# AMC Radiation Monitoring Module for xTCA Based Low Level RF Control System

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***Abstract*—Modern Advanced/Micro Telecommunications Computing Architecture (ATCA/$\mu$TCA) standards gain popularity, not only in telecommunication industry, but also in High Energy Physics (HEP) area. These platforms are considered as the future platform for the Low Level RF (LLRF) control system of the X-ray Free Electron Laser (XFEL) project realized at Deutsches Elektronen-Synchrotron (DESY) facility. One of the most important features of an ATCA/$\mu$TCA based control system is its high reliability, which can be decreased by negative influence of neutron and gamma radiation produced during normal operation of linear accelerators. The XFEL laser will be built in a single tunnel to decrease costs of the project. Therefore, the LLRF system will be exposed to harmful radiation. It is recommended to monitor doses absorbed by electronic equipment. The gathered data could help to estimate lifetime of electronic devices and to schedule essential equipment replacement. The radiation detector should be integrated with the ATCA/$\mu$TCA system to allow measurements in close proximity to the electronisc, which helps to increase the accuracy of measurements. The paper describes a radiation monitoring module capable of monitoring gamma radiation and neutron fluence in real-time which fulfills the mentioned requirements and is designed in accordance with the AMC specification.**

***Index Terms*—Intelligent Platform Management Controller, Advanced Telecommunications Computing Architecture, Carrier Board, IPMI**

## I. Introduction

THE Advanced/Micro Telecommunications Computing Architectures (ATCA/$\mu$TCA), which belong to xTCA standard family, were designed to provide a unified standard for communication equipment, which results in a computing system characterized by higher reliability, availability and serviceability than those used before. The architecture features make it increasingly popular not only in typical industrial applications, but also in High Energy Physics (HEP) experiments. Many leading research centres i.e. Deutsches Elektronen-Synchrotron (DESY), Joint European Torus (JET), CERN, etc. consider the one of the xTCA standards as a base architecture for their control systems [1]. Electronics systems in HEP experiments are often exposed to extremely hard environmental conditions that include high temperatures, strong electric and magnetic fields or different types of radiation e.g. gamma and neutron radiation.

ATCA or $\mu$TCA are the leading candidates for the Low Level Radio Frequency (LLRF) control system base architecture for X-ray Free Electron Laser (XFEL), which is currently under construction at DESY facility [2]. The XFEL will be driven by 1.6 km long linear accelerator located in a single underground tunnel. Therefore, many electronic systems will be installed next to the main beam pipe and exposed to gamma and neutron radiation produced during normal operation of the machine [3]. A great majority of electronic devices is sensitive to these kinds of radiation. Many researches have been conducted to find the mechanisms and estimated scale of parameter degeneration [4]-[5]. The gamma radiation interacts with semiconductors mainly by the Compton Effect and electron-positron pair creation process and leads to charge build up and changes in Si/SiO2 interface state [4]. The basic parameters of MOS devices e.g. threshold voltage, transconductance, leakage currents are altered. It may be a reason of change in behavior of electronic circuits. The neutron fluence has different influence on electronics. It causes displacement damage effects and increases Total Ionization Dose (TID) through secondary level effects. Moreover, it is responsible for triggering Single Events Effects (SEEs) [4]. The most common Single Event Upset (SEU) affects digital devices and causes a change of the device state to te opposite one. Therefore, SEUs are usually observed in digital memories, microcontrollers and Field Programmable Gate Array (FPGA) chips. The unexpected change in memory cell of FPGA or microcontroller may lead to inappropriate behavior of the device and result in system failure. The ATCA or $\mu$TCA based LLRF Control System will consist of many complex circuits based on FPGA and DSP devices and should be characterized by reliability. Unexpected failures of the control system are undesirable, mainly, due to high cost of accelerator maintenance. The reliability could be decreased by negative influence of radiation, thus knowledge of radiation doses absorbed by electronics is desirable. It helps to estimate the life time of electronics, point out devices, for which absorbed dose of radiation exceeded a given threshold and should be replaced or reprogrammed.

