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The CMD-3 Data Acquisition System

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Abstract
The specialized data acquisition system designed for CMD-3 detector is presented at the electron-positron collider VEPP-2000 to the Budker Institute of Nuclear Physics, Novosibirsk, Russia. The structure of electronic hardware and firmware is described.

Keywords
Data acquisition; signal processing; fast electronics; trigger; digitizer.

1 Introduction

The electron-positron collider VEPP-2000 [1] is installed at the Budker Institute of Nuclear Physics (Novosibirsk, Russia). The design parameters of the VEPP-2000 collider are the following: the center-of-mass (c.m.) energy covers from 0.3 GeV up to 2 GeV. The peak luminosity is 10^{32} cm^{-2} s^{-1} at c.m. energy of 2 GeV. Two detectors SND[2] and CMD-3[3,4] are installed at the interaction regions of the collider. One of the goals of experiments at VEPP-2000 is the study of electron-positron annihilation into hadrons at the available energies. In particular, the precise measurement of cross sections of electron-positron annihilation into hadrons is extremely important for calculating the contribution of hadron polarization of vacuum to the anomalous magnetic moment of the muon [5].

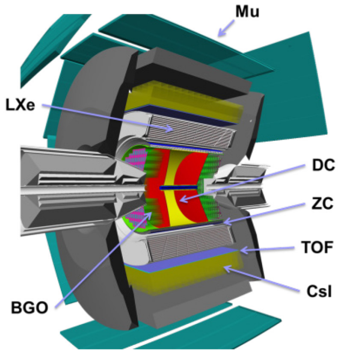

Fig. 1: The CMD-3 detector

The CMD-3 (Cryogenic Magnetic Detector) is a general-purpose detector shown in Fig. 1. The detector includes a magnetic spectrometer and an electromagnetic calorimeter. The magnetic spectrometer consists of the cylindrical drift chamber (DC) and the two layer multiwire proportional chamber (ZC), placed outside the DC. Coordinates, angles and momentum of charged particles are measured by the DC of a hexagonal wire structure. The ZC provides measurement of the Z coordinate of the track with an accuracy of about 0.5 mm. The magnetic spectrometer is immerged in a magnetic

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field produced by a thin superconducting solenoid, placed between the DC and barrel the calorimeter [6]. The average field strength is 1.3 T.

The energy deposition of particles is measured by the electromagnetic calorimeter. The electromagnetic calorimeter is divided in the three path liquid Xenon-based internal barrel, outer CsI crystal based barrel and the $Bi_4Ge_3O_{12}$ (BGO) crystal based endcap calorimeter. The detector also includes the time-of-flight (TOF) counters, placed between two barrel calorimeters, and the muon range system (Mu system), placed outside the magnet yoke.

The CMD-3 is equipped with a data acquisition (DAQ) system specially developed for the experiments. The DAQ system of the CMD-3 detector solves several problems simultaneously: data acquisition and transfer to first-level trigger systems, generation of synchronization signals for time meters, triggering of measurements, collection of digitized data, interaction with accelerator facility, calibration of coefficients and efficiency, and monitoring of the status. The CMD-3 DAQ capacity is to process some 12k channels with mean trigger rates up to 1kHz thus producing about 3.8Gbps data rate. Here the structure of the electronic hardware and firmware of the CMD-3 DAQ is described.

2 The CMD-3 DAQ system

The overview picture of the CMD-3 DAQ electronics is shown in Fig. 2. The analog signals from the detector subsystems are amplified and shaped in the front-end electronics. Then it goes into the trigger electronics, which is organized as a pipeline and makes decisions at the collision rate (each 80 ns). If the first level trigger takes a positive decision the digitized data from digitizing electronics are readout by the DAQ.

