RADIATION HARDNESS OF COMMERCIAL SEMICONDUCTOR DEVICES FOR FIRST SLOVAK CUBESAT

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1. Introduction

In February 2016, the first Slovak satellite, the skCUBE, is going to be launched into the orbit of the Earth [1].The satellite will be of a CubeSat type, based on a 10 cm cube weighing less than 1 kg. The CubeSats[2] are increasingly important for research and educational space missions. They are far less expensive than traditional satellites. To reduce their weight, they use the frame based on composite material, providing little shielding from the space environment. To minimalize their costs, they use commercial electronics, relying on low Earth orbits and short mission durations, to avoid radiation damage. The skCUBE will be sent by the Falcon 9 space rocket to the elliptic orbit, with an apogee altitude of 720 km, a perigee altitude of 450 km and an inclination angle of 98˚. At this orbit, it is assumed, that the mission is going to take more than one year(maximum 3 years) and the total ionizing dose exposure can reach up to 400 Gy per year (40 krad/year) for effective shielding thickness of 0.254mm of aluminum [3]. The purpose of this work is to examine the radiation hardness of commercial semiconductor devices, which are going to be used in skCUBE power supply unit and to choose those types of devices, which are more radiation stable concerning their functionality.The skCUBE power supply unit will consist of six photovoltaic panel pairs, six solar battery chargers, two batteries and a processor unit.

2. Experiment

The radiation tests of commercial semiconductor devices for skCUBE power supply unit were done by linear electron accelerator with scanning beam UELR-5-1S [4] at University Centre of Electron Accelerators in Trenčín. The X-ray irradiation mode was chosen, using a tungsten target to convert the 5 MeV electrons to bremsstrahlung X-rays. First the appropriate dose rate was selected for the experiment. In the distance of 98 cm from the exit window of accelerator, the ionizing chamber was placed, to measure the surface dose. The dependence of the dose rate at selected position as a function of the accelerator beam repetition rate is shown in Fig. 1. The dose rate shall be low, to simulate the irradiation in the space. On the other hand, the feasibility of the experiment should be considered as well. For our experiment, the dose rate of 26 Gy/h was chosen, ensuring the exposure time to be a few hours to obtain the dose of 100 Gy. The tested devices were mounted on PCB (Printed Circuit

Board) 10 cm wide and 20 cm long. Then, the homogeneity of dose distribution in the area corresponding to the PCB board dimensions was measured. In Fig. 2, the dose distribution in direction perpendicular to the beam scanning is shown. It can be seen that the dose varies less than 5% in 12 cm wide area, where 10 cm wide PCB with electronics will be irradiated. The dose in the whole area of tested PCB differs less than 5%.The scanning width of electron beam was set at 40 cm and the scanning frequency to 0.25 Hz. The beam power was 49W.

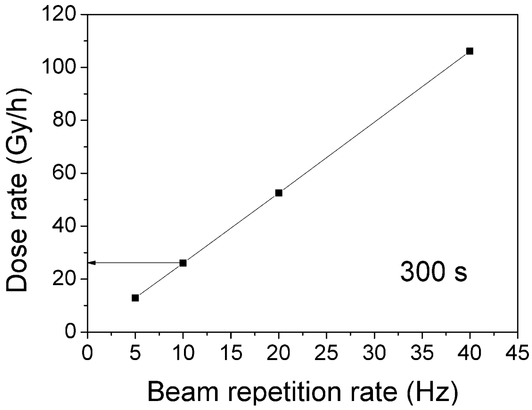

Fig.1: *Dose rate as a function of accelerator beam repetition rate.*

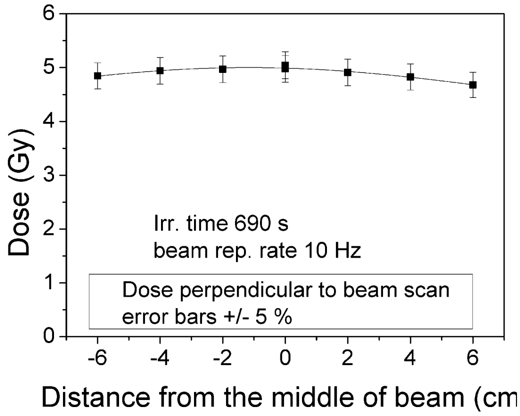

Fig.2: *Measured dose depending on the position from the centre of the beam in direction perpendicular to beam scanning.*