## II. Requirements for Radiation Monitoring System for XFEL

The XFEL main linac will consist of 116 accelerating modules and other special components like bunch compressors and arrays of magnets. Each four accelerating modules will be driven by a single RF station [3]. The accelerating field in cavities used for speeding up the electrons to essential velocities will be controlled by the LLRF system. The radiation level will be varying in different sections of the accelerator. The higher radiation doses are expected near bunch compressors and beam dump than accelerating modules. Therefore, a distributed architecture of radiation monitoring system is recommended. The system should monitor radiation in the nearest proximity of the LLRF control system, which will be installed in different locations of the tunnel. One of the crucial requirements for developed system is on-line accessibility of data to allow real-time doses measurement and assure fast response on radiation level changes. Moreover, it is impossible to enter the linac tunnel during normal operation of the machine. The measured data should be collected in an external database for further analysis. The chosen dosimeters ought to fulfill the requirements for radiation doses resolution and ranges, which are presented in Table I.

TABLE I
REQUIREMENTS FOR GAMMA RADIATION AND NEUTRON FLUENCE DOSIMETERS [5]

| Detection ability | Gamma radiation and neutron fluence |
|---|---|
| Fluence range | $10^6 - 10^{10} neutrons \cdot cm^{-2}$ |
| The lowest fluence | $10^4 - 10^5 neutrons \cdot cm^{-2}$ |
| Dose range | $10^2 - 10^3 Gy$ |
| The lowest dose | $10^{-3} - 10^{-2} Gy$ |
| Energy range | up to 20 MeV |

## III. CONSIDERED RADIATION MONITORING SYSTEM ARCHITECTURES

The developed radiation monitoring system will have a distributed architecture to provide possibility to gather data from several dozen spots of the tunnel. Two concepts of the system architecture were proposed. The first one assumes development of the whole system, which needs to tackle issues associated with communication interfaces, wires and power supplies. The prototype system based on CAN bus was developed [6]. The other idea integrates radiation monitoring system with the LLRF control system. This approach solves problems connected with communication interfaces, powering, and extra cabling. The solution is not as flexible as a standalone system, but measurements should be performed mainly in the nearest proximity of the control electronics exposed to radiation. Integration of the LLRF control system with radiation monitoring system in a common architecture brings better unification of systems installed in the accelerator and, as it was mentioned, solves problems associated with wiring, powering, data interfacing and location of radiation sensors. Finally, it should decrease the costs of the project. Therefore, this kind of architecture has advantages over a standalone system. The Free-Electron Laser in Hamburg (FLASH) accelerator currently performs the role of a test facility for technologies essential for XFEL project. The LLRF system of FLASH is based on Versa Module Europa (VME) cards [7]. The VME is an almost 30-year old standard and nowadays it is becoming obsolete. Therefore, a new version of LLRF system will be developed with application of ATCA or $\mu$TCA standards. The demonstrative ATCA version of the LLRF system was installed in the ACC1 of the FLASH during the tests performed in September 2009 [8]. If ATCA is finally chosen as LLRF base architecture, LLRF control system will consist of a set of ATCA chassis, where ATCA Carrier Boards will be installed. Up to four Advanced Mezzanine Cards (AMCs), which may perform different tasks, can be installed in AMC slots available on the carrier board. The ÎĽTCA standard covers smaller systems, thus it provides chassis where only AMC modules are installed. The AMC is the common part of ATCA and ÎĽTCA, thus it was proposed to build device capable of monitoring gamma and neutron radiation level in real time as an AMC board.

