A customized lightweight and low-power radiation micro-tracker has been constructed for the microsatellite RISESAT (Rapid International Scientific Experiment Satellite) developed by Tohoku University for scientific experiments in space. The instrument is based on hybrid semiconductor pixel detector technology developed by the Medipix Collaboration. These Timepix detectors consist of an array of $256 \times 256 = 65$ k pixels with 55 $\mu$m pitch distributed over an area of 2 cm$^2$. Each cell is connected to the corresponding pixel on the 300 $\mu$m thick silicon sensor. Each pixel integrates electronics which enables counting of the number of particles, to measure the energy deposited or to register the time of interaction of ionizing particles per-pixel. Two independent detector layers operate as a radiation micro-telescope and provide high resolution and high sensitivity tracking and directional detection of energetic charged particles (electrons, muons, pions, protons, light ions up to heavy and relativistic ions). Also X-rays and even neutrons can be detected. The pixel detectors provide noiseless detection of single radiation quanta, measure their energy, position, direction of trajectory and time of interaction. Different types of particles and interactions can be identified and distinguished thanks to the detector’s high spatial granularity.

Key Words: Radiation Tracker, Particle Telescope, Space Radiation, Space Weather, Timepix

1. Introduction

Knowledge and characterization of the near-Earth space radiation environment is essential for a wide-range of areas such as space weather, space radiation health protection and dosimetry, radiation damage effects on components and instruments, space radiation shielding and space situational awareness. Sources include direct solar radiation, galactic cosmic rays and extragalactic astrophysical objects. Subjects of study include Earth radiation belts, trapped radiation and understanding solar modulation and solar cycle phenomena such as solar flares and coronal mass ejections. Besides precise and more complete information about the particle flux composition and spectrum which are highly desired, additional information such as the direction of trajectory of energetic particles would be similarly highly valuable in particular in space. Detailed characterization and visualization of the energetic and mixed radiation field in space is valuable as well to assess single event effects in electronic equipment and health hazards to crews on manned missions. Besides conventional passive detectors, the deployment of active real-time data acquisition and position-sensitive radiation detectors on board spacecraft would be highly advantageous for space radiation detection and spacecraft radiation monitoring.

In order to provide a precise and more complete detection of the mixed radiation field in space with track visualization we have constructed a compact and lightweight particle tracker with particle telescope capability based on the hybrid semiconductor pixel detector Timepix. This paper describes the engineering model (EM) for the customized payload for the RISESAT(Rapid International Scientific Experiment Satellite) micro-satellite and summarizes the payload principle and physics goals.

2. Timepix-Based Miniaturized Radiation Micro-Tracker

The payload consists of two Timepix pixel detector devices assembled into a single synchronized radiation micro-tracker. Each detector has its own custom made readout interface (see Figs. 1, 2) which is derived from the Spacewire compliant readout interface developed by the IEAP CTU (Institute of Experimental and Applied Physics, Czech Technical University) in Prague (development funded by ESA). The whole payload was fully designed and constructed by the IEAP CTU. The block scheme for one detector device consists of FPGA-based DAQ and power board, one Timepix detector chip and chipboard and necessary connectors (Fig. 3).

Both detectors communicate and are powered via the $\mu$RTU ($\mu$RTU = Micro Remote Terminal Unit) interface. The whole payload is small sized (50x100x150 mm$^3$), weighs less than 0.5 g (mostly by the payload metal casing), requires a single 5V DC supply, consumes no more than 5W of power and produces no more than 12 kbytes of data per second or equivalently 84 kbyte/min = 50 Mbyte/h = 1.2 Gbyte/day. Custom-made control and DAQ software were written to...
comply with the satellite on-board protocol based on space plug and play avionics standard.\textsuperscript{12,13)}

![Fig. 1. Engineering model of the micro-tracker Timepix payload consisting of two detector devices each equipped with a Timepix chip, chipboard and data acquisition/power board.](image1)

The whole device will be preconfigured by per-pixel configuration matrices stored in the µRTU. The device operates in a stand-alone default configuration which is pre-programmed or can be also modified by short uplinked command. Data, taken in the form of so-called "frames", will be time-stamped to allow correlations with the satellite position and eventual correlation with other spacecraft onboard instruments.

