SRS VMM readout for Gadolinium GEM-based detector prototypes for the NMX instrument at ESS

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Abstract. We report on further development and application of a general purpose readout system, the Scalable Readout System (SRS). The SRS was introduced by the RD51 collaboration in 2009 in a common effort. Several front-end Application Specific Integrated Circuits (ASICs) were implemented in the system, of which the APV25 is most commonly used. Recently, we implemented the VMM ASIC, developed to read out detectors of the ATLAS New Small Wheel. We developed hardware components as well as FPGA firmware and computer software. With this latest implementation called SRS VMM, other groups intend to perform experiments and detector R&D. In our application targeted at the NMX macromolecular diffractometer, one of the instruments foreseen at the European Spallation Source (ESS), SRS VMM was used to read out prototype detectors. Small scale versions were successfully tested at neutron sources and a full scale version was constructed. In those test beams, the feasibility of the detector and readout electronics design could be demonstrated.

1. Introduction

In 2009, the RD51 collaboration introduced the versatile Scalable Readout System (SRS) [1]. It is designed as a general purpose system that can be used in different applications. The architecture simplifies the implementation of different front-end Application Specific Integrated Circuits (ASICs) due to a common hardware part. Examples are the Timepix [2] and the most commonly used APV25 [3].

Within the Horizon2020 project BrightnESS, the VMM ASIC [4], designed for the ATLAS New Small Wheel upgrade was implemented [5]. The specific application that guided that project was the development of a prototype detector for the NMX macromolecular diffractometer at the European Spallation Source (ESS).

2. The Scalable Readout system

Figure 1 shows the architecture of the SRS. The core component is the Front-End Concentrator (FEC) card that hosts the main Field Programmable Gate Array (FPGA) with firmware. The

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front-end ASICs are hosted on hybrids, which are directly mounted on the detector. The graphic shows different ways in which the hybrids could be realised for specific ASICs. In case of the VMM, two ASICs are mounted on one hybrid, while for the APV25 it is only a single chip. Other configurations as for example four ASICs per hybrid are imaginable. The scalability is achieved by the fact that several hybrids can be connected to one FEC via an adapter card. In case of the VMM and APV25 implementation, the adapter card has eight HDMI connectors. The data of two APV25 hybrids can be combined in a master/slave configuration as shown in the figure. To combine data from several FECs, the Scalable Readout Unit (SRU) or a commercial Ethernet switch can be used. In the latter case, an additional Clock Trigger Generator Fan-out (CTGF) is required for synchronous operation of all FECs. The readout chain consists of general components (FEC, SRU, CTGF) and ASIC specific components (hybrid and adapter card) as well as commercial components (Ethernet links, switch, computer).

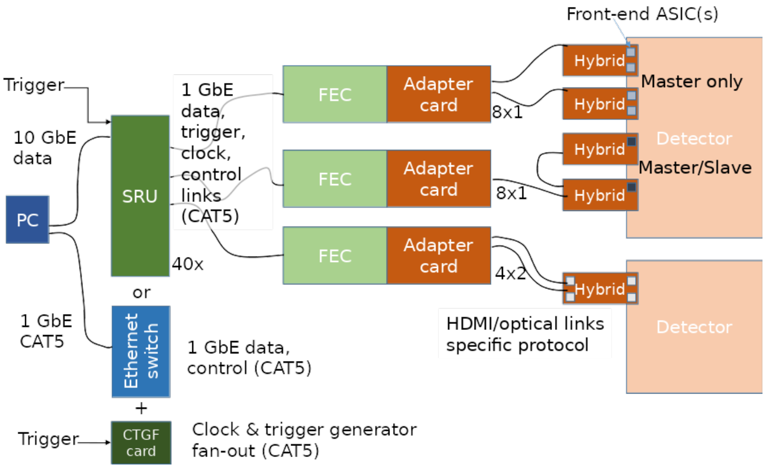

Figure 1. SRS readout chain architecture. The detector is shown on the right with front-end electronics boards called hybrids, hosting the ASICs. Different possibilities of hybrid designs are displayed. The FEC with adapter card is the central part of the system and holds the main FPGA with ASIC-specific firmware.

3. The SRS with the VMM ASIC

As the currently most applied ASIC with the SRS, the APV25, is outdated and not produced any longer, the RD51 collaboration decided to implement a recent ASIC into the SRS. In benefit for the whole collaboration, the project was realised in the framework of R&D for the NMX instrument at ESS and the VMM ASIC was selected. Compared to other front-end chips, the VMM comes with a broad band of configuration possibilities, such that it fits the idea of a general multi-purpose system. For example, the shaping time of the pre-amplifier can be set to 25 ns, 50 ns, 100 ns and 200 ns and the input capacitance can range from about 3 nF to 1 pF.

