Proton Testing of the NXP P4080 Processor at the COSY Accelerator

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***Abstract*—The NXP P4080 processor is tested for SEE using a proton beam of up to 500 MeV. Single and multiple bit upsets of the L2 and L3 cache were measured as well as core crashes with different signatures.**

***Index Terms*—SEE, Protons, P4080.**

I. Introduction

COMPUTING systems in space need to increase their processing power in order to handle the processing of the large amount of data provided by experiments and other payloads. Example applications would be complex docking maneuvers or autonomous landing approaches.

Fraunhofer FOKUS is addressing these challenges in two recent studies MUSE and OBS-SA. Although the aim of the projects was somewhat different, in both cases the NXP P4080 processors was chosen. Being an 8-core processor with 1.5 GHz clock rate and a performance of theoretical 60 GIPS, it would be a large step forward to currently used processors. Although it is a COTS processor, its 45 nm silicon on insulator (SOI) process provides it with single event latchup (SEL) insensitivity and very low power consumption.

To investigate its sensitivity to Single Event Upsets (SEU) and to develop a possible mitigation scheme the chip has to be tested. This was organized by the radiation effects group at Fraunhofer INT. Based on the challenges the JPL faced when testing the less powerful P2020 processor [1], it was considered not feasible to do a test with an opened device. Unfortunately this made tests with heavy ions impossible, since there was no possibility during the project to get beam time at a high energy heavy ion accelerator. The only testing that could be done was a proton test.

II. Accelerator

The COSY accelerator facility, operated by the Institute for Nuclear Physics (IKP) at the Forschungszentrum Jülich GmbH, consists of the injector cyclotron JULIC and the Cooler Synchrotron COSY [2]. It contributed significant results to the understanding of the hadronic structure of matter since its commissioning in 1993 [3]. It provides protons and deuterons in the broad energy range from 20 MeV up to 2.5 GeV by de- or accelerating the 45 MeV protons or 76 MeV deuterons provided by the injector cyclotron. The number of particles is up to 10^{11}/spill. There are several internal targets as well as three external beam lines.

For the last 15 years Fraunhofer INT and IKP have been operating a dedicated radiation effects test facility at an external beam line of the JULIC cyclotron [4]. It was mainly used for displacement damage testing of electronics, optoelectronics and optics. Recently the opportunity has emerged to use COSY for more than hadronic physics experiments, like testing of detector systems, accelerator components, investigations on radioisotope-production

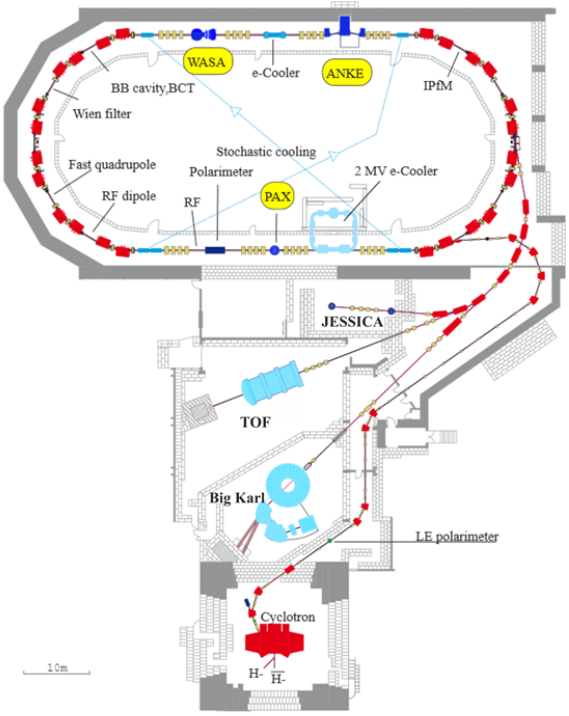

Fig. 1. Layout of the cooler synchrotron at FZ Jülich. Radiation effects testing can be done at the cyclotron with 39 MeV or at the JESSICA or Big Karl external beam lines..

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Fig. 2. MUSE board, used for the SEE testing of the P4080. On top of the P4080 a tungsten shield can be seen, which was used to shield the cores for cache tests to avoid crashes. This was only possible for the runs at 50 MeV, since protons of higher energy are too penetrating.

properties or for radiation effects studies [5][6]. For radiation effects tests there are two external beam lines available that are marked in Fig 1 as “Jessica” and “Big Karl”.

One of the challenges for the new applications is the dosimetry. Since the original hadronic physics experiments provided their own flux measurements, there was no dosimetry infrastructure provided for external users. Fraunhofer INT and the IKP setup a system of ionization chambers and Gafchromic® self-developing foils [7]. At the time of the experiment this system was absolutely calibrated against the ESA SEU-monitor [8] and therefore only usable up to 500 MeV for which there exists a trustworthy calibration of the SEU-monitor [9]. An extension of the calibration to higher energies with activation foils is currently in development.

