Space Weather Monitor Based on the Timepix Single Particle Pixel Detector

Vaclav Kraus, Michael Holik, Jan Bartovsky, Vjaceslav Georgiev, Jan Jakubek and Dominik Schneider

Abstract — **this article deals with the space weather measurement system on the low Earth orbit. There are radiation sources of trapped protons, trapped electrons, neutrons, galactic cosmic ray ions, solar flare protons and solar flare heavy ions. The Timepix pixel particle detector brings advanced capabilities of the particle detection, energy measurement and particle recognition. We were focused on a design of the electronic system for a space application called SATPIX that is based on the Timepix pixel particle detector. The measurement system will be a part of the PilsenCUBE picosatellite which is currently under development at the Faculty of Electrical Engineering at the University of West Bohemia.**

Keywords — **Cosmic Weather, Particles Detection, Medipix, Particles, Picosatellite, PilsenCUBE and Timepix.**

I. Introduction

THE research of space weather effects is presently the important task. The reason of the space weather research is to get more knowledge about effects of the malfunction and damage in the terrestrial communications, satellite communications, aviation and other technological systems, which are exposed to the radiation. Also a priori knowledge of the space weather allows us to predict the radiation incoming from space. The primary source of the space weather is the Sun which emits electromagnetic radiation in the range from radio waves up to γ-rays, protons, neutrons, nuclei and electrons (energy span is from keV to GeV). The secondary source is the Galactic cosmic rays. The Galactic cosmic rays are more energetic compared to the space weather of the Sun (up to 10^6 GeV). Many detection techniques and electronic devices [1] are available to measure different kinds of the radiation. The Timepix [2] detector has been developed in the CERN. It is used in the elementary particle research. The semiconductor pixel detector Timepix contains an array of 256 × 256 square pixels with a pitch of 55 μm. In addition to high spatial granularity, the Timepix can provide information about the count, energy and time in the each pixel. This device is a powerful tool for the particle detection, imaging and tracking. The Timepix detector is the best candidate for a space research thanks to uncommon properties. It is necessary to develop an appropriate electronic system driving the detector for the space weather research which will meet the space quality requirements. The core of our development was the interface which connects the Timepix detector to the host computer of the PilsenCUBE. It also supports concatenated projects in the Medipix Collaboration [3].

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II. The Timepix Detector

The Timepix (Fig. 1) is next generation of pixel particle detectors from the Medipix family [4]. The semiconductor pixel detector Timepix is a single quantum counting detector which can provide three kinds of information [5] from measurement. However, these informations cannot be obtained simultaneously. The first mode of detector provides information about the count of detected particles. The second mode is Time over Threshold (TOT) which provides information about energy of the particles in each pixel. The latest mode of the Timepix detector provides information about arrival time of the particles in each pixel.

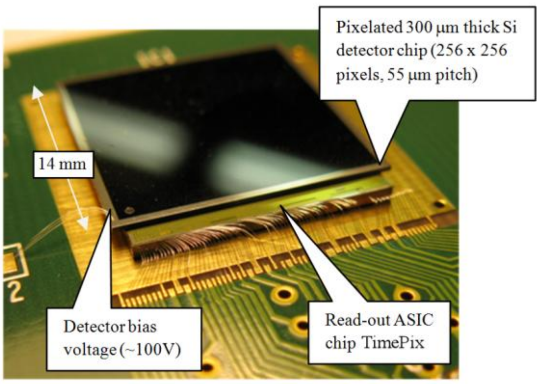

Fig. 1. Picture of the Timepix ASIC chip.

The Timepix ASIC chip can be combined by the bump-bonding technology with the different semiconductor sensors (Si, GaAs, CdTe, and others) which convert the ionizing radiation into electric signals. The sensor sensitive area is 14.1×14.1 mm.

The Timepix chip contains a special electronic circuit for each pixel of the sensor. This electronic circuit is divided into the analog and digital part. Each pixel contains the preamplifier, discriminator, 14-bit counter and shift register. Measured values are stored in counters and can be readout through shift registers. The Timepix chip provides two alternatives how to read data from the chip. The first approach is a serial readout through LVDS lines, and the second approach is a parallel readout through the 32-bit CMOS bus. Several Timepix detectors can be easily connected into the chain through LVDS serial interface. We can obtain bigger sensitive area this way. Thanks to separated analog and digital parts of Timepix electronics, it has unique properties compared to the other detection technologies. The great advantages of the Timepix are the linearity and "infinite" dynamic range. The Timepix can detect all charged particles including heavy ions, X-rays, γ-rays and neutrons (with convert material).

