Small Dosimeter based on Timepix device for International Space Station



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# Small Dosimeter based on Timepix device for International Space Station

**D. Turecek,[a,1] L. Pinsky,[b] J. Jakubek,[a] Z. Vykydal,[a] N. Stoffle[b] and S. Pospisil[a]**

[a] *Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague, 128 00, Czech Republic*

[b] *University of Houston, 4800 Calhoun Rd., Houston, Texas 77004, U.S.A.*

*E-mail:* daniel.turecek@utef.cvut.cz

ABSTRACT: The radiation environment in space is different, more complex and more intense than on Earth. Conventional devices and detection methods used nowadays do not allow to discriminate single particle types and the energy of the single particles. The Timepix detector is a position sensitive pixelated detector developed at CERN in a frame of the Medipix collaboration that provides capability to visualize tracks and measure energy of single particles. This information can be used for sorting the particles into different categories. It is possible to distinguish light charged particles such as electrons or heavy charged particles such as ions. Moreover, the Linear Energy Transfer (LET) for charged particles can be determined. Each category is assigned a quality factor corresponding to the energy a particle would deposit in the human tissue. By summing the dose of all particles an estimate of the dose rate can be calculated. For space dosimetry purposes a miniature device with the Timepix detector and a custom made integrated USB based readout interface has been constructed. The entire device has dimensions of a USB flash memory stick. The whole compact device is connected to a control PC and is operated continuously. The PC runs a software that controls data acquisition, adjusts the acquisition time adaptively according to the particle rate, analyzes the particle tracks, evaluates the deposited energy and the LET and visualizes in a simple display the estimated dose rate. The performance of the device will be tested during a mission on International Space Station planned towards the beginning of year 2012.

KEYWORDS: Data processing methods; Dosimetry concepts and apparatus; Detector control systems (detector and experiment monitoring and slow-control systems, architecture, hardware, algorithms, databases)

[1] Corresponding author.


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2011 JINST 6 C12037

## Contents





## 1 Introduction

The radiation environment in space is unlike anything encountered on Earth in the sense that it is dominated by very high-energy charged particles including heavy ions with significant fluences for elements out to iron. Further, the potential effects on astronauts who are exposed to this environment are not well understood, and the fundamental dosimetric endpoints are still evolving. Current trends are tending towards the use of risk assessment analyses being based on combinations of both the detailed charge and velocity of the individual ions as well as the energy deposit rate per unit track length with a risk enhancement factor for the energy deposited by these particles varying as much as a factor of up to 100 over the range of values that will be encountered. As such, providing dosimeters with capabilities to assess these fundamental properties of the incident radiation on a particle-by-particle basis is an emerging requirement. At present, there are no active portable compact devices in use that can provide this capability. The research being reported here is part of an effort to develop such a device based on a new pixel-based active electronic detector technology.

The Timepix detector [1] possesses suitable properties for measurements of the dose in space. It is a position sensitive pixelated detector (300 $\mu$m thick silicon sensor, 256$\times$256 square pixels with 55 $\mu$m pitch) developed at CERN in a frame of Medipix Collaboration [2]. Its ability to visualize tracks of ionizing particles was already demonstrated [3].

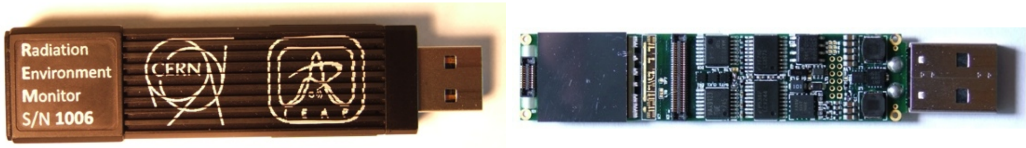


**Figure 1**. The Timepix USB Lite Interface in the casing (left) and the device's PCB (right).

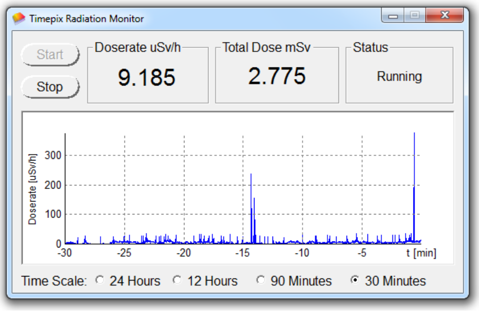


**Figure 2**. Control and display window of the software showing the equivalent dose rate, the total cumulated equivalent dose and a plot of history of dose rate.

