Performance of a front-end ASIC for JEM-EUSO

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Abstract: The SPACIROC (Spatial Photomultiplier Array Counting and Integrating ReadOut Chip) is a Front-End ASIC designed for the space-borne fluorescence telescope JEM-EUSO[1][2]. The device is designed for features of single photon counting, dynamic range of 1 photoelectron (PE) to 1500 PEs, double pulse resolution of 10 ns, and low power consumption (<1 mW/ch). SPACIROC reads output signals from a 64-channel Multi-Anode Photomultiplier Tube (MAPMT). Input photons are measured in the two features as following: photon counting mode for each input and charge-to-time (Q-to-T) conversion mode for the multiplexed channels. The combination of these two features enables the large dynamic range as described above. We will report the performance of the ASIC such as power consumption, double pulse resolution, dynamic range and linearity.

Keywords: JEM-EUSO FRONT-END ASIC DAQ

1 Introduction

JEM-EUSO (Extreme Universe Space Observatory on board Japanese Experiment Module) is a mission which aims the observation of Extreme Energy Cosmic Rays (EECRs) with a space-borne fluorescence telescope on the International Space Station (ISS). The detector will consist of five thousand 1-inch-square MAPMTs, and will allow an area of about 400 kilometers in diameter of Earth's atmosphere to be imaged in the field of view. Since 2006 the Phase A study of JEM-EUSO has been continued with extensive simulations, design, and prototype hardware developments that have significantly improved the JEM-EUSO mission profile, targeting the launch of 2016 in the framework of the second phase of JEM/EF (Japanese Experiment Module/Exposure Facility) utilization.

The main physical sources of interest of JEM-EUSO are the fluorescent and Cherenkov UV photons induced by cosmic rays with energies higher than $10^{19} eV$ impinging on the atmosphere leading the development of an Extensive Air Showers (EAS) in the troposphere. The JEM-EUSO telescope will determine the energies and directions of extreme energy primary particles by recording the tracks of EAS with a time resolution of about $1\mu s$ and an angular resolution of about $0.1°$.

About the JEM-EUSO status and general project information, see also [3] and [4] in this conference.

2 JEM-EUSO Focal Surface

The Focal Surface (FS) of the JEM-EUSO telescope consists of a curved surface of about 2.35 m in diameter which is covered with 5,000 of 64-channel MAPMTs (Hamamatsu R11265-M64). A JEM-EUSO FS Photo-Detector Module (PDM) consists of an array of 3×3 Elementary Cells (ECs), each of which consist of 2×2 MAPMTs. About 1,233 ECs, corresponding to about 137 PDMs, are arranged on the on the whole FS (See the Fig.1). MAPMTs capture the photons from the Earth atmosphere, convert them in its photocathode into photoelectrons and induce pulses from the charges on their anodes and dynode output. The Front-End ASIC transforms the charges from MAPMTs into digital numbers which can be processed

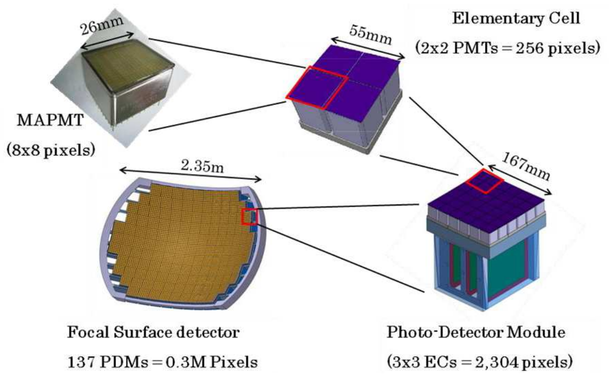

Figure 1: FS detector modules.

in next stages by digital electronics. Similarly the trigger stages process digitally those charges which have been previously converted into numbers.
About the JEM-EUSO focal surface, see also the contributions[5][6][7] in this conference.