The board with semiconductor devices was irradiated in 13 steps, reaching the accumulative doses of 10, 25, 50, 100, 150, 200, 300, 400, 500, 600 and 700 Gy. The devices were divided into 2 groups proceeding the irradiation up to doses of 800 and 900 Gy in the first group and 900 and 1100 Gy in the second group. After each irradiation the electrical parameters of tested devices were evaluated. Two basic kinds of degradation were observed: the preservation of the input current with changes in output voltage and the preservation of the device functionality with rapid increase in its input current.

3. Results

The degradation of a first kind was observed for example with voltage references intended to provide the AD (analogue to digital) converters in the processor unit with constant voltage. Two different types of voltage references were examined: the REF3312, a low-power, low-dropout voltage reference applicable in a wide range of temperatures (- 40 up to 125 °C) and the ADR1581A, an accurate stable voltage reference with wide operating current range. In Figs. 3 and 4, the changes in voltage provided by the voltage references of both types induced by increasing accumulative dose are shown. The horizontal lines in both graphs determine the ranges of acceptable values of provided voltage. As it can be seen in Fig. 3, the REF3312 voltage reference preserves its correct function up to a dose of 700 Gy. At higher doses, one of tested samples exceeded given acceptable value of provided voltage. On the other hand, the output voltage of references ADR1581 gradually raises with increasing accumulative dose and exceeds the given limits at a dose of 200 Gy (Fig. 4). The radiation induced defects in device substrate expressed in output voltage increase. The change in input current of REF3312 references was minimal after irradiation. It increased from initial value of 3.32 μA and 3.41 μA; to 3.7 μA and 3.6 μA, respectively, at the most. The input current of ADR1581 voltage references changed within the range of 9.8 % from initial value of 335 μA during irradiation.

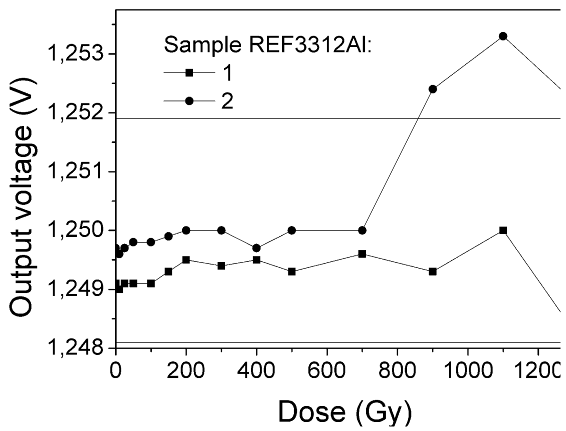

Fig. 3*The output voltage of a voltage reference, type REF3312Al, as a function of accumulative dose.*

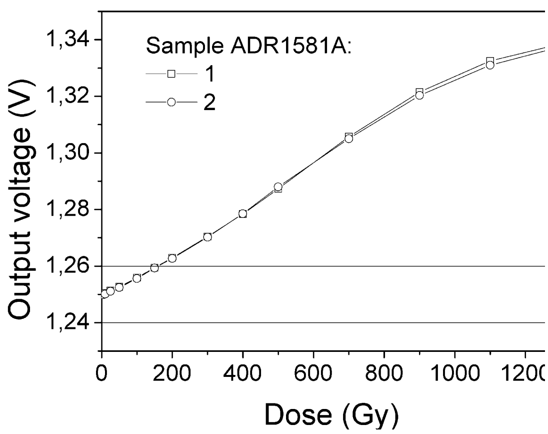

Fig.4*The output voltage of a voltage reference, type ADR1581A, as a function of accumulative dose.*

