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Development of a Radiation-Tolerant Component for the Quench Protection System

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The increase of the Large-Hadron-Collider (LHC) luminosity over the next years will also increase the levels of ionizing radiation in the accelerator surroundings. Critical systems like the QPS need to be upgraded for higher radiation tolerance. A high resolution ADC for a future QPS component was tested for its radiation tolerance using a 230MeV proton beam up to a dose of 3.4kGy. The error modes discovered were analysed and countermeasures to mitigate them were developed. To validate these countermeasures a prototype system utilizing them was tested. The results show a sufficient suppression of 99% of all errors.

Summary

The beams of the LHC are a strong source of ionizing radiation. Critical systems like the Quench-Protection-System have to be able to work in an environment of about 0.5-10 Gy of yearly irradiation. New radiation tolerant components are necessary for redesigning systems for such an environment. The ADS1281 is a high resolution (24bit) ADC which is planned to be used during the redesign of the 600 A QPS system.
The 600A QPS detects quenches by comparing the expected voltage drop over the magnet circuit with the measured value. The expected value is calculated from the measured current and voltage over the circuit. A high resolution ADC with high radiation tolerance is necessary to measure those values. Preliminary testing of the ADS1281 had already shown the latch-up immunity of the ADC. To further test the behaviour of the device under radiation an irradiation campaign at the Paul-Scherrer-Institute was conducted. The goal of the campaign was to identify any radiation induced error modes, especially those caused inside the digital filter subsystem of the ADC. With a simulated magnet ramp as input the complete ADC output during irradiation was stored. This data was then analysed for errors.
Four distinct error modes were found. The cause of two was the corruption of data-words inside the digital filter chain of the ADC. If the SEU occurred after the last FIR filter of the chain such a corruption only causes one wrong sample in the data stream. An SEU in previous stages leads to an error signal stretched over multiple samples. SEUs were also detected in the ADC configuration registers. This causes changes in the gain stetting of the ADC. Other possibilities for change most likely exist but were not observed. The last error mode discovered was a temporary stop of ADC functionality.
All discovered error modes have the potential to cause the sensitive QPS to trigger. This would lead to premature beam dumps and to a loss in beam availability. For the ADC to work as part of the QPS a system was developed to mitigate all of the discovered error modes. A chain of digital filters was developed to suppress the errors caused by data-word corruption to a degree that would not trigger the QPS.
The ADC configuration register is continuously monitored for corrupted settings. Upon discovery the ADC operation is paused and the configuration data is rewritten.After implementing some safety features most stops from the last error mode are not long enough to disturb operation. For the rare aberrant stops with length strongly exceeding the normal length a system to detect them and restart the ADC was implemented.
A prototype system implementing the first 3 countermeasures was already tested during another irradiation campaign. As results about 99% of all errors could be suppressed. A third campaign to test the restart countermeasure and analyse the behaviour in a mixed field will be conducted soon.

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