High Voltage System for JEM-EUSO Photomultipliers

JACEK KARCZMARCZYK[1], PHILIPPE GORODETZKY[2], YOSHIYA KAWASAKI[3],
JACEK SZABELSKI[1], TADEUSZ WIBIG[1] FOR JEM–EUSO COLLABORATION
[1]*NCBJ, Cosmic Ray Laboratory, PL-90-950, Lodz, Poland*
[2]*APC, University Paris Diderot, 10 rue A. Domon et L. Duquet, 75013 Paris, France*
[3]*RIKEN Advanced Science Institute, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
js@zpk.u.lodz.pl
DOI: 10.7529/ICRC2011/V03/0216

Abstract: JEM-EUSO, the UV telescope to be installed on the ISS, has a camera (focal surface) composed of 4932 Hamamatsu new M64 photomultipliers, making a total of 315648 pixels. One pixel (2.88 x 2.88 mm) represents on the Earth surface a square of 500 m side.
Two major specifications of JEM-EUSO are:

a) the total power allocated for all the instrument should not be above 1000 W, so that the power allocated to polarize with high voltage should be less than 50 W (using normal resistive voltage dividers requires nearly 2 kW!).
b) the light intensity reaching JEM-EUSO has a dynamic range larger than 10^6 going from the background (one photo–electron per pixel per 2.5 μs) to storm lightnings.

Solution for a) is to use separate power supplies for each dynodes, regrouping identical dynodes at the same power supply. The groups can be at the level of the Elementary Cell (4 PMTs) for a total power of 50 W. The solution chosen for b) is not to shut off the telescope at the approach of the storm, but to study the events producing a lot of light (allowing for instance to measure meteors or TLEs). The voltage applied to the cathode is reduced in a fast (< 3 μs) switch driven by the integrating parts of the front–end ASICs. The focusing properties of the tubes are modified in such a way that the "gain" is reduced in a range of 10^6, by steps of 10^2.

Keywords: The highest energy cosmic rays, satellite telescope, new detection methods, multianode photomultipliers

1 JEM-EUSO telescope – TPC.

JEM-EUSO telescope is going to measure the highest energy cosmic rays by monitoring the atmosphere (at dark side of the Earth) not from the ground, as has been observed for many years, but from the top: from the altitude of the International Space Station (ISS) [1, 2, 3]. The advantage is the huge geometrical factor, as the area of radius of about 200 km would be monitored. The UV telescope (lenses and focal surface) will have the nearly circular area of about 2.3 meters in diameter. The light detector must be very fast, to monitor extensive air shower (EAS) development, which typically lasts about 30 μs, and the angular resolution (pixelisation) should be fine enough to see space development of EAS from 350–400 km altitude of ISS. To meet these requirements the light detector consists of 4932 multianode photomultipliers (MAPTM), each with 64 anodes (315648 pixels, each corresponding to about 500m x 500m at the Earth's ground level). In the basic mode, single photo–electrons would be counted in each pixel, and integrated every 2.5 μs (GTU - Gate Time Unit) (400 thousand times per second). The JEM–EUSO telescope would work as a TPC (time projection chamber) allowing 3D reconstruction of the EAS.

2 Focal Surface detector structure.

Hamamatsu – the manufacturer of M64 Multi-Anode Photomultiplier Tubes (MAPMTs) for JEM–EUSO – developed 12 stage photomultipliers with additional grid near to anodes for better focusing of internal photo–electron (pe) cascades. As the telescope will be open viewing the night atmosphere, most of measured light would come from the UV background in the telescope field of view. We expect to measure on average about 1 pe in each pixel during GTU (for UV background analysis see [4]). The gain will be about 10^6. So we expect the anode current of 4.1 μA from each MAPMT. 4 MAPMTs form the basic unit – Elementary Cell (EC), and 9 ECs form Photo Detection Module (PDM), where there are 6 x 6 photomultipliers. There would be 137 PDMs on the Focal Surface (FS).
This kind of MAPMTs requires a high voltage of about -900 – -1000 V at the cathode with grounded anodes, to achieve the gain of 10^6. One High Voltage Power Supplier (HVPS) is planned for every EC (4 MAPMTs). The anode current (background measurements) for one PDM is equal to 0.147 mA, and for the whole FS it is equal to 20.2 mA.

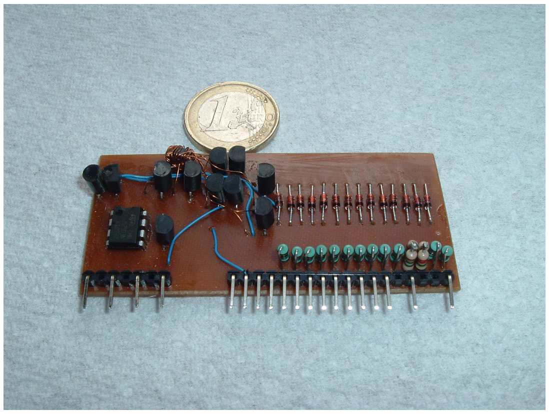

Figure 1: The Cockcroft–Walton high voltage photomultiplier supplier.

3 High voltage supply for JEM-EUSO photomultipliers – standard approach.

Standard approach requires the resistive voltage divider in parallel to the MAPMT, and, to provide stability and linearity of MAPMTs, the current in the divider should be larger than 100 times the anode current. The superposition principle acts here, so the required divider current (or sum over all dividers) shall be 100 x 20.2 mA = 2.02 A. As the required voltage is -900 V, the power which would go to the divider would be more than 1.8 kW. This value is nearly twice the limit for JEM–EUSO power consumption for all instrument devices. Therefore the standard approach to powering photomultipliers is excluded.

4 A photomultiplier model.

In photomultiplier the single pe emitted from the cathode is accelerated in electric potential U_1 between the cathode and the first dynode D_1. On average k_1 electrons are emitted from D_1 for each electron arriving from the cathode. In the next step each electron emitted from D_1 is accelerated in electric potential U_2 between the first and the second dynode (D_2), and k_2 electrons are emitted on average from D_2 per every electron from D_1, and so on. The last multiplication takes place at D_{12}, and electrons emitted from D_{12} are collected by anode. Assuming that U_n = constant (which is very common for all dynodes but 1 or 2), and k_n is proportional to U_n, we might express the phototube gain as equal to k^{12}, and for k = 3.16 we get the gain 10^6. Constant k implies constant U_n, and for 13 steps we would have U_n = 900 V / 13 = 69 V.
It is important to notice that on the last step D_{12} – anode we have the largest current i_A, then between D_{11} – D_{12} the current i_{12} is k_{12} times smaller, then between D_{10} – D_{11} i_{11} is still k_{11} times smaller etc. Similarly the power released in the photomultiplier itself is the largest at anode: $i_A \times U_A$, then at D_{12} is $i_{12} \times U_{12}$ then at D_{11} is $i_{11} \times U_{11}$ etc. 60% of power is deposited at anode, 20% at D_{12}, 7% at D_{11}, 2% at D_{10} and 1% at other dynodes.

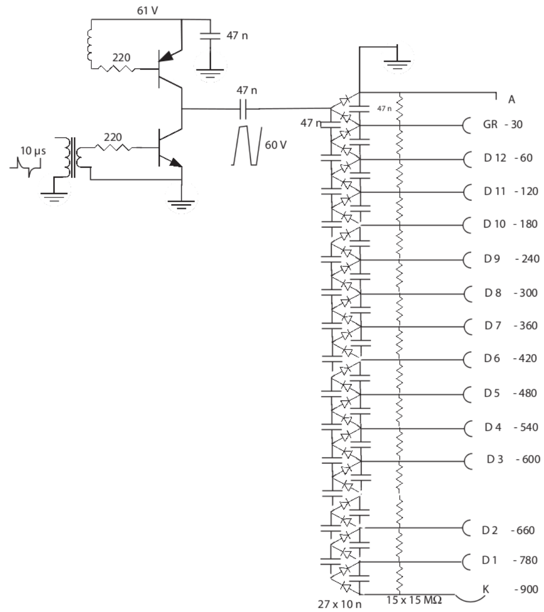

Figure 2: The Cockcroft–Walton solution for high voltage photomultiplier supplier without resistor divider.

5 The Cockcroft–Walton voltage multiplier – solution to the power problem.

The recomended photomultiplier voltage ladder is very near to the simplified description presented in the Section 4. The Cockcroft–Walton scheme shown in the Figure 2 is close to the real voltage ladder. For dynodes with large indexes the ΔU are constant, and on the first 2-3 dynodes ΔU are larger but the currents (and power) there are very small. We have made a high voltage power supply (HVPS) using the Cockcroft–Walton voltage multiplier circuit with constant ΔU approximately equal to 60 V. The idea is presented in the Figure 2. First steps near to anode (grounded) have constant ΔU and are directly connected to corresponding dynodes and near to cathode we use resistive voltage divider (however required currents are so small, that power losses there are negligible).
Large resistors presented in the Figure 2 are for diode polarization and to discharge the HVPS when turned of. For the background load as described in the Section 2 the HVPS power consumption per PDM is about 120 mW (which corresponds to about 16 W per all FS, i.e. 100 times less than a standard solution presented in the Section 3).
We have found that similar solutions for high voltage power suppliers for photomultipliers were used in the past, e.g. in CERN [5].

