

AMC-BASED RADIATION MONITORING SYSTEM

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Abstract

This paper reports a novel radiation monitoring system able to monitor gamma and neutron radiation in an accelerator tunnel in the nearest proximity of electronic components of the control system. The monitoring system is designed as an Advanced Mezzanine Card (AMC) module and it is dedicated for the Low Level Radio Frequency (LLRF) control system based on the Advanced Telecommunication Computing Architecture (ATCA). The AMC module is able to communicate with the LLRF control system using both I²C interface defined by the Intelligent Platform Management Interface (IPMI) standard and PCI Express. The measured gamma radiation dose and neutron fluence are sent to the data acquisition computer using Ethernet network and stored in a database. Static Random Access Memory (SRAM) is applied as a neutron dosimeter. The principle of the detector is based on the radiation effect initiating Single Event Upsets (SEUs) in high density microelectronic SRAMs. A well known RadFET dosimeter is used to monitor gamma radiation.

INTRODUCTION

Bremsstrahlung gamma radiation and photoneutrons are produced during the operation of high-energy linear accelerators [1]. Therefore, the electronics of the LLRF control system is exposed to mixed neutron and gamma radiation field present in the linear accelerator environment. The control system of a linear accelerator is a complex electronic device and can be affected by radiation. Ionizing radiation continuously damages electronic components because of the Total Ionizing Dose (TID) effect. Since, mainly neutrons with energy lower than 30 MeV are produced, the particles affect mainly digital components by Single Event Effects (SEEs) [2]. Knowledge of neutron and gamma doses is crucial to understand and interpret radiation effects on electronic devices dedicated to the operation in the environment of high-energy linear accelerators. Indeed, it is advisable to monitor radiation produced in accelerator tunnels in real-time to estimate the danger and the life-time of electronic components and devices. Moreover, the increased neutron fluence in the accelerator tunnel causes generation of Single Event Effects (SEEs) in the sensing memory of the neutron detector. The electric field supplying accelerating cavities can be lowered when an unexpected increase of neutron fluence will be detected.

An on-line radiation monitoring system was installed in five various places of the Free Electron Laser in Hamburg (FLASH) to monitor both gamma and neutron radiation. Radiation detectors are installed opposite accelerat-

ing modules ACC 1 - ACC 5, two meters away from the beam line [3]. However, it is planned that the LLRF control system of the X-ray Free Electron Laser (X-FEL) will be designed with the application of ATCA and AMC standards. The ATCA and μ TCA crates with electronic hardware will be installed in the nearest proximity of the beam line. Therefore, its is desired to monitor gamma and neutron fluence inside the ATCA crate. Gamma radiation dose and neutron fluence registered in the tunnel should be gathered in a database. An unexpected neutron fluence increase should be registered as well. In such a situation an interrupt signal should be sent to the LLRF control system.

RADIATION MONITORING SYSTEM

The presented radiation monitoring system was designed according to the AMC standard. The designed AMC module can be used for gamma radiation and neutron monitoring inside the ATCA when installed on the ATCA carrier board or in the μ TCA crate. Radiation measured by gamma and neutron detectors is converted into electrical signal then digitalised and sent to the Intelligent Platform Module Controller (IPMC) - the ATCA carrier supervisory circuit. The IPMC circuit sends data to the Shelf Manager

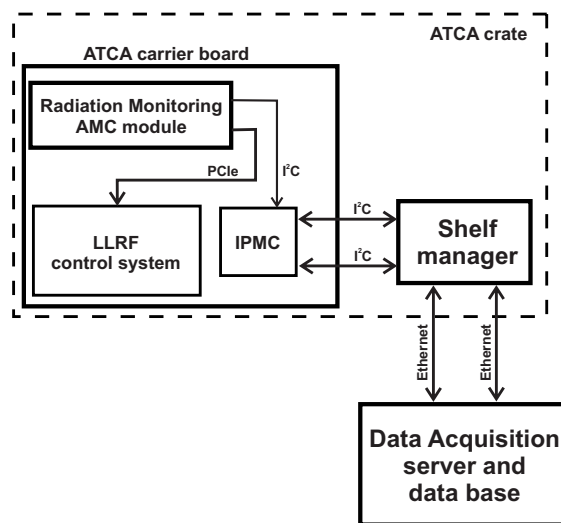


Figure 1: A block diagram of the radiation monitoring system

(ShM), the device responsible for the management of the whole ATCA crate. When the device is installed in the μ TCA crate data are directly sent to the ShM. The Shelf Manager forwards received data to the external data acquisition computer. Finally, data are stored in a database. The block diagram of the radiation monitoring system is pre-

