Experimental Conformation of Ionizing Sensing for Space Radiation Environmental Awareness

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Abstract— **A prototype system has demonstrated the capability to use a custom-designed multi-channel sensor to monitor high energy radiation strikes by coupling the silicon sensing elements with a radiation tolerant computer system. The computer system uses triple modular redundant soft processors and custom signal conditioning circuitry to monitor single event effects caused by high energy particles passing through semiconductor materials. The operation of the system was confirmed by exciting the radiation sensing elements with high energy krypton ions from a cyclotron and monitoring the number of current spikes generated by the generation of electron–hole pairs as the ions lose kinetic energy through collisions within the silicon lattice of the sensors.**

Index Terms— **Radiation sensors, radiation tolerant computing, silicon radiation sensors, single event effects.**

I. INTRODUCTION

COMPUTER systems that operate in space must be able to withstand the detrimental effects of ionizing radiation. A Field Programmable Gate Array (FPGA) based computer has been developed to operate in this harsh environment by monitoring the environment and physically moving the processing to a backup portion of the fabric array [1]. This is enabled by a double-sided strip detector that has orthogonal strips on each face yielding x-y location of the ionizing radiation strikes [2]. The custom 16 × 16 channel silicon radiation sensor is positioned over the FPGA. The sensor monitors the locale of radiation strikes which can cause single event effects impeding the operation of the FPGA computer [3]. The system uses triple redundant soft processors programmed into a 9-tile computing system implemented on the FPGA. Three processors are operating at any given time with 6 spares. The three software processors are running identical circuits and a voter compares the outputs to detect possible discrepancies. If a fault is detected the affected tiles are removed from operation and a spare processor is brought online while the damaged section of the FPGA is partially reconfigured and repaired [4]. In a high flux environment the position sensing allows the computer fabric to monitor and maintain damage-free backup tiles ready for implementation. To confirm successful operation of the radiation sensing system, experimental testing was performed at the Texas A&M Radiation Effects Facility. Radiation testing was completed using a 25 MeV/amu krypton ion beam.

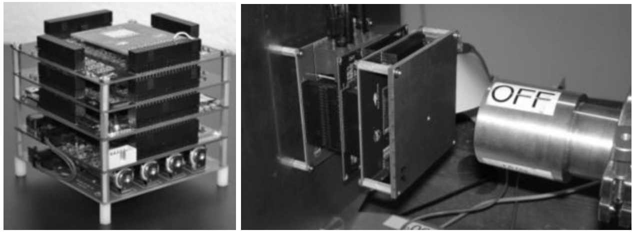
(a) (b)

Fig. 1. (a) The 1-U CubeSat form-factor approximately a 4 inch cube. The printed circuit boards from top to bottom are: sensor, signal conditioning, data interface FPGA computer, power and voltage regulation, and battery. (b) A stack subset with shielding to isolate the ion flux to one area of the sensor is ready for testing at the cyclotron.

II. EXPERIMENT DESIGN

The entire system consists of a stack of printed circuit boards each with different functionality shown in Fig. 1a. The first board holds the position sensitive sensor and is mounted on a board that amplifies and broadens the current pulses so that they can be counted by the FPGA computer. This is followed by the data interface board, the FPGA computer, the power and voltage regulator board and finally the optional battery pack. The system has been previously described [3]. The geometry was selected such that it could be used in 1U Cube Satellite structure for future space testing either on a high altitude rocket, on the International Space Station or as components in a stand-alone satellite. For this radiation awareness sensing demonstration the stack was reduced to only the pertinent sensor and conditioning circuitry. The Figure 1b image exhibits the experiment in the cyclotron testing chamber with an aluminum shield that has a small hole to limit the flux of ions to a specific region of the position sensitive sensor. Different shielding plates were used to excite different regions of the sensor.

III. RESULTS

Numerous tests were run that varied the shielding plate hole position, hole size, biasing of the sensor, and amplifier gains in the experiment. Figure 2 & 3 show examples of test run results.

