Conceptual outline of charged particles monitor for ChemiX solar X-ray spectrophotometer for the Interhelio-Probe interplanetary mission

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Abstract
Scientific equipment of long-term space missions undergoes constant cosmic radiation illumination from both: corpuscular and electromagnetic constituents of different energies. Cosmic particle radiation damages electronics, optics, sensors and detectors. It is therefore important to prevent the failure of CCDs, semiconductor detectors, electronics, etc. during passing through regions of enhanced charged particle fluxes. In particular, particle flux pulsations can badly affect the regular X-ray measurements of ChemiX instrument being constructed for Interhelio-probe interplanetary mission. In order to detect presence of referred enhanced particle fluxes the Background Particle Monitor (BPM) has been developed constituting now a vital part of ChemiX. BPM measurements of particle fluxes will assist to determine periods of X-ray spectra being contaminated by enhanced particle fluxes. The BPM will also measure the energy spectra of ambient particles.
We present overall structure, technical and scientific characteristics of BPM, and its components. Detector head consists of three-layer detector stack placed behind conical collimator limiting the solid angle of view. First two layers consist of silicon PIN detectors; the third one is based on the p-terphenyl scintillation crystal optically coupled with highly pixilated silicon photomultiplier. By such multilayer structure in combination with coincidence logic we are going to collect systematic data on particle sorts and their energy. Digital signal processing unit is constructed based on Actel ProAsic3e A3PE1500 FPGA. Digital unit contains coincidence logic, forms telemetry data and housekeeping frames, communicates with ChemiX digital signal processing unit and executes telecommands. The BPM is capable to sort out in situ abundances of individual particle constituents.
Keywords: charge particles, satellite device, scintillation detector, printed board, FPGA

1. INTRODUCTION

Investigations of the Sun is performed from the Earth‘s ground and by instruments installed onboard of spacecraft. Last decades scientific equipment preferable provided measurements from the Low Earth Orbits (LEOs) or at L1 Lagrangian point. In the nearest future solar missions will be appended by the series of recent spacecraft that will study the Sun from its close vicinity. The list of such missions includes „Solar Orbiter“ (Muller et al., 2013); „Solar Probe Plus“ (Kinnison et al., 2013); „Solar Polar Orbit Radio Telescope“ (Wu et al., 2011); „Solar-C“ (Watanabe, 2014).

Payload of the Interhelio-Probe two spacecraft (Kuznetsov, 2010) crossing an ecliptic plane at the angle of up to 31 degrees will consists of scientific equipment that will observe the Sun with finest temporal, spatial and energy resolutions. The soft X-ray photometer ChemiX (Chemical composition in X-rays) of referred interplanetary mission is aimed to observe micro- and nano- X-ray bursts, to define elemental abundance of coronal plasma of flares and active regions as well as to study variations of solar activity in the energy band $\Delta E = 0.5 \div 15$ keV (Siarkowski et al., 2016).

The Background Particle Monitor constitutes a vital part of the ChemiX instrument. Enhanced particle fluxes with changing energy spectra may penetrate ChemiX shielding thus reaching delicate CCDs in the spectrometer module. This will affect the ChemiX routine X-ray measurements resulting in enhanced background levels. The BPM measurements of particle flux intensity will be able to indicate periods when there is increased particle flux. For high levels of particle flux detected by the BPM a dedicated flag will be used to switch off entire ChemiX instrument or some of its sensitive subsystems to prevent their damage.

Main tasks of BPM during the flight are: monitoring of corpuscular radiation conditions on the way of spacecraft; generation of alarm electric signals of potential dangerous of radiation damage to sensitive semiconductor sensors of the X-ray spectrophotometer; registration of temporal and spatial dynamics of charged particle fluxes accelerated in flares, and on fronts of interplanetary shocks or coronal mass ejections (Dudnik et al., 2013, 2015a, 2015b, 2015c). BPM measurements of particle fluxes will assist also to determine periods of X-ray spectra being contaminated by enhanced particle fluxes.