3.1. Implementation of the VMM ASIC in the SRS

Because of the SRS architecture, the implementation of a new ASIC requires the design of a new hybrid, adapter card and FPGA firmware for the FEC. Prototyping of all components has been completed and the project is currently in the transition phase to industrial production. The final adapter card is shown in Figure 2 connected to a FEC. The firmware includes all basic features, such that the system could be used at test beams since 2016. Further improvements are continuously developed as upgrades. Slow control software, online monitoring and data recording software have been developed in collaboration with the ESS Data Management and Software Center (DMSC).

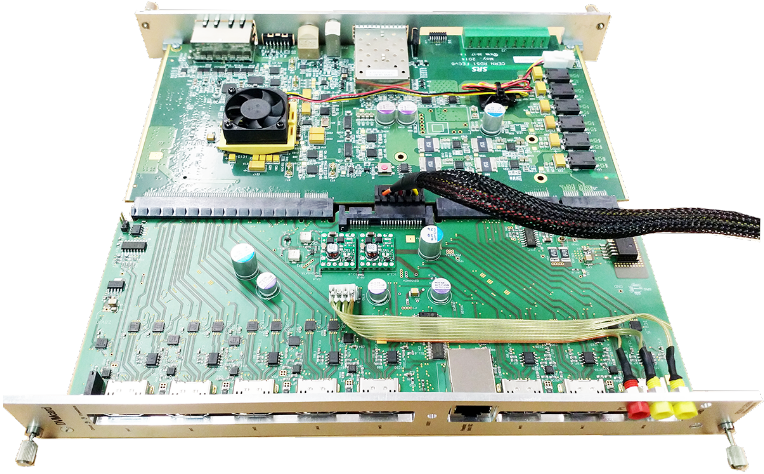

Figure 2. Adapter card for the VMM connected to a FEC. Eight HDMI ports can connect up to eight hybrids. The same panel also holds an RJ45 connector for further upgrades.

3.2. Applications

Groups from different fields are committed as primary users for testing and supporting the developments. Examples are the MAGIX experiment in Mainz [6] or generic R&D for several new types of detectors. Other groups intend to apply the system in medical science, neutron scattering, cosmic ray detection and fundamental physics research.

4. Application of the SRS VMM at the NMX instrument at ESS

The specific experiment that triggered the development of SRS with the VMM ASIC was the NMX instrument for ESS, which will be introduced in the following subsection.

4.1. The ESS and the NMX instrument

The ESS [7] is currently the largest research facility under construction in Europe. The European Research Infrastructure (ERIC) currently has twelve member states and two observer states, mainly from the European Union. The spallation source itself will be located in Lund, Sweden and consists of a proton accelerator, spallation target and several instruments that use the highest neutron flux for experiments related to a diverse field of fundamental research as material science, medical science or archaeology. The DMSC is located in Copenhagen, Denmark and provides software for instrument slow control and data treatment.

One of the envisioned instruments at ESS is NMX, a macromolecular diffractometer. Neutrons from the target are scattered on a sample under investigation and the diffraction pattern is measured by new types of detectors. The three detectors will have an active area of 50 × 50 cm^2 each and can be moved by robotic arms to scan the diffraction pattern.

4.2. R&D for an NMX prototype

Prototype NMX detectors have been designed at CERN applying established technology of particle physics instrumention. Figure 3 shows the cross section of a schematic gaseous detector design. The neutron is converted to an electron and a photon (not shown) on a gadolinium cathode of a drift region The electron emitted from the cathode ionises atoms of the Ar/CO_2 gas mixture along its track in the drift region of the detector. An electric drift field separates the ions and ionisation electrons and attracts the latter towards a stack of several Gas Electron Multipliers (GEMs) [8], where they are multiplied. The electron avalanche leaving the GEM induces a measurable signal on a segmented anode. This anode is made of isolated copper strips in x- and y-directions to achieve spatial resolution. Readout electronics, in our case the VMM ASIC, is able to determine the arrival time of charge, such that a three dimensional track reconstruction of the electron from the neutron conversion can be obtained. With this so called micro-Time Projection Chamber (μTPC) method the impact point of the neutron is found.

