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IONIZING RADIATION SENSOR FOR NANOSATELLITES, MICRODRONES AND SMALL UNMANNED GROUND VEHICLES

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Abstract

The purpose of this paper is to present an ionizing radiation sensor suitable for nanosatellites, small drones and other types of unmanned vehicles. When implemented on an airborne or ground-based unmanned vehicle the sensor is beneficial in disaster management scenarios such as inspection of buildings and facilities for ionizing radiation contamination and measurements of the ionizing radiation dose.

Herein, a design and laboratory tests of the sensor are presented. The instrument is a lightweight module having low power consumption suitable for nanosatellite platforms and for mobile use by having it installed in an unmanned system (airborne or ground-based).

For test purposes a 36-rotor drone was developed along with a mobile ground based unmanned vehicle. With all implementations the radiological sensor is directly connected to the main processor unit of the platform. In the case of the drone and ground-based vehicle systems the processor unit is the microcontroller of the autopilot.

Experimental results of laboratory measurements of different radiation sources are shown and discussed. The experimental setup demonstrates a few advances related to specific problems encountered in the existing ionizing radiation measurement systems.

Introduction

The need for space research in the area of ionizing radiation sources on the one hand, and the ever rising requirements for nuclear safety and readiness for nuclear disaster management define new technological limits that should be overcome by the radiation measurement instrumentation.

We have focused our research and development efforts on investigating the possibility to realize a lightweight ionizing radiation sensor for use on such platforms as nanosatellites and very small unmanned aerial vehicles — also known as micro-drones — having total weight of less than or equal to 250 g. Other platforms that could benefit from this type of sensor are unmanned ground-based vehicles with very small sizes and weights.

The novel sensor described herein is vibration resistant, lightweight, PIN photodiode based and uses the microprocessor of the host system in order to minimize weight, complexity, cost and failure rate.

State of the art

For the purpose of nuclear disaster management and radiation inspection within buildings there have been developed robotic platforms of various kinds. These systems are categorized into two major groups: airborne and ground systems. Water vessels employed for this task are rare. Examples of ground based robots for radiological surveying are the CARMA 2 platform, the JAEA-3 robot, and the Quince robot among others. Most such platforms are equipped with a Geiger Müller tube for γ- and β-surveying. There are some advanced designs employing solid state sensors. Connor et al. [1] have compiled a good overview of the existing airborne radiation mapping systems. The most elaborate developments in the field have been commenced after the Fukushima Daiichi nuclear disaster in 2011 [2–4].

The literature shows that the existing airborne platforms are above 0.9 kg while the ground-based systems are over 10 kg [5]. Due to their significant weights and sizes such ground vehicles are hardly usable in narrow corridors and rooms. The airborne counterparts, on the other hand, are totally inapplicable in closed spaces. In order to solve this discrepancy we established a total weight for an airborne system to be below 500 g and of a ground-based platform to be below 2 kg. It is obvious that the airborne systems impose more stringent requirements on the ionizing radiation sensor weight. We concluded that a sensor of 10 g weight or less shall be suitable for all systems without exceeding the limit for the payload weight.

We chose to compare our design with the Liulin family of ionizing radiation sensors [6–7] for their proven qualities. Liulin instruments are developed at the Space Research and Technology Institute — Bulgarian Academy of Sciences. We were to choose between two technologies as those were evaluated to deliver higher reliability, lower weight, spectrum analyser capabilities and detection of the broadest variety of particle types.

Both technologies are solid state and do not use tubes or high voltages, which is a great benefit. The first method is implemented in the Liulin devices, this is the PIN photodiode technology [8–9] and eventually we developed our sensor after that approach. The second technology that was considered is the scintillation sensor using photodiode readout. This method was decided to be implemented in our next prototype and testing stage.

Ionizing radiation sensor

With our current choice of technology we can achieve spectral identification of the radioactive sources along with radiation dose measurements. Further, the PIN photodiode based sensor can detect fast neutrons with energies above 1 MeV, accelerated protons and heavy ions besides beta and gamma rays.