In this work we present overall structure, design, technical and scientific characteristics of BPM, some properties of analog signal processing and secondary power supply units, block-scheme of FPGA project of the digital signal processing unit.

2. OVERAL DESIGN AND BLOCK-SCHEME OF BPM'S ELECTRIC STRUCTURE

Figures 1 and 2 represent overall views of the measurement block of ChemiX instrument, and of Background Particle Monitor. In Figure 1 detector head of BPM (1) consists of three-layer detector stack placed behind conical collimator limiting the solid angle of view. Axis of the field of view of BPM's detector head was selected based on expected proffered direction of particle flux with respect to the spacecraft orientation. First two layers consist of silicon PIN detectors; the third one is based on the p-terphenyl scintillation crystal optically coupled with highly pixielated silicon photomultiplier. For such multilayer structure in combination with appropriate coincidence logic we

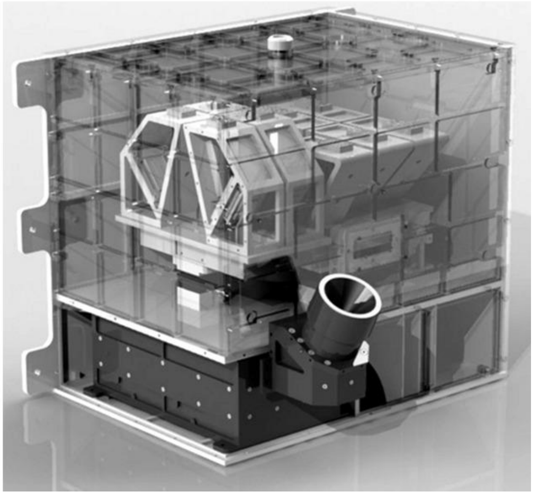

Figure 1. Overal view of the measurement block of the soft X-ray spectrophotometer ChemiX.

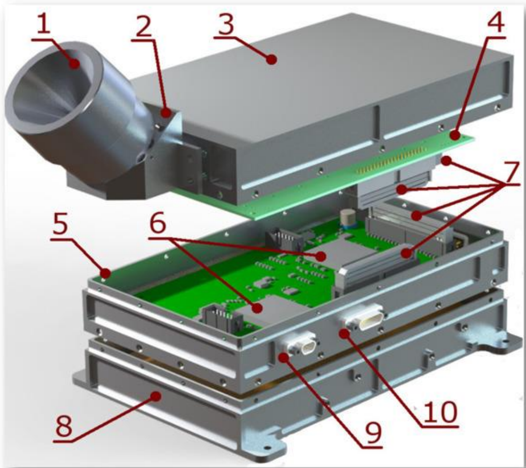

Figure 2. Overal view of the Background Particle Monitor.

expect to collect systematic data on particle species and energy spectra with 1 and/or 10 s time resolution.

The mount construction of detector unit (2); boxes of analog signal processing unit (3), of digital signal processing unit (5), and of power supply unit (8) are the solid-milled light-weigted metallic cases. Printed circuit board of analog signal processing unit (4) is placed next to detector stack. The analog unit is fixed directly to detectors. Printed board with semisets of digital signal processing module (6) is situated between the board of analog signal processing unit, and the board of secondary power supply unit. As far as BPM needs to operate independently of ChemiX (including the power off state), the monitor has a dedicated power supply line. There are also the set of internal connectors (7) joiningh electric signals between boards of BPM; the extenal connector for getting primary power from the satellite (9), and the interface connector between BPM and measurement block of the ChemiX instrument (10).

Figure 3 shows internal electric structure of the BPM.

