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Timepix-based radiation environment monitor measurements aboard the International Space Station

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A B S T R A C T

A number of small, single element radiation detectors, employing the CERN-based Medipix2 Collaboration's Timepix Application Specific Integrated Circuit (ASIC) coupled to a specially modified version of the USB-Lite interface for that ASIC provided by the Institute for Experimental and Applied Physics (IEAP) at the Czech Technical University in Prague, have been developed at the University of Houston and NASA Johnson Space Center. These detectors, officially designated by NASA as Radiation Environment Monitors (REMs), were deployed aboard the International Space Station in late 2012. Currently six of the REM units are operating on Station Support Computers (SSCs) and returning data on a daily basis. The associated data acquisition software on the SSCs provides both automated data collection and transfer, as well as algorithms to handle adjustment of acquisition rates and recovery and restart of the acquisition software. A suite of ground software analysis tools has been developed to allow rapid analysis of the data and provides a ROOT-based framework for extending data analysis capabilities.

1. Introduction

Characterization of the ionizing radiation field aboard the International Space Station (ISS) is necessary to evaluate risk to both hardware and humans alike. The Radiation Environment Monitor (REM) hardware is a technology development payload experiment intended to evaluate the performance of small, silicon based Timepix hybrid pixel detectors in the Low Earth Orbit radiation environment.

Use of a single silicon Timepix detector presents a low-mass, low-power solution to the challenge of radiation monitoring aboard space vehicles. The Timepix hybrid pixel detectors utilize a Wilkinson-type Analog-to-Digital Converter to generate a Time Over Threshold (TOT) value for each pixel, proportional to the charge collected [1]. Utilizing a TOT to energy calibration, the Timepix detectors provide an energy resolved pixel map of particle tracks through the silicon detector [2]. Such tracks take the form of clusters of correlated (mostly adjacent), non-zero valued pixels.

The long term goal of this investigation is to assess the capability of the hardware to be used as operational active radiation monitors for crewed space missions and investigate the resolution possible in track-by-track estimates of particle charge and velocity [3].

This work describes the hardware and software that comprise the ISS REM units, and reviews the general hardware performance since initial deployment on board the International Space Station in October of 2012.

2. Hardware description

The REM hardware is a modified version of IEAP's USB Lite interface [4] with modifications allowing utilization of a Timepix detector assembly [1] and a USB type A connector for direct interface to the ISS Station Support Computers (SSCs) [5]. The Timepix device provides a 256 by 256 array of 55 μm square pixels that provide a mapping of the charge collected during the acquisition period, referred to as a data frame. The current REM devices have a maximum frame collection frequency of 4 frames per second, due to the limitations

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Fig. 1. The ISS Cupola deploy location is shown with the REM unit plugged into the SSC laptop on the lower left. Units are deployed at various locations aboard the ISS. The inset shows the ISS REM unit with and without the aluminum housing. The NASA logo is reflected in the silicon detector. On-orbit imagery is courtesy of www.spaceflight.nasa.gov.

imposed by the USB 1.1 interface [4], but the Timepix itself is capable of operating several orders of magnitude faster.

Each ISS REM unit weighs approximately 20 g with dimensions of 8.6 by 2.1 by 1.0 cm. Power is supplied through the host laptop USB port, and individual unit power draw remains below 2 W [4]. Aside from deployment of the units and physical relocation of the devices within ISS, there is no required on-orbit maintenance.

The REM hardware is fitted with an aluminum housing sealed with black RTV silicone. The sealant is used to block ambient light, which has been shown in ground testing to produce a background noise signal due to the interaction of near ultraviolet light with the fluorescing tracer material in the conformal coating applied to the electronics. Fig. 1 shows the hardware deployed in the ISS Cupola.

3. Flight software

The REM Flight Software is adapted from the Pixelman acquisition control software developed at IEAP [6] with software additions and modifications made in order to operate while deployed on the ISS systems and to interface with the ISS network [5]. The software allows basic dose equivalent information display and acquisition control, along with the display of current operational status. This allows ISS crew to start and stop data collection, as well as verify REM unit operation. Fig. 2 shows the flight software interface along with the trajectory corresponding to the time period covered in the display window.

