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INDRA electronics upgrade

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Summary. — The INDRA charged particle multidetector has been operating since 1993, and up to the first experiment coupling it with FAZIA performed in 2019 it has always functioned with the same electronics developed at the beginning of the 1990s. A major upgrade of the full electronics (both for data acquisition and power supplies) has recently been completed, in time for the next INDRA-FAZIA experiment, scheduled for April 2022. In this contribution we will present this new electronics.

1. – Introduction

INDRA ("Identification de Noyaux et Détection avec Résolutions Accrues") [1] was built at the beginning of the 1990s as one of a second generation of 4π detection arrays for charged particles, with characteristics optimized for the study of heavy ion collisions using the beams and energies available at GANIL. The large number and variety of nuclear species emitted at these energies, especially in central collisions, require detectors with not only 4π solid angle coverage, but also high granularity and large dynamic range in both identification and energy measurement capability. The latter requirements impose

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strong constraints on the electronics to be used with such an array, in terms of the elevated number of channels to be handled, the means of triggering the associated DAQ in order to record the data produced by each collision, and the achievement of a large energy range without sacrificing resolution.

To best meet these specifications in the early 1990s required a high degree of innovation, and the original INDRA electronics was in many ways the first of its kind in nuclear physics [2]. In order to record the signals produced by the 96 ionization chambers (ChIo), 196 silicon detectors, 324 CsI(T1) scintillators and 12 NE102/NE115 phoswich detectors of the original array, custom-made electronics modules based on the VXI (VME Xtensions for Instrumentation) standard were developed specifically by the laboratories of the collaboration:

- 7 constant fraction discriminator modules for the Si and ChIo detectors (48 channels each);
- 10 dual-range charge integrating ADC modules (12-bit resolution) for the Si and ChIo detectors (32 channels each);
- 14 modules for CsI(Tl) signal processing, combining CFD and pulse-shape discrimination (fast and slow gates) (12-bit resolution) (24 channels each);
- 1 module for processing the signals of the 12 phoswich scintillators (12-bit resolution);
- 7 modules to provide individual time markers for each fired detector with a precision of 10ns (10-bit resolution), relative to the trigger of each event;
- and last but not least, 2 dedicated modules to handle event triggering and liaise with the data acquisition system.

These 41 modules were housed (see fig. 1) in 4 size D VXI crates, alongside 3 CAMAC crates containing 59 custom 8-channel modules (38 variable gain amplifiers and 21 variable amplitude pulser modules for the Si and ChIo detectors) and 3 NIM crates containing the 30 custom modules of the "regrouper" system which generated multiplicity signals and non-programmable logic functions of the trigger (ensuring recording of coincidences in the ChIo-Si/CsI telescopes). Last but not least, the high voltage supplies for all detectors were provided by 8 CAEN crates each handling 64 individual channels, while low-voltage supplies for Si and ChIo preamplifiers were provided by separate custom-made modules. The full setup was housed in 5 full-sized bays with a dedicated air conditioning plant that was essential during operation in order to evacuate the heat generated by the different crates, especially VXI and CAMAC.

At the time, for an array of 628 detection channels, the electronics of the INDRA array was seen as a cutting-edge system in nuclear physics, not only in terms of its (relative) compacity, but also for the fact that the vast majority of the settings for the different channels could be performed remotely by computer, thus allowing to install the electronics in the experiment room as close as possible to the detectors. Not only was it used successfully for more than 25 years for every experiment performed with INDRA since 1993 (including the first experiment coupling INDRA with FAZIA in 2019), but, remarkably, the whole installation was relocated twice during its history, the first time in 1998/9 for the fourth INDRA campaign at GSI, and then again in 2007 for two experiments coupling INDRA with the VAMOS spectrometer in a different experimental room at GANIL.

