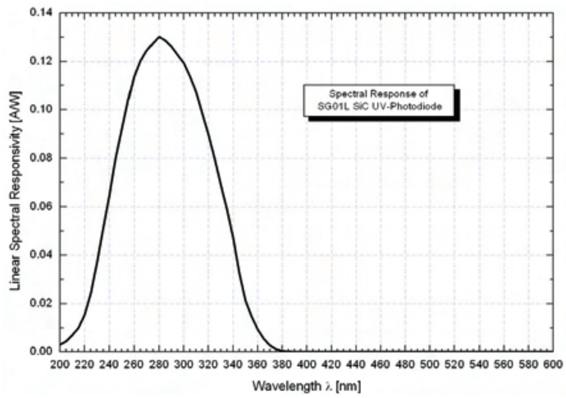
Fig. 2. Classification of UV sensors depending on the mechanisms of detection that they use

The most numerous group of photoelectric sensors are semiconductor sensors. Therefore, the analysis in this paper are focused on the photonic sensors and on the photoelectric semiconductor UV sensors.

Semiconductor UV sensors have a negative feature to the very extreme absorption and high intensity of radiation which induces aging effect in the majority of semiconductor materials. Because of that, at one point of time, development of highly efficient semiconductor quantum UV sensors was a slow. Semiconductor UV sensors can be used in both modes, in photoresistive and in photovoltaic mode. There are several variants of photovoltaic sensors and they depend on the applied effect, so there are: Schottky barriers, PIN diodes, avalanche photodiodes, phototransistor with heterogeneous connection, or devices based on the principle of CCD (charge coupled devices).

Studies in modern semiconductor UV photodetectors are focused on modification of wide semiconductor barriers and on various applications of adequate materials in this structure, such as silicon carbonate (SiC), diamond, gallium and aluminum nitride (AlGaN) alloy, GaAsP, etc.., with characteristics of the materials that make up this family of semiconductors unique for the use in UV sensors. In general, semiconductor UV sensors are combination of photodiode chips based on previously mentioned alloys (SiC, AlGaN, GaAsP) and adequate UV filters. In addition, these sensors must meet the appropriate demands in terms of physical robustness, they must be chemically inert, they must have high corrosion resistance and must not be toxic. On the other hand, modern measuring systems require the use of miniature compact UV sensors with the extra peripheral circuits located in the sensor.

The developed measuring system uses the UV photodiodes developed by *Sglux SolGel Technologies Germany*, with labels *SG01L*-5 and *Eryca* whose spectral characteristics are shown in Fig. 3 [4].



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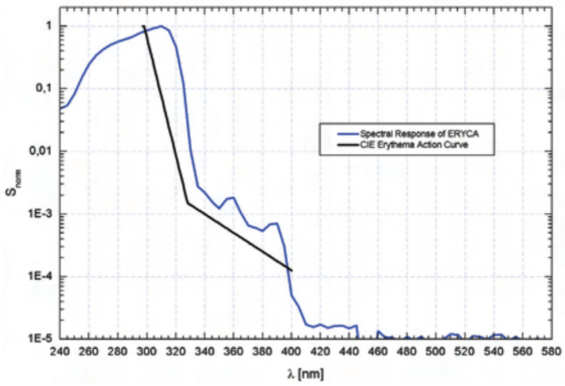


(b)

Fig. 3. Characteristics of UV photodiodes: (a) *SG01L-5*; (b) *Eryca*

These UV photodiodes have been made of detector materials based on silicon carbide (SiC), with an approximative spectral band of 210nm to 380nm and are not sensitive to UV radiation outside this band. The application of these diodes depends of spectral characteristics. Thus, the UV photodiode *Eryca* has a spectral response curve matching to erythemal's curve as shown in Fig. 3b, making measurements more accurate with an accuracy of ±0.5 UVI.

These UV photodiodes are ideal detectors for reliable use in tracking of UV spectrum due to their exceptional durability, and due to long-term enduring to UV radiation. Practice has shown that the diode detectors made of materials such as Si, TiO_2, GaN or diamond, by its characteristics can not compete with UV photodiodes based on SiC because of the following benefits:

- internal spectral response is limited to a band of 200nm to 400 nm, and doesn't require additional blocking of unwanted visible and infrared radiation;
- outstanding long-term stability even when exposed to high doses of UV radiation up to the value of 1000W/m^2;
- exceptional temperature stability, temperature coefficient Tk<-0.06%/K provides stable operation on temperatures up to 150°C;
- by integrating with different filters they can be applied in water, flame detection, spectroscopy, food inspection at different UVA, UVB, UVC, UVBC, UVBC2 measurements and in measurements of various biological effects of UV radiation.