## IV. RADIATION MONITORING AMC MODULE

### A. Dosimeters for Radiation Monitoring Module

The gamma radiation and neutron fluence affect electronic devices in a distinct way. Thus, it should be measured separately by different dosimeters. As gamma radiation dosimeter the radiation sensitive Field Effect Transistor (RadFET) was chosen. A RadFET is a modified P type MOS transistor, whose threshold voltage changes due to an oxide charge build-up process caused by gamma radiation and, in minority, by neutrons through secondary effects. The voltage shift can be presented as a function of absorbed gamma dose [5]. The sensitivity of the dosimeter shows dependency on oxide thickness, thus sensitivity can be adjusted to the application′s needs [9]. The readout configuration of RadFET is presented in Figure 1. The advantages of RadFET include small size of device, low unit costs and simple readout circuit.

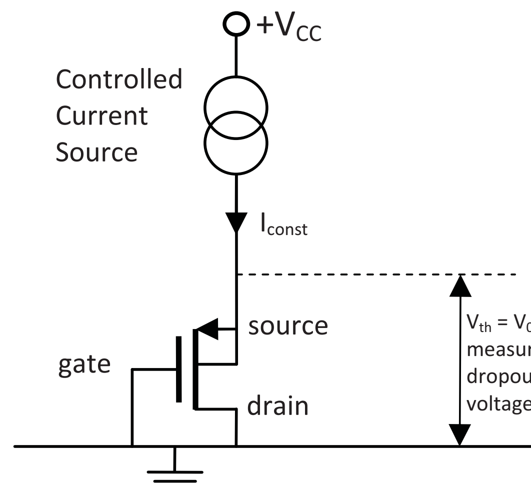


Fig. 1. RadFET dosimeter readout circuit

The neutron fluence is responsible for triggering SEUs in volatile digital memories like SRAM. The number of generated errors is proportional to the fluence intensity [5]. Therefore, if the memory is filled with a constant known pattern, one can estimate neutron fluence by counting the number of errors triggered in SRAM memory. A set of SRAM memories characterized by different sizes, manufactured technologies, supply voltage and vendors was investigated to determine the chip with the highest sensibility, which will be used as neutron radiation detector [5]. The research shows the newest memory chips are more immune to radiation than those produced in older technologies [5]. For needs of this project the 512 kB Samsung K6T4008C1B SRAM was chosen.

Previous research showed that both selected dosimetry methods should fulfill the requirements for XFEL radiation monitoring system [5]. Moreover, they can be easily integrated with digital readout subsystems, represent low unit cost and high selectivity, which is an important factor in radiation mixed environment characterized for linear accelerators.

### *B. Radiation Monitoring Module hardware*

The AMC Radiation Monitoring Module consists of two printed circuit boards (PCBs), AMC A and AMC B. Both PCBs are connected together by a 120 pins connector. The block diagrams of AMC B and AMC A are presented in Figure 2.

