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Instrumentation for multi-detector arrays

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Abstract. The new generation of detector arrays require complex instrumentation and data acquisition system to ensure increased reliability of operation, high degree of integration, software control and faster data handling capability. The main features of some of the existing multi-detector arrays like MSU 4π array, Gammasphere and Eurogam are summarized. The instrumentation for the proposed INGA array in India is discussed.

Keywords. Multi-detector array; electronics and data acquisition system.

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1. Introduction

Presently a common characteristic trend in low and medium energy nuclear physics is to develop more complex detector systems to form multi-detector arrays. The main objective of such an elaborate set-up is to obtain a comprehensive information about all reaction products produced in a reaction. Some examples of existing very large arrays are Gammasphere, Eurogam, Exogam, MSU 4π array and Indra. Currently the most challenging development in multi- detector arrays is in the area of electronics and data processing for gamma ray energy tracking array (GRETA). In India, a multi-detector charged particle and neutron detector array (MEGHNAD) is under construction, and a gamma detector array INGA has been planned as a national facility.

Due to the increased complexity of the required instrumentation, the front-end electronics for a large detector array must meet the following criteria:

1. Precise information about the energy, timing, position, pulse shape etc.
2. Measurement of all reaction products with nearly 4π efficiency
3. Large multiplicity of reaction products require high granularity detectors
4. Very large scale of instrumentation required to process the multitude of signals from many detectors
5. High trigger rates require fast processing and readout
6. Very high throughput $\sim 10^6$ data words/sec

The need to provide a large number of data channels in a typical experiment puts severe constraints on the design of the front-end electronics. From the users point of view, some of the desirable characteristics of the instrumentation are:

1. Increased reliability of operation
2. High degree of integration to minimize the space and power requirement and reduction of inter-connecting cables
3. Replacement of manual controls by software control
4. Provision of remote monitoring of data
5. Faster data handling to support the large event rate and increased number of parameters per event
6. Modular development to allow integration with data from auxiliary detectors

In making a comparison of the instrumentation at various multi-detector array facilities, it is important to note that the requirements for particle detector arrays and gamma detector arrays are somewhat different. The first requires a high dynamic range of detected particles ranging from protons to fission products; the energy resolution required is modest ($\sim$ 1%) and short shaping times are needed to handle the fast pulses from the particle detectors. On the other hand, gamma ray spectroscopy requires very high resolution (better than 0.1%) and long shaping times ($\sim$ microsec). Faster processing and pulse shape analysis are the new requirements for the highly granular Ge detectors envisaged for the GRETA (gamma ray energy tracking array) facility.

2. Instrumentation for MSU 4π array

Let us review some of the existing multi-detector arrays in order to highlight their salient features. The Michigan State University 4π array [1] has been designed to detect with nearly 4π efficiency, all charged particles ranging from protons to fission products produced in intermediate energy nucleus–nucleus collision. The basic instrumentation is incorporated in a soccer ball chamber with 20 hexagon and 12 pentagon sides. Except the backward pentagon for beam entry and forward pentagon for detecting the particles scattered at the extreme forward angles, the remaining 30 surfaces have the combination of the following detectors:

- Multi wire proportional counter (MWPC) for x-y position readout.
- Bragg curve chamber (BCC) for heavy ion detection [2].
- Phoswich detectors for light particles [3]. Each detector is composed of both fast and slow phosphors (BC412 and BC444) viewed by the same photomultiplier tube. To handle the high multiplicity of light particles, each surface is further subdivided into six segments for a hexagon and five segments for a pentagon. (The total number of phoswich detectors is 170.)

The forward pentagon surface is similarly subdivided into many detectors.

- High rate forward array (3°–20°) consisting of 45 element fast-slow phoswich detectors.
- Maryland forward array (1.5°–2.9°) with 16 element Si detector backed by phoswich.
- Zero degree detector (0.5°–1.5°) having 8 segment fast-fast scintillators.