3 Front-End ASIC : SPACIROC

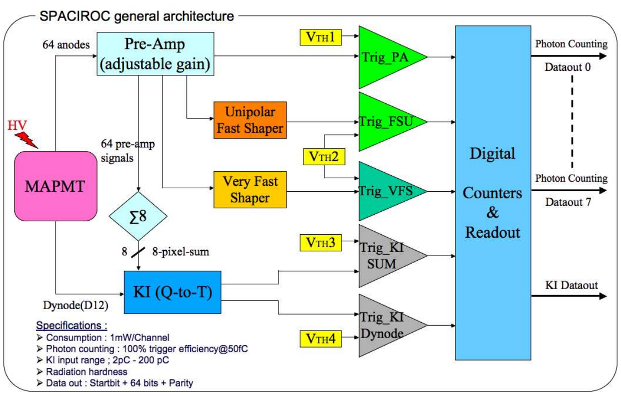

Figure 2: SPACIROC general architecture.

Fig.2 shows the general architecture of the SPACIROC. SPACIROC consists of two analog blocks and one digital part. One of the analog parts is dedicated for Photon Counting, and another is for so called "KI" Charge to Time (Q-to-T) converter. The digital part is build to count the detected photons. The 64-channel Photon Counting block discriminate the preamplifier signal into trigger pulses. Each of 64 channels of photon counting block consist of a preamplifier, two shapers and three compartors (trigger discriminators) as below:

- Trig_pa : Trigger of the signal coming directly from preamplifiers
- Trig_FSU : Trigger of signal from Unipolar Fast Shaper (FSU)
- Trig_VFS : Trigger for Very Fast Shaper (VFS).

Charge signals from 64 anodes of a PMT are first fed into preamplifiers before sent to various shapers and discriminators in the latter part of ASIC. Then divided to 3 photon counting (PC) and outputs : preamp, FSU, VFS. At the end of each acquisition window, so called Gate Time Unit (GTU=2.5μs), the counter values are readout through 8 serial links in order to reduce overhead. The first 8 inputs of KI takes the pre-amplified signals from the photon counting (sum of every 8 channels), while 9th input takes a signal coming directly from the last dynode of the MAPMT. In a similar manner to the photon counting readout, the counter data are sent through a serial link at the end of each GTU.
For more details of design and specification of SPACIROC, see also[8] in this conference.

3.1 Requirement

The electronics system is required to keep a high trigger efficiency with a flexible trigger algorithm as well as a reasonable linearity in the energy range of 4×10^{19} to $10^{21}eV$ for EECRs.
The Front-End ASIC is required to count single photoelectrons, i.e., with considering the MAPMT gain of 5×10^{5}, 0.08 pC.
Number of photoelectrons per GTU per pixel by the fluorescent light from EAS generated by EECR with 10^{20}eV is obtained by simulations to be roughly 250 at around the shower maximum. By multiplying a safety factor of 2, it becomes 500 PEs/GTU/pixel which correspond to 40 pC/GTU/pixel.
Also, to operate JEM-EUSO under a quite limited power in the space, a power consumption of less than 1mW/ch is essential.
SPACIROC achieves 100 % trigger efficiency for charge greater than 1/3 PEs, a dynamic range of over 1000 with having two analog processing modes as described below, low power consumption of 1 mW/channel and thus fulfills the requirement for the JEM-EUSO electronics.

3.2 Test Method

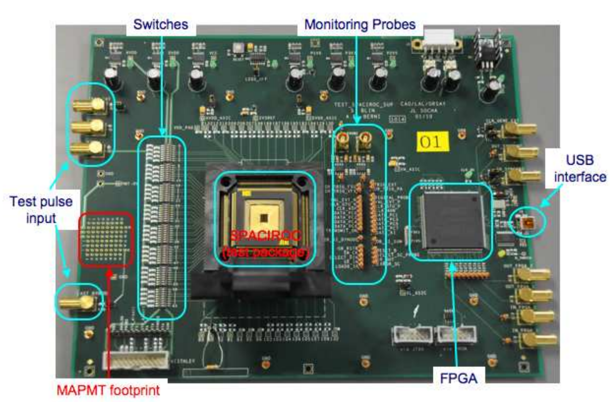

Figure 3: Test board for SPACIROC.

Various tests have been done by using a test board shown in Fig.3. The test board consists of a socket for ASIC, FPGA and USB connection to PC, MAPMT 64 anodes and a dynode footprint, and various test points. Test pulses are fed into the board from a pulse generator. PMT signals are also fed into the board after the test pulse measurement. The registers inside the ASIC are controlled by a PC using a LabView software via an FPGA and USB connection.