## 2 Hardware and software

### 2.1 Hardware

A new read-out hardware Timepix USB Lite Interface (see figure 1) was developed for dosimetry measurements on the ISS. This interface is based on the Medipix2 USB Lite Interface [4]. Unlike the original version the new interface features Timepix detector and a USB-A connector. The whole device has the dimensions of a USB flash memory stick. All the necessary detector power sources including bias source are integrated in the device.

### 2.2 Software

The current data acquisition and control software Pixelman [5] for Medipix and Timepix detectors was extended and upgraded for dosimetry measurements on board the ISS. An extension module (plugin) was created that automatically controls the acquisition of the data from the Timepix detector and performs an online data analysis. Acquisition parameters such as detector shutter time are adjusted automatically according to the current radiation environment to reach best possible quality of the measured data. The software also implements an automatic error recovery feature that monitors hardware status and in the case of single event effects (e.g. device latch-up, configuration corruption) or other hardware error, tries to recover and reinitialize the device. The graphical user interface (GUI) of the software was intentionally made very simple (see figure 2) so that no special training of the ISS crew would be required. The crew can start or stop the measurement from the GUI and see the current equivalent dose rate, the total cumulated equivalent dose or a history (plot) of the equivalent dose rate at different time ranges (from last 90 min to last 24 hours). Nevertheless, the software is highly configurable through over 170 parameters that can be changed in configuration files. These files can be modified by the specialized operator on Earth and then

2011 JINST 6 C12037

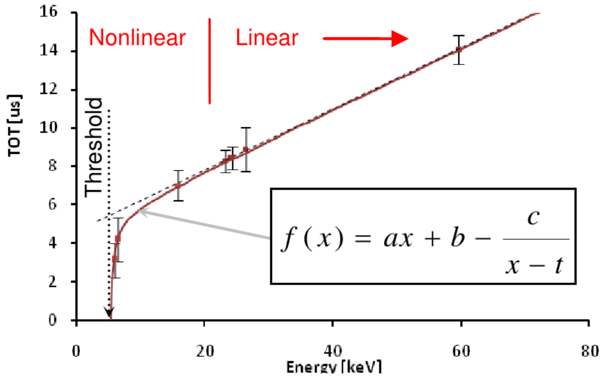


**Figure 3**. Dependence on the particle energy of the TOT signal measured by a single Timepix pixel. The dependence is modeled by a surrogate function $f$ depending on four parameters [5].

uploaded to the ISS. The software automatically checks for changes in the files and updates the configuration accordingly. The raw data from the detector together with log files are saved on a server on board the ISS and are sent back to Earth for further analysis. The granularity of the log files can be adjusted for each software part individually. This allows to debug problems or find the best setting values for the data analysis algorithms by operators on Earth while running the software on the ISS.

# 3 Data analysis

The raw data from the Timepix detector are analyzed in several steps in order to determine the equivalent dose rate and the total cumulated dose rate.

## 3.1 Energy calibration

For dosimetry measurements the Timepix detector is operated in TOT (time-over-threshold) mode, where it can measure the amount of charge collected in each pixel. This allows for measuring of the total energy of the particle by summing over all pixels in its track.

Since the response of all pixels is not identical, an energy calibration has to be performed. The calibration method [6] is based on a measurement of the characteristic X-ray fluorescent radiation using only single pixel clusters. As a result, for each pixel a calibration curve (see figure 3) is calculated. This curve is determined by 4 parameters: a,b,c and t. As a result 4 calibration matrixes are generated for the detector that are used during measurement for converting TOT values to the energy.

## 3.2 Cluster analysis

The dose equivalent is dependent on the type of incident radiation. Therefore it is necessary to distinguish different particle types. The Cluster Analysis [3] is a pattern recognition algorithm that identifies incident particles and sorts them into different categories.