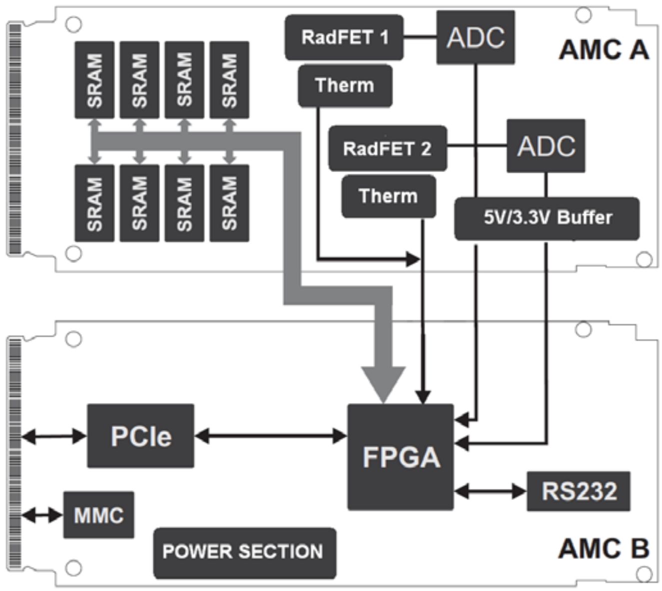


Fig. 2. AMC Radiation Monitoring Module block diagram

The AMC B is a general purpose AMC built in accordance with ATCA specification. A Field Programmable Gate Array (FPGA) chip - Xilinx XC5VLX50T from Virtex 5 family - is located on the PCB. It is a powerful device, where sophisticated algorithms and logic suited to the requirements can be implemented. The FPGA provides communication interfaces like PCIExpress or Ethernet. The AMC B includes a Module Management Controller (MMC) and supplies AMC A with 3.3 V management power, 3.3 V and 12 V payload powers. The AMC A is dedicated to be mounted inside an xTCA chassis, but it is also equipped with extra power connector and USB connector as a communication interface. As a result, it can work standalone, which is a useful feature during tests and development.

All elements responsible for radiation measurements are located on the AMC A. Eight Samsung SRAM memories, with a total capacity of 4 MB, are installed on the module and connected directly to the FPGA. The power supply of memories is decreased to 3.3 V from 5 V. It allows to increase the sensitivity to neutron fluence and to eliminate necessity of buffering between FPGA and memories. The number of memory chips located on the PCB was increased in order to raise measurement accuracy. As it was mentioned before, RadFET transistors were selected for gamma radiation detection. Two RadFETs are mounted on AMC A with essential, separated for each transistor, readout circuits. The readout circuit consists of RadFET configured as shown in Figure 1, adjustable current source, operationalamplifier set as a voltage follower circuit and 16-bit serial analog to digital converter (ADC). The ADC resolution determines the minimum dose which can be detected by the readout circuit. The measurement data from ADC are available via Serial Peripheral Interface (SPI). Because the ADC works in 5 V power supply domain, extra buffers need to be placed between the FPGA and ADCs. The RadFETs with readout circuits create the analogue part of the PCB, which was designed with special care to reduce noise. Two digital thermometers were located near RadFET transistors. The temperature measurement is essential, because parameters of RadFET are temperature dependent and appropriate compensation should be ensured.

### *C. Radiation Monitoring Module firmware*

The Virtex 5 chip is the heart of the AMC Radiation Monitoring Module. Therefore, all functionality essential for measurement performing was developed in VHDL language. Block diagram of VHDL modules implemented in the FPGA is presented in Figure 3.

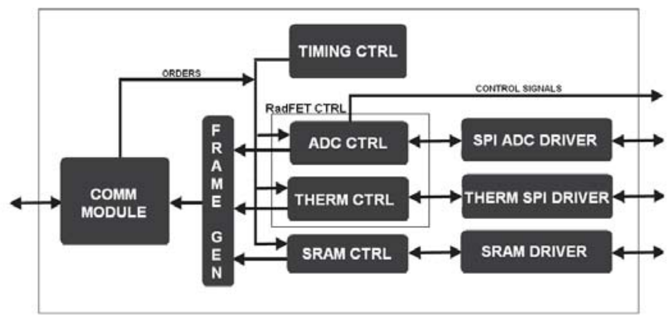


Fig. 3. Block diagram of VHDL modules for Radiation Monitoring AMC

The SPI_ADC_DRIVER and THERM_SPI_DRIVER are dedicated blocks which carry out ADCs and thermometers measurements. The SRAM_DRIVER is able to write to and read from the K6T4008C1 memory. The ADC_CTRL and THERM_CTRL, which together can be consider as the RadFET controller, are responsible for controlling, initializing and gathering data from ADCs and thermometers. After system startup ADC_CTRL starts the initialization procedure of both ADCs. Afterwards, every 10 minutes the voltage on both RadFETs is measured. The state of both RadFETs is changed from sense to reader mode 30 seconds before measurement proceeds. The temperature is collected together with data from ADCs. The device can operate in one of two modes:

- Independent Mode
- MMC Mode

In Independent Mode transmission of measurement data is initialized by the module. The gathered raw data are transferred to the frame generator module (FRAME_GEN), where communication frames are formed. Every frame carries information about module ID number, type of frame, raw data and calculated checksum. The frames are then put into the communication module (COMM_MODULE). The task of this block is to send frames via a specified interface e.g.