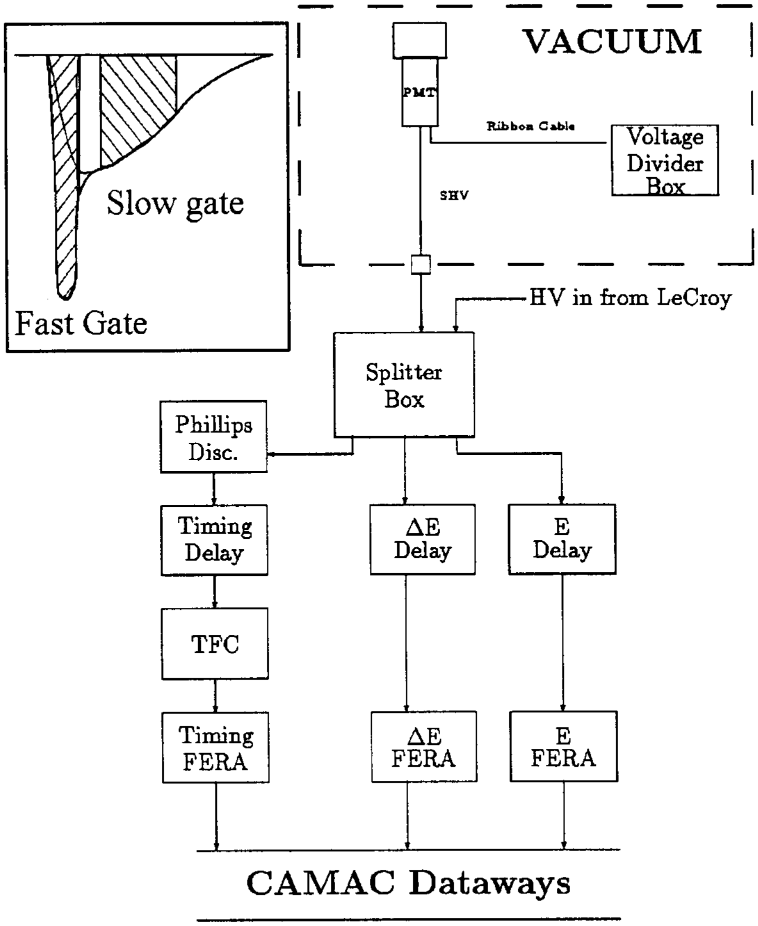

Figure 1. Phoswich detector electronics for MSU 4π array.

The detailed experimental setup can be obtained from the user manual [4] of the array.

In order to digitize the signals from the large number of detectors incorporated in the 4π array, high density electronics with each module processing the signals from a large number of detectors has been employed. The CAMAC based electronics has the following features:

- Each module provides similar processing for a large number of channels.
- The module interconnection is done through 100 Ω ribbon cables, allowing multiple channels to be connected simultaneously.
- Parameter setting is done through the CAMAC bus that allows for software adjustment of threshold, delay, pedestral subtraction etc.

The basic block diagram for the phoswich detector electronics is shown in figure 1. To minimize the number of cabling, the same cable is used to provide high voltage to the PMT

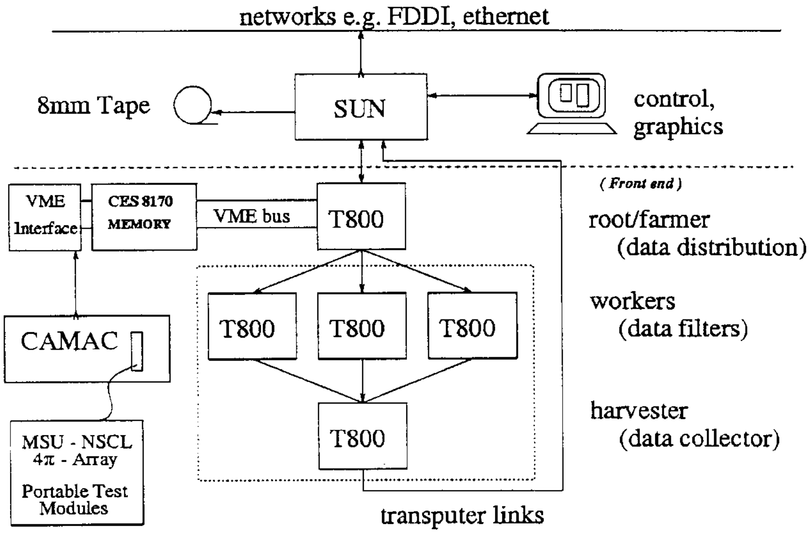

Figure 2. Parallel processing data acquisition system for MSU 4π array.

and also to bring out the anode pulses. The anode signal is composed of a fast and a slow component from the two types of phosphors (inset in figure 1). The signal is split in three ways using a passive network. One signal determines the timing and the trigger logic and the other two are integrated in charge sensitive ADCs (QDC) using a ‘prompt fast gate’ and a ‘delayed slow gate’ derived from the timing logic. Some of the commercially available modules used in the MSU setup are:

Timing: Phillips scientific 715 and Lecroy 4413 timing discriminator; EG&G Octal CFD for multiplicity output.
Energy: Lecroy 4300 FERA ADC, 11 bit 10 μs conversion, 16 channels/ADC for phoswich detectors; Silena 4418 ADC with 8 channels (12 bit 4 μs/channel) for BCC detectors.
Time interval: Lecroy 4303 Time to FERA conversion.