3. Payload Goals and Physics Capability

Timepix provides noiseless detection of single radiation quanta, measure their energy, position, and time of interaction. Thanks to the detector’s high granularity and per-pixel energy sensitivity, the stopping power of single particles can be directly measured in addition to registering and visualizing particle tracks in the pixelated sensor with particle type sensitivity. For energetic charged particles moreover the direction of trajectory can be registered – see Fig. 4.

Using a single-layer Timepix detector, the direction of trajectory of energetic particles can be determined with angular resolution of few degrees. By coupling two sensitive layers of Timepix detectors into a pixel stack device\textsuperscript{15}) we constructed a particle micro-tracker which operates as a particle telescope with high sensitivity tracking and high resolution directional detection of all energetic charged particles (Fig. 5) i.e., electrons, muons, pions, protons, light and heavy ions. Also X-rays and even neutrons can be detected – when equipped with neutron convertors. The device will provide a sky mapping of energetic charged particles with high spatial resolution ($\approx 0.1^\circ$).

![Radiation sensitive Timepix chip (14 x 14 mm$^2$)](image2)

![Fig. 2. Assembled EM of the micro-tracker Timepix payload (see Fig. 1). Dimensions 50×100×150 mm$^3$.](image3)

![Fig. 3. Block scheme for one detector device composed of DAQ and power board, the Timepix chip and chipboard and the uRTU connectors.](image4)

![Fig. 4. Detection and visualization of 1 GeV $^{12}$C ions by Timepix operating in per-pixel energy mode (so-called Time-over-Threshold ToT mode where the energy deposited in each pixel is independently recorded as shown in color by the vertical bar in keV). The beam was taken from a radiotherapy ion synchrotron at the Heidelberg HIT (Heidelberg Ion-Beam Therapy Center) facility in Germany and was incident from right to left at 5$^\circ$ to the sensor plane. The undeflected primary $^{12}$C ions (PRI) are registered as well as secondary particles (SEC) which can be grouped into light- (LCP), medium- (MCP) and heavy- (HCP) mass charged particles. Morphology and stopping power of the single particle tracks over the pixelated sensor provide information on the particle type and also their direction of trajectory.](image5)
4. TIMEPIX in the RISESAT Project

4.1. Micro-satellite RISESAT

RISESAT is a 50 kg class international scientific satellite developed by Tohoku University within the frame of a Japanese FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program. The launch and operational configurations of RISESAT is illustrated in Fig. 6.

Fig. 6. Micro-satellite RISESAT. Dimensions 50×50×50 cm³.

The orbit is planned to be a sun-synchronous orbit with an altitude of around 700 km and an inclination of about 98°, where the satellite will conduct observations and experiments by different types of scientific instruments mainly focusing on Earth and its environment. The characteristic of the sun-synchronous orbit is that the spacecraft passes over the same region of the Earth at the same local solar mean time each day. The launch of the satellite is planned in Japanese fiscal year of 2013 with planned mission life time of 2 years.

4.2. Payload instruments of RISESAT

In addition to the Timepix-based radiation micro-tracker, RISESAT carries also a TRITEL-JMS (Three-dimensional Silicon Detector Telescope for Micro Satellites.) three dimensional silicon detector telescope for space dosimetry measurements, a High-precision multi-spectral Telescope (HPT) with two liquid crystal tunable filters, an Ocean Observation Camera (OOC) with four channels, a Dual-band Optical Transient Camera (DOTCam) for observing transient luminous events in Earth upper atmosphere, and a MEMS-technology-based magnetic field sensor (μMAG), as scientific payloads. The positioning of the Timepix payload in the RISESAT satellite is shown in Fig. 7. The instrument will monitor and characterize the radiation field in the surroundings of the satellite along its orbit. It will furthermore provide the directional sky mapping of energetic charged particles as illustrated in Fig. 8.