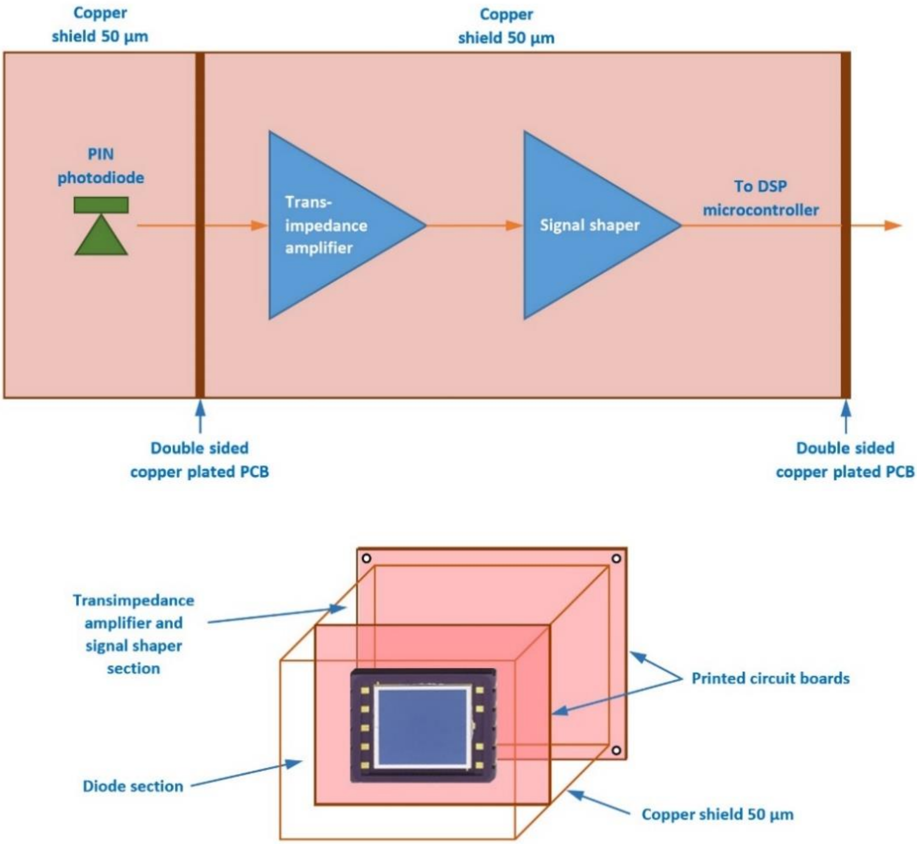

Fig. 1. Ionizing radiation sensor diagram and 3D model. The sensor enclosure consists of two compartments — one for the PIN photodiode and one for the electronics

The sensor enclosure was built using copper foil and printed circuit boards (PCBs) to achieve the required 10 g weight (see Fig. 1). The shielding stops incident light and electromagnetic interference and keeps the sensor interior isolated from air contaminants and moisture. The shielding foil is only 50 µm thick and allows the sensitivity of gamma rays to be well below 60 keV. Beta particles are also let through the shielding. The sensor does not use a dedicated microcontroller nor any kind of digital electronics circuitry — it is a purely analogue device. The sensor is connected directly to the host platform control board.

The PCBs form two interior sections (Fig. 1). In the front compartment the PIN photodiode is deployed. This section is completely sealed — no light nor air may penetrate or exit. The employed PIN photodiode is Hamamatsu S5107 with 100 mm^2 active area. The thickness of the sensitive silicon volume is 0.3 mm. This diode has 30 V max reverse voltage. We chose to bias it with 28 V.