3.3 Power Consumption

Due to the limited electrical power available from the ISS for the JEM-EUSO experiment, a maximum of 0.8 mW is allowed per detection channel in the ASIC. For the first prototype of SPACIROC, the measured power consumption is 1.1 mW/channel. This is partially because of the design bugs which makes some unused componet always on and non negligible power dissipation is occuring. Therefore, the next version of SPACIROC is expected to reduce the power consumption and fulfill the requirement.

3.4 Radiation Hardness

For the experiments in the space, the radiation hardness is essential. Two effects have been clearly identified as harmful to the ASIC. One is “Single Event Latchup” which can destroy the circuits, another is “Single Event Upset” which may affect the SPACIROC functionalities. In case of the analogue part of SPACIROC, it has been designed to take into account the radiation effects on electronic systems. For example, the layout is done carefully in order to minimize the single event latchup effect. Also, a mechanism to detect single event upset is added. For the total ionizing doze effect, we exposed the ASIC chip against the radiation of 70 MeV proton beam with the ASIC running with maximum gain and all the capacitors and registers on to see if it causes any effects. As a result, we confirmed no significant effect or difference in configuration parameters such as threshold and preamplifier gains before and after the test in the operation. For other effects, we are also planning to test the ASIC with a heavy ion beam near future.

3.5 Single Photoelectron response

Fig.4 shows the differential of a Trig_PA S-curve. The input charge is $80fC$ which corresponds to 1 photoelectron for a PMT gain of $5{\times}10^5$ generated by a pulse generator Tektronix AFG 3102. The single photoelectron peak is clearly seen thus we obtained the minimum threshold of 0.13 PEs on the average of 64 channel outputs. Fig.5 shows the amplitude, i.e., subtract pedestal from 1 PE peak, of all 64 channel outputs of preamplifier and FSU respectively. The fluctuation in an ASIC is $\sim$1.3 for preamplifier and $\sim$3.7 DAC unit for FSU.

3.6 Linearity and dynamic range

In photon counting mode, the measured double pulse resolutions for Trig_PA is 36ns, and 30ns for Trig_FSU. Currently, further tests with input pulses of random timing are ongoing to estimate the actual linearity and dynamic range in photon counting mode for the PMT signal readout.

Fig.7 shows the KI_SUM counts, which corresponds to the measured width of KI_SUM output pulse as a function of input charge (pC). It is shown that there is a sufficient linearity between the input charge and output pulse width within a dynamic range of the input charge of 0.3 PEs to 80 PEs. In this case KI reaches the maximum counter bit (7 bit dedicated for KI_SUM) while the linearity of KI itself still continues. The study on the optimum KI parameters

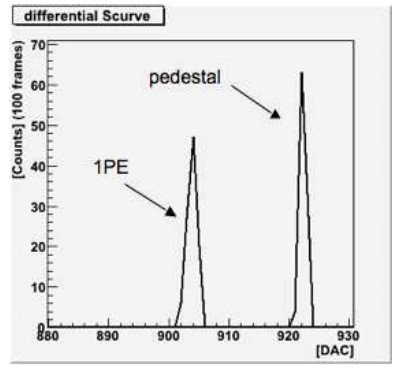

Figure 4: Differential S-curve from preamplifier output with the input charge of 80fC which is corresponding to 1PE for the gain of $5{\times}10^5$.

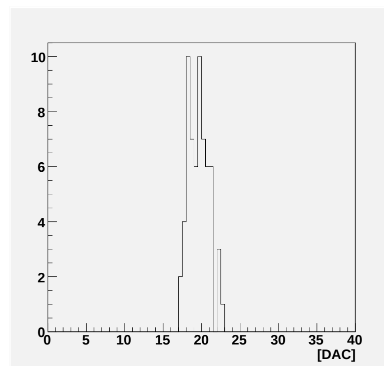

Figure 5: Amplitude of 64 ch preamp. RMS is 1.32 DAC unit.

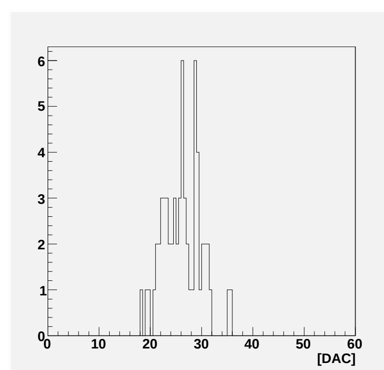

Figure 6: Amplitude of 64 ch FSU. RMS is 3.67 DAC unit.

such as of KI pulse width and dynamic range adjust for the Q-to-T conversion is still ongoing.

