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ELECTRONIC READOUT SYSTEM DESIGNED FOR **MCORD** IN THE **NICA** EXPERIMENTS

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Электронная система считывания, разработанная для детектора MCORD для экспериментов на NICA

Система многоцелевого детектора (MPD) является частью нового ускорительного комплекса (Nuclotron-based Ion Collider fAcility — NICA), расположенного в Дубне (Россия). Для соответствия всем функциям и требованиям MPD была разработана дополнительная триггерная система (старта и синхронизации), которая выполняет две основные задачи: она отвечает, во-первых, за калибровку субдетекторов MPD вне луча, а во-вторых, за идентификацию и отбрасывание частиц космических лучей. Кроме того, систему можно использовать для наблюдения космических ливней, инициированных первичными частицами высокой энергии. Для детальной разработки требований к детектору космических лучей MPD (MCORD) и других задач был сформирован консорциум NICA-PL. В консорциуме участвуют многие польские ведущие научные учреждения. В данной статье представлена электронная система считывания для проекта MCORD. Также кратко описываются тракт данных сигналов и все подсистемы обработки сигналов: сцинтилляторы, оснащенные детектором SiPM (кремниевые фотоумножители), аналоговые интерфейсы (AFE), HUB и система обработки MTCA.

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Electronic Readout System Designed for MCORD in the NICA Experiments

Multi-Purpose Detector (MPD) system is a part of new accelerator complex (Nuclotron-based Ion Collider fAcility — NICA) located in Dubna (Russia). To meet all functionalities and requirements of MPD, another trigger system should be designed. That trigger system has two main tasks: first, responsibility for off-beam calibration of MPD subdetectors, and second, identification and rejection of cosmic-ray particles. Additionally, the system can be used to observe cosmic showers initiated by high-energy primary particles. To define in detail requirements of the MPD Cosmic Ray Detector (MCORD), the NICA-PL consortium has been formed. Many Polish scientific institutions participate in it. This paper presents an electronic readout system for the MCORD project. It briefly describes the data path of the signals and all signal processing subsystems: scintillators equipped with SiPM detector, Analog Front-End (AFE), HUB, and MTCA processing system.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 2020

INTRODUCTION

The primary task of the MPD system is to measure parameters of hot and dense nuclear products emitted during collisions of high-energy heavy ions. MPD is currently being developed within the measurement system in the NICA project [1]. The project is a part of a new accelerator complex and is developed and managed by JINR in Dubna.

MPD developed for NICA has to provide relevant information about every collision event [2]. Unfortunately, many cosmic particles can generate similar or even identical events as those produced by collisions. The role of MPD is to detect and distinguish events induced by the collision and cosmic showers.

MPD designed by NICA-PL consortium is called MCORD [3, 4]. It is responsible for detecting events and processing measurement data like time, position, direction and amplitude of the signal induced by particles passing through the accelerator. Additionally, MCORD algorithms can classify the source of the signals, whether they came from a cosmic shower or ion–ion collisions.

The authors present the current status of the MCORD detector demonstrator and processing systems. They briefly describe the electronic readout system and data path of the signals starting from the scintillators to the final processing stages. The article also includes some necessary information about software and tools used for development.

1. ELECTRONIC READOUT SYSTEM

The first MCORD system demonstrator is presented in Fig. 1, and a block diagram of the dataflow is shown in Fig. 2. There are two SiPMs light sensors installed on both scintillator's ends. When a muon or other charged particle hits a scintillator, it starts to emit light. A SiPM illuminated by that light generates an electrical current proportional to the number of detected photons. The analog output signals from two SiPMs go directly to one AFE module. It is mainly responsible for monitoring and controlling the SiPMs, electronic protection, temperature measurements, and failure notifications. It also contains modules of the simple transconductance amplifier and shaper. The role of these modules is to form the output pulses. These pulses have a reduced bandwidth and thus increased duration. The bandwidth limitation reduces hardware requirements for the readout equipment and minimizes RF interferences. The AFE modules are located just close to the SiPMs (a few cm).