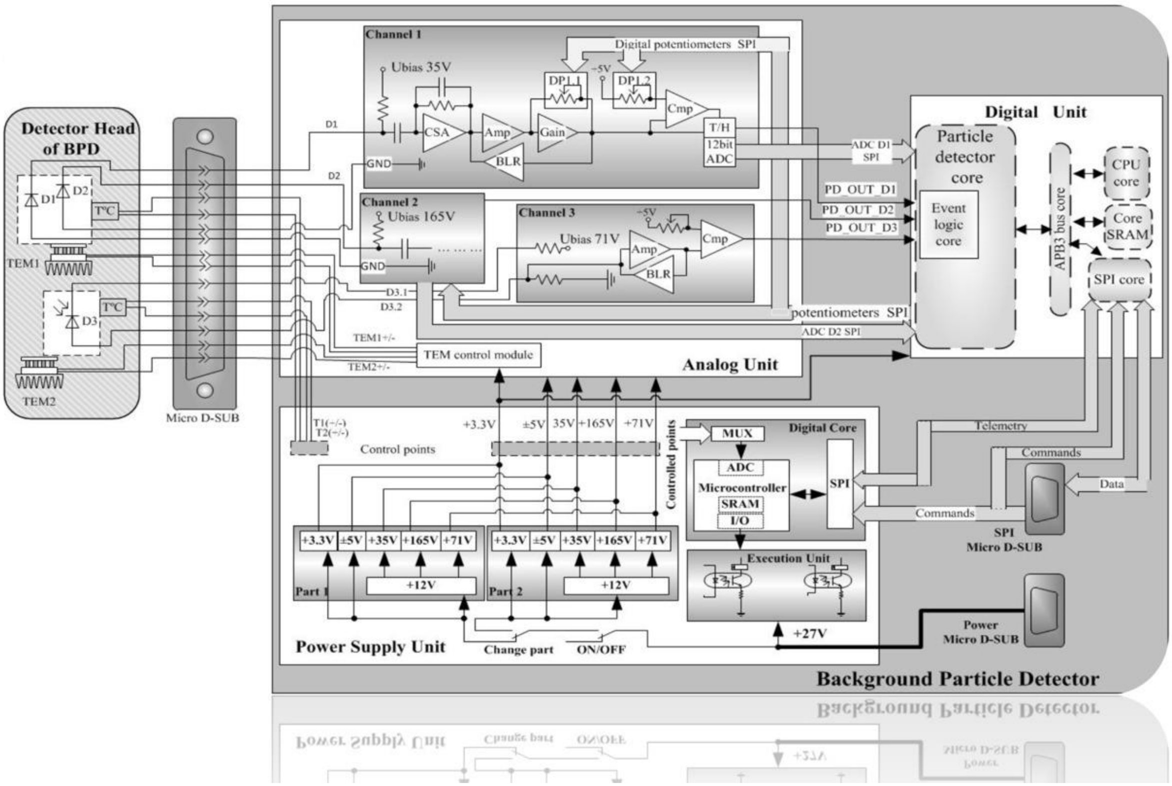

Figure 3. Block-scheme of internal electric design of the Background Particle Monitor.

The analog unit performs processing of analog electric signals incoming from silicon and scintillation detectors. Spectrometer channels of two high purity silicon PIN detectors do not change functionally from each other, and consist of charge-sensitive preliminary amplifiers (CSA), forming amplifiers (Amp), scalers (Gain), peak detectors (T/H) and 12-bit analog-to-digital converters (ADC). Digital potentiometers DP1.1 and DP1.2 perform an operation by comparator's threshold levels of peak detectors, and by gains of the channels. Baseline restorer (BLR) circuits allow holding shaper's output signal close to zero-level at higher counting rates. Channel 2 of large area "Hamamatsu Photonics" silicon photomultiplier does not require CSA because of very high internal coefficient of amplification.

The power supply printed circuit board consists of two identical semi-sets generating output voltages to analog and digital signal processing units, and bias voltages to semiconductor detectors and photomultiplier. DC-DC converters provide galvanic isolation between primary and secondary circuits protecting channels against background noises and possible voltage jumps on the input board voltage.

Digital unit is based on the Flexible Programmable Gate Array (FPGA) Actel ProAsic3e A3PE1500 part. Digital unit forms telemetry data and housekeeping frames, communicates with ChemiX's digital signal processing unit and executes telecommands. Due to application in the FPGA of the coincidence logic with appropriate special software, the BPM is capable to sort out in flight abundances of individual particle constituents from electrons up to much heavier oxygen nuclei.

