The Focal Surface Detector of the JEM-EUSO Telescope

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***Abstract*. The Extreme Universe Space Observatory on JEM/EF (JEM-EUSO) is a space mission to study extremely high-energy cosmic rays. The JEM-EUSO instrument is a wide-angle refractive telescope in near-ultraviolet wavelength region to observe time-resolved atmospheric fluorescence images of the extensive air showers from the International Space Station. The focal surface is a spherical curved surface, and its area amounts to about $4.5\mathrm{m}^2$. The focal surface detector is covered with over 5,000 multi-anode photomultipliers (MAPMTs). The focal surface detector consists of Photo-Detector-Modules, each of which consists of 9 Elementary Cells (ECs). The EC contains 4 units of MAPMTs. Therefore, about 1,300 ECs or about 150 PDMs are arranged on the whole of the focal surface of JEM-EUSO. The EC is a basic unit of the MAPMT support structure and the front-end electronics. The PDM is a basic unit of the focal surface structure and the data acquisition system.**

***Keywords*: PMT, Photodetector, JEM-EUSO**

I. INTRODUCTION

The Extreme Universe Space Observatory on JEM/EF (JEM-EUSO) is a space mission to study extremely high-energy cosmic rays. The JEM-EUSO instrument is a wide-angle refractive telescope in near-ultraviolet wavelength region to observe time-resolved atmospheric fluorescence images of the extensive air showers from the International Space Station. The focal surface is a spherical curved surface, and its area amounts to about $4.5m^2$.

II. OVERVIEW

The Focal Surface (FS) of JEM-EUSO has a curved surface of about $2.3m$ in diameter, and it is covered with more than 5,000 Multi-Anode Photomultipliers Tubes, MAPMTs, (Hamamatsu R8900-M36). The FS detector consists of Photo-Detector Modules (PDM), each of which consists of 9 Elementary Cells (EC) arranged in an array of 3×3. About 1,233 ECs, corresponding to about 148 PDMs, are arranged on the whole FS (Figure 1).

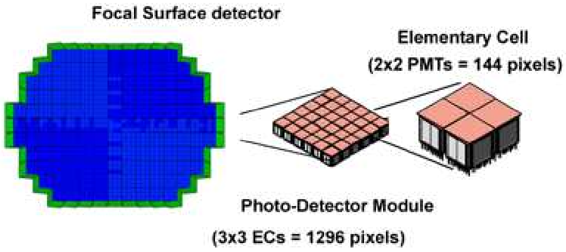

Fig. 1. Focal surface detector and its structure.

The detector on the focal surface is essentially composed by:

- Photo-detector, PD (array of multi-anode photomultipliers, MAPMTs)
- MAPMT support structure
- High Voltage divider
- High Voltage power supply
- FS structure

III. PHOTO-DETECTOR

JEM-EUSO is a photon-hungry experiment and its FS detector should have high detection efficiency. The FS detector should have the single photon counting capability in near-ultraviolet wavelength region to avoid the systematic errors, which may be introduced by the gain drift. It should be reliably and stably operational in Space environment for at least 3 or 5 years mission period. For the above reason, MAPMTs with UV-glass entrance window are employed as sensors of the FS detector.

Present baseline choice is the Hamamatsu R8900-03-M36 [1] (see Fig. 2), which was developed by RIKEN in collaboration with Hamamatsu Photonics K.K. It has an ultra-bialkali photo-cathode, which transforms photons into electrons then focuses them by means of a weak electric field, and amplifies photo-electrons by means of a stack of metal channel dynodes. The signals are taken from the anode which is formatted as an array of 6×6. Compared with the former R7600 series, selected at the beginning of ESA-EUSO Phase-A study, the R8900 MAPMT has 1.75 times higher in quantum efficiency and 1.9 times larger sensitive area. The total detection efficiency of R8900 is over 3 times higher than that of R7600.

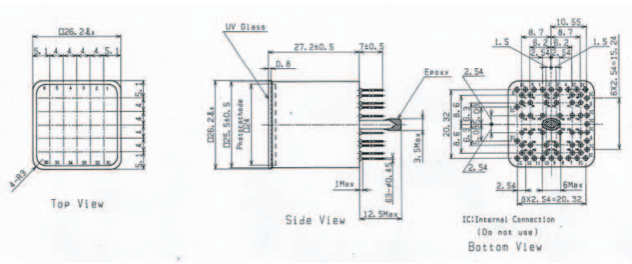

Fig. 2. The MAPMT for the JEM-EUSO photo-detector (R8900-03-M36).

IV. MAPMT SUPPORT STRUCTURE

The main functions of the MAPMT support structure are:

- To allow packing of the MAPMT as close as possible with precise relative positioning.
- To have common high voltage inputs and every anode signal outputs.
- To be able to support MAPMTs safely against the vibration at the launch.
- To minimize outgas.

The main specifications of the prototype model of the MAPMT support structure, sketched in Figure 3, are:

- The base board is made with PEEK and bonds PMTs with HYSOL.
- It supports 4 MAPMTs.
- It has a pair of high voltages input and provides them to 4 MAPMTs.
- It has every anode signal output.
- It doesn't destroy the MAPMT when the PDM is vibrated with $20Grms$.
- Physical dimension: $55mm \times 55mm \times 7mm$.

V. HIGH VOLTAGE DIVIDER

Active high-voltage dividers of power saving type are used to supply high voltage to the MAPMT dynodes. In addition, the divider current is defined as 10 times higher than the anode current for the standard nightglow background. The High-Voltage power supply is designed to supply arbitrary voltage in the range between $0V$ and $1,000V$. The above characteristics have been verified through the designing, production, electrical tests, radiation tests and a balloon flight, etc.

In addition, we have developed the high-voltage divider including a protection circuit. It protects the MAPMT from an instantaneous large amount of light such as the lightning. We can operate it more safely by quickly interrupting the photoelectron multiplication using a Photo-MOS relay, as sketched in Figure 4.

The high-voltage divider circuit is built into the frontend electronics board.

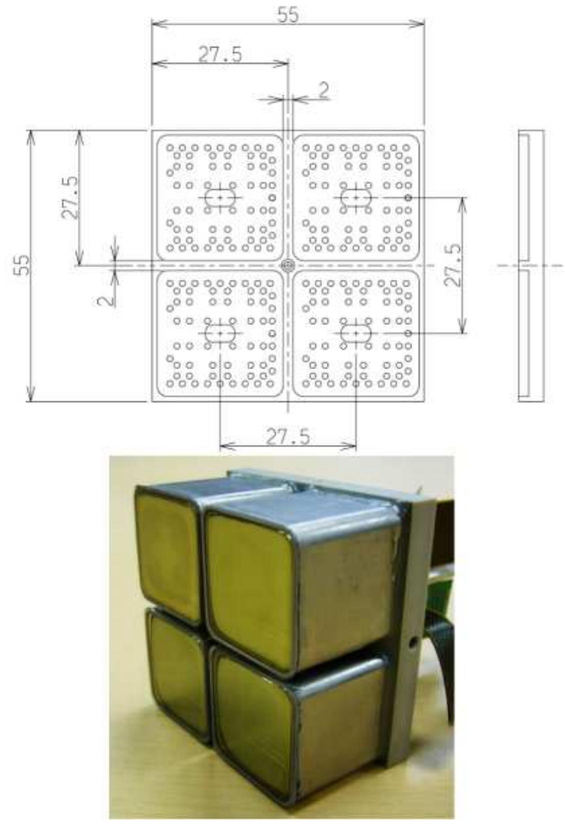

Fig. 3. Drawings of the MAPMT support structure and its prototype.

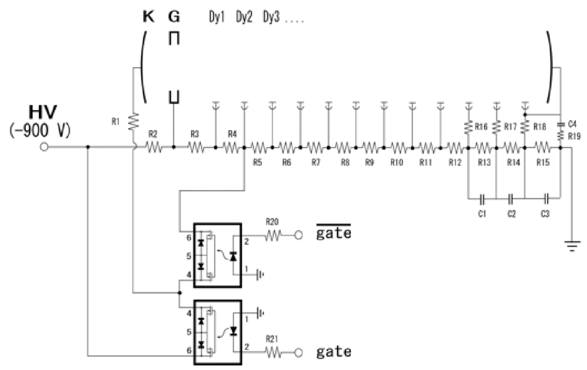

Fig. 4. Test circuit of the HV divider with protection from large amount of light.

VI. HIGH VOLTAGE POWER SUPPLY

The High-Voltage Power Supply, HV-PS, system is designed to decrease the failure rate, the complexity of wiring and the danger associated with it, by means of the distributed control method shown in Figure 5.

The structure of each HV-PS is shown in Figure 6. Mission Data Processor (MDP) gives instructions of the high voltage value, and then it is converted to an analog value from $0V$ to $+5V$, by the DA converter. When the DC-HV converter receives this voltage, it generates a high voltage from $0V$ to $1,000V$. This is then transferred to the divider resistance of the MAPMT, which starts its operation. This voltage is supposed to be monitored

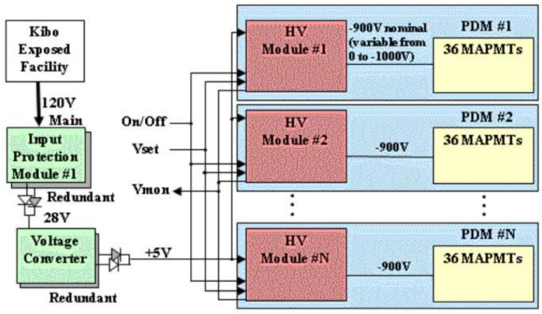

Fig. 5. Basic diagram of the HV-PS system for the JEM-EUSO focal surface. Each HV-PS module is mounted on the PDM. The module drives 36 MAPMTs of each PDM.

through the AD converter after reducing its value.

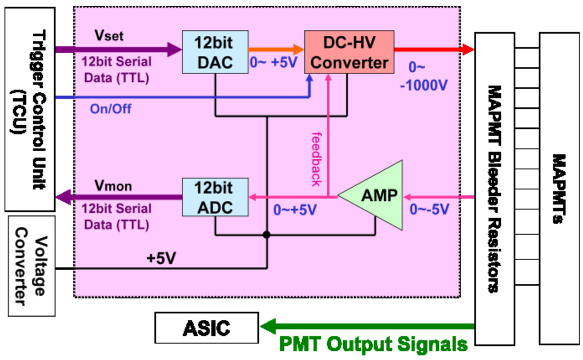

Fig. 6. Basic block diagram of the HV-PS module.

This high voltage device was stowed on a balloon flight and its operation has already been verified. In addition, its radiation tolerance has also been tested at the National Institute of Radiological Sciences, by using proton beams.

VII. FS STRUCTURE

The shape of the focal surface is a spherical surface with about $2,505mm$ radius. The PDMs should have a layout which minimizes the gaps on that surface. Figure 7 shows the PDM layout in case of 148 PDMs.

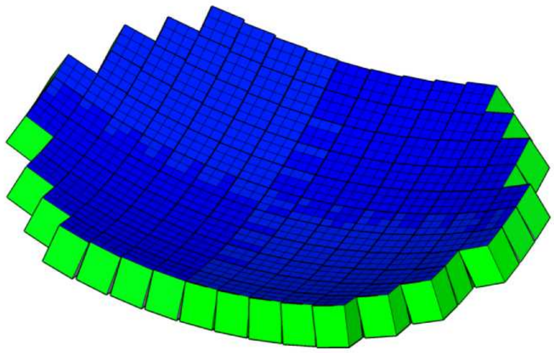

Fig. 7. The PDM layout

Figure 8 shows the concept design of the FS structure. This is made by an aluminum alloy type 7075 T4. At a later stage, the material could be different if necessary by other requirements like thermal problems.

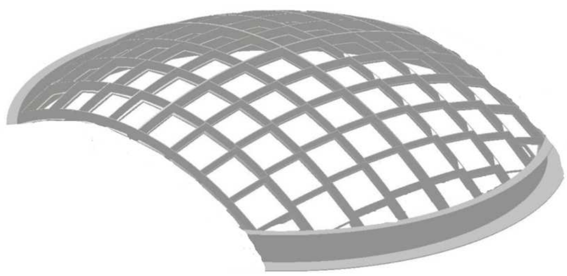

Fig. 8. The concept design of the FS structure.

VIII. BREADBOARD MODEL

For the vibration test of the MAPMT support structure and the HV-PS, we made the breadboard model of the PDM. This model has 9 MAPMT support structures with 36 MAPMT, a HV-PS board and 3 dummy front-end electronics boards (Figure 9). It has passed $20Grms$ vibration test, and we found that $0.5mm$ space between each MAPMT is enough to avoid glass breaking.

IX. ADVANCED OPTION

A significant effort is going on to reduce the spot size of the optics, in order to improve the detection efficiency of cosmic rays. In fact, a reduction of the spot size will allow to cover the FS with MAPMTs with smaller pixel size, which match the spot size of the optics. In this way, the same signal from the air shower will be concentrated on a smaller area while the intensity of the background will decrease because it will be integrated on a smaller area. Consequently, the S/N will improve. As the analysis shows that the energy threshold roughly varies inversely to $S/\sqrt{N}$, if the pixel size will get smaller, the energy threshold will decrease.

At present, the M36 MAPMT is considered, because the spot size is about $5mm$, and the MAPMT is $1" \times 1"$

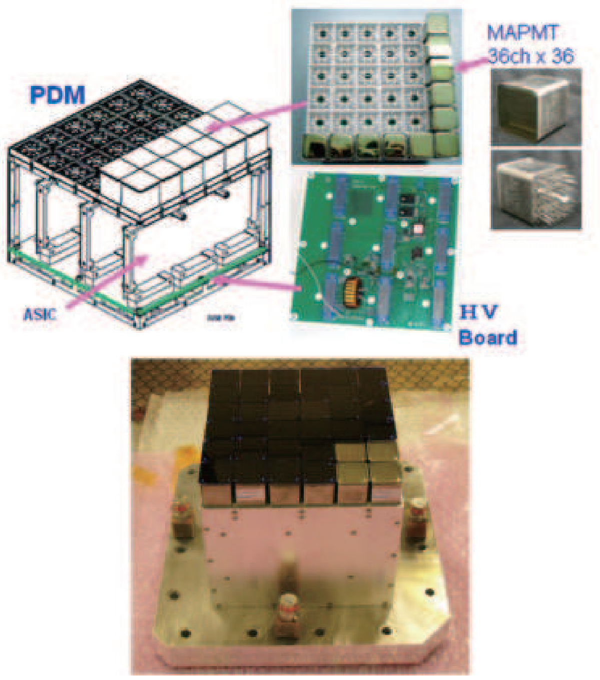

Fig. 9. The PDM Breadboard Model for the Vibration Test.

(6×6 channels). If the spot size will be reduced, a MAPMT with 64 is considered. However, due to the optical cross-talk of the MAPMT, the S/N improvement mentioned above can not be completely achieved with the present type of MAPMT. Therefore, the design of the dynode structure has been changed for the M64 MAPMT version (8×8 channels in 1" square). The performance of this new MAPMT will be reported soon.

In parallel, we are also developing a detector system using SiPM (Pixelized Photon Detector, MPPC) which have high detection efficieny in the UV region. The details of this type of detectors are described and reported in [2]."

X. Summary

We have developed a very large area photodetector system for the JEM-EUSO focal surface, based on the Photo Detector Module. We will decide the final design of the FS within this year, and we will start to build full system when the JEM-EUSO mission is started.

References

[1] Y.Kawasaki *et al.* , *Nuclear Instruments and Methods in Physics Research A*, **564** (2006) 378-394.
[2] H.Miyamoto *et al.* , *Proceedings of the 31th ICRC, Łódź* (2009)