For the selection of a valid event, the multiplicity outputs from the Octal CFDs (50 mV/channel) are added together to make the following groups: (i) Ball multiplicity, (ii) high rate array multiplicity and (iii) total particle multiplicity. These signals are sent to a discriminator with CAMAC selected threshold for identifying events of interest. The discriminator also generates gates for FERA and SILENA ADCs and initiate a data conversion-readout cycle. For the data readout, the basic limitation of 1 μs/data word for a CAMAC cycle is circumvented by using a proprietary FERA hardware (fast encoding readout ADC) that allow hardware zero suppression and a fast readout at the rate of 100 ns/channel using a front panel ECLine connector.

The data acquisition system for the 4π array is incorporated as a multinode transputer board mounted in a VME crate (figure 2). The data from the ADC and QDCs are transferred to a buffer memory (CES 8170) using FERA bus. A bank of transputers processes the event-mode data and transfers the filtered data buffers to a UNIX host based memory using a transputer link. The host workstation can save the data on 8 mm magnetic tape or transfer to another workstation for displays etc. Currently data rates are restricted by the secondary storage devices (500–550 kbytes/sec) or event rates which are restricted to the ADC deadtime plus 180 nsec/dataword.

3. Instrumentation for CHIMERA and INDRA

The instrumentation for other multi-detector arrays for charged particle detection .i.e. CHIMERA [5] and INDRA [6] are very similar in nature. For the CHIMERA (charged heavy ions mass and energy resolving array) system, a set of 1192 detection cells, each consisting of detector telescope of 300 μm thick silicon detector followed by a CsI(Tl) crystal, are arranged in a cylindrical geometry around the beam axis. Analogue pulses from the Si detectors are processed to obtain the energy deposited and time of flight of the reaction products. The 'slow' and 'fast' component from the CsI(Tl) detectors are used for total energy and particle identification of light reaction products. The analogue processing modules are distributed into several CAMAC and NIM crates [7]. The first contains the octal CFD, trigger generator and Si amplifiers with remotely controlled gain setting. The NIM crates house the CsI amplifiers whose gain can also be remotely set by a host computer using RS232 network.

The digitization of the analogue signals are done by CAEN VN1465 QDC modules for charge and CAEN VN1488 TDC modules for time measurement. The modules are housed in VME crates and each module can digitize up to 64 channels. A 100 mega bytes/s fast data link (FDL) transfers the data from the digitisers to a central VME crate. The event data buffers can be distributed to the analysis workstations through a dedicated ethernet link. The data acquisition system can handle a data rate of 1 kHz with an overall throughput of 1 Mbytes/sec.

The detection system for the INDRA array [6] is composed of ionisation chambers, CsI(Tl) scintillators, Si detectors and fast-slow phoswich detectors to cover a wide dynamic range of the detected particles. In order to have a highly integrated system with remote monitoring facility, most of the electronics [8] have been developed in the VXI bus standard. We would discuss the advantages of the VXI standard in more detail in the next section in connection with the electronics for gamma spectroscopy.

4. Instrumentation for gamma spectroscopy

The instrumentation for multi-detector gamma spectroscopy puts severe constraints on the performance of the processing electronics. The main requirements for the instrumentation for gamma spectroscopy are:

- Low noise high stability amplification with resolution $\sim$ 2 keV at 1.33 MeV.
- Optimum shaping for high count rate and input rise time spread.
- Adequate shielding between neighbouring channels. This requires shielded cables for interconnection between various modules.
- At least 13 bit conversion with good integral and differential non-linearity.
- Fast conversion to reduce system dead time.
- Reduction of cost per channel.