3. MAIN CHARACTERISTICS OF THE BACKGROUND PARTICLE MONITOR

The design and manufacture of the mechanical boxes, soldering components onto circuit printed boards of the analog signal processing and secondary power supply units (Figure 4) of BPM's breadboard model and the laboratory tests of electrical characteristics gave us the possibility to fix some principal technical and scientific characteristics of the instrument. They are presented in Table 1.

Figure 4. Overal view of the secondary supply unit

Table 1. Main technical and scientific characteristics of the Background Particle Monitor's breadboard model.

Specification	BPM breadboard model
Weight, kg	≤ 1.1
Dimensions: height, mm width, mm length, mm	 78 (121 max with detector head); 142; 210 (272 max with detector head)
Power consumption at U = 27 Volt, Watts	~ 7
Output interface	SPI
Angle of view	~ 36^0
Active areas of detectors: 1st (Si PIN) and 2nd (Si PIN, mm^2	10 x 10
Types of particle detectors	1st: silicon (Si PIN); 2nd: silicon (Si PIN); 3rd: p-terphenyl scintillator
Energy range of detected particles, MeV	electrons: 0.06 ÷ 2.4; protons: 1.2 ÷ 14; deuterons: 1.6 ÷ 18; alpha-particles: 5 ÷ 52
Dtected nuclei:	H, He, Li, Be, B, C, N, O
Number of energy channels	50 for each particle sort
Time resolution, seconds	1 and 10
Telemetry rate, bits / s	~ 5000

4. SOME FEATURES OF ANALOG SIGNAL AND SECONDARY POWER SUPPLY UNITS

Principal electric schemes and corresponding to their PCB-design manufactured printed circuit boards of the analog signal processing unit (Figure 5) and of the secondary power supply unit of the BPM's breadboard model have some specific features. The three spectrometer channels of analogue unit provides formation of the identical quasi-gauss form's analogue signals with equal pulse durations for the purpose of detecting the coinciding events, which are then being processed by the digital signal processing unit. The gains of shapers are adjustable remotely from the ground by telecommands in order to change the packets of particle sorts. Additionally, on the analog unit printed board we carry out digitization of pulse amplitude by 12-bit's ADC as well as transmission of logical data to the digital signal processing circuit board through the SPI interface. Apart from electronic spectrometer channels the analog unit's board is equipped with two schemes of automatic thermo stabilization of particle detectors that are based on the micro automatic controller and Peltier coolers.

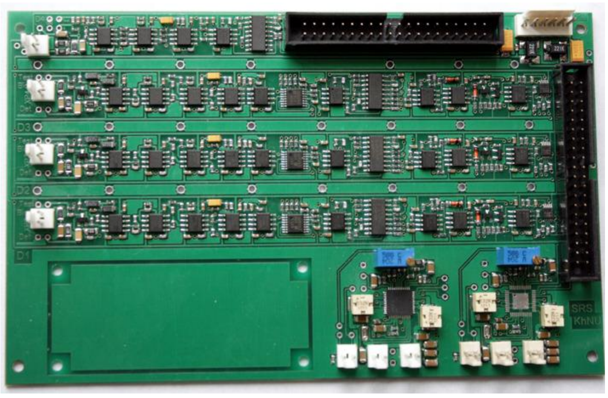

Figure 5. General view of the printed circuit board of analog signal processing

The main features of the secondary power supply unit are: the "cold" redundancy of the work of any of the two identical semi-sets. This substantially reduces the probability of the unit's radiation damage, and prolongs its lifetime during the long-term interplanetary mission. The power supply unit works in a number of regimes that are controlled by external telecommands. These commands can be generated "from the ground", and enter to BPM via the main board computer of the satellite. Beforehand the coded telecommands can also be transmitted from the digital signal processing unit of the ChemiX instrument itself. These are: the switch on/switch off BPM, select semi-set, control of primary and all secondary voltages, etc. At last, the electric scheme of the secondary power unit contains self-repairing circuits protecting against short-circuits in the loads, and the circuit protecting against overvoltage in the circuit of the board power supply.