III. Picosatellites and PilsenCUBE Project

A CubeSat [6], [7] is a 10 cm cube picosatellite with a mass of up to 1 kg (which is denoted by abbreviation 1U). Other available dimensions are multiples of 1U: 0.5U, 2U and 3U. It was developed and standardized by California Polytechnic State University and Stanford University's Space Systems Development Lab. In order to participate in a CubeSat Program, one shall design a satellite conforming to all CubeSat Standards [8].

A picosatellite launch is coordinated by CubeSat Program. The process of launching is facilitated so that a reliable deployment system is provided. The deployment system occupies a very little space and can be mounted into any launch vehicle. The launch cost is as low as $40,000 per a CubeSat. Also, there are companies [9] which produce prefabricated mechanical parts satisfying space requirements (Fig. 2). Therefore, a developer can focus entirely on the design and development of electric and electronic equipment rather than on obtaining licenses. Over 60 universities have already discovered research and educational benefits resulting from accessing space.

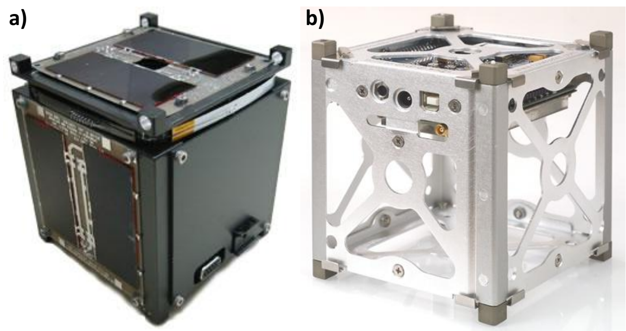

Fig. 2. a) example of picosatellite with size 1U, b) the chassis for 1U picosatellite.

A. PilsenCUBE

The PilsenCUBE [10] is a CubeSat picosatellite currently developed at the University of West Bohemia. The research intention is threefold: (a) design of software-defined telecommunication transmitter with modern modulations, (b) increase of efficiency and reliability of switching-mode supply sources [11] and modern solar systems, usage of supercapacitors [12], and (c) measure the space weather using the SATPIX measurement system. Fig. 3 shows block diagram of PilsenCUBE picosatellite. The SATPIX is the electronic interface designed for the Timepix pixel particle detector.

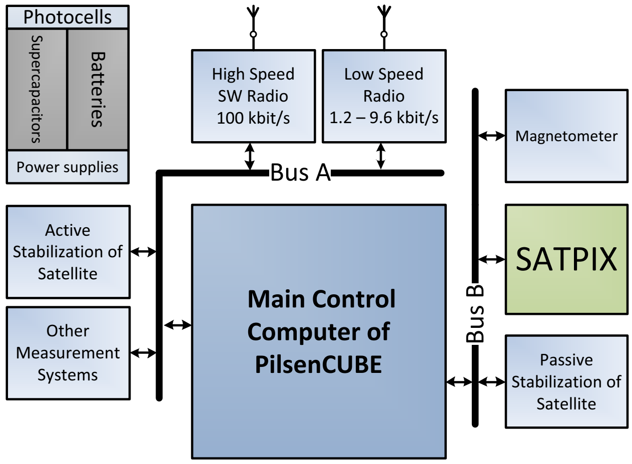

Fig. 3. Block diagram of PilsenCUBE picosatellite.

The electronic equipment of PilsenCUBE consists of two groups. Firstly, Standard blocks are determined by the power supply subsystem (solar cells, batteries, switching-mode supplies), standard command radio (low bandwidth), and the diagnostics system. Those Standard blocks provide basic features and support of the PilsenCUBE. Secondly, Experimental blocks form an independent subsystem with separated power supplies (using supercapacitors instead of batteries), configurable telecommunication channel, special bus interface for further boards to be added, and the last but not least the SATPIX measuring device. Transfer rate is between 1.2 - 9.6 kbit/s for the low speed standard command radio and 100 kbit/s for the high speed software-defined radio.

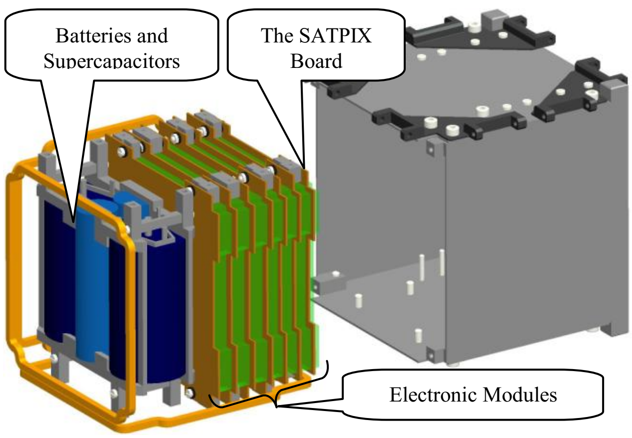

Fig. 4. Model of PilsenCUBE. The picture shows the arrangement of parts in the satellite.

