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SIMULATION OF SPACE RADIATION FOR NANOSATELLITES IN EARTH ORBIT*

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Abstract. This paper presents ongoing research in quantifying space radiation effects on satellite subsystems. For this purpose, various particle models were used in computing radiation fluxes estimates for low Earth orbit. The predicted spectrum of these charged particles was selected to be used in modelling the radiation transport inside the spacecraft.

Key words: radiation, radiation effects, Monte Carlo Simulation, satellites, cosmic rays.

1. INTRODUCTION

This paper focuses on estimating the performances of small satellites under the influence of space radiation typically encountered in Earth's orbit. Traditional spacecrafts use custom, radiation hardened devices that are designed and manufactured to withstand high radiation levels. Small satellite systems generally use COTS (commercial off the shelf) components that are built for on ground operations. This research is justified by the need to better understand the radiation environment inside spacecrafts, identify vulnerable subsystems and means of providing additional protection. Thus our studies are directed towards increasing the reliability of small scale satellites.

This paper presents an analysis of the radiation environment for typical orbits. Also the implementation of the radiation vulnerability analysis on a nanosatellite class spacecraft is illustrated together with preliminary results.

2. RADIATION ENVIRONMENT ANALYSIS

The driving factor in assessing the radiation environment for a space mission is the orbit of that mission. The description of this environment takes into account

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the particles trapped in the Earth's magnetic field, particles emitted by the Sun together with particles from the Galactic Cosmic Rays (GCR) in order to describe the radiation field based on its contributors [1, 2, 3, 4].

The present paper focuses on LEO (low Earth orbit), the orbit of choice for small satellite missions. The radiation environment was analyzed using two online estimators: particles from the radiation belts together with solar generated particles where analyzed using Spenvis [5]. For high energy GCR (galactic and extragalactic cosmic rays) the expected fluxes were calculated with the Creme96 model [6, 7].

For all the cases studied a quiet magnetosphere was presumed (no magnetic storms). For completeness all fluxes were estimated at both solar minimum and solar maximum.

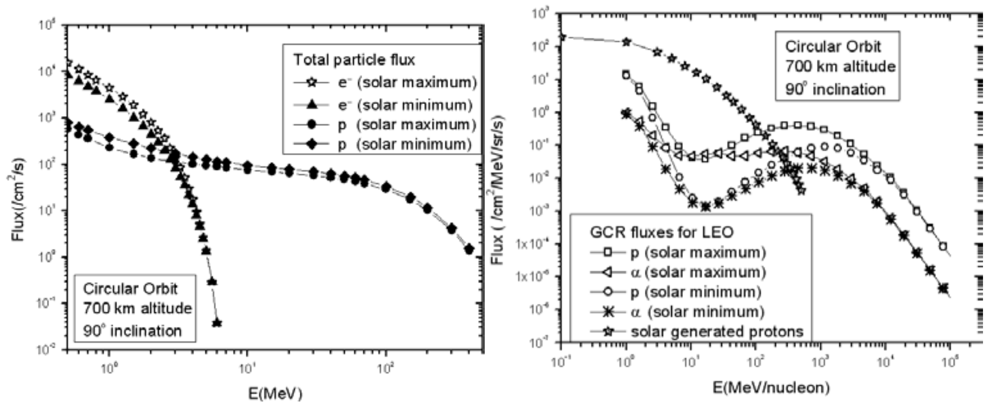

Fig. 1 – Estimated particle fluxes for a circular polar orbit.

Initial estimations of the radiation levels were made for the most encountered orbit: circular polar orbit at 700 km altitude and 90^{o} inclination. A comparison between the expected differential electron and proton fluxes during solar minimum and solar maximum is represented in the left graph of Fig. 1. One can observe that for this low orbit the radiation levels change very little during a solar cycle.

The right graph of Fig. 1 shows the variation of the Hydrogen and Helium ions (the most abundant ions in GCR) at solar activity extremes. It is easy to observe that a maximum in solar activity results in a decrease of the intensity from this radiation source. The decrease is more pronounced between 1 MeV and 500 MeV. For very high energy particles this attenuation is unnoticeable.

The fluence for protons emitted by the sun during a one year period of solar maximum was also calculated and plotted on the graph. It is important to note that the fluence accounts for several emission events and not a continuous emission. It is therefore more damaging to the spacecraft since an unusual number of errors can be triggered in a short period of time. For comparison purposes the fluence value was averaged and plotted on the same graph with GCR. We can observe that the

Sun particle emissions during maximum supplements the decrease in GCR fluxes and the total number of particles is actually greater than at minimum.