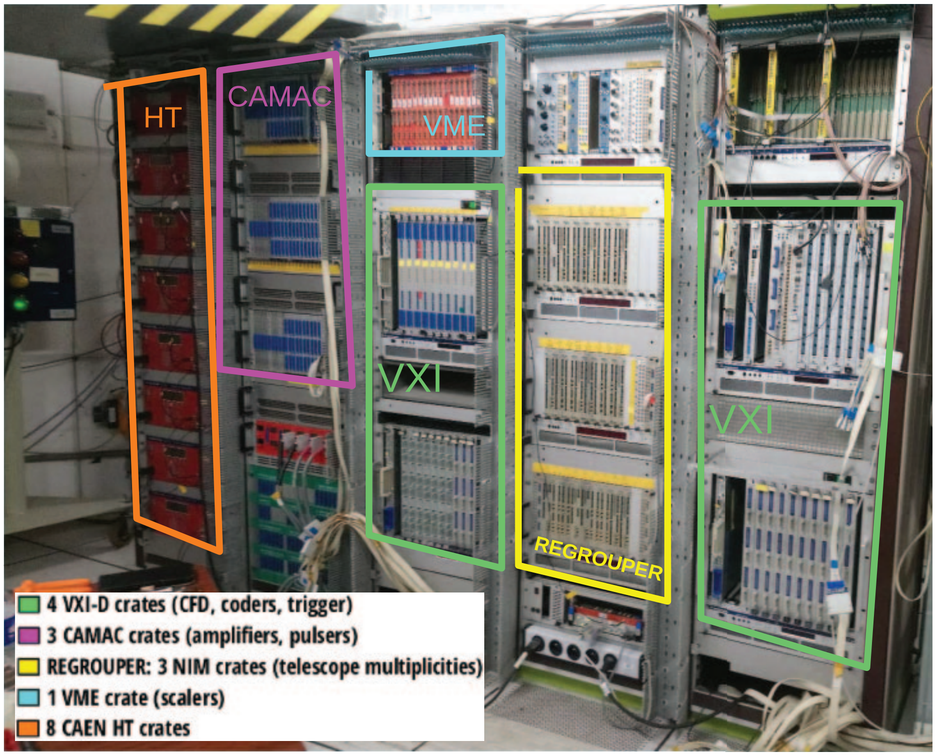

Fig. 1. – The original INDRA electronics (with all cables removed, prior to dismounting) in the D5 cave.

Nevertheless, by the time of the first tests of the coupling of the DAQ systems of INDRA and FAZIA in 2018, it rapidly became clear that the *status quo* could not hold indefinitely. First of all, more and more of the irreplaceable and unrepairable custom-made VXI modules had developed faults; thanks to the removal of the first five rings of INDRA in order to install the FAZIA demonstrator, we were able to replace the faulty modules with these newly available "spares", but this was clearly not a long term solution. The CAEN high voltage supplies had been similarly afflicted for many years, and only by further reducing the number of channels could they continue to be fit for purpose; low-voltage supply modules were also beginning to fail. Secondly, the coupling to FAZIA revealed a large disparity in the dead time of the two arrays: whereas for the modern digital electronics of FAZIA [3] a dead time of $\sim 10\,\mu$s is achieved, the dead time of INDRA with analogue VXI electronics was measured to be 150–200 μs. Consequently, in the coupling of the two systems, FAZIA could not operate to full capacity, always obliged to wait for her older, slower sister device. Lastly, and perhaps most fatally, the large air conditioning plant, itself in fact older than the electronics for whose operation it was essential, had become in continual need of repair in order for it to keep going. It would never regain its nominal efficiency after the replacement of its original coolant with a more environmentally friendly fluid in order to conform to new regulations. The safe operation of the electronics for the nearly two months of the first INDRA-FAZIA experiment was made possible only by the addition of a large, mobile ventilation system placed directly in front of the bays.

It was therefore in this context that we began to look for a solution to replace the INDRA electronics, both for data acquisition and power supplies, in 2019–2020. We will now present the resulting upgrade which is currently undergoing final testing before the next INDRA-FAZIA experiment, scheduled for April 2022.

2. – Data acquisition electronics

The solution retained for the acquisition electronics is based on commercial VME modules manufactured by Mesytec Detector Readout Systems. The full electronics for INDRA is contained in a single VME crate housed in an air-conditioned bay in the experiment room (see fig. 2). All settings and acquisition control are fully remote-operable via a Gigabit ethernet link to the MVLC trigger/controller unit (see below), using open-source software provided by Mesytec [4]. We have also adapted our own previously-developed software in order to provide user-friendly graphical interfaces for INDRA detector settings.

2·1. *Signal processing.* – The MDPP-32 module [5] is a 32-channel VME digital signal processing unit which combines a variable gain amplifier stage, individual channel triggering with adjustable threshold settings, and different signal processing firmware which can be loaded into the on-board FPGA processors. Whatever the firmware, baseline restoration and pile-up detection is applied to the signals. The signal processing is based on 80 MHz sampling ADCs with all outputs having a maximum 16-bit resolution. The settings of all modules are fully remote controllable thanks to the Mesytec MVLC VME controller and trigger module [6].

MDPP-32 modules with two different types of firmware are used for the CsI and Si detectors currently installed in INDRA:

- *Si detectors*: The "SCP" (Charge Sensitive Preamplifier) firmware is used. In this case, the module provides a 16-bit value for the input signal amplitude. Shaping time, pole-zero (decay-time) correction, and gain can be adjusted by the user.