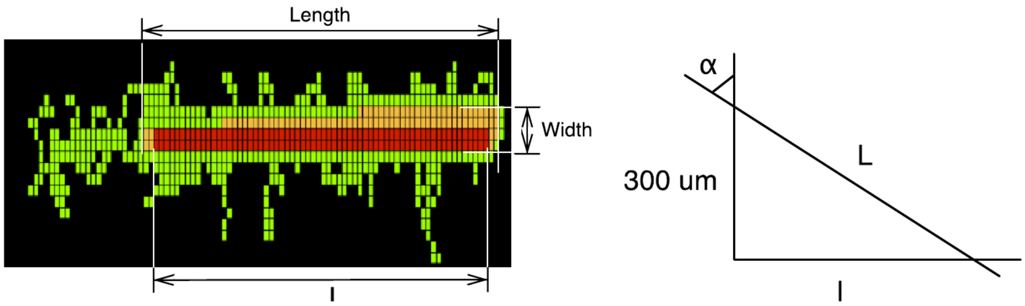


**Figure 4**. Track of 400 MeV $^{56}$Fe measured in the Timepix detector (left). Yellow and red pixels represent the core charge of the particle, green is the charge caused by charge diffusion and delta rays. Red is the skeleton of the track, whose length is the projected path-length $l$. Calculation of the traversed length $L$ (right) from the projected path-length $l$ and the sensor thickness.

### 3.3 LET calculation and quality factor

To calculate the dose equivalent, each type of radiation is given a so-called Quality Factor, which is a simple linear multiplier of the dose deposited by each type of the radiation. The total deposited energy is determined by summing energy deposition in all pixels of the track that the particle leaves in the sensor. For strongly interacting particles such as protons or heavy ions, the dose equivalent is not only dependent on the particle type, but is more acurately a function of the LET (Linear Energy Transfer) of the traversing particle.

The LET is a factor calculated by the total deposited energy $E$ divided by the length $L$ of the traversed mass. When an incident particle travels through the detector it leaves a charge cloud that is the projected path-length $l$ of the traversed length $L$ and the surrounding charge caused by charge diffusion phenomenon and delta rays. To determine the projected path-length, the surrounding charge needs to be filtered out so that only the core charge remains (see figure 4). The projected-length is then calculated as a difference between the core charge length and width:

$$l = (\text{Length} - \text{Width}) \times 60 \;\; [\mu\text{m}]$$

where 60 is conversion from pixels to $\mu$m (55 $\mu$m pixel pitch, 5 $\mu$m space between pixels).

Having the projected path-length and knowing that the thickness of the sensor is 300 $\mu$m, the LET can be calculated:

$$L = \sqrt{l^2 + 300^2} \;\; [\mu\text{m}]$$
$$\text{LET} = \frac{E}{L} \;\; [\text{keV} \cdot \mu\text{m}^{-}1]$$

The Quality Factor as a function of the LET is shown in figure 5. The algorithm uses the nominal quality factor curve. The deposited energy of the particle is multiplied by the quality factor corresponding to its LET. The energy from all incident particles is summed and the dose in silicon is calculated. This dose is then converted to the equivalent dose in water by correcting for different densities.

2011 JINST 6 C12037

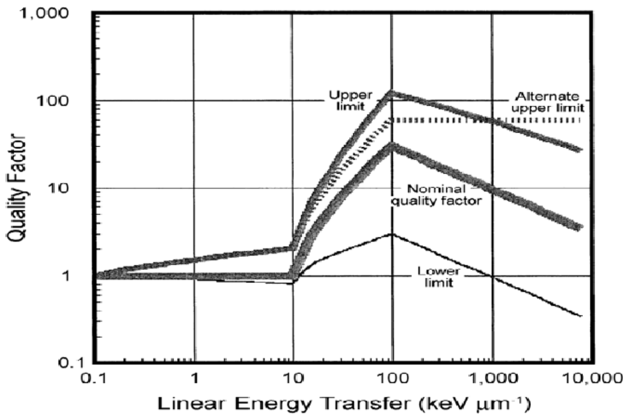


**Figure 5**. The Quality Factor as a function of LET as proposed in NCRP 153 (2008). The upper and lower limits are roughly comparable to 95% confidence limits, although they are actually based on a risk-assessment analysis. The nominal factor peaks at 30 at 100 KeV/mm, but remains at 1 up to 10 KeV/mm. These values are based on long-term risks (e.g. cancer), and the reason for the decline at LETs above 100 KeV/mm is the increasing probability of cell death. In this scenario, cell death is preferable to survival in a mutated form because a dead cell poses no risk that it or its progeny will become cancerous.

### 3.4 Frame rate algorithm

In the radiation environment on board the ISS the level of radiation is changing continuously. The differences in the intensity in different positions during the orbit can be in orders of magnitude (e.g. South Atlantic Anomaly). The cluster analysis algorithm can recognize single particles only when their tracks are not overlapping. It is crucial to continuously adapt the acquisition time (detector shutter time) so that the frame occupancy is constant and tracks are not overlapping. The Frame Rate Algorithm automatically adjusts the frame rate according to momentary radiation conditions by performing an analysis of occupancy of the previous frames. It takes into account pixel count, pixel volume, cluster count or cluster types.