Fig. 7. Micro-tracker Timepix payload accommodation in RISESAT.

Fig. 8. Sky mapping of energetic space radiation by means of spatial- and directional-sensitive tracking of single charged particles by the Timepix-based radiation micro-telescope in low Earth orbit.

4.3. Satellite system

The bus system of the RISESAT is based on the technologies obtained by predecessor microsatellite missions, such as RISING-1 (SPRITE-SAT) and RISING-2, which were also conducted at Tohoku University. RISESAT newly employs Space Plug and Play Avionics (SPA) interface standard to control scientific instruments. The payload system’s main computer Science Handling Unit (SHU) deals with this interface. Timepix is controlled by this SHU via SPA interface. The actual physical layer of the applied SPA architecture on RISESAT is based on USB. Command processing and data handling of payload instruments is done by a dedicated Remote Terminal Unit (RTU). Measurement data and housekeeping data are forwarded to the Mass Memory Unit (MMU) in the SPA network, which also performs data pre-processing for the downlink before sending the data to the X-band transmitter.

4.4. Operation of the Timepix radiation micro-tracker

RISESAT operates multiple payload instruments in a time-divided manner. The bus system of the RISESAT is designed in the way that selected payload instruments can be operational throughout a complete revolution of one orbital period. With this capability, Timepix will be able to obtain valuable information about the space radiation condition.
RISESAT is capable of both fine-pointing and coarse-pointing attitude control, depending on the mission requirements and instrument’s power consumption. RISESAT is also equipped with several pointing modes, such as nadir-, sun-, inertial-, rim-, and target-pointing modes. It is planned that Timexip is operated for complete orbits around the Earth at least every 7 days or more often in order to obtain periodical and extensive measured data.

The main computers of the RISESAT are designed in the way that they can withstand certain level of harsh radiation situations such as coronal mass ejections by applying different kinds and levels of radiation mitigation methods, so that Timexip can obtain meaningful scientific data in such occasions. The engineering model of the RISESAT is now under final verification which is illustrated in Fig. 9.

Fig. 9. Engineering model of RISESAT.

A combination of more than one payload instruments can be also operated during the mission, in case it will provide scientifically more detailed and complete information. For example, Timexip and TRITEL-JMS can be operated at the same time for inter-comparison of their obtained mission data about the space radiation environment from different viewpoints. Attitude control capability of the RISESAT will fulfill comprehensive operational demands from payload instruments.

5. Conclusions

The RISESAT satellite will enable deployment of a novel scientific instrument based on state-of-the-art technology (hybrid semiconductor pixel detector Timexip) in outer space. The mission will serve as flight demonstrator for this technology. The Timexip payload is highly integrated, lightweight and low-power and will provide characterization of the mixed radiation field in the outer space environment of the satellite path. The particle micro-telescope capability will provide the sky mapping of energetic charged particles in low Earth orbit.

Acknowledgments

This research was carried out in frame of the Medipix Collaboration based at CERN. The authors thank M. Martisikova, B. Hartmann and O. Jaekel of the German Cancer Research Center (DKFZ: Deutsches Krebsforschungs-zentrum) Heidelberg for the test measurements at the Heidelberg ion synchrotron at the HIT facility in Heidelberg.

The RISESAT project is funded mainly by the Japan Society for the Promotion of Science (JSPS) through the “Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program),” initiated by the Council for Science and Technology Policy (CSTP). RISESAT project is also partly supported by Grant-in-Aid for Scientific Research on Innovative Areas KAKENHI:24760658 from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

8) Lanzerotti, L.J.: Public awareness of space weather, Space Weather 7 (2009), S08003.