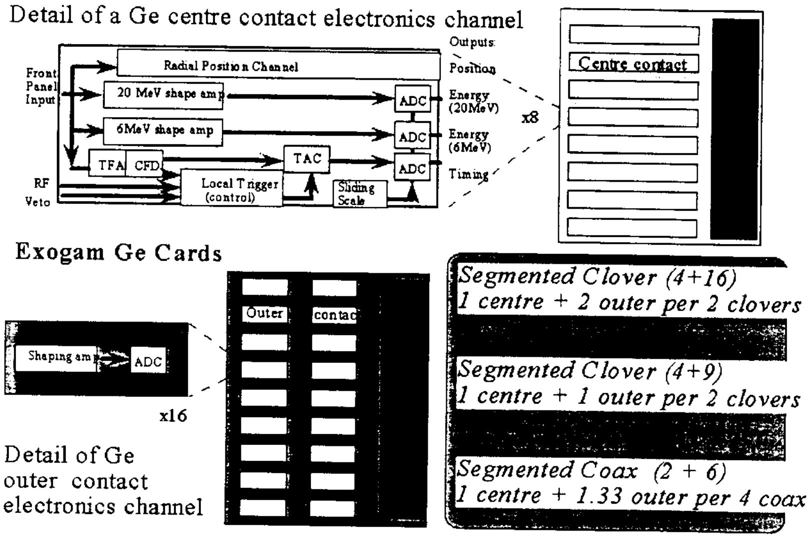

Figure 3. Basic features of Exogam Ge card.

For increased reliability, the number of cable interconnections should be minimized. This requires that each module should incorporate all the functions required for the processing of the signal from a detector (i.e. amplification, digitization, timing and control logic). The high degree of integration required for incorporating so many features on a single board has been obtained by the extensive use of multi-layer boards, ASIC chips and digital signal processing (DSP). The digital controls have been implemented using field programmable gate arrays (FPGA) that allow a very large number of logic circuits to be realised in a single chip.

Early developments in the area of high-density instrumentation were carried out using VXIbus [9] D-size format that supported a very large PCB area (367 mm × 340 mm) for higher performance instrumentation. The main advantage of the VXI based systems arises from the close integration between the analogue and digital part of the circuit that allow faster communication and processing, while retaining excellent shielding between the analogue part of the board and the digital backplane. Typically the equivalent of 4–6 crates of NIM modules can be compressed into one D-size VXI card.

One of the major achievements in VXI based design is that all manual controls like gain setting, pole zero correction, and time delay settings could be done through software control with greatly increased reliability. In addition, remote monitoring of the analogue signals is possible through software controlled inspection lines supported in VXI bus specification. Most of the electronics in Eurogam [10] and Gammasphere [11] were implemented using D-size VXI boards.

Several types of VXI cards in D-size format have been developed for gamma spectroscopy work, i.e. for coaxial Ge, Clover and Cluster detectors, charged particle detectors, inorganic scintillators (BGO, NaI, CsI) and neutron detectors. For the Clover detectors in Eurogam, five Ge channel and one BGO channel have been integrated in a single card. A block diagram of the electronics for the segmented Clover cards for Exogam [12] is shown in figure 3.

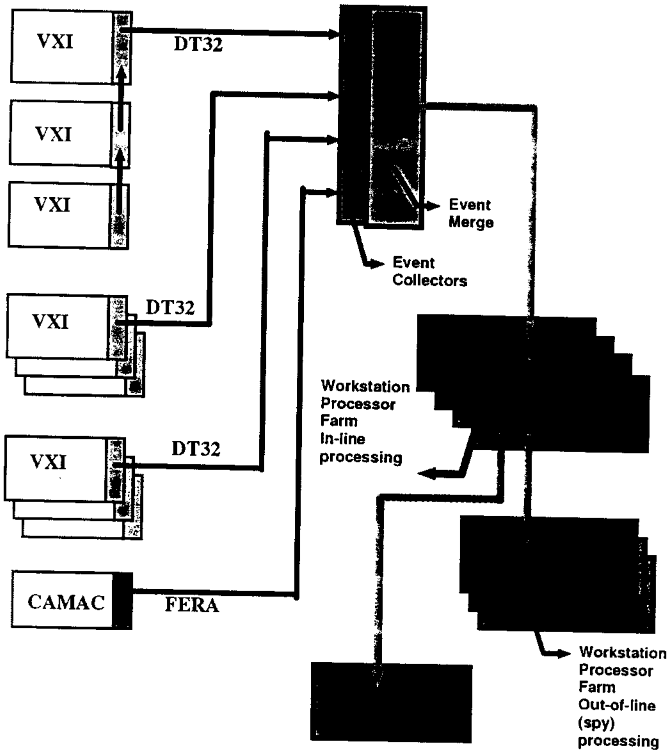

Figure 4. Euroball data acquisition system.