3.1. Automated acquisition

The REM flight software has the capability to handle device upsets by monitoring hardware status and re-initializing the hardware if upsets are detected [5]. The flight software is also designed to allow the software to restart without crew intervention in the event of a computer restart or unexpected reboot. The software has algorithms to adjust acquisition parameters within configurable bounds based on feedback from previous data frames. Data transfer from local laptop storage to the ISS file server is performed automatically, and checks for configuration file updates are performed on a regular basis to allow ground controllers to modify on-orbit software configurations.

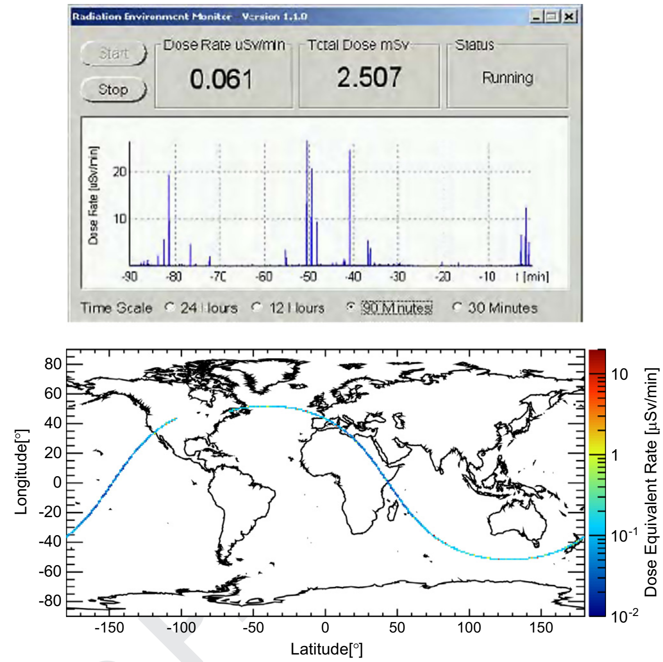

Fig. 2. ISS REM Flight Software user interface display and related orbital map. The screenshot of the ISS REM user interface (upper) during on-orbit operation for a single orbit (lower) beginning over North America shows intermittent, high dose equivalent rates during high latitude passes that result from the per-track nature of the ISS REM flight software calculations. The “Total Dose” value tracks the dose equivalent sum since the last software restart, while “Dose Rate” displays the dose equivalent rate for the most recent frame in the data acquisition.

3.2. Frame rate adjustment

The radiation environment in Low Earth Orbit is highly variable, ranging from relatively low particle flux at the equator due to highly energetic Galactic Cosmic Rays (GCR), to short periods of high flux during transits through a portion of the Earth's trapped radiation belts known as the South Atlantic Anomaly (SAA). Solar Particle Events can also modify the particle flux in the high latitude regions of the ISS orbit over North America and the Indian Ocean. Since data analysis of individual particle tracks is more difficult when the tracks are superimposed, algorithms have been developed which utilize real-time analysis of preceding frames. These algorithms adjust the acquisition time to achieve reasonable track separation within individual frames while maintaining data collection efficiency.

The Frame Rate Algorithm incorporated into the REM flight software includes a chain of logical checks which can be individually activated to allow the use of relatively complex logic in adjusting the acquisition time for each subsequent data frame. The most basic method used compares total pixel occupancy (non-zero pixel count) to a preset occupancy limit and adjusts the acquisition time for the subsequent frame based upon the ratio of the two occupancies. In addition, logic exists to allow the trend in pixel occupancy over the last three frames to determine the magnitude of the adjustment for the next data frame.

The same basic method is also applied to the count of separate pixel clusters within a frame, along with the ability to use a trend over the last 3 frames for cluster count. This requires some additional logic because above a certain pixel occupancy, the number of separate clusters identified begins to drop as the individual particle tracks in a single frame begin to overlap one another. This phenomenon is accounted for in the adjustment logic within the cluster count algorithm by performing an additional check on total pixel occupancy.

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