3. SPACECRAFT SIMULATION

The present research is applied to a nanosatellite developed at the University of Bucharest and the "Politehnica" University of Bucharest. For this purpose an analogue Monte Carlo simulation code was developed for a physical model of the satellite [8]. The model was initially implemented in GEANT 3.21 and later developed for Geant 4 [9]. Each of the satellites' subsystems was represented with the geometric shape and its associated material. Therefore each subsystem is approximated as a homogeneous geometric body with properties defined by its chemical composition and mass.

Represented subsystems are: *Struct* (mechanical structure), *OBC1* (primary on board computer), *MHX* (2.4 GHz radio transceiver), *UHF* (433 MHz radio transceiver), *EPS* (electronic power supply unit), *BAT* (two Li-Ion rechargeable batteries), *CAM* (digital camera interface board), *uCAM* (DSP microcontroller for the digital camera), *DET* (scintillator for radiation detection), *OBC2* (secondary on board computer), *OBV* (camera lens mount with its aluminum chassis). The materials for these subsystems are defined in Table 1.

Table 1
Material definition table

Material		C	F	Sn	Pb	Al	Si	O	Density (g/cm3)
Z element		6	9	50	82	13	14	8	
A element		12.01	19.00	118.71	207.20	26.98	28.09	16.00	
Atom ratio	*OBC*	0.20	0.20	0.09	0.06	0.10	0.25	0.10	2.5
Mass ratio		0.06	0.09	0.28	0.29	0.07	0.17	0.04	
Atom ratio	MHX	0.15	0.15	0.09	0.06	0.25	0.25	0.05	2.7
Mass ratio		0.04	0.07	0.27	0.27	0.16	0.17	0.02	
Atom ratio	UHF	0.23	0.23	0.09	0.06	0.05	0.25	0.10	2.3
Mass ratio		0.07	0.11	0.28	0.29	0.03	0.18	0.04	
Atom ratio	EPS	0.25	0.25	0.09	0.06	0.05	0.25	0.05	2.2
Mass ratio		0.08	0.12	0.28	0.29	0.03	0.18	0.02	
Atom ratio	CAM	0.20	0.20	0.06	0.04	0.05	0.35	0.10	2.3
Mass ratio		0.07	0.11	0.22	0.22	0.04	0.29	0.05	
Atom ratio	OBC2	0.20	0.20	0.06	0.04	0.10	0.30	0.10	2.4
Mass ratio		0.07	0.11	0.22	0.23	0.08	0.25	0.05	
Atom ratio	uCAM	0.15	0.15	0.03	0.02	0.30	0.27	0.08	2.7
Mass ratio		0.06	0.10	0.13	0.13	0.28	0.26	0.04	
Atom ratio	OBV	0.00	0.00	0.00	0.00	0.40	0.20	0.40	2.5
Mass ratio		0.00	0.00	0.00	0.00	0.47	0.25	0.28	

For the batteries a composition of Li, Co, O and C was used. The scintillation detector was considered as $C_{14}H_8O_2$ according to the specifications of the manufacturer.

The satellite was placed in a galactic material simulating the interplanetary space. We used the estimated radiation fluxes as input for the radiation source of a Monte Carlo simulation for the nanosatellite. Radiation is considered to be isotropic since any anisotropy in the radiation environment is cancelled by the satellite's constant spinning. Therefore the radiation source was considered to be a spherical surface outside the spacecraft. Particles were emitted isotropic from random points on the sphere. The energies of the particles were randomly selected based on a distribution law derived from the estimated fluxes. Fig. 2 presents the evaluation of the random energy generator by showing a comparison between the normalized expected flux and the energy spectrum of the simulated particles.