Fig. 2. A typical Americium-241 (top) and Uranium-238 (bottom) ionization events

The second compartment hosts the transimpedance amplifier and the signal shaper. The backmost PCB is used to mount the sensor to the host platform by means of four springs. Such a sprung suspension (see Fig. 4 and 5) guarantees no interference by vibrations coming from the host platform. Due to the very thin shielding the sensor is prone to registering vibrations as parasitic signals. The analogue signal is connected to an analogue to digital converter (ADC) of the host system using shielded cable. The shaper filter central frequency is 16 kHz. A 12-bit ADC mode with the maximum sampling frequency for our test microcontroller of 530 kHz gives high enough resolution for the apparatus to work without additional circuitry such as sample and hold modules, threshold detectors, etc. The signal is purely digitally processed in the host system and a detailed image of the signal is received and visualized in our test setup (see Fig. 2). Due to the very high oversampling rate the digital signal processing that follows is made efficient and accurate.

We computed the noise voltage RMS to be 15 mV. Americium-241 60 keV gamma ray in Fig. 2 (top) generates a signal with 120 mV positive amplitude. By measuring only the positive part of the shaped impulse and adjusting channel 1 to correspond to 60 keV gamma ray energy we record the first 512 channels of ionizing radiation particle energies (Fig. 3). Fig. 2 (bottom) shows a typical Uranium-238 gamma event.

Experimental Test

Our laboratory tests were carried out with 5 different radioactive sources. Table 1 gives account on the radioactive sources measurements by showing the counts per minute our device has registered for each source.

Fig. 3 demonstrates the spectra of the background radiation and the test radioactive sources in 512 channels. All sources except Americium-241 have wide spectra.

Table 1. Tested radioactive materials

Radioactive source	Counts per minute
Background	5
Americium-241	590
Radium-226	1239
Uranium-238	48
Thorium-232	54
Potassium-40	15

