Study to Identify Detector Systems for Small Low Energy Particle Detector Instruments

Summary

RFQ/3-10706/03/NL/PA

Document No	:	SPM-FRS-PSI-001
Issue		: 1.0
Date		: November 30, 2004

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Summary

During last decade several new technologies for radiation measurements were developed and significant progress was achieved in miniaturisation and power reduction. Together with modern simulation tools such novel devices will allow for implementation in space simple but powerful detection systems capable to meet wide range of requirements. The study of these detectors was also motivated by lack of measurements and difficulties in radiation belts modelling still persisting after over 40 years from their discovery. Current data does not cover the whole range of particle energies and their space distribution. In particular the low energy electrons (up to few hundred keV) are still short of data. Such electrons can provide new facts about acceleration processes in the magnetosphere. They can also cause background increase in the X-ray observations or create radiation hazard for spacecraft instruments. Therefore new instruments optimised for space radiation measurements need to be developed and flown.

After an extended inquiry of suitable detector technologies the microstrip detector was chosen as the most promising candidate. In the selection procedure a set of requirements posed on the radiation monitor in space has been defined and applied. Modern detection technologies like Silicon microstrip detectors are good candidates for space applications as radiation monitors. Such miniaturized instruments can be easily modified to various particle types and energy ranges and adapted to different and harsh space environments. The potential of the microstrip based device for space measurements has been demonstrated in course of this work with the help of already existing detector models and extensive computer simulations.

The candidate detector - Small Particle Monitor (SPM) - was defined using as an example the MYTHEN microstrip system developed at PSI. The model detector is a Si semiconductor consisting of 128 strips, 50 μm wide and 8 mm long. Their thickness of 300 μm has the advantage of being fully depleted even with standard spacecraft bus voltages. Moreover, the electrons with energies up to about 250 keV deposit their all energy inside of the waver. In the first step of the study such components as sensor dead layers, collimator geometry and veto detector were defined and optimized. Several assumptions were also made on the whole device like the housing shape, dimensions and thickness, total mass and on number of printed boards and connectors. Prototype design has dimensions of L=5, W=5 and H=3 cm and full weight of 150 g. Power consumption is estimated to be about 200 mW. Detector response toward different radiation sources was modelled using GEANT4 packet. Analysis of the electron responses demonstrates detector ability for its space use. The data for mono-energetic electrons reveal the low energy threshold of 8 keV and the peak to tail ratio reaching a factor of 4. The response matrix is almost flat up to ca 200 keV with the maximum around 150 keV. At energies larger than 200 keV, the response matrix values quickly decrease. Therefore measurements at higher energies shall be correspondingly longer.

Spectral contamination by higher energy electrons (as well as heavier particles) could be only partially prevented by the use of a veto detector. Considering electron spectra and fluxes in space it will not pose any problems. The high energy particle intensities are orders of magnitude lower and they cause only small contamination below few hundred keV. Simulations did not indicate any troubles with enhanced levels of secondary radiation like bremsstrahlung. This conclusion however, was drawn using only results from the whole particle monitor but did not include any secondary radiation generated by spacecraft materials in the monitor vicinity.

It was also found that single electrons can cause multiple events as they cross through several strips. Number of such events depends on the strip width and strongly increases with the electron energy. In order to keep their level low the strip size should be modified by

increasing the strip widths or by clipping several strips together. The suggested width of the detector strip pitch is equal to 250 μm. In order to keep the detector area unchanged one might reduce the strip length accordingly. In addition, the collimator opening geometry should prevent detection of particles coming at large angles.

Performance of the monitor in orbit was simulated for both electrons and background particles: protons and X-rays, taking their characteristic energy spectra in space. Static radiation belt models AE8MIN and AP8MIN (NASA) and CREME Cosmic Ray model from the SPENVIS suite were used for this purpose. Results were obtained for LEO (500 km, 51°), polar (700 km, 89°), GEO (36000 km, 0°) and GTO (300-36000 km, 31°) orbits. They all show smooth electron responses with acceptable counting rates. Thus, even for the highest anticipated fluxes the detector rates should be still tolerable by existing read-out electronics.

Simulations based on the static models show that for regions with higher electron flux concentrations like electron belts the spectral contamination with orbit averaged proton fluxes is on the level of few percent. Thus the detector is very well suited for measurements in predominantly electron environments. Background sources like diffuse X-ray photons or Cosmic Rays have levels of only few counts per second and will not mess up with higher rate detections of electrons. However, bigger background separation difficulties may arise in regions dominated by protons. In the current monitor design the low energy responses for all particles look similar. Therefore one must apply special measures for better discrimination between different particles and in order to get rid of the unwanted proton events. The first method takes advantage of differences the multi-strip response distributions between protons and electrons. As protons deposit their whole energy practically always in only one strip, this information can used to determine their contamination level. Another method utilises difference in the stopping power between protons and electrons of the same energies. It implies covering of several strips with a thin layer of absorber. Protons with energies up to 1000 keV will be fully stopped in only 10 μm thick Al foil (the same layer barely stops 35 keV electrons). It will reduce proton fluxes by even three orders of magnitude. Other methods are also possible but they are either technically difficult like depletion layer changes with the applied voltage or often not allowed onboard like sweeping out unwanted particles by using magnetic fields.

Detector response simulations were complemented and verified by irradiating a test microstrip detector with low energy photons using secondary X-ray sources. The prototype developed for PSI X-ray crystallography was already equipped with the readout chip designed in radiation hard technology. Measurements showed a good agreement with the simulations and allowed for confirmation of the detector performance requirements: noise level (5σ) $\approx$ 6 keV, energy resolution $\approx$ 3 keV and maximum read-out rates $\approx$ 1 MHz/strip.

Current monitor design can be also easily adapted to measure other particles and energy ranges. Using already existing GEANT4 simulation tools such a study is readily possible.

Overall results from this study imply that the proposed detector fulfils initial conditions put on its space implementation and is a good candidate for future measurements on satellites. Present development of the small particle monitor can be continued with more refined modelling. Further, detailed requirements studies including their experimental testing can also be performed in the laboratory using already existing detector and readout-chip prototypes.