5. DEVELOPMENT OF THE FPGA PROJECT FOR BPM'S DIGITAL SIGNAL PROCESSING MODULE

In order to obtain the data on radiation environment conditions during spacecraft on the way to the vicinity of the Sun special software is being currently under development. Table 2 contains brief information about category and function of the software with pointing out an appropriate hardware.

Table 2. Functions of the software being under development for FPGA A3PE 1500 Starter Kit and ChemiX simulator.

Software category	Function
FPGA A3PE 1500 (*VHDL, assembler*))	a) reading the ADC's codes, b) definition of particle's sort, c) downloading the data on to RAM, d) formation and transmission of telemetry frames to ChemiX, e) data reception from ChemiX and execution of telecommands.
ChemiX's simulator: personal computer (*C#*)	a) transmission of on-board time codes to BPM , b) generation and transmission of telecommands to BPM, c) reception and holding of BPM's telemetry information, d) conversion of raw telemetry data into suitable format.

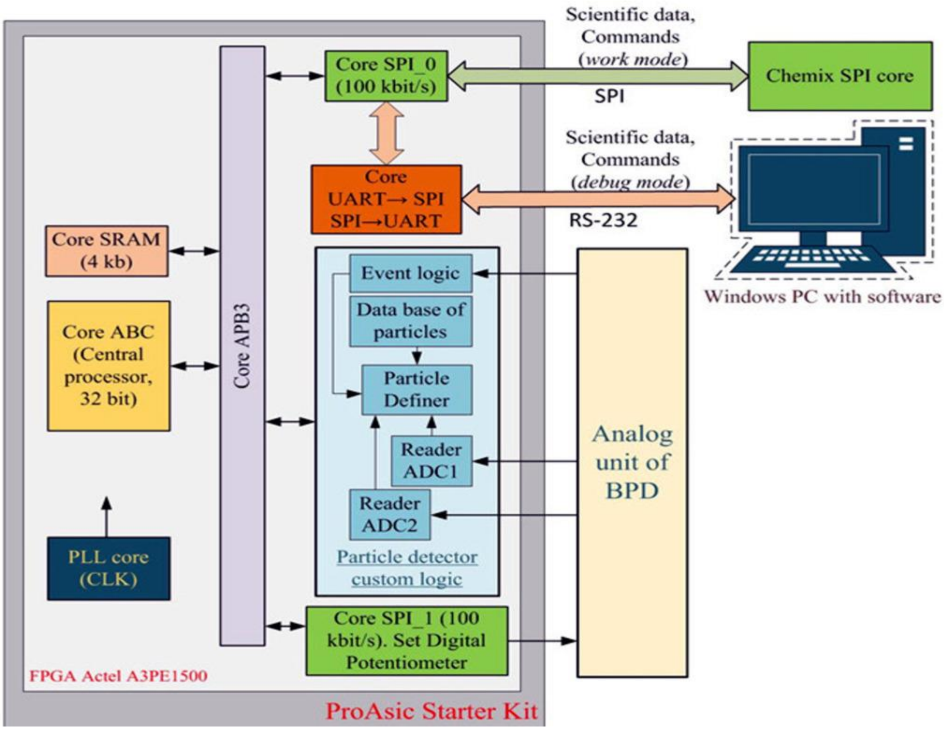

Figure 6. Block-scheme of the Actel ProAsic3e A3PE1500 FPGA project; structure of procedure for signals exchange procedure between FPGA and the BPM's analog units and ChemiX's simulator.

Figure 6 presents the block-scheme of the Actel ProAsic3e A3PE1500 FPGA software functionality, currently incorporated in the ProASIC3 Starter Kit board, and the structure of the signal exchange procedure between FPGA, from one side, and BPM's analog unit and personal computer acting as ChemiX's simulator, from the other side. The FPGA project contains 32-bit central processor on the base of core ABC, SRAM core (4 Kbytes), particle detector custom logic core, cores of interfaces and the SPI core for setting the digital potentiometers.

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