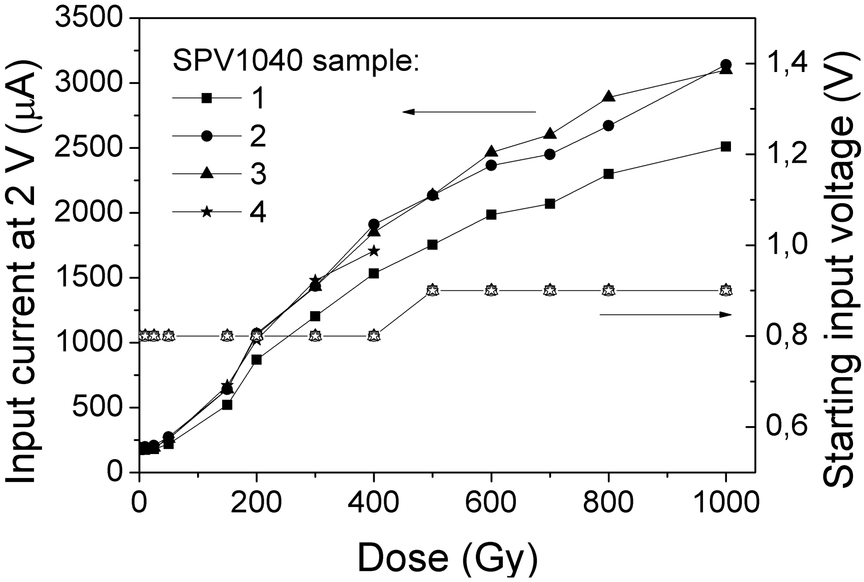

Fig.5: *The input current and thestarting input voltage of solar battery charger SPV1040 as a function of applied dose.*

In Fig. 5, another kind of device degradation is shown, represented by samples of solar battery charger. The SPV1040 is a low power, low voltage, monolithic step-up converter with embedded MPPT (Maximum Power Point Tracking) algorithm. It is capable to maximize the solar energy harvesting from a solar cell at low input voltage. Its aim in the satellite is to charge the battery by the current from solar cell at cell's highest output power. During irradiation, the input current of all samples of SPV1040 battery chargers was increasing (Fig. 5). Similar behavior of input current was observed also in [5] with voltage comparators and in [6] with CMOS devices. We can observe a dramatic raise in input current after an accumulative dose of 150 Gy in Fig. 5. The radiation induced defects in device probably caused the increase in leakage current, which contributed to a total current flow and lead to current increase. On the other hand, the functionality of battery chargers is preserved even after a maximum applied dose of 1 kGy.The voltage at which they start to charge the battery remains 0.8 V up to a dose of 400 Gy and then it slightly increases to 0.9 V. The value of voltage when the chargers stop charging the battery of satellite stayed unchanged at 0.4 V for all tested samples.

4. Conclusion

The radiation hardness of commercial semiconductor devices for skCUBE power supply unit was tested. Two basic kinds of radiation degradation were observed. In the first, the output voltage of device changes and the input current preserves with applied dose. This tendency exhibited the samples of voltage references. However, the output voltage change of REF3312Al reference was far smaller than in the case of ADR1581A. The REF3312Al withstand the dose of 700 Gy, which assumes its correct function in space for almost 2 years. The ADR1581A should terminate its function after a half of year in space. In the second kind of device degradation, the functionality is preserved, but the input current dramatically increases. An example of such degradation is the battery charger SPV1040. Its functionality was kept up to maximum testing dose of 1 kGy, but the input current increased and the power conversion efficiency of device decreased with the dose. This work helped the constructors of satellite power supply unit to choose those types of semiconductor devices, which will keep their functionality in space for longer period concerning the radiation.

Acknowledgement

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