Fig. 1. MCORD system demonstrator with one scintillator

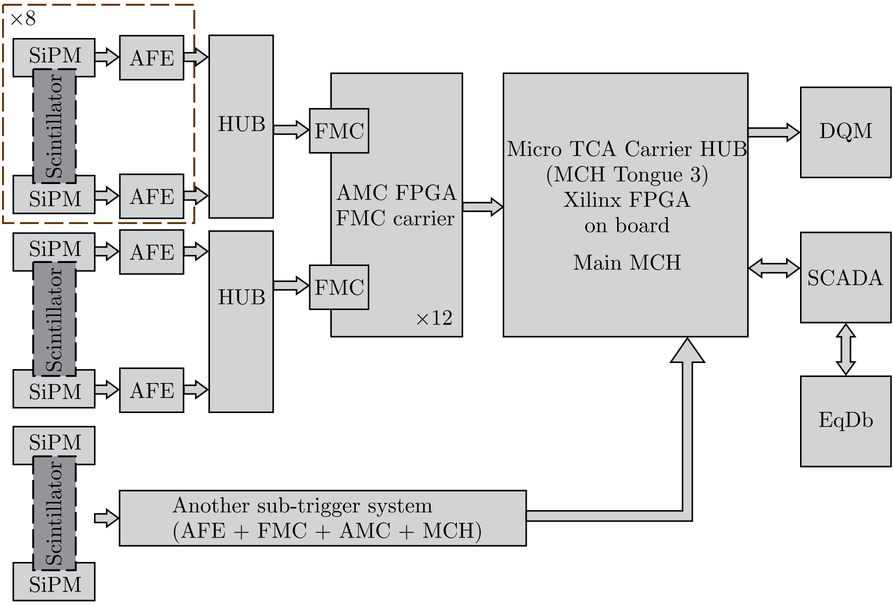

Fig. 2. NICA system architecture based on MTCA standard

Analog signals from the AFE are transmitted to the passive HUB, which supports up to eight scintillator assemblies. The HUB does not process the SiPM signals at any level. It is mainly responsible for power delivery, controlling and transferring physical and diagnostic data from AFE to the next processing stages. The HUB will be located close to the MCORD modules (maximum 0.5 m). The SiPM's output signals of the HUB are transmitted (length about 20–30 m) to the ADC (Analog to Digital Converter) and TDC (Time to Digital Converter) subsystems located on the FMC (FPGA Mezzanine Card) boards. Every FMC card receives 16 analog signals. At the next stage, already digitalized signals are routed from the FMC card to the AMC (Advanced Mezzanine Card) board. Each AMC board holds two FMC boards, which means that it can process up to 32 SiPM signals.

Up to 12 AMC cards are installed in the Micro TCA.4 chassis. The MTCA is a modular system for acquisition, control, management, and data processing adapted for high-energy physics (HEP) experiments. The MTCA Carrier HUB (MCH) module receives data from AMC boards over the gigabit link and can be connected with other MCH modules to form a larger acquisition system. Every MCH contains Kintex FPGA, which performs further processing.

At the last stage, data coming from the MCH is transferred to two different devices:

- DQM (Data Quality Management). All physics measurement data is sent to that database system. The main goal of the system is to perform various algorithms calculations on delivered data to recognize the event parameters, its quality, rates, etc.
- SCADA control system connected to the Equipment Database (EqDb). All diagnostic data is sent to that system in order to verify any failures in the system, detect unspecific behavior and parameters or values beyond the limits. Additionally, the SCADA system can store all settings for SiPMs, which can be used during the configuration of the whole electronic system, in EqDb.

2. THE AFE MODULE

Analog readout electronics consist of two module types — AFE and HUB. The AFE is connected directly to the SiPMs and is placed very close to them. The basic functionality of the AFE is depicted in the schematic in Fig. 3. One AFE board cooperates with two SiPMs dedicated to one scintillator.

The heart of the AFE module is an STM32 microprocessor [5]. The software is written in the ANSI C language. GCC tool chain is used for development. The microprocessor is responsible for managing and controlling all on-board and SiPMs hardware parts:

- two temperature sensors of SiPMs (located a few mm from each SiPM);
- two LDOs (Low-DropOut regulator) dedicated to SiPMs voltage controllers;
- two SiPMs calibration blocks;
- two SiPMs signal transmitters;
- CAN network driver [6];
- external memory interface for remote firmware update.

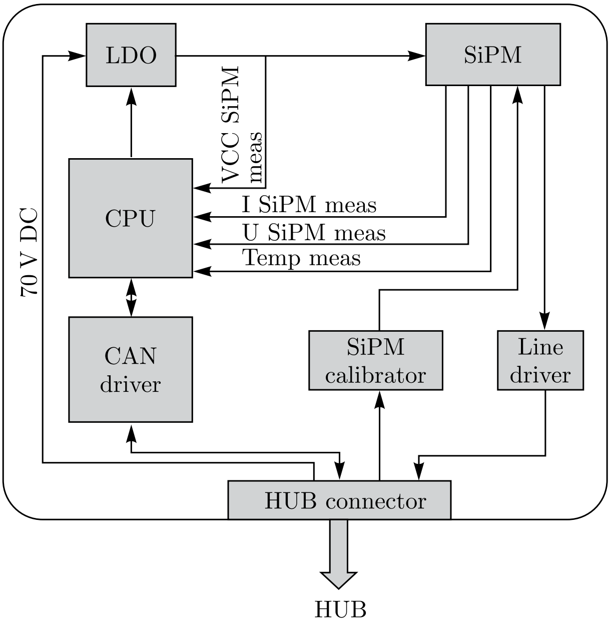

Fig. 3. Basic functionality of the AFE module

The AFE is connected to the HUB by the connector where the following signals are available:

- CAN interface (both directions);
- calibrations signals (to AFE);
- SiPMs analog signals (to HUB);
- power (to AFE).