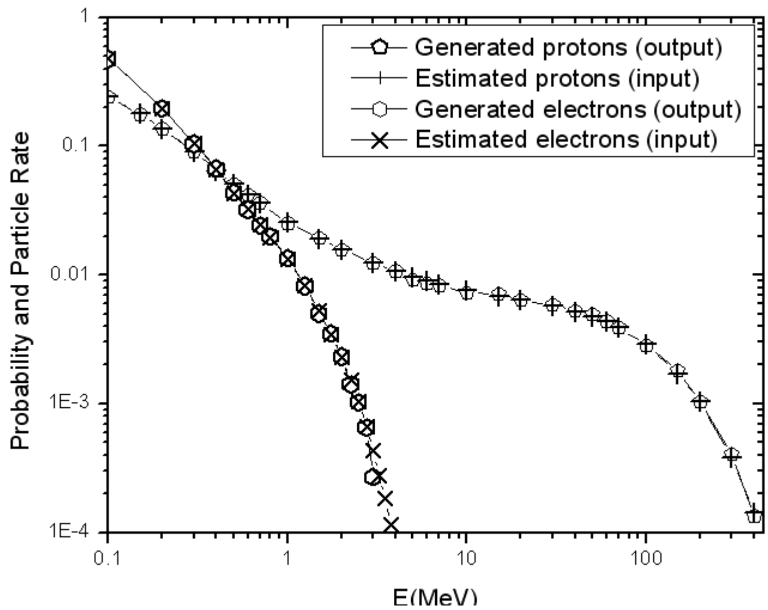

Fig. 2 – Simulated particle rate *vs*. normalized expected flux.

4. INITIAL RESULTS AND CONCLUSION

For estimating the ionizing effects the total deposited energy for each of the modeled subsystems was evaluated. For measuring single event effects the linear energy transfer was computed using the deposited energy, the step length and the density of the subsystem environment [10, 11].

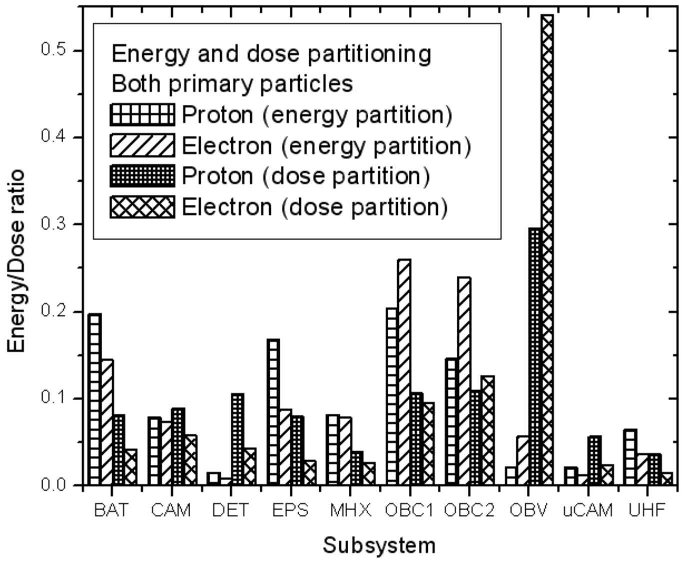

Fig. 3 – Frequency of simulated particles *vs*. normalized expected flux.

From the energy deposited in each subsystem and the material properties we compute the radiation dose estimate for each of the subsystem. The intial results include partitioning of the deposited energy and dose estimate for each satellite subsystem (Fig. 3). The radiation received by the external satellite structure is not shown in Fig. 3 since it accounts for more than the cumulated value for the other subsystems (59% of the total energy for protons and 98% of the total energy for electrons is deposited in the structure). These results, obtained using the Geant 4 simulation program are in accord with the previous model that used GEANT 3.21.

The radiation doses for both electrons and protons were calculated and estimates are given for a period of 1 year in Table 2.

Table 2

Dose estimate per subsystem (krad) for 1 year mission

	MEC	BAT	CAM	DET	EPS	MHX	OBC1	OBC2	OBV	uCAM	UHF
e−	6.05	0.022	0.031	0.022	0.015	0.014	0.051	0.068	0.29	0.013	0.008
p	2.60	0.39	0.43	0.51	0.38	0.19	0.51	0.53	1.43	0.27	0.18
Total	8.65	0.412	0.461	0.532	0.395	0.204	0.561	0.598	1.72	0.283	0.188

The ratio of the doses received by different subsystems is less sensitive to the flux considered in simulations. Therefore reliable estimates of the dose in various subsystems can be obtained by multiplying the real dose recorded by the onboard radiation detector with the computed ratio of the corresponding dose. Thus, the simulation enables the identification of the dose in each of the satellite subsystems.

Moreover it is possible to correlate computer errors with the momentary dose measurements, leading to better understanding of the radiation effects.

Data from these initial results can be used to apply shielding to vulnerable subsystems. It is also possible to shift subsystems and try different configurations for obtaining optimum radiation shielding of sensible components.

Current results can indicate the average radiation level per subsystem however there is no way to differentiate between an integrated circuit and a resistor in that system. Thus a further discretization of the model is required in order to identify and shield specific components and not whole subsystems.

The main future development of the research is the validation of the expected results with satellite data and proving that COTS components can be used reliably in space system with minimal efforts.

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