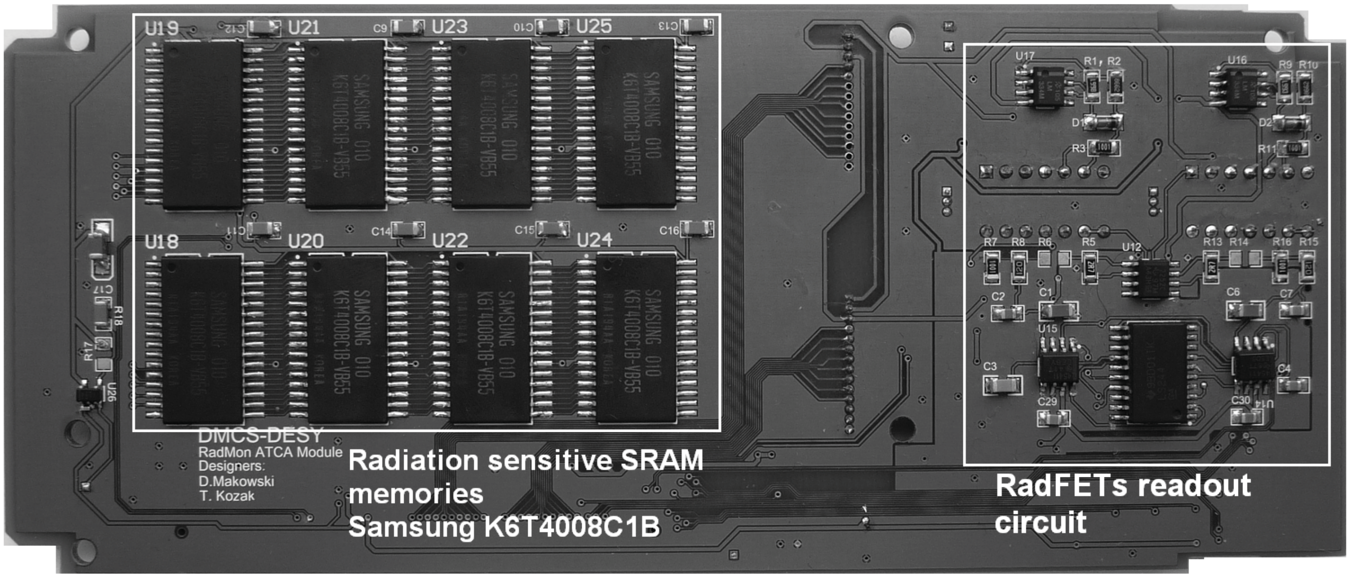


Fig. 4. Radiation Monitoring Module designed as AMC module

PCIe or Ethernet. This kind of VHDL modules organization allows easy adjustment of the AMC if another communication interface is required. The signals, which initiate RadFETs measurement routine, are generated by TIMMING_CTRL module. It is also responsible for triggering the heartbeat frame, which is sent every second and confirms correct functioning of the device. The SRAM_CTRL block constantly scans the attached SRAM memories in order to find SEUs generated by neutrons. Firstly, after module startup, all SRAM chips are formatted to a known pattern. If SEUs are found, the corrupted cell is reformatted to the initial value. The SRAM controller may work in two modes. In the first one, frames with information about the amount of detected SEUs are sent periodically. In the second one, a frame is generated every time a specified number of SEUs is registered. In MMC Mode device is visible in the system as a set of IPMI sensors - two Gamma Sensors and single Neutron Sensor. The principle of operation in this mode is different than in Independent Mode. The MMC reads periodically actual value of ADCs 16-bit register and calculates voltage shift between current and previous readout. Similarly, MMC receives from Radiation Monitoring Module number of SEUs registered between two subsequent registers readouts. Therefore, data from Gamma Sensor and Neutron Sensor should be interpreted as a radiation dose absorbed in time between last two readout. Since the IPMI sensors allow only 8-bit values, the number of registered SEUs and ADC voltage shift are limited to 255 SEUs and 0.046 V (for 16-bit ADC and 12V maximum RadFET voltage value), which also limits the period between readouts performed by MMC. The time between readouts should be adjusted to assure that no overrun of sensors occurrs. IMPI allows to define alarm levels for sensors in the system. Thanks to this feature, user can be informed about fast increase of radiation level. Third mode of operation, which will be combination of Independent and MMC modes, is planned to be defined in the nearest future. It will allow to store precision radiation measurement in database for future analysis and concurrently inform user about fast changes of radiation level.