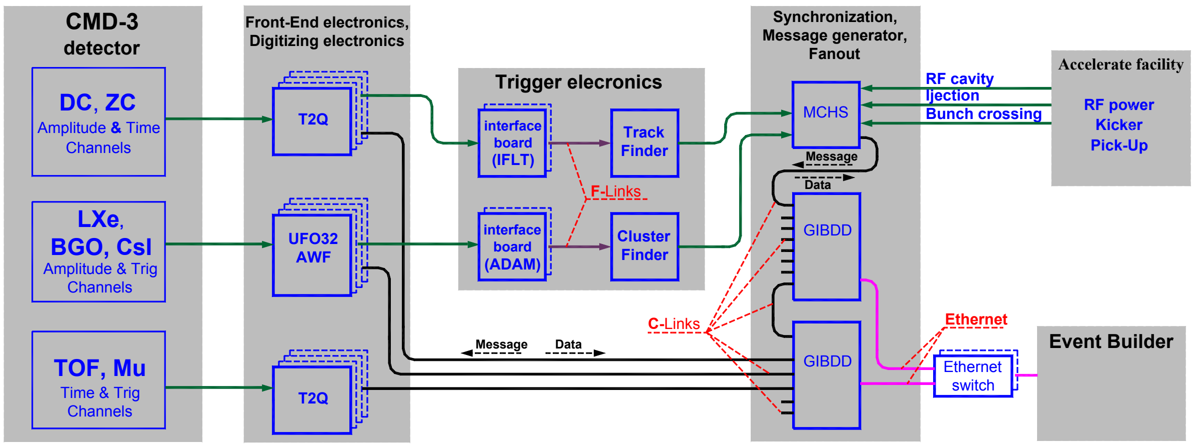

Fig. 2: The CMD-3 data acquisition electronics layout

The MCHS board ("Master Chronopher System board") receives information from the first level trigger, resynchronizes it with the RF cavity frequency because it is the source with lowest possible jitter and the highest stability to the bunch position. Then the MCHS initiates the transaction with a command to start measurements which fanout to each digitizer of the CMD-3 DAQ via a C-Link, which is described in detail below. It is a special interface for synchronization and the data transport in the CMD-3 DAQ system. The fanout is provided by the General Interface Board for Data Delivery (GIBDD). Each digitizer sends data back to the GIBDD. Here these data are buffered in memory, packed and transmitted with a local Ethernet network to the Event Builder. Each GIBDD board can be connected by C-Links to up to 30 boards. To increase the number of C-Links GIBDD boards can be cascaded.

The first-level trigger system consists of interface boards (interface of first level trigger (IFLT), adder discriminator adder module (ADAM)) that prepare arguments for Finders (track and cluster finders, see Fig. 2). The arguments are transferred from interface boards to Finders via an F-Link (Fast-Link). It is a serial line of data transfer with a rate of 375 Mbit/s. The operation of the triggering electronics is based on the pipeline algorithm of data processing.

The digitizing electronics is presented by three unified families of boards (referred as T2Q, UFO32 and AWF) designed for different types of measurements. Each family has several modifications unified in terms of the base of elements, basic internal architecture solutions, and overall design. More details about CMD-3 electronics can be found in the article "The CMD-3 TOMA DAQ Infrastructure" [7].

3 The CMD-3 C-Link

A unified approach for the data transport and synchronization was used during the development of the CMD-3 DAQ. A special interface has been developed, referred to as C-Link. The unified requirement on the data transport allows using a single method for different tasks, such as physical data and scaler data readout or digitizer status control. So each link transaction is associated with an event. If an event occurs the transaction starts. And the end of the transaction terminates the current event.

The C-Link provides massage transport to the boards and data gathering from the boards. On physical level it is low voltage differential signal (LVDS) based two twisted pairs serial bus, which allows low electromagnetic interference (EMI), low power and low cost. The basic parameters of the C-Link for CMD-3 are listed in Table 1.

Tab 1: Technical parameters of C-Link

Modulation	Two levels: log.0 = high, log.1 = low
Data transfer rate	25 Mbit/s (50 and 100 Mbit/s also possible)
Voltage levels	LVDS, 4 mA, as in the IEEE1394 standard
Transfer environment	Two twisted pairs
Electrical connector	USB, type A

The clock signal is always transferred through one twisted pair from the transmitter (Down-Link) to the receiver (Up-Link). This is a meander whose frequency is 25 MHz. It is used for synchronization of time meters rather than for synchronization of data. The data are transferred through the second twisted pair. No special interface hardware is used – the signals are transmitted and readout directly by the C-Link. The logical part of the C-Link is FPGA-based.

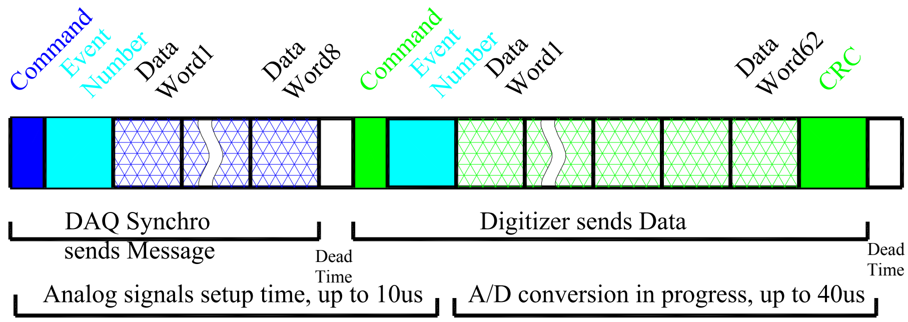

Fig. 3: C-Link transaction format

The C-Link is designed for asymmetric traffic (see Fig. 3). This means that in response to a short C-Link command a large amount of data is returned. The exchange between the transmitter and receiver occurs in two phases. The first phase of transaction sends a command, event number and eight data words from the DAQ to the digitizer. The second phase of transaction returns status and data from the digitizer to the DAQ.