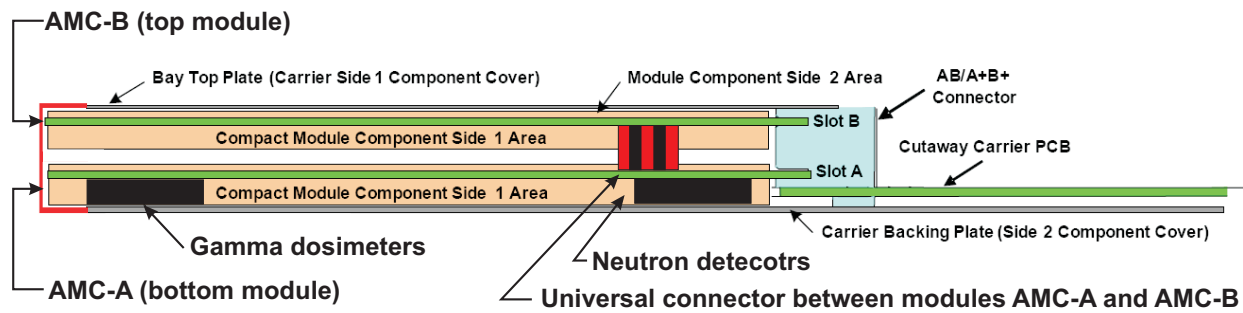


Figure 2: A single full size AMC module

sented in Fig. 1. The ATCA standard requires a duplicated Shelf Manager that has a redundant I²C bus and an Ethernet connection. Therefore, the data acquisition server has also a redundant connection to the shelf manager. Measured gamma dose, neutron fluence and temperature can be available via a simple web page, web-service protocol and DESY's internal DOOCS server.

RADIATION MONITORING AMC MODULE

The radiation monitoring module was designed as a single full size module (30 x 74 x 31 mm). The module consists of two submodules: the top AMC-B and bottom AMC-A, see Fig. 2. The top submodule contains the main controller and the Module Management Controller (MMC) responsible for the communication with an IPMC or ShM. Gamma and neutron detectors, signal conditioning circuits and analog-to-digital converters are installed on the bottom the AMC-A module, see Fig. 2. Both submodules are connected with a single 120-pin connector. The block diagram of the radiation monitoring module is presented in Fig. 3.

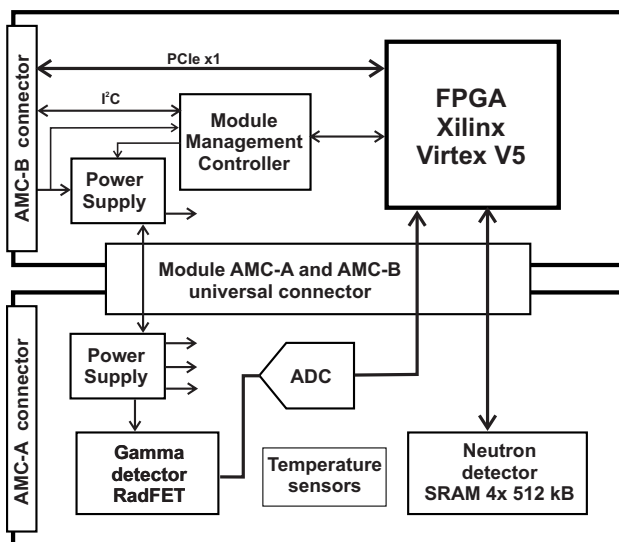


Figure 3: A block diagram of the radiation monitoring AMC module

The Module Management Controller was built with an application of ATMEL microcontroller Atmega 64. The MMC device is responsible for the AMC module supervision, its configuration after the insertion into AMC slot and deactivation when the module is extracted. The MMC communicates with the IPMC or ShM with a single I²C bus. When the module is inserted and activated, MMC makes data from all available sensors described in Field Replaceable Unit (FRU) and Sensor Data Records (SDRs) available. The MMC controller generates events that are sent to the ShM and logged when measured gamma radiation dose or neutron fluence is too high (according to the threshold level in the SDR). The MMC device is also responsible for the power management on the AMC module and the temperature measurement. The temperature is measured in three different spots of the AMC-B submodule and is measured in the nearest proximity of both gamma detectors and power supply on the AMC-A submodule.

The main controller was designed with Xilinx Virtex XC5VLX30T FPGA for the reading of data from radiation dosimeters. A simple state machine was implemented for checking static memory contents and reading digitalised voltage of the RadFET dosimeter. The state machine is protected against SEUs with the Triple Modular Redundancy (TMR) technique. The Xilinx FPGA is equipped with PCIe transceivers, therefore it is used for communication with the main LLRF controller.