### D. *Calibration of Radiation Monitoring Module*

In order to increase the accuracy of measurements, every AMC Radiation Monitoring Module should be calibrated before being installed inside the tunnel. The sensitivity factor for RadFETs may vary due to parameter scattering. The RadFET section should be exposed to influence of reference gamma source, which allows calculating the calibration factor. Similar procedure should be applied in case of SRAM chips. There are two suggested methods of calibration. The first one requires a precise reference source of neutron and gamma radiation, the second one involves others pre-calibrated measurements devices. The main drawback of the first method is low accessibility of references sources, but its accuracy is higher than the second method, which relies on other devices and may multiply errors done during their own calibration process.

## V. Conclusions

The AMC Radiation Monitoring Module, which is a base unit of Distributed Radiation Monitoring System for ATCA, was designed. An example PCB was assembled and tested in laboratory conditions. All subsystems responsible for gamma and neutron doses measurement are working as it is desired. The main advantages of the proposed solution include:

- integration with the LLRF system, which eliminates problems with powering and communication interfaces,
- measurements are performed right next to the control electronics, what increase accuracy,

- modular construction of the device (AMC A and AMC B) makes this solution highly reconfigurable,
- module is built in accordance with ATCA specification which makes it reliable.

The AMC B PCB is s general purpose module and carries Virtex-5 chip whose resources are excessive in comparison to the needs of Radiation Monitoring Module. It may be considered as the main drawback of presented solution. The AMC module is ready to be tested in target environment of a linear accelerator. The plan predicts the module to be used during radiation sensitivity test, which will be carried out at dedicated teststand located in FLASH accelerator tunnel in the beginning of 2011.

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## REFERENCES

[1] B. Goncalves et al., ATCA Advanced Control and Data acquisition systems for fusion experiments, 16th IEEE-NPSS Real Time Conference, 2009
[2] S.N. Simrock et al., Conceptual LLRF design for the European XFEL, Proceedings of LINIAC 2006, Knoxville, USA, 2006
[3] M. Altarelli et al., The European X-Ray Free-Electron Laser Technical design report, 2006
[4] G. Barbottin, A. Vapaille, Instabilities in Silicon Devices, New Insulators, devices and Radiation Effects, Elsevier, 1999
[5] D. Makowski, The impact of Radiation on Electronic Devices with the special consideration of Neutron and Gamma Radiation Monitoring, PhD Thesis 2007
[6] T. Kozak, D. Makowski, A. Napieralski, Distributed Radiation Monitoring System for Linear Accelerators based on CAN Bus, 16th Mixed Design of Integrated Circuits and Systems MIXDES, June, 2009
[7] V. Ayvazyan et al., Digital RF Control System for the DESY FLASH Linear Accelerator, The International Conference on "Computer as a Tool", EUROCON 2007, Warsaw, Poland, September, 2007
[8] S.N. Simrock et al., Demonstration of an ATCA based RF Control System at FLASH, 12th International Conference on Accelerator and Large Experimental Physics Control Systems, ICALEPS 2009
[9] G. Sarrabayrouse, S. Siskos, Radiation Dose Measurement using MOSFETs, IEEE Instrumentation & Measurement Magazine, 1998

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