III. Test Setup

All testing was performed with the MUSE boards (see Fig 2). At its core they contain a P4080 processor (the DUT) and a ProAsic3 FPGA for housekeeping and control. The P4080 based MUSE boards have been developed to evaluate the benefits of multi-core processors for future space applications with very high demands on processing power. In the context of the German OBC-SA effort Fraunhofer FOKUS developed a new version of the P4080 processor board which complies with the new CompactPCI® Serial Space standard.

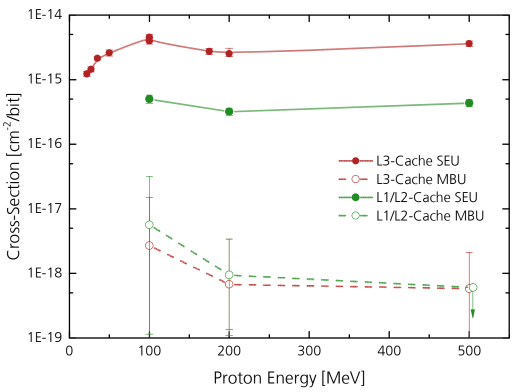

Fig. 3. Cross sections of the cache SRAMs per bit

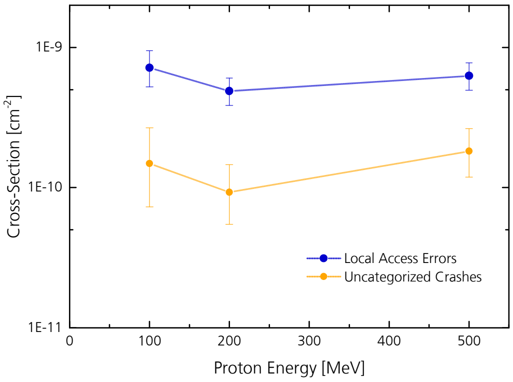

Fig. 4. Cross sections for core crashes and local access errors of the core coherency network.

Beyond radiation testing the processor board was subjected to a complete qualification process to raise the quality status to the level of a qualified prototype, corresponding to TRL6 within ESA’s qualification category. By this, the P4080 processor board and other components required for a complete space computer system are ready to be used in future missions [10].

First tests were done at the cyclotron running a Linux system on the P4080. This resulted in a lot of crashes and the system took a long time to reboot and be responsive again making the extraction of meaningful cross sections virtually impossible. A first solution was to manufacture small aluminum masks that only leave holes over certain parts of the chip with different function (e.g. L3 cache). This allowed the extraction of meaningful cross sections, but it is no solution to irradiations with higher proton energy, because shielding those protons with a mask will not be possible.

Before doing the high energy test runs it was decided to develop new test software [11]. This software features a backend program, running on the P4080, with a very small footprint. It is a small program running directly on the first stage boot loader (U-boot). The program is modular and can be reconfigured before each run to test only specific parts of the chip. It is checked by a watchdog running on the FPGA. Since one loop of the test program takes about 30 ms, the watchdog is set to 100 ms until it triggers a hard reset. After the reset the timer is set to 1s to wait for the bootloader to finish booting, which takes about 800 ms.

IV. Results

The results of the irradiation campaigns are shown in Fig 3 and Fig 4.

Fig 3 shows the cross sections of the cache SRAMs. The L3 cache is the only memory where reliable data from the early low energy runs at JULIC are available. The sensitivity of the L3 cache regarding SEU seems to be about an order of magnitude higher as that for the L2 cache. The L1 cache was not tested but it is assumed that it is similarly made and therefore of similar sensitivity as the L2 cache.

Multi-bit upsets (MBU) are multiple upsets in one read word. Since the scrambling of the cache memories is not known to the authors, there is no information on multi-cell upsets (MCU). Only very few MBU were measured during the irradiation campaign (<4), which accounts for the large error bars in Fig 3.

Since the final test setup was able to recover from crashes very fast, it is possible to give a cross section. There were primarily two kinds of crashes: the “uncategorized crashes” that showed no meaningful additional signature and “local access errors” of the core coherency framework (CCF).

V. CONCLUSION

The L2 and L3 caches as well as core crashes of a P4080 Processor were investigated with protons of energies up to 500 MeV. The MBU cross-sections are below 1E-17 cm²/bit and the cross section of core crashes is below 1E-9 cm². This demonstrates the feasibility of using the P4080 at least in a LEO environment, where the upset rate is dominated by protons.

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