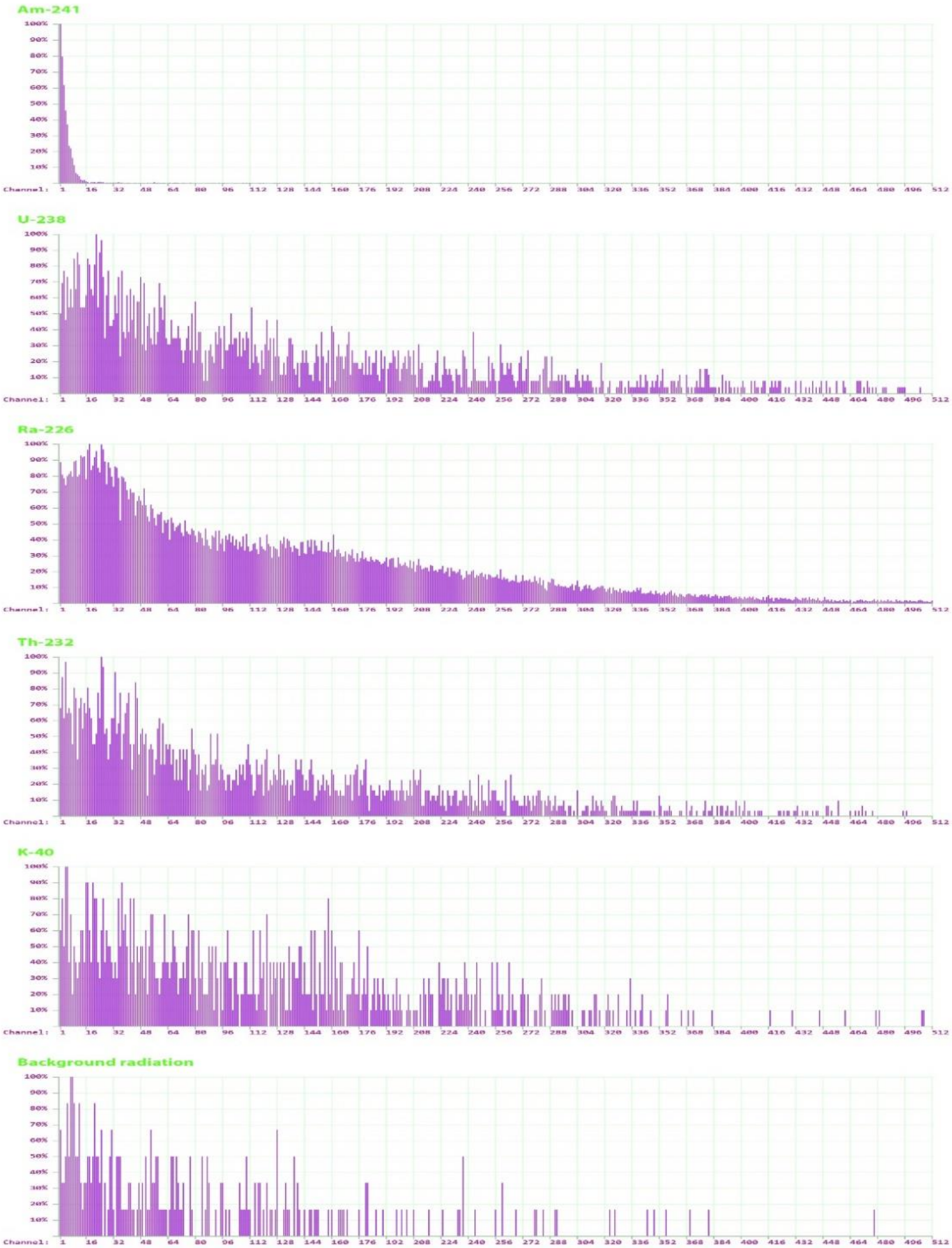

Fig. 3. Spectra of Am-241, U-238, Ra-226, Th-232, K-40, the background radiation

Some characteristic spectra are shown in Fig. 3. It becomes clear that the sensor is suitable for identification of radioactive sources. What also should be mentioned is that besides Potassium-40 and Americium-241 all other sources have daughter nuclides, most of which are already in dynamic equilibrium. A good example is the daughter nuclide Bismuth-214 in the Radium-226 and Uranium-238 samples. A registered drawback of the PIN photodiode sensor is its low sensitivity to high energy gamma rays.

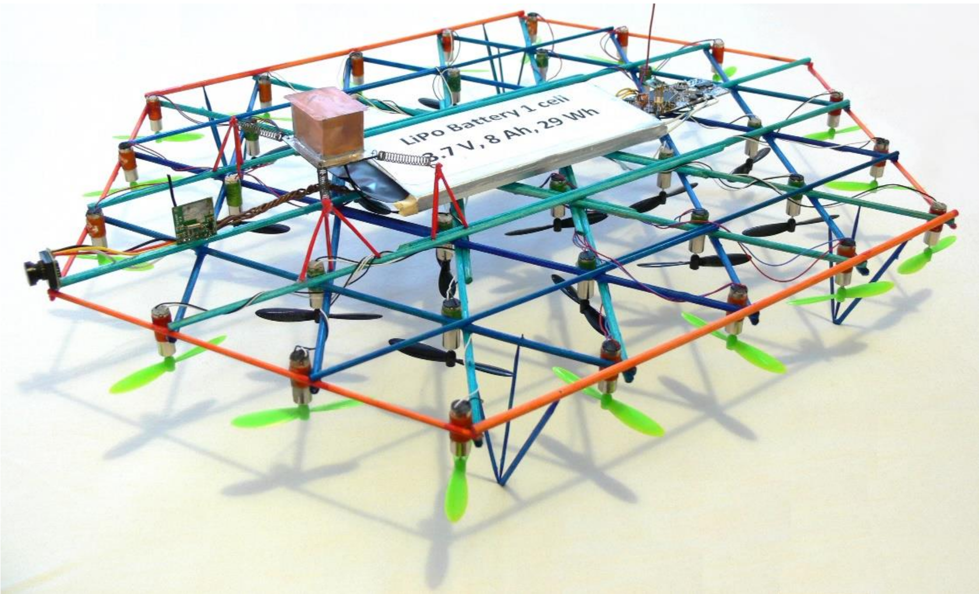

Fig. 4. A 36-rotor drone designed for indoor surveying of ionizing radiation sources. The sensor is mounted on sprung suspension.