- *CsI detectors*: The "QDC" firmware is used, which provides two 16-bit values corresponding to two user-defined gates for fast and long ("total") integration times. For this we use $\Delta t_{fast} = 400\,\text{ns}$ and $\Delta t_{long} = 3.5\,\mu\text{s}$, where the former gate is the same as that used in the original VXI signal processing for INDRA CsI detectors, and the latter is the maximum possible integration time for this firmware.

With 240 CsI detectors and 96 Si detectors in the current setup, 8 modules using "QDC" firmware and 4 modules using "SCP" firmware are needed for the whole array, which, along with the MVLC trigger/controller module, fit easily into a single standard (21-slot) VME crate. Sufficient MDPP modules have been acquired in order to equip the full INDRA array, including ionization chambers (ChIo, for which the SCP firmware will also be used), for future experiments.

2·2. *Triggering.* – Triggering and data acquisition for the MDPP modules are based on the "Window of Interest" (WoI) concept. Each module expects an input trigger to generate this WoI, which can be shifted in time by $\pm 25\,\mu\text{s}$ with respect to the trigger and has an adjustable width of 1.5 ns to 25 μs. All triggers generated by the CFD discriminators from the channel inputs which fall into this window are sent to a large data buffer for read out by the VME bus. In the simplest configuration, the logical OR

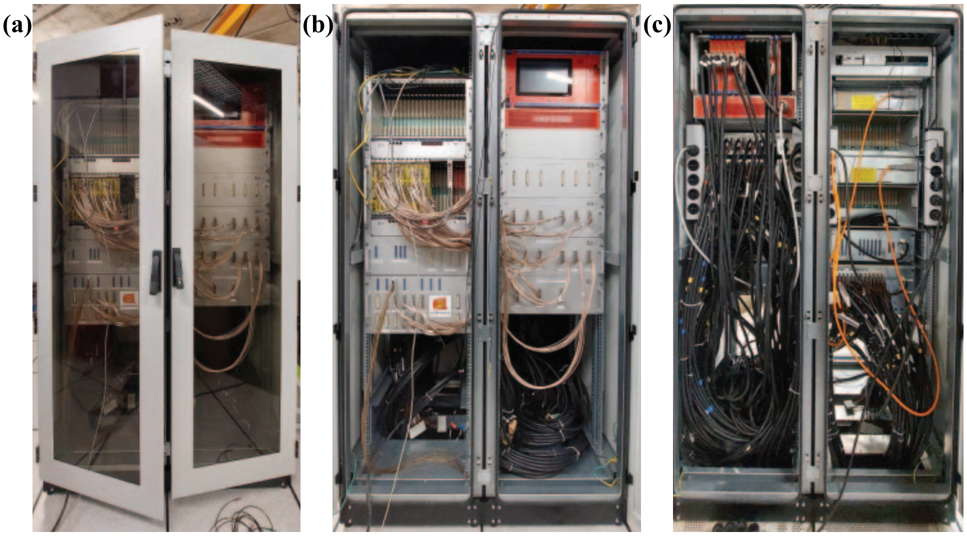

Fig. 2. – The new INDRA electronics in its dedicated air-conditioned bay: (a) doors (almost) closed, normal functioning mode; (b) doors open, showing the Mesytec electronics (yellow modules, left), CAEN power supply mainframe (red crate, top right), and signal routing boxes (grey); (c) rear view, showing arrival of cables from the reaction chamber.

of the module's channel inputs can be fed back internally to the WoI trigger input to allow self-triggering; then each module fires independently of the others.

In our case, in order to mimic the asynchronous trigger mode of the INDRA VXI electronics, the logical OR of each module's trigger output is fed via the IRQ lines of the VME backplane to the MVLC trigger/controller module. The latter then distributes a common WoI start trigger to all modules in the crate, sufficiently advanced (offset $\sim -650\,\mathrm{ns}$) to ensure that the individual channel which triggered the "event" falls within the window. The window width can then be adjusted in order to ensure that all detectors firing in the same reaction are recorded, while minimising the rate of random coincidences. As a rule of thumb, we can note that the width of the coincidence window used in the former INDRA trigger was 240 ns. It should be noted that, for each fired channel, we also dispose of a "time marker" which gives the trigger time of the channel relative to the opening of the WoI, with a resolution of 24 ps, thus any random coincidences, beam packet pile-up, etc. can be discarded *a posteriori* in offline analysis.