The AFE communicates with a HUB by the CAN 2.0A protocol, which provides access to all AFE settings and data. Currently, the bus works with a 100 kHz baud rate. Each AFE node has a unique CAN ID, which is based on 96 bits ID field different for every STM chip. The communication protocol is open and available for all users. The protocol contains a definition of all transactions between AFE and HUB. The HUB is always a master in communication. The AFE always responds to any request coming from the master. In the CAN frame, the first two words of the data field define the request, and the next words define the arguments if needed. The frame data field examples are presented in the table.

Power supply (up to 70 V) for the SiPMs is generated in the HUB and is later on regulated by the AFE. The microprocessor controls and adjusts the SiPM operating points by setting internal DACs outputs. There is no control loop implemented at this stage. The input voltages to the SiPMs can be set by the HUB. At the current state of the work, the microprocessor

Examples of CAN transactions between HUB and AFE

Function	Function individual code	Argument	Return data
Get version	0x0001	—	Firmware version
Get ADC data Reg. 1	0x0010	—	Data of 3 ADC channels
Get ADC data Reg. 2	0x0011	—	Data of 3 ADC channels
Set SiPM voltage 1 and 2	0x0012	ADC values	—
Set bits in a Control Register	0x0040	Bits to set	—
Clear bits in a Control Register	0x0041	Bits to clear	—
Get bits in a Control Register	0x0042	—	Bit values in the Register

monitors the following parameters and sends them to the HUB for diagnostic purposes:

- the supply voltage of each SiPM;
- the current of each SiPM;
- the voltage of each SiPM;
- the temperature of each SiPM.

3. THE HUB MODULE

The second part of the analog readout electronics is a passive HUB module. Up to eight scintillator assemblies can be connected to one HUB. The main functionality of the HUB is depicted in Fig. 4.

STM32 microprocessor placed in the HUB is responsible for the following tasks:

- controlling the power delivery to the AFE boards (5 V, 70 V);
- controlling the CAN interface for the AFE boards;
- generating/distributing calibration signals to AFE boards;
- distributing analog signals from AFE to MCA processing system;
- controlling the Ethernet/Modbus/CAN/USB interfaces;
- managing status LEDs on HUB panel for quick fault identification;
- storing diagnostic data in the external memories (EqDb or on local microSD card);
- controlling procedure of firmware update.

The HUB is supplied by the PoE standard, which can deliver 12 V at 30 W of power. The HUB contains DC/DC converters, which produce 5 and 70 V from 12 V and deliver them to the AFE.

The HUB does not process any SiPM analog signals coming from the AFE. It only transfers those signals to the next stage (MCA card) through 2xSAS cables. The HUB software does not execute any advanced control

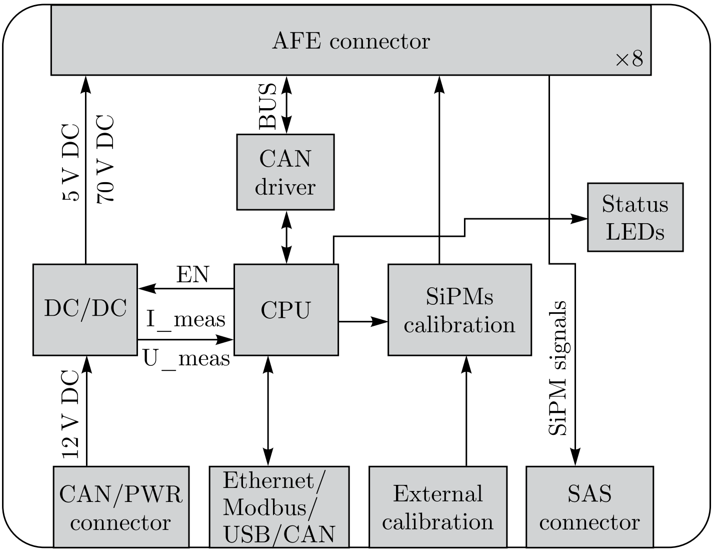

Fig. 4. Basic functionality of the HUB module

algorithms. Basically, it mainly delivers and receives parameters, settings, controls data to/from the AFE boards. Additionally, it informs about any errors that occurred on the AFE boards.