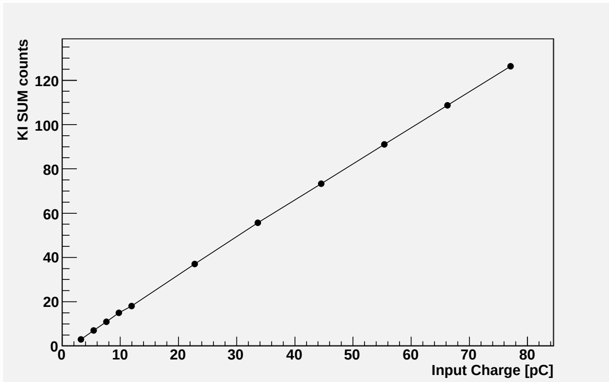

Figure 7: example of KI_SUM digital output.

3.7 PMT response

Fig.8 shows setup of the integration measurement. A 64 ch MAPMT on a PDM frame is connected to the ASIC test board which is controlled by a PC. The MAPMT is illuminated by a blue LED fired by an Agilent waveform generator 33250A to give roughly 1.8 PEs on average in 200 ns. The trigger of waveform generator is synchronized to the GTU clock on the ASIC test board. Fig.9 shows the distribution of number of photoelectrons (PEs) which is obtained by one of the 64 anodes. The width of the broad peak in the figure is roughly consistent with an error caused by the Poisson fluctuation.

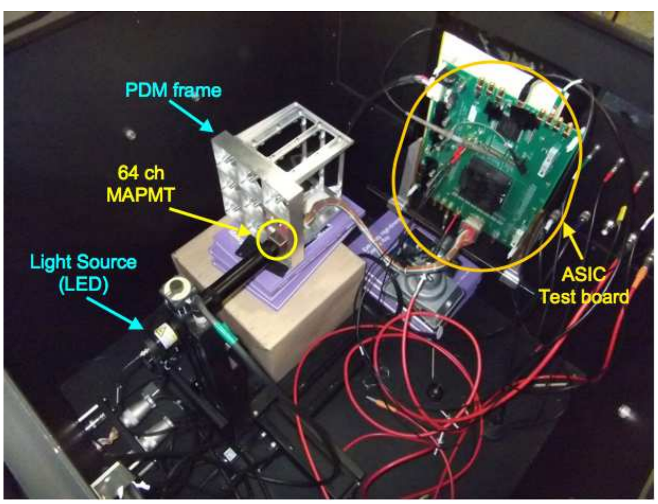

Figure 8: Integration test of MAPMT on a PDM frame connected to SPACIROC.

4 Conclusion

The first version of Front-End ASIC for the focal surface detector of JEM-EUSO mission has been examined. It has been shown that the fundamental functions of the ASIC work quite well without any critical problems. We also succeeded to readout MAPMT signals by the ASIC and we obtained the distribution of number of detected photons. More examinations such as searching for the optimum configuration parameters to achieve the largest dynamic range, best signal to noise ratio and minimum power consumption are still ongoing. Also, further work to improve the chip itself is ongoing and in the next design, the power consumption will be improved to be about 0.8 mW/ch, the noise level will be further suppressed.

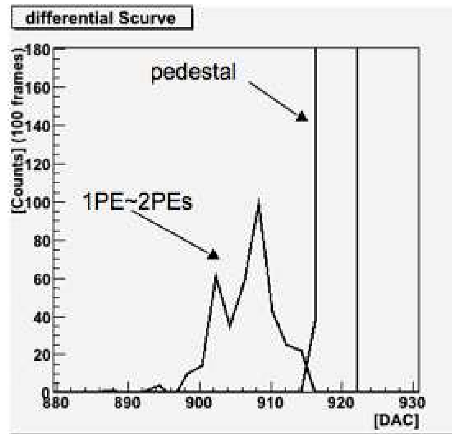

Figure 9: Distribution of number of input pulses using Trig_PA.

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