Typical levels of electric current generated in the silicon UV photodiode sensors are in range of nA and therefore it is necessery to use different amplifier configurations in order to increase the power of a signal. A standard transimpedanse amplifier which converts electric current into voltage was used in the prototype.

The amplifing stage, with the current into voltage converter, is consisted of three parts, and its block diagram is shown in Fig. 4. The first part converts current flowing through the UV photodiode into the voltage. A fixed level of an amplifier's gain is defined which corresponds to the selected sensor.

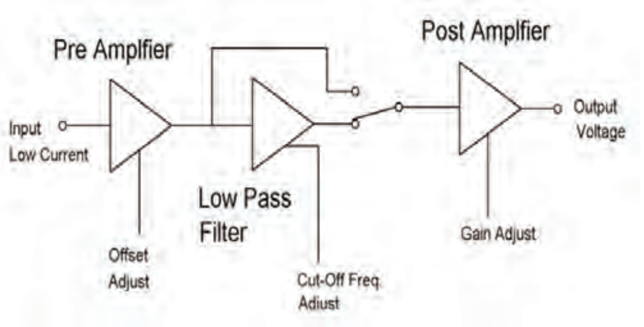


Fig. 4. Block diagram of the amplifing stage

The second part of the amplifing stage is a low-pass filter which attenuates noise signals up to 100Hz. In the third part of the amplifing stage aditional amplification of signal is carried out, so that an output signal corresponds to the level of input signal of A/D converter in PIC16F887 microcontroller.

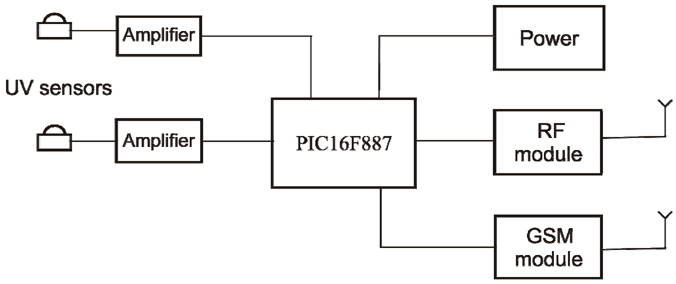
For adjustment and calibration of the measuring system in a specified band of UV radiation it is necessary to use highly specialized sources of radiation, but due to high cost of these sources a variant with currently available UV sources was selected. For calibration of UV sensors in a certain bands a different sources of UV radiation were used (*blacklight blue* fluorescent tube made by *GE Lighting* with power of 6W, UV lamp *Type3* with label *Philips HPA 400W*, a commercial lamp used in mercury lamps, fluorescent tubes with labels *Philips 5M/5W*).

III. System Development

A wireless measuring detector has a flexible hardware configuration and with the minimum hardware and software changes it can become the basic unit of an automatic, mobile, measuring system for tracking and measuring of various physical quantities and parameters in environment. Basic features which such a measuring detector must possess are: automatic operation, power autonomy, wireless communication, compatibility with various sensor elements, the ability to memorise a certain number of data, alarm level settings, autonomy in decision making at the first level of degree, reliable transfer of measured data, measuring multiple values, etc.

In this case, the intelligent wireless measuring detector has a two channels, for measuring the intensity of UV radiation and for measuring UV index. Its basic components are:

1. PIC microcontroller (PIC16F887);
2. UV diode *SG01L-5* and UV diode *Eryca*;
3. RF transceiver *ST-TR1100*;
4. GSM/GPRS module *Telit GM862*;
5. Amplifier *LPC660AIM*;
6. Power circuit.