Radiation detectors

Silicon sensors were used for the radiation measurement, RadFET as a gamma radiation dosimeter and Static Random Access Memory (SRAM) chip as a neutron fluence detector. Radiation detectors that were used are presented in Fig. 4. The RadFET is subjected to radiation in the sense mode when the drain and source electrodes are grounded. The device is switched into the reader circuit before the readout. The source electrode is reconnected from the ground to the current source. A 20 s delay after the reconnection is recommended to assure the stabilisation of switching traps created inside the Si-SiO₂ interface and silicon oxide [4, 5]. Defects made by gamma radiation cause an increase of the drain-source voltage of the transis-

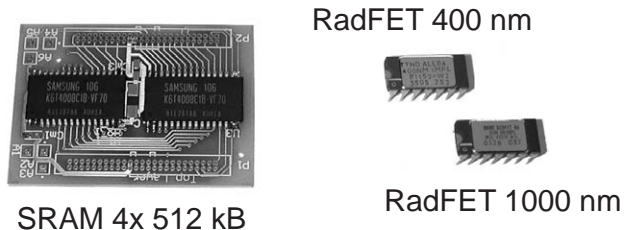


Figure 4: A neutron detector on the left hand side and gamma detectors on the right hand side of the figure

tor when a constant current flows through the device. The voltage drop on the conducting RadFET transistor is amplified and digitalised. The main state machine built with FPGA device is responsible for reading the digitalised RadFET voltage drop every 10 minutes. The maximum measured dose is limited because of the readout system's and RadFET's linearity. The irradiation is a destructive process, therefore RadFET must be replaced after a long-term irradiation when the radiation-increased threshold voltage is out of the readout range or a RadFET's linear region. Therefore, two boron implanted RadFETs fabricated by Tyndall company with different sensitivities were applied as gamma dosimeters: 10 kÅ and 4 kÅ, 80 mV/Gy and 46 mV/Gy respectively.

Four 512 kB K6T4008C1B-VB55 Samsung memories manufactured in 0.4 μm technology were chosen as a neutron dosimeter. Efficient methods were elaborated to improve their sensitivity to SEU. The reduction of the memory supply voltage from 5 V to 3.0 V resulted in 5.6 time multiplication of its sensibility. A further design of a suitable moderator allows also to increase memory's sensibility by 3.9 times. Finally, the sensitive volume of the memory-based sensor was enlarged four times by the application of four chips. Therefore, the total sensitivity of the neutron dosimeter was enhanced almost two orders of magnitude. The SRAM device can be also used as a simple SEU counter. The number of detected SEU within a given period of time is measured. When the number of detected SEU is increased above threshold level, MMC sends the alarm message to ShM, and the FPGA controller sends the interrupt to LLRF controller.

MEASUREMENTS IN FLASH

The initial radiation measurement was carried out in FLASH tunnel at DESY. The module was installed in the FLASH tunnel from 5th January 2008 until 28th April. The number of registered SEU in the sensing memory and increased RadFET voltage drop is presented in Fig. 5. The radiation monitoring system was disabled from 24th March until 8th April, therefore SEUs generated in the memory were not registered (the flat characteristics). However, the radiation was produced in the FLASH tunnel - gamma photons created more defects in the RadFET and the voltage drop on the transistor was increased, see Fig. 5.

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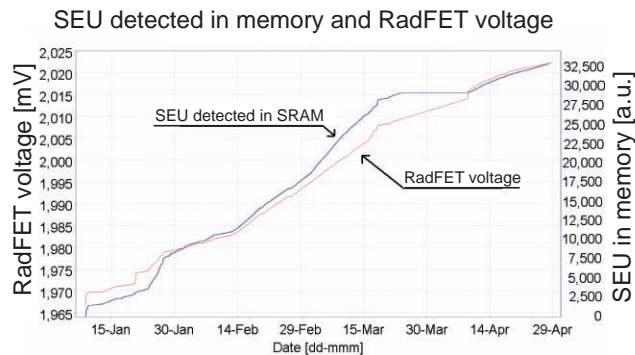


Figure 5: SEU generated in the sensing memory and RadFET voltage drop registered during the three-month operation in the FLASH accelerator tunnel at DESY

CONCLUSIONS

A radiation monitoring system dedicated for a ATCA-based LLRF system of a linear accelerator is presented. The system consists of the module with gamma and neutron radiation sensors designed according to the AMC standard specification. The measured data are sent using IPMI bus to the Shelf Manger and collected in the external database. The initial test of the system were executed in the FLASH accelerator at DESY. Dosimeters installed on the AMC module were not yet calibrated, however the number of registered SEUs in the sensing memory and the voltage drop on the RadFET detector were registered. It is planned to carry out in-situ calibration soon.

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