## 4 Software testing

Software algorithms were tested during several experiments. The LTE calculation algorithm was tested with data from the HIMAC facility in Japan and the NASA Space Radiation Laboratory at Brookhaven with heavy ions. The measurements were performed for different (known) angles of incident particles and the their tracks in the detector were analyzed by the software. Figure 6 shows the application of the algorithm to some 60-degree incident tracks. While there is some spread in angular resolution, when converted to the effect on the LET, the errors are very small. Table 1 shows average calculated angles for different known angles of incident particles and standard deviation (variance) of the corresponding calculated LET. It is visible that the standard deviation of LET determination is for all angles less than 1%.

The Frame Rate Algorithm was tested with an X-ray tube by changing the tube current. With higher X-ray intensity, the acquisition time was decreasing and visa versa. However, the dose rate normalized to the current remained constant (see figure 7).

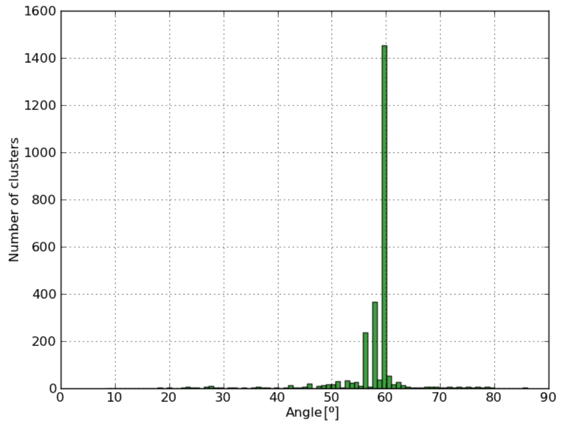


**Figure 6**. Distribution of calculated narrow angular bins from measurements of known 60-degree incident particles.

**Table 1**. Calculated angles and std. dev. of LET from particle tracks ($^{56}$Fe ions, 400 MeV/u) for different angles.

| Incident angle | 30° | 60° | 75° | 85° |
|---|---|---|---|---|
| Determined angle | 28.5° | 57.9° | 75.1° | 84.3° |
| Std. dev. LET | 0.07 % | 0.02 % | 0.02 % | 0.79 % |

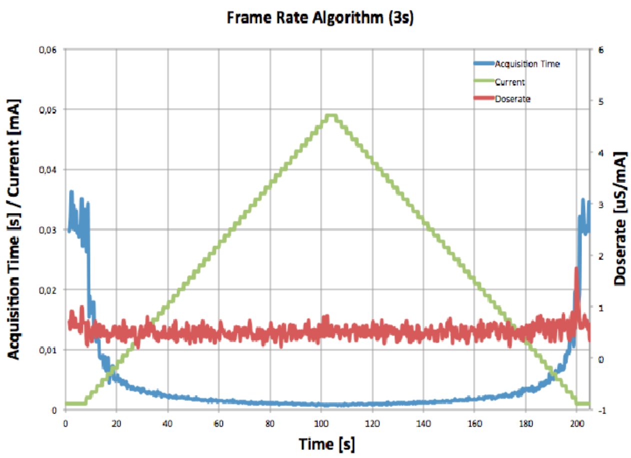


**Figure 7**. Test of Frame Rate algorithm on an X-ray tube with different intensities. With changing X-ray intensity (green), the frame rate (blue) changes accordingly whilst the dose rate remains constant (red).

## 5 Conclusions

It has been shown that the Timepix detector is suitable for accurate and sensitive dosimetry measurements. A new dedicated hardware for such measurements was developed and tested. The current Timepix control and data acquisition software was upgraded and extended for dosimetry purposes. The software automatically analyzes data from Timepix detector and distinguishes each particle type. Moreover, for heavy particles it calculates the LET and assigns a Quality Factor. As an output it shows the estimated equivalent dose rate and the total cumulative dose taken since the beginning of the run. The software performs the measurement automatically and adjust the parameters according to the particular instantaneous radiation environment. It also features extended possibilities of configuration.

The data analysis and the frame rate adjustment algorithms were tested during several experiments on accelerators or with an X-ray tube. The software and the hardware will be evaluated during a mission on the ISS towards the beginning of 2012. The data measured on the ISS will be then used for further analysis and improvements of the software.

## Acknowledgments

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