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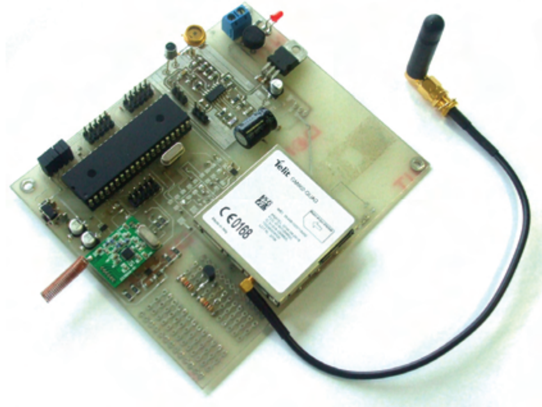

(b)

Fig. 5. Detecting unit: (a) block diagram; (b) photo of realized unit

Due to many advantages, microcontroller PIC16F887 was selected for development of the detecting unit. Besides the basic functions such as data acquisition, testing of conditions, data processing and sending and SMS sending, microcontroller also has a total of 14 10-bit analog inputs for A/D conversion, allowing connection of multiple sensors. The detecting unit transfers measured values to the receiving unit using RF transceiver. Data transfer can also be done by using GSM/GPRS module directly on a web server via GPRS, or to a mobile phone via SMS. Measured values can be directly displayed on the detecting unit using the optional LCD display which may exclude the use of the receiving unit. Block diagram of the detecting unit is shown in Fig. 5a, and photo of realized detecting unit is shown in Fig. 5b.

Since the secondary focus was on a RF transmission and therefore the receiving unit is consisted only of a microcontroller PIC18F2550 and the RF transceiver. The receiving unit can be connected to the PC via USB or serial port, if it is necessary measurements can also be displayed on the optional LCD. Additional sensors can also be connected on this unit with minimal hardware and software modification.

Developed wireless measuring system is shown in Fig. 6. The presented measuring system measures UV radiation from the spectrum of solar radiation at the projected distance. After each measurement, the system wirelessly sends measured data which are then displayed on a PC. PC application conducts data processing and memorising. Main window of the PC application is shown in Fig. 7.

Fig. 6. Developed measuring system

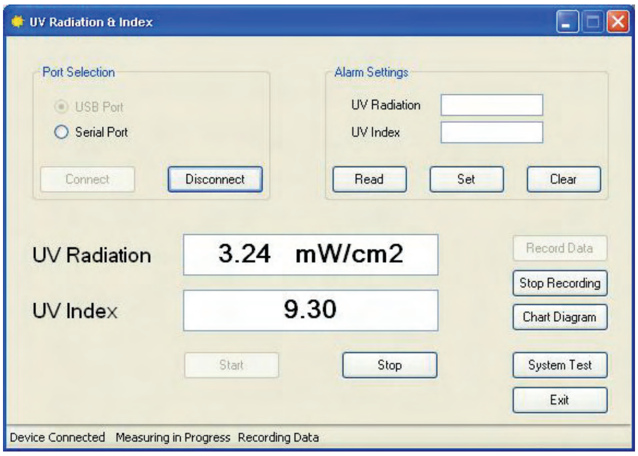

Fig. 7. Main window of the PC application

The PC application supports both USB and serial communication and the selection is made by checking on the appropriate port at the top left corner of application window. After the communication selection it is necessary to connect the PC application with the receiving unit by clicking on the *Connect* button. If the connection was successful a message "Device Connected" will appear in the status bar. Displaying of measured results begins by clicking on the *Start* button, after which a message "Measuring in Progress" is displayed in the status bar. Current measured results are displayed in two text boxes, for the intensity of UV radiation and for the UV index. Displaying of results is stoped by clicking on the *Stop* button.

The application can memorise measuring results into the database by clicking on the *Record Data* button, followed by appearance of "Recording Data" message in the status bar. Data memorising is done in programmable discrete steps. The application can draw a chart diagram of UV radiation and UV index from database by clicking on the *Chart Diagram* button. The application can set the value of alarm levels for intensity of UV radiation and for UV index. Upon the alarm triggering system automatically sends SMS message, while on the PC a new window appears with "The alarm level reached" message. Alarm level settings are stored in the microcontroller's internal EEPROM memory. *Disconnect* button interrupts the communication between the application and the receiving unit followed by appearance of "Device disconnected" message in the status bar, but measuring system continues to operate.

The goal of the development was on the automatic transmision of measured data when the programmed conditions are reached. All conditions can be programmed in the PC application.

IV. Conclusion

This paper presents a developed version of two-channel measuring system for measuring the intensity of UV radiation and UV index. Future research in applying these types of sensor elements will be based on the various modifications of the amplifing stage.

Because of its complexity and mobility selected hardware structure enables development of our own families of various wireless measuring devices. By developing an appropriate PC software these devices would, due to many advantages, quickly became an integral part of most research labs, as well as a standard part of many weather stations.

Acknowledgement

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