Conclusions and future work

Nanosatellites are becoming increasingly accessible platforms for scientific research. Specifically they are suitable for space ionizing radiation research and can be used as testbeds for small sized innovative ionizing radiation sensors. Furthermore, potential nuclear disasters require preparedness for disaster management using state of the art unmanned systems for ionizing radiation measurements. The avoidance of human involvement in such cases is obligatory.

We envisage the implementation of our sensor on an airborne platform, namely our XZ series 36-rotor micro-drone (Fig. 4) specifically developed for that purpose. Another ongoing experiment is a ground–based small unmanned vehicle being used as a test platform for our sensor (Fig. 5).

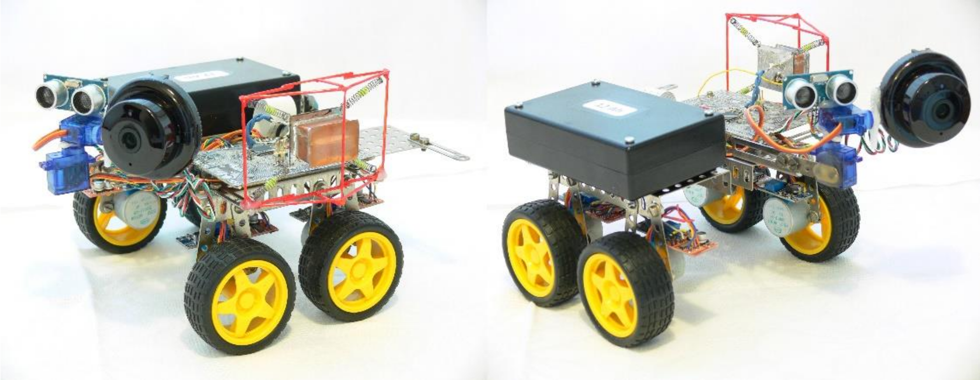

Fig. 5. The radiation sensor mounted on a small and lightweight ground-based unmanned vehicle for testing purposes. The sensor is installed on the right deck of the vehicle by the use of sprung suspension.

By our further research and development we aim at lowering the devices initial and maintenance costs, achieving smaller sizes and weights but at the same to obtaining higher resistance of the used electronics to ionizing radiation — specifically we assume implementing a radiation resistant microcontroller from the same family of MCUs [10].

Certain improvements to the navigation system within confined spaces is desirable too [11–14].

We intend to increase the ionizing radiation sensor sensitivity to high energy gamma rays. This can be achieved by implementing a scintillator as the sensor element instead of a PIN photodiode.

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СЕНЗОР ЗА ЙОНИЗИРАЩО ЛЪЧЕНИЕ ПРЕДНАЗНАЧЕН ЗА НАНОСПЪТНИЦИ, МИКРО-ДРОНОВЕ И МАЛКИ ДИСТАНЦИОННО УПРАВЛЯВАНИ НАЗЕМНИ ПЛАТФОРМИ

Р. Митева, С. Забунов, Г. Мардиросян, Т. Кунчев, Р. Памукова-Майкълсън

Резюме

Целта на настоящата публикация е да представи сензор за йонизиращо лъчение, подходящ за наноспътници, микро-дронове и други видове платформи, които се управляват дистанционно. Поставен на борда на микро-дрон сензорът е подходящ при борба с бедствия като например инспекция на сгради, в които има радиоактивно замърсяване.

В статията са представени дизайн и лабораторни тестове на предложения сензор. Инструментът е много лек и има нищожна консумация на електрическа мощност. Това го прави приложим в наноспътници и мобилни системи, на борда на които няма хора.

За целта на тестване беше разработен специализиран 36-роторен дрон, а също така и мобилна наземна платформа с дистанционно управление.

Експериментални резултати на лабораторните измервания на различни радиоактивни източници са представени и дискутирани. Експерименталната постановка показва подобрени резултати в сравнение със съществуващата техника.