4 The CMD3 “Skeletal" project for the board’s unification

During the DAQ system development, particular attention was paid to the unification of the internal block structure of the electronic boards. For this purpose, a special “Skeletal” project was developed for a field programmable gate array (FPGA). The internal structure of the “Skeletal” project is shown in Fig. 4.

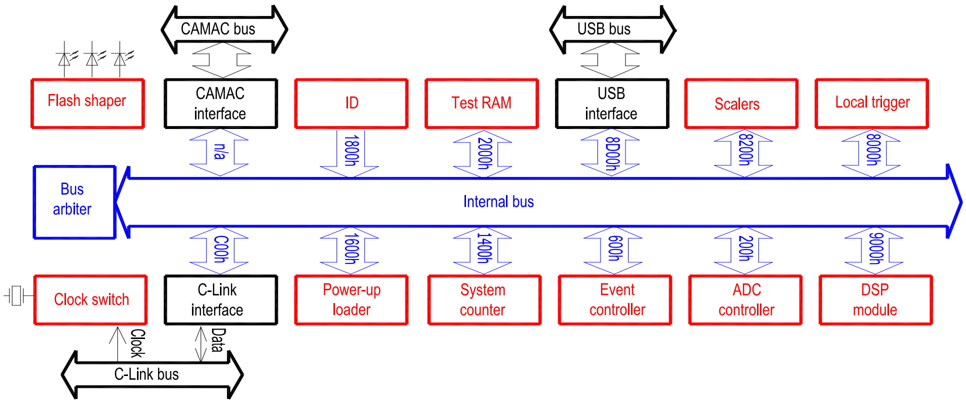

Fig. 4: The “Skeletal” project structure

The main goal of the “Skeletal” project development is to use the same solutions in different devices and their versions. The project is a set modules, possessing unified interfaces and common methods of their implementation.

The hardware part of the project is described in the form of isolated modules aimed at solving particular problems performed by the electronic devices. The basis of the “Skeletal” project is the internal bus and the bus arbiter module. All modules are connected to the internal bus of the project in a standard manner, which simplifies the connection of new modules and their arrangement in the address space. This bus has a 16-bit width both for data and for addresses of the modules connected to it. The rectangles in Fig. 4 show the service modules implemented in most electronic boards of the CMD-3 DAQ system.

Three types of modules are available on the bus: master, slave and arbiter modules (see Fig. 5). The master module can request access to the bus. The slave module supports data transfer only. The arbiter module can initiates the bus cycle, provides the bus for the data transfer and prevents conflicts by building a request queue.

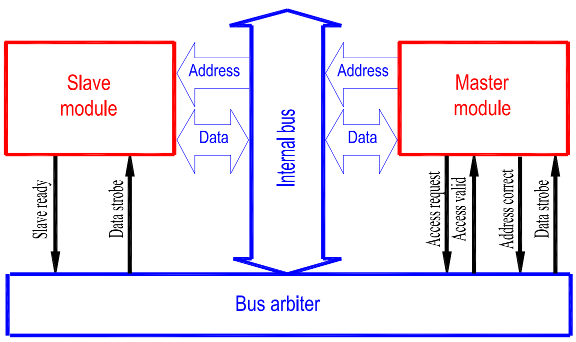

Fig. 5: Bus access control

The access cycle time can vary due to the response of the slave module, so a handshake mechanism is used. It is based on the readiness acknowledgement signal. In Fig. 6 the sequence of the bus states during the data exchange cycle is shown.

