IO-06 Mon. 16. 06., 11^{50}-12^{10}

GEM-2D detector based reconfigurable measurement system for hot plasma diagnostics

A. J. Wojeński[1]*, G. Kasprowicz[1], K. T. Poźniak[1], A. Byszuk[1], M. Chernyshova[2], T. Czarski[2], S. Jabloński[2], B. Juszczyk[1] and P. Zienkiewicz[1]

[1]*Institute of Electronic Systems, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland*
[2]*Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warsaw, Poland*

Keywords: ITER, plasma visualization, plasma diagnostics, GEM detectors, FPGA, reconfigurable measurement systems

*e-mail: A.Wojenski@elka.pw.edu.pl

In future thermofusion research reactors (tokamaks, i.e. ITER), precise determination of the level of the soft X-ray radiation of plasma with temperature above 30 keV (around 350 mln K) will be very important in plasma parameters optimization[1].

Soft X-ray radiation, emitted by plasma structures, is characterized by very high radiation emissivity, from several W/m^3 up to 20 W/m^3. Observed photon fluxes in soft X-ray energy region could generally reach values from 10^6/s·cm^2 to 10^7/s·cm^2. In case of such intensive photons streams, the measurements system requires not only adequate detectors characteristics, but also very fast electronics or data acquisition.

Conceptual works and Authors previous experience has demonstrated that multichannel proportional gas detectors are good candidates to fulfill the constraints of soft X-ray imaging of tokamaks'plasma structures and that the GEM (Gas Electron Multiplier) technique, when configured in multistep structure, can provide sufficient detection characteristics [2-3].

The paper describes modular and reconfigurable measurement system used for diagnostics of hot plasma. The system is able to measure plasma energy and position in 2D mode. The system can provide from 64 up to 512 measurement channels.

At system's input stage, GEM detector is used. Several configurations of the detector have been developed for future tests.

The system is using high-speed serial data communication interfaces, i.e. PCIe [4] and SERDES. Analog-to-digital converters have 12 bits accuracy for each channel, working at 125MSPS speed. With all input channels active, the data flow to the system reaches up to 96 Gbps (64*12bits*125MHz). The acquired data is then passed through analog front end (AFE) boards to FPGA backplane boards.

The analog part of the design allows detection of very short pulses, with very low charge (order of 100 fC). The pulses are generated by absorption of photons inside the detector sensitive volume passing through the GEM detector window. They last for about 20 ns, and intervals between pulses can be also very short. Thus, due to very narrow signals, input channels can be configured in different modes, i.e. amplifier or integrator, increasing the time resolution of photons detection.

On FPGA backplane boards, fast, online data processing is done by FPGA units. As input data flow, signals from AFE boards are connected through ADCs to FPGA units. Different algorithms can be implemented in FPGAs depending on measurement types. The processed data can be stored in DDR3 memory or internal FPGA RAM memory.

Currently developed firmware operates as a histogramming device (for plasma X-ray spectroscopy [5]) or as a multichannel digital oscilloscope. It allows detection of simulated photon pulses (test mode implemented on AFE boards). After detection, signal is registered with up to 1024 samples per one channel in FPGA internal memory. This gives up to 32MB of data per one AFE board (one event). Implemented oscilloscope algorithm can be widely configured (edge detection, delay, etc.). Once data of single photon absorption is acquired, information about this event is stored in FPGA registers. Specially designed software (FPGA/FMC Configuration Software [6]) monitors continuously the status of data acquisition and downloads data through PCI-E when it is available. Since the whole hardware of the system is built in a modular way, firmware automatic generation software can be used to speed up the development process and allow easier handling of different hardware configurations of measurement [7].

Despite of processing pure input data signal, there are also implemented in firmware components responsible for configuration of used electronics (i.e. digital interfaces, offset compensation, integrator mode, etc.).

System is highly modular, allowing interconnecting multiple FPGA backplane boards together using high speed gigabit transceivers (known as GTP links). This improves overall system performance in terms of working algorithms and provides multichannel, high-speed measurement system for different purposes.

Backplane boards can work with various number of AFE boards, depending on user needs. Due to edge connectors mounted on backplane boards, different compatible cards can be inserted in system. Advantage of using edge connectors is a high number of signals that can be connected to FPGA unit.

In order to download processed data from FPGA units, PCI-Express Gen2 interface is used. This approach provides high-speed data link for each board. Backplane boards can be connected directly to PC. Drivers and acquisition software are developed for Linux system.

Dedicated PCI-Express concentrator board was developed. It allows connecting up to 8 backplane boards to the PC unit using one PCI-E x16, Gen3 slot. Data concentrator board provides also several control signals used by backplane boards (i.e. power management, configuration interfaces).

Configuration and monitoring of AFE and backplane boards is done by FPGA mounted on the PCI-E switch. The FPGA is managed by PC computer, using USB interface.

Whole measurement system is controlled by software installed on PC. The FCS was used for this purpose. FCS provides development framework for fast development of software drivers. The main tasks performed by FCS are management, monitoring and configuration of complex electronic systems. FCS can also provide fast and easy for implementation data output of running measurement algorithms implemented on FPGA devices.

FCS is used for many other different purposes, i.e. offset regulation of AFE boards, automatic training of high-speed, serial digital interfaces (SERDES) of ADC chips. This can be easily done, thus, of modular software construction, based on different levels of data interfaces.

Data downloaded from measurement system is processed on PC computer. This can be done using FCS with adequate driver implemented (data parsing) or by direct PCI-E driver access. PC unit implements mathematical algorithms. The offline processing may be done on common PC unit, on different ways, using MATLAB or specially developed software in many languages (C, C++, Java, etc.).

Acknowledgements: This work was performed within the strategic research project "Technologies supporting the development of safe nuclear power" financed by the National Centre for Research and Development (NCBiR). Research Task "Research and development of techniques for the controlled thermonuclear fusion", Contract No. SP/J/2/143234.

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