The microprocessor placed in the HUB runs the MicroPython environment [7]. This is a Python compiler optimized to run on microcontrollers and in constrained environments. The whole software and functionality of the HUB are developed in that language. An example of the routine is depicted in Fig. 5. The HUB connected to the PC behaves as a USB disk. The software can be written in any editor. This approach

```
def GetVer(id):
  can = pyb.CAN(1)
  can.init(pyb.CAN.NORMAL,extframe=False,prescaler=8,sjw=1,bs1=7,bs2=2,auto_restart=True)
  can.setfilter(0, 0, 0, (0x00,0x7ff))
  can.send("\x00\x01",id)
  time.sleep(1)
  buf = bytearray(8)
  lst = [0, 0, 0, memoryview(buf)]
  can.recv(0, lst)
  print("ID: ", lst[0])
  print("RTR: ", lst[1])
  print("FMI: ", lst[2])
  VerH = (lst[3][2] << 8) | (lst[3][3] & 0xff)
  print("VerH: ", VerH)
  VerL = (lst[3][4] << 8) | (lst[3][5] & 0xff)
  print("VerL: ", VerL)
  VerD = (lst[3][6] << 8) | (lst[3][7] & 0xff)
  print("VerD: ", VerD)
```

Fig. 5. Example of the MicroPython routine

allows developing control routines by non-embedded software engineers (i.e., physicist). MicroPython, in a simple way, gives access to the CAN interface and all AFE data. That solution means that the system can work fully remotely. In the future, the access will be not only by the USB but also by the ethernet interface. Currently, functions written in MicroPython language allow us to read analog data from the AFEs, set SiPMs voltage, and calibrate SiPMs.

4. NEXT STAGES OF THE PROCESSING

Output analog signals from the SiPMs go from the HUBs to the next stage — the FMC boards located on the AMC–FMC cards (Fig. 6). On the FMC card, the signals are processed in two ways in parallel: by ADC (Analog to Digital Converter) and TDC (Time to Digital Converter) ICs. Both paths work simultaneously and support up to 16 channels each. Due to many FMC boards working in parallel, timing synchronization is available. The FMC boards can work with internal or external clocks and trigger signals.

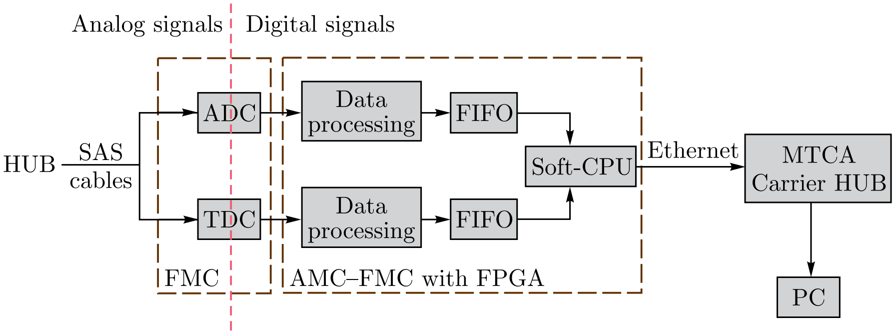

Fig. 6. Dataflow on FMC and AMC cards

The ADC digitalizes the signals and sends them to an FPGA IC. Because the signals are very narrow, the conversion process would need ADCs working at a very high sampling rate. The ADC path has a differential amplifier and two-pole RC filter at the input to stretch the incoming signal.

On the other hand, the TDC processing is a very precise method to detect edges of the signals, so full bandwidth is required. The TDCs calculate times of incoming samples with a resolution of a dozen of ps.

At the next stage, the digitalized signals from ADCs and TDCs are transferred to the FPGA (placed on AMC–FMC boards) where they are initially processed. Both digitalization methods play a big role in data processing because each method allows for getting different information. The ADC digitalization allows calculating the charge and energy of the signal, its quality, correlation between various pulses, and other parameters. The TDC digitalization allows one to precisely calculate the position trajectory of the muons, time of arrival, and the time difference between channel pairs.

The data after processing in the AMC FPGA are transferred using the MTCA backplane to the MCH module. Data from MCH can finally be transferred to the detector control system over the gigabit fiber interface.

SUMMARY

The article describes the whole data path of the signals and current status of the work on the MCORD detectors development for the NICA projects. This work is a part of the activities of the NICA-PL consortium. All electronic hardware and software are mainly developed by the Warsaw University of Technology. The scintillators are developed by the National Centre for Nuclear Research (Swierk). The current stage of the project allows running the readout system and measuring the events. The HUB can read data from analog channels for diagnostic purposes. Setting and controlling the voltages of the SiPMs are possible. The nearest plans include the development of the automatic CAN addressing and control loop for a SiPM supply voltage, ADC/TDC processing algorithms and fast trigger generation functionality.

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