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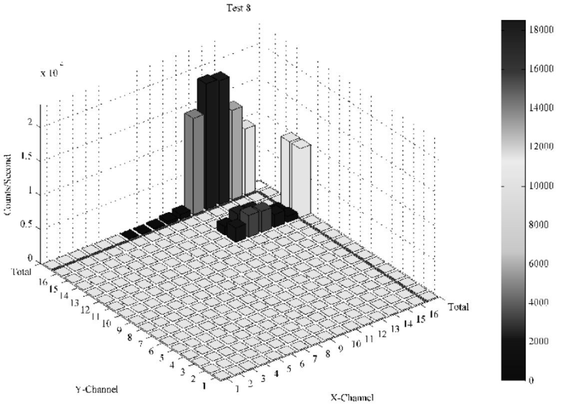

Fig. 2. Plot of the radiation strikes counted by the radiation monitoring electronics. The front channels (x-channel) were more sensitive, but generated some false counts (x-channels 7-10) that can be attributed to lateral diffusion of the electrons with reduced reverse bias.

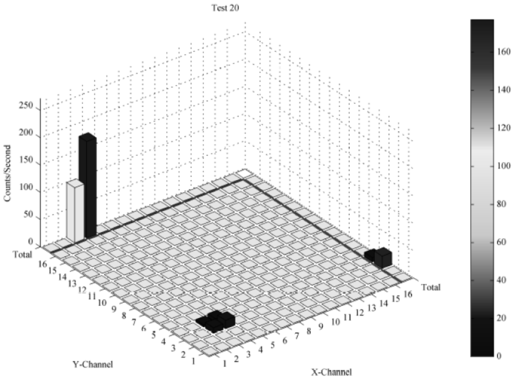

Fig. 3. An example of a "small" aperture test with reduced amplifier gain. This test greatly reduced the number of false counts and demonstrated a more optimal configuration for monitoring localized radiation strikes.

Test #8 shown in Figure 2 used a large hole in the upper right that spanned several 1mm × 1mm pixels of the 256 channel detector in both the x and y directions. Test #20 shown in Figure 3 resulted from using a smaller hole to focus the ion flux over only a two by two pixel area. Current pulses corresponding to Kr ions impinging on the sensor were counted for the front x-channel data as well as the rear y-channel data. It should be noted that the front channels recorded more strikes in all cases. This can be attributed to the energy of the Kr beam not being high enough to consistently penetrate the entire thickness of the radiation sensor. Also, the rear channels are designed to collect the hole current. The reduced hole mobility limits the diffusion length and ultimately the number of the rear current pulses. Furthermore, the rear counts were reduced by lowering the reverse bias voltage. This can be explained by the reduction of the depletion width and the collection volume of the sensor. This collection volume reduction limits the charge that is swept out of the depletion region so that it is below the threshold of the comparator circuit. Figure 4 shows the effect of reducing the reverse bias voltage; interestingly, counts were still generated without the need of reverse biasing the sensor. Even without fully depleting the sensor, charge will be collected if it is within a diffusion length of the unbiased depletion region. This led to postulating that no bias is required if the correct amplifier gain and threshold are selected, which will have the benefit of reducing the power consumption of the system for future space missions.

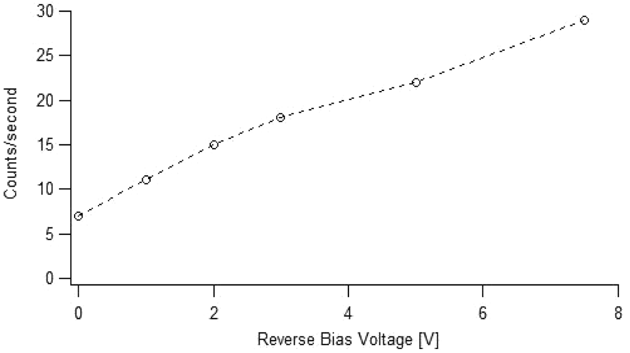

Fig. 4. Reduction of the reverse bias voltage decreases the number of counts recorded per second on the rear channels, but still recorded ion strikes without a bias applied to the sensor.

IV. CONCLUSION

A high energy ionizing radiation monitoring system was demonstrated by placing a position sensitive sensor in a cyclotron Kr ion beam (~25Mev/amu) and counting the number of current pulses generated by the ion collisions with the sensor. The sensor proved to have the position resolution capabilities required for the radiation mitigation scheme. The environmental awareness allows for the system to maintain undamaged spare processors operating in the background ready for implementation into the computing system when necessary.

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