The low speed radio can transmit up to 4 frames from the Timepix to the Earth per one fly-around and the high speed radio can transmit up to 40 frames in the same time. Fig. 4 shows model of PilsenCUBE picosatellite. The launch of PilsenCUBE is scheduled for the end of year 2011.

IV. SATPIX – MEASUREMENT SYSTEM WITH THE TIMEPIX

A. Dimensions and Mechanical Settings

The SATPIX printed circuit board has dimensions according to the CubeSat standard. The SATPIX measurement module is placed on the cube side under the case. The detector is exposed to space through a window 14.1×14.1 mm and the detector has no shielding materials in front of the sensor. The mass of whole system does not exceed 150 g.

B. Design of Hardware

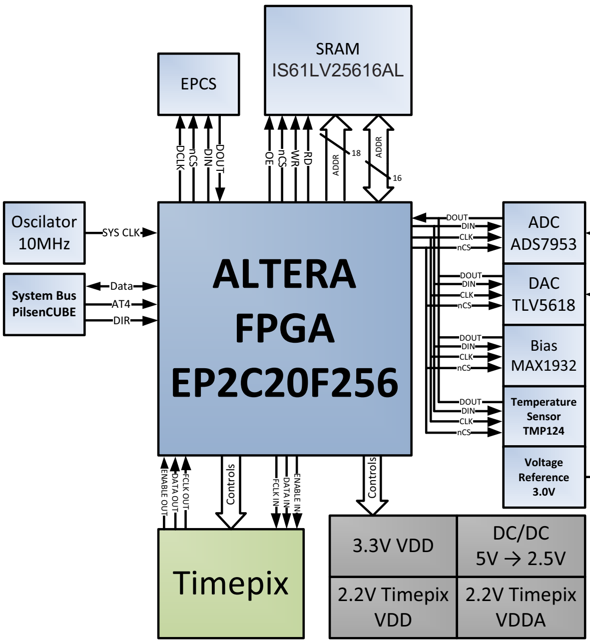

Fig. 5. Block diagram of SATPIX.

Fig. 5 shows block diagram of the SATPIX. The emphasis was given to lifetime of the SATPIX. The components were selected from a military range and tested for radiation hardness. The FPGA EP2C20F256 from the Altera uses 90 nm technology which is robust component for using in the space despite the fact that it is not radiation tolerant component. The radiation tolerant FPGA exists but they are not needed for the prototype devices and the cost is extremely high. Radiation tolerant FPGAs are based on the OTP technology (non-reprogrammable) which is not appropriate component for development and evaluation of the hardware. The FPGA offers special feature error detection by the Cyclic Redundancy Check (CRC). If an error detection CRC feature is enabled, the device checks the validity of the configuration file in the FPGA. Error in the configuration data causes rebooting of the FPGA. That is a useful tool when configuration is corrupted. The external 4 Mbits SRAM memory is used as buffer to store data before transmission to the Earth. This capacity is enough for storing four frames from the Timepix (the size of one frame is 0.875 Mbit). Each frame is stored in the buffer immediately after measurement. Then the detector is switched off during the whole transmission time until the next measurement when the detector is switched on again. The reason is that the detector consumes 0.8 W of power. The power management is important part of the design because there is only 1Wh of electric energy per day for the measurement system available. The maximum power consumption of the SATPIX is 1.25 W. If the detector is switched off, the power consumption is 0.45 W. The equation (1) determines maximum number of frames from the Timepix per day.

$$F_{cnt} = \frac{P_i}{P_{ON}\cdot\left(\frac{ML_T}{f_{readout}}\right) + C_F \cdot P_{OFF}\cdot\frac{ML_B}{br_{bus}\cdot 3600} + P_{ON}\cdot\frac{ML_B}{br_{bus}\cdot 3600}} \qquad (1)$$

F_{cnt} is the number of frames that we can measure. P_i is the total amount of energy allocated to the SATPIX (1 Wh), P_{ON} is the power consumption when detector is powered (1.25 W), P_{OFF} is the power consumption when detector is not powered (0.45 W), ML_T is the size of the frame from the Timepix (112 kB), ML_B is the size of the packed frame (140 kB), $f_{readout}$ is the readout frequency for the detector (100 MHz), C_F is the compression factor and br_{bus} is the bit rate of the PilsenCUBE bus in the satellite (115,2 kbit/s). These parameters allow up to 60 frames per day.

C. Design of Firmware

The whole digital system is placed in the FPGA mentioned above.