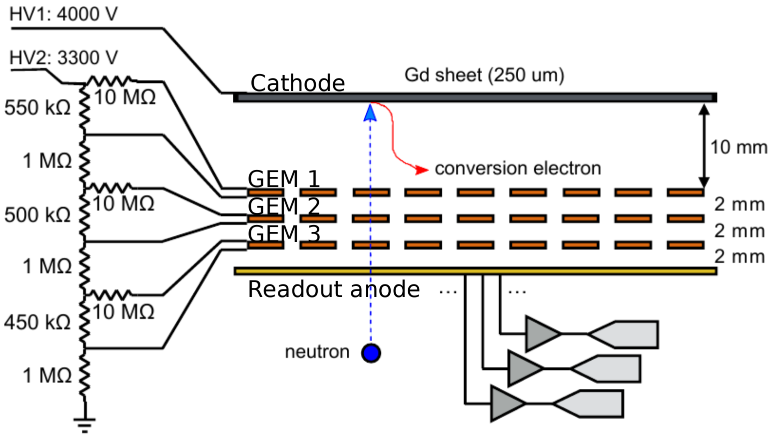

Figure 3. Schematic design of the NMX detector principle, from [9].

Several small scale versions of a size of 10 × 10 cm^2 were constructed and tested with the SRS VMM at test beams. Figure 4 shows the setup at the Budapest Neutron Center from July 2018 (left) and Institut Laue-Langevin Grenoble from October 2018 (right) as examples. In both cases, four VMM hybrids connected to one FEC were used to read out 512 anode strips in x- and y-directions, respectively.

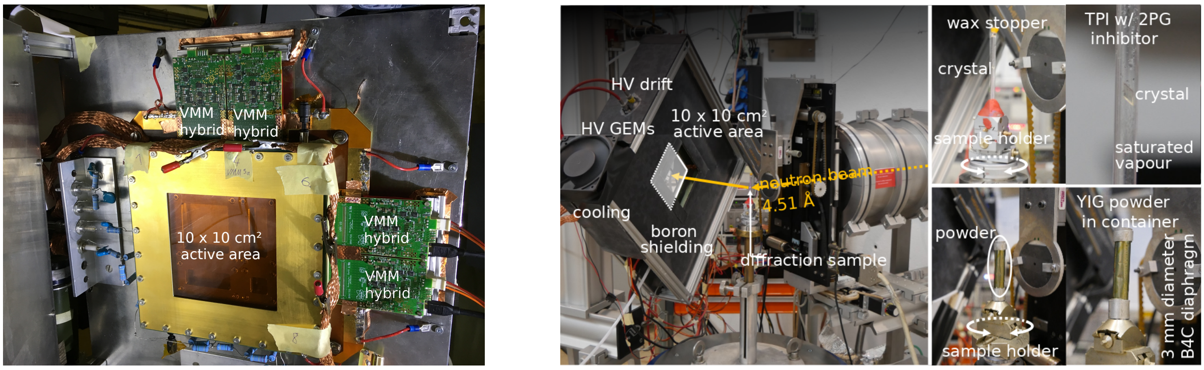

Figure 4. Small scale 10 × 10 cm^2 NMX prototype detector with VMM readout at a test beam at the Budapest Neutron Center (left) and Institut Laue-Langevin in Grenoble (right).

At the Budapest Neutron Center, neutron transmission through a cadmium mask with 1 mm holes, separated horizontally by 2 mm center to center, was measured at the Triple-Axis Spectrometer Athos with a wide beam of 2.7 Å wavelength. The reconstructed neutron impact points are shown in Figure 5 (left). At the D16 beam line of the Institut Laue-Langevin, the diffraction of a 4.51 Å neutron beam on a Yttrium Iron Garnet (YIG) powder (bottom right picture in Figure 4) and on a 2-PhosphoGlycolate (2PG) crystal (top right picture in Figure 4) enclosed in saturated vapour of a Triose Phosphate Isomerase inhibitor (TPI) was investigated. The samples were placed on a rotatable and movable sample holder. The final beam focussing was achieved with a 3 mm diameter boron carbide diaphragm. However, the instrument used is not optimised for a suppression of photons from the beam line. The boron shielding, with openings only for fans to cool the VMM hybrids, was not sufficient, such that the recorded scattered neutrons are reconstructed in a constant background, see Figure 6.

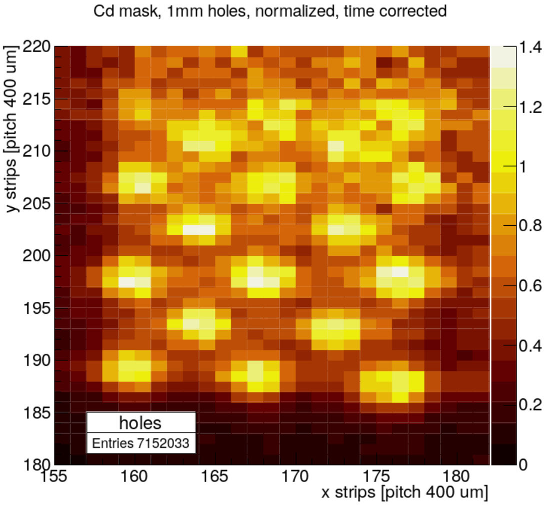

Figure 5. Reconstructed neutron impact points from small scale NMX prototype detector with VMM readout test beam in Budapest. Neutron transmission through a cadmium mask with 1 mm holes, separated horizontally by 2 mm center to center, from [10].

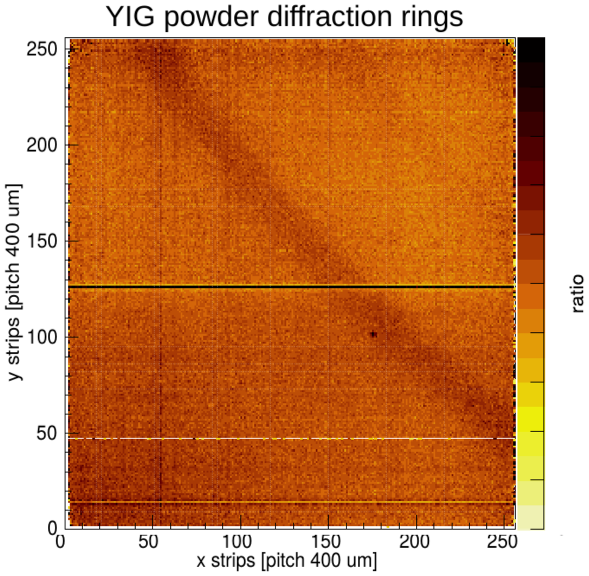

Figure 6. Reconstructed neutron impact points from small scale NMX prototype detector with VMM readout test beam in Grenoble. Neutron diffraction on a powder with significant photon background.

Both measurements as well as previous results [9] show that the proposed detector concept is feasible and fulfils NMX requirements. Detailed analysis of the latest test beam campaigns is ongoing and quantitative results will be published.

The technological challenge to construct a detector of the full size envisioned for the NMX instrument has been demonstrated with a large prototype designed and built at CERN. Details of the construction and planning are available in [10] and [11]. Figure 7 shows some pictures of the 51.2 × 51.2 cm^2 active area large prototype, so far without electronics. The design follows the same basic principle as shown in Figure 3. However because of the size, the GEM foils are separated into 25 sectors and strengthened by a support grid. The dead area of this detector is minimised on three sides, as it would be required in the NMX setup to allow the robotic arms to string together detectors with only little gaps.

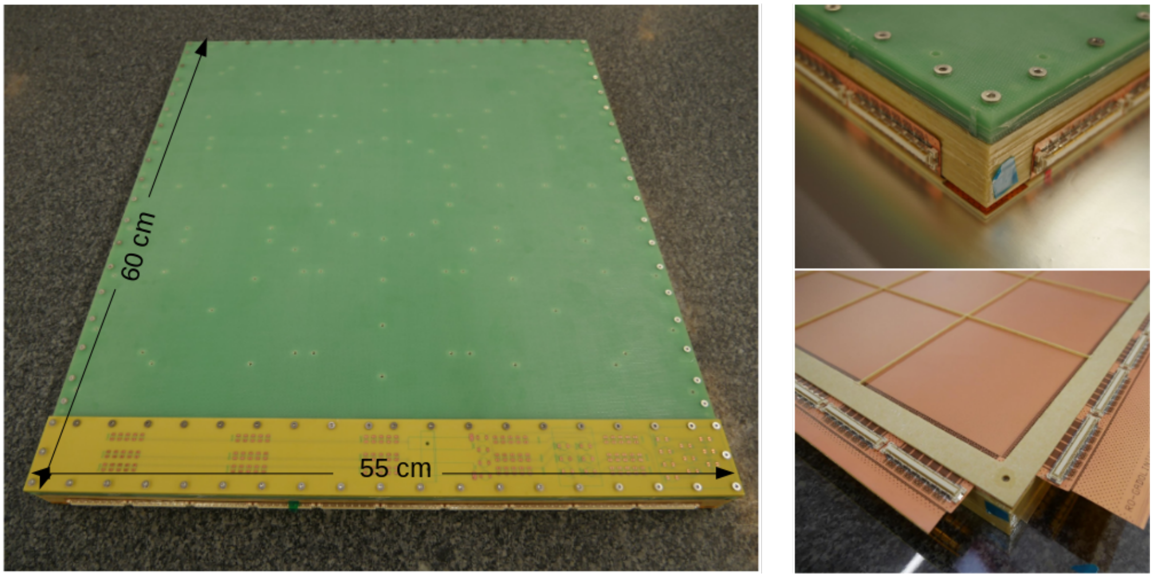

Figure 7. Large 51.2 × 51.2 cm^2 size prototype NMX detector, from [11].

Acknowledgments

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