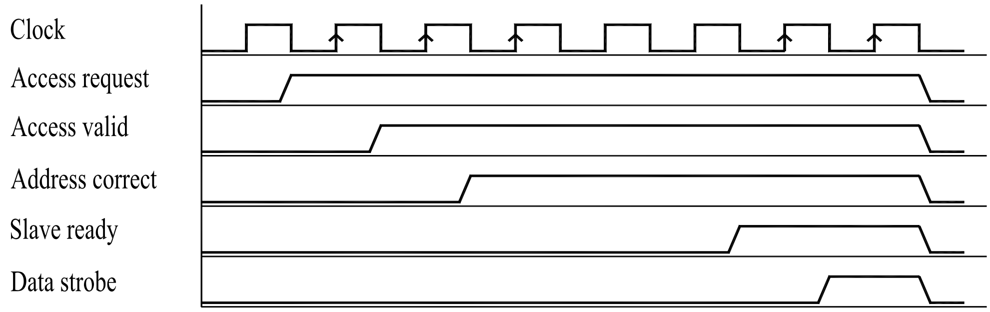

Fig. 6: The access cycle to the internal bus

To perform a data exchange the master module activates the signal "access request". This signal goes to the bus arbiter. If several requests arrive simultaneously, the arbiter uses the priority diagram to choose which master module request will be processed first. The arbiter returns the “access valid” signal to the selected master module. The master module sets the address of the slave module to the internal bus and sends the “address correct" signal. The slave module decodes this address. It sets the acknowledgement signal "slave ready" if the address is identified. This signal is transferred to the arbiter. In response, the arbiter sets the “data strobe” signal for one period of the clock generator. The slave module takes the data by this signal. The “data strobe” signal finishes the cycle of exchange on the internal bus. After that, the next cycle of exchange on the internal bus can be started. If none of the slave modules responds, the cycle is terminated after the timeout period, and the arbiter sets the error signal.

5 Performance example

One of the parts of the CMD-3 detector tracking system is the drift chamber [8]. It has uniform structure of hexagonal cells with size of about 0.9 cm. The charge division technique is used to measure hit coordinates along the wire. The maximal drift time at the nominal high voltage value and magnetic field of 1.3 T is 650 ns. To process DC signals a special digitizing board (T2Q) was designed and produced. Each T2Q board allows to measure two amplitudes and one time from 16 independent cells in the DC. The spatial resolution of the CMD-3 detector drift chamber is shown in Fig. 7.

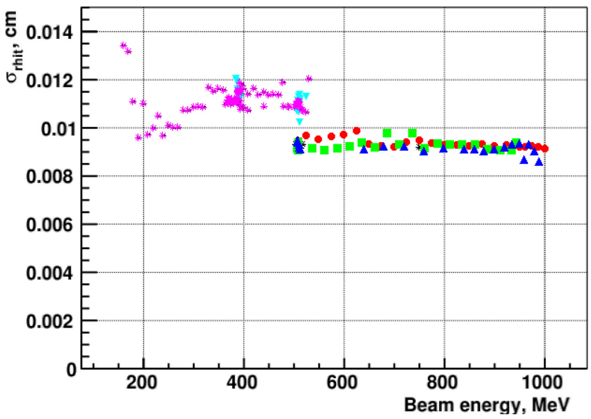

Fig. 7: The spatial resolution of the CMD-3 Drift Chamber

The average time resolution is less than 100 μm which corresponds to the DC project parameters. So the CMD-3 DAQ system does not limit the time resolution of the detector subsystem.

6 Conclusion

The CMD-3 detector has been collecting experimental information for a few years. During experimental runs design parameters of the DAQ system were achieved, the system demonstrated good performance and stability. All electronic blocks were designed and produced by experts at BINP. The electronics for each physical subsystem of CMD-3 have reached the target parameters. All data transfer rate requirements have been met. The CMD-3 DAQ system does not limit the time resolution of the detector subsystem. At the moment about 300 electronic blocks are in operation in the CMD-3 DAQ. The CMD3 DAQ can be scaled to the DAQ for a super c-tau factory.

Acknowledgements

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References

[1] D. Berkaev, et al., *Nucl. Phys. Proc. Suppl*. **225-227** (2012) 303.
[2] M. N. Achasov et al., *Nucl. Instr. and Meth*. **A598** (2009) 31.
[3] G.V. Fedotovich, et al., *Nucl. Phys. Proc. Suppl.* **162** (2006) 332.
[4] B. I. Khazin et al., Nucl. *Phys. B, Proc. Suppl.* **181-182** (2008) 376.
[5] G. W. Bennett, et al., Muon G-2 Collaboration. Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL, *Phys. Rev. D* **73** (2006).072003.
[6] K. Yu. Mikhailov, et al., *Nucl. Instr. and Meth.* **A732** (2013) 463.
[7] A. N. Kozyrev, et al., The CMD-3 TOMA DAQ Infrastructure, *J. Instrum.* **9** (2014) C10016.
[8] F. Grancagnolo, et al*., Nucl. Instr. and Meth.* **A623** (2010) 114.