It should be noted that there is no possibility to implement a DAQ trigger based on a multiplicity of hit telescopes with this setup, as we cannot access the triggers of the individual channels in order to implement a digital equivalent of the formidable "regrouper" module that lay at the heart of the original INDRA trigger (see sect. **1** and fig. 1). The trigger of the new DAQ is effectively always minimum bias, $M \geq 1$. This is not necessarily problematic, as the main reason for using higher multiplicity triggers with INDRA in the past was the large dead time of the old system. With the current setup, the measured dead time is only 10–15 μs, in other words, a factor of 15–20 smaller than before.

2˙3. *Event timestamping and coupling with FAZIA.* – During the E789 INDRAFAZIA experiment in 2019, a VXI module was used as a universal clock to timestamp INDRA and FAZIA events, in order to enable on-line merging of events within a predefined time window. This CENTRUM VXI module developed by GANIL can provide 48-bit timestamps to up to 7 separate acquisition systems, and the FAZIA Regional Board was conceived with an integrated CENTRUM receiver specifically for the coupling with INDRA. Despite the INDRA electronics no longer being based on a VXI solution, it is therefore mandatory to continue to timestamp INDRA events produced by the setup presented above using an interface with the CENTRUM.

This has been achieved by the addition of a VME module in the crate containing the Mesytec electronics. The TGV is a VME trigger module developed at LPC Caen, and long used in many experiments at GANIL. With the addition of a CENTRUM receptor plug-in developed at GANIL, it becomes possible to use it in a VME setup in order to request and receive timestamps from a CENTRUM in an external VXI crate not associated with the main acquisition electronics. This is the solution which has been implemented and tested for INDRA. The Mesytec MVLC trigger/controller unit is highly flexible and programmable, notably in order to be used with non-Mesytec VME modules. For every event trigger generated by the MDPP modules, the MVLC signals the TGV in order to request a timestamp, which is duly read from the module registers and added to the event along with the MDPP data.

3. – Power supply electronics

As for the signal processing and acquisition electronics, a new far more compact solution than previously has been adopted, using commercial power supply units manufactured by CAEN. The full high- and low-voltage power supplies for INDRA are now contained in a single SY4527 mainframe crate [7]. The crate is housed in the bays with the electronics in the experiment room, and all settings are fully remote controlled via Gigabit ethernet network using the GECO2020 software provided by CAEN. An interlock system is used to protect the photomultiplier voltage supply from vacuum failure.

Currently, the individual components housed in the mainframe crate for the detectors which are mounted in the INDRA-FAZIA setup are:

- 5 A7030N 48-channel negative power supply units (max: 3 kV) for the 240 CsI photomultipliers [8];
- 1 A7040N 48-channel negative power supply unit (max: 100 V) for the 96 Si detectors [9];
- 2 A2519A 8-channel low voltage supplies for Si preamplifier circuits [10].

As for the signal processing electronics, sufficient modules have been acquired in order to equip the full INDRA array for future experiments.

4. – Signal routing, cabling and connectors

As important as the new digital electronics and power supplies are, they would be useless without the necessary cables to connect them to the detectors. The present upgrade does not concern the connections inside the reaction chamber (although many long-standing problems on that side have also been resolved during the upgrade process): on the other hand, from the feedthroughs on the exterior of the chamber flanges up to the new electronics modules, everything has been replaced.

Prior to the upgrade, a huge effort was made to document the configuration of the different feedthrough connectors, where detector signals, high/low voltages and ground lines are interleaved. Once this was done, design could begin for new signal routing boxes to provide an interface between the interleaved chamber-side cables on the one hand and separated signal and power-supply cables on the other, built at LPC Caen. The 170 cables connecting chamber feedthroughs to the routing boxes, each between 8 and 11 metres long, were prepared on-site in the D5 cave, using both new and reconditioned connectors from the original electronics; in all cases, great care was paid to the design and soldering of new PCBs for the connectors in order to ensure correct grounding and transmission of all signals up to the electronics. In total, close to 2 km of cable (each "cable" being made up of 8 individual coaxial cables) were necessary, along with nearly 250 different connectors. Finally, the cables connecting the CAEN modules to the routing boxes were supplied by CAEN, and the cables connecting the MDPP modules to the routing boxes were supplied by Mesytec.

5. – Conclusions

The entire INDRA electronics has been replaced after nearly thirty years of operation. This operation was carried out in a relatively short time: after an initial beam test using only two Mesytec modules in April 2021, dismounting of the original electronics began in May of the same year. On 27th January 2022 we were able to acquire data from cosmic rays and alpha source using the full setup for the first time. It is worth noting that not a single cabling error has been observed throughout the tests. INDRA is now equipped with modern fully digital electronics, with true 16-bit resolution for all channels, fast and total light outputs for CsI detectors, and minimal dead time. The new setup will be used for the first time for the next experiment coupling INDRA and FAZIA, scheduled for April 2022.

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