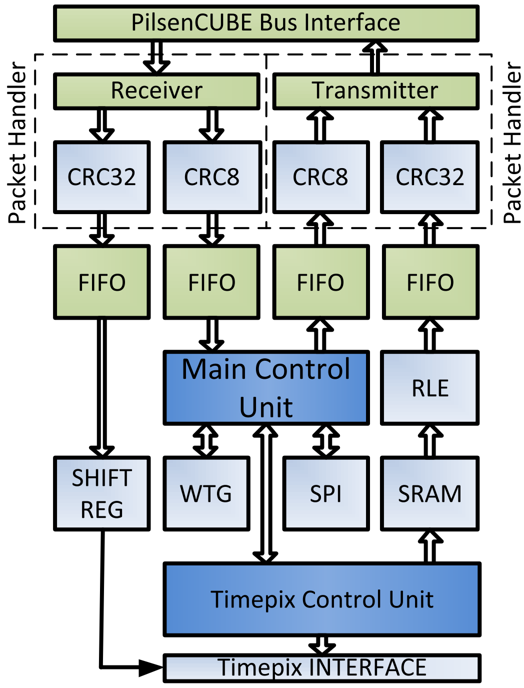

Fig. 6. Block diagram of firmware placed in the FPGA circuit written by VHDL.

Fig. 6 shows block diagram of the firmware. The firmware contains two parts. The first part is the Control Unit which is responsible for the communication with the control computer through the PilsenCUBE bus. The unit decodes commands and passes the parameters to the adjacent units. The UART protocol is the physical communication layer in the PilsenCUBE. There are two types of packets. The first type is the control command which is 16 Bytes long. The second type is data packet with length 528 Bytes. The communication is secured by the CRC checksum. The command packet uses 8 bit CRC checksum and the data packet uses 32 bit CRC checksum. The block Packet Handler is responsible for data coding, decoding, packing and un-packing. If the packet is corrupted the data are not repaired and the packet is removed. The second part is the Timepix Control Unit. It fully controls Timepix detector according to commands from the control computer of the PilsenCUBE satellite. The first operation after power up is the detection of number of concatenated detectors. The multiple detectors support is dedicated to a future advanced measuring, but it is not required at the current PilsenCUBE project. The SATPIX is able to control up to 12 detectors. This feature will be used in future projects for further recognition of particles. The maximum readout speed is 90 frames per second (78.75 Mbit/s) with single detector chip (readout frequency is 100 MHz). If the detection of the Timepix chips is finished then SATPIX sends essential information to the control computer like the number of detectors, system clock and readout clock. Fig. 7 shows the flowchart of the SATPIX behavior.

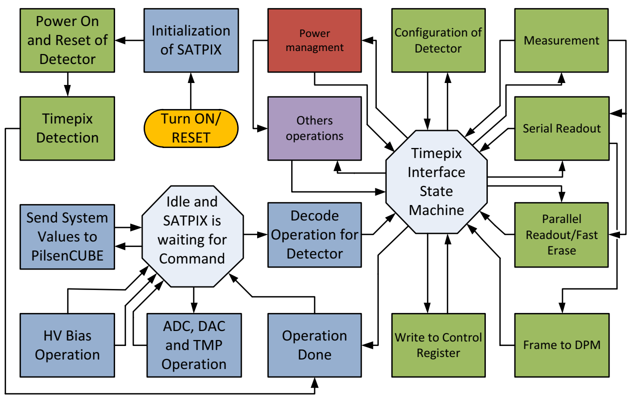

Fig. 7. Flowchart of SATPIX system.

The Timepix Control Unit supports all functions of the Timepix and brings the hardware triggering system. Three modes of hardware trigger have been implemented: hardware trigger which starts the measurement, hardware trigger which terminates the measurement and hardware trigger which controls measurement fully. The Hardware Trigger is an important tool when a synchronized operation is required. The data are stored in the SRAM memory temporarily which enables reductions of power consumption. The Timepix is switched off after transfer of the data to the SRAM. The data are transferred to the main memory of PilsenCUBE and the SATPIX can be completely switched off. The SATPIX also includes temperature measurement of the detector, sensing of voltage for power supplies and sensing of analog values from the detector.

V. Conclusion

We have designed the measurement system based on the pixel particle detector Timepix which is dedicated for space applications. The PilsenCUBE project does not use full capacity and functionality of the SATPIX. The SATPIX project benefits from the PilsenCUBE project in testing of circuitry in space. On the other hand the PilsenCUBE project benefits from the SATPIX project in extending functionality of the picosatellite. The SATPIX is low-weight low-power consumption compact device. The insufficiency of electric energy which is common for space applications needs to keep these parameters as low as possible. The results from measurement will be presented after launch.

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