The digital information (energy, time etc) from the VXI cards are transferred over the VXI backplane into a buffer in the crate readout controller (STR8080). Readout from the STR8080 to the event collector uses the DT32 bus [13]. The DT32 bus is very similar to FERA except that it is 32 bits wide. Data can be transferred synchronously at a transfer rate of up to 10 MHz. The signals are all differential ECL, carried over ribbon cables.

For very large arrays requiring the readout of thousands of parameters, the system dead time during a read cycle can be reduced by using separate readout controllers for each VXI crate which transfer data in parallel to a buffer memory. Each segment of the memory contains only a partial list of parameters for an ‘event’ which may be reassembled later using software. The event building and online data analysis functions take place within the processor farm composed of standard commercially available workstations. The Euroball data acquisition system is able to collect the data generated by event rates up to 50–100 kHz with the corresponding raw data rates up to 20 Mbyte/sec. A simplified block diagram of the Euroball data acquisition system is shown in figure 4.

5. Instrumentation for the Indian National gamma array (INGA)

In India, a major experimental facility for studying nuclear structure at high spin is currently planned to be set up in collaboration with various institutions, i.e. TIFR, VECC,

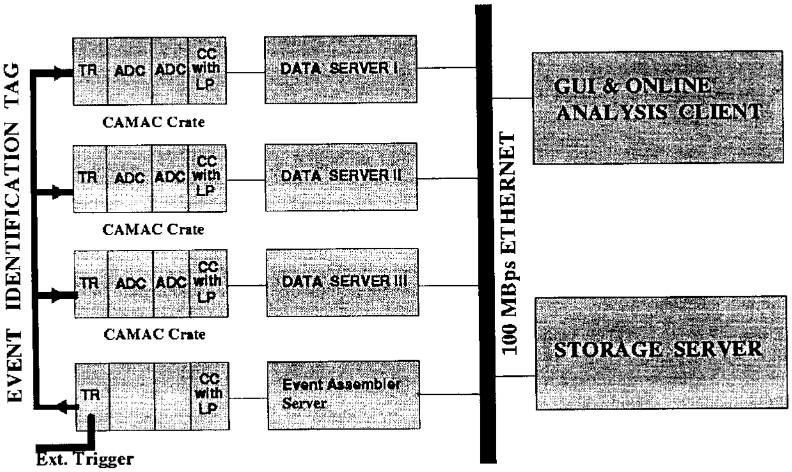

Figure 5. Distributed data acquisition system for INGA.

SINP, IUC-DAEF, NSC and the universities. This common facility, Indian National gamma array (INGA) [14] would be rotated among the three heavy ion accelerator centres in the country. It would be possible to couple the array with various auxiliary facilities in the three centres, i.e. RMS set up at TIFR, MEGHNAD at VECC and HYRA at NSC for additional selectivity and sensitivity.

The basic array will be made of 24 Clover detectors consisting of 96 Ge channels each requiring energy and timing information. It is planned to develop part of the high density data acquisition electronics in-house as it would allow for easy integration with the electronics for auxiliary facilities. Some preliminary work to develop computer controlled fast instrumentation for gamma spectroscopy has been undertaken at NSC in collaboration with BARC. Prototype building blocks like digitally controlled amplifier and timing circuitry have been tested and the present aim is to implement all the required features for a Ge detector on a single CAMAC card. To develop the expertise in designing VXI electronics in the country, a collaborative project with GANIL to jointly develop the electronics for Exogam array has also been undertaken.

A block diagram of the proposed data acquisition system of INGA is shown in figure 5. A common event trigger is used to synchronise the digitization and readout of data from the modules that are distributed over many crates. An FPGA based list processing crate controller transfers the data to local memory using CAMAC readout cycles. An event assembler server combines the different fragments of data to make a complete data buffer and transfers to another client for on-line analysis. The basic features of the multi-crate operation has been tested and an overall data transfer rate of 2 Megabytes/sec has been achieved with a combination of four CAMAC crates, with all the overheads like network transfer, event reconstruction and storage to disk. The system is expected to be fully functional within two years.

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