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Design and Construction of a 1m×1m Thermal Neutron Imager Operating in Ionization Mode with Pad Readout

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Design and Construction of a 1m×1m Thermal Neutron Imager Operating in Ionization Mode with Pad Readout*

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Abstract– **We have developed a ^{3}He based thermal neutron imager with an active area of 1m×1m, for the small-angle neutron scattering beamline QUOKKA at the Australian Nuclear Science and Technology Organisation (ANSTO). The detector operates in ionization mode without any electron multiplication in the gas. The electrons created by the neutron-^{3}He interaction are collected by discrete anode pads, each connected to an input channel of an ASIC directly mounted on the back of the anode pad plane. These custom ASICs and their readout boards can process up to 25k /s per channel. Combining the nearly 40,000 parallel channels on this detector, a total count rate of 10^8 cps can be achieved.**
Design and construction details of this detector, as well as some early test results are described.

I. INTRODUCTION

The new generation of neutron facilities, either being built or recently in commission, offer an order of magnitude more neutron flux than previously available. The beamlines at these facilities will ultimately require detectors with much higher rate capability than presently achievable, with also an emphasis on dynamic studies over wide time-slice scales. Our group has been developing ^{3}He filled MWPCs for position sensitive thermal neutron detection [1]. However, these instruments incur dead-time losses as counting rate exceeds 10^5 cps. One solution to this problem is to segment the detector and implement parallel readout. But as the neutron flux reaches higher, the stability of the avalanche gain and wire aging become issues. To achieve the ultimate parallelism and to avoid the problems associate with the electron multiplication process, we developed ^{3}He based imaging detectors operating in ionization mode with 2D anode pad readout [3,4]. This technique is made possible by the low noise custom ASIC developed specifically for this mode of operation [5].

In this work, we describe the design and construction of a new detector with an active area of 1m×1m and with 4×10^4 parallel readout channels, commissioned for the small-angle scattering beamline QUOKKA at ANSTO as an upgrade for its existing MWPC based detectors.

II. DESIGN AND CONSTRUCTION

The heart of this detector is a 4×4 array of 16 anode pad boards. Fig. 1 shows photos of the front and back of an anode pad board, and the FPGA based readout board plugged into the pad board. Each 64 channel ASIC covers 8×8 pads, and there are 36 ASICs on each board. Each anode pad is 5mm×5mm in size, resulting in an active area of 24cm×24cm per pad board. Each readout board has one flexible ribbon cable for power and data communication to the outside of the pressure vessel. The 16 board pairs are mounted on a rigid aluminum frame with a gap of 0.5mm between pads of adjacent boards. Overall, the total active area of the detector is 960mm×960mm, with 36,864 pads.

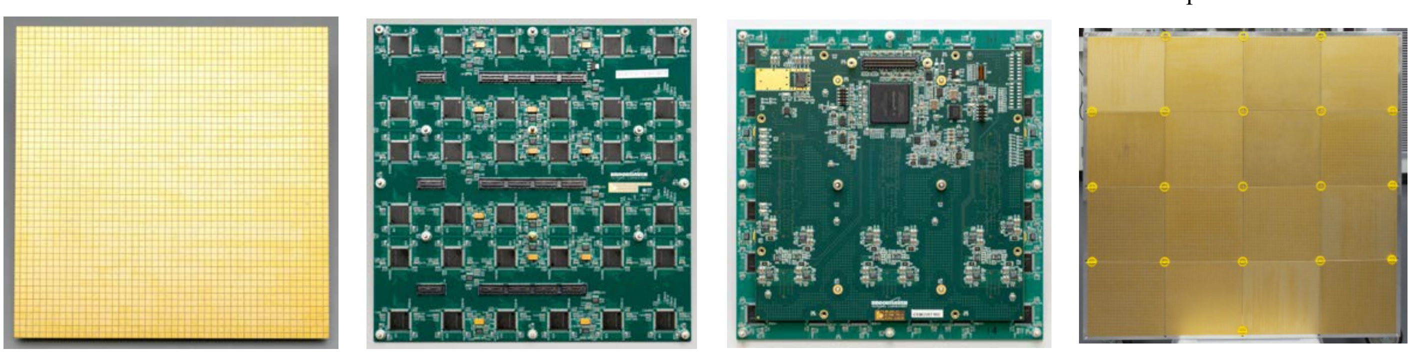

Fig. 1. Left: the front of the anode pad board, showing an array of 48×48 pads. Middle left: the back of the pad board, showing an array of 6×6 ASICs, each connecting to 8×8 pads on the front. Middle right: The readout board (IMPROC) with an Altera Cyclone V FPGA is plugged into the pad board. Right: 16 pad boards installed on a mounting frame forming the 1m×1m active area.

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Fig. 2 is an exploded view of the major components of the detector. The 16 anode pad and readout board pairs reside inside a common pressure vessel enclosed by a front window and a back plate made from 7075-T6 aluminum. The designed maximum operating pressure of this vessel is 47 psig. At this pressure, both the front window and the back plate have some deflection. In order the maintain the flatness of the pad plane, the aluminum frame holding the pad boards is attached to the back plate only at the 4 corners.

An aluminized Mylar film is bonded to the inside of the window and biased at about -1.5kV. A set of field shaping electrodes encloses the volume between the window electrode and the pad plane to ensure a uniform drift field to the edges of the active volume. The active gas depth between the window and the pad plane is 4cm. The pressure vessel is filled with a mixture of ^{3}He and CF_4, with a gas recirculation and purification system to remove impurities outgassed from the detector components.

At ANSTO, this instrument is installed inside a large vacuum tank to reduce the neutron scattering with air. The highly integrated analog and digital readout electronics inside the detector greatly simplified the electrical interface: only an AC power cord and an optical fiber bundle are needed to operate the detector. In order to remove the heat generated by the various on-detector electronics components from the vacuum tank, an additional enclosure is attached to the back of the pressure vessel, forming a sealed chamber to house the power supplies and gas recirculation system. This chamber is connected to the atmosphere outside of the vacuum tank through hoses with forced air cooling. A total of 220W of power inside the pressure vessel is transferred to the back plate

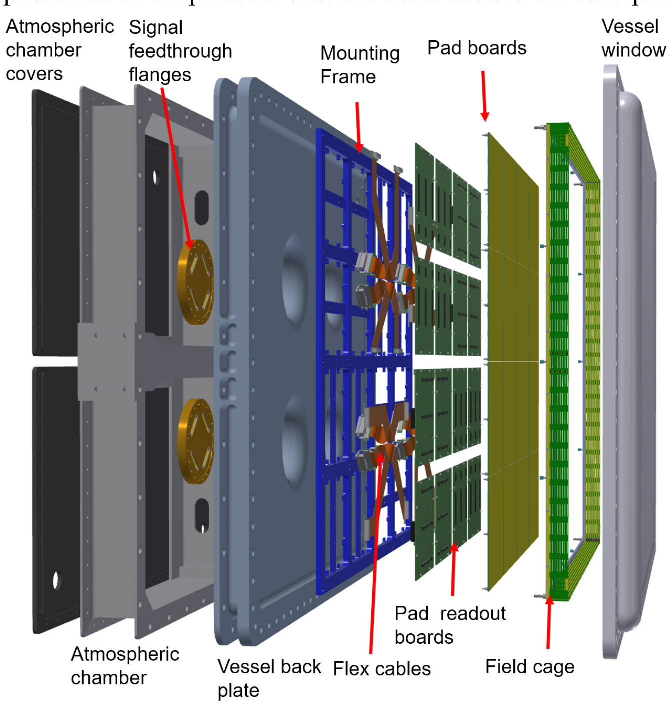

Fig. 2. An exploded view of the key components of the detector.

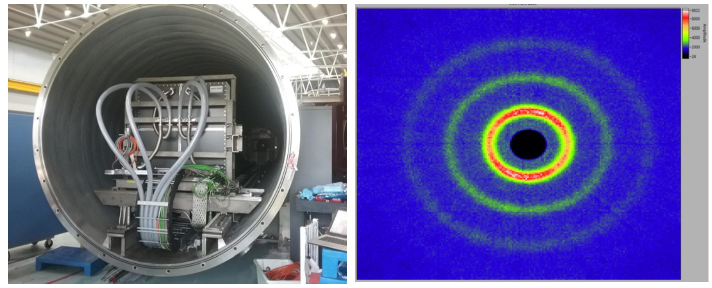

Fig. 3. Left: Detector installed inside the vacuum tank on the QUOKKA beamline. 4 air hoses are used to provide cooling to the detector electronics. Right: SANS image from silver behenate showing multiple diffraction rings. Data were collected with global count rate of 510 kHz.

through conduction and convection by the counter gas. This, and an additional ~80W from the DC power supplies and electronics in the atmospheric chamber is removed by the cooling air. The in-detector electronics stabilize at 40°C.

III. Summary

The detector was installed on the QUOKKA beamline in Nov. 2018. It is filled with a gas mixture of 2 bars of ^{3}He and 0.5 bar of CF_4. Fig. 3 shows the detector inside the vacuum tank at the beamline, and one of the first SANS images obtained shortly after the detector was installed.

The most unique feature of this detector is its counting rate capability. Preliminary tests have shown that the detector can process up to 2.5×10^4 cps per pad, and 2×10^7 cps per pad board (2304 pads), limited by the data throughput of the Gigabit Ethernet interface. The overall rate limit of the 16 board detector is about 3×10^8 cps.

A more detailed description of the detector and its performance will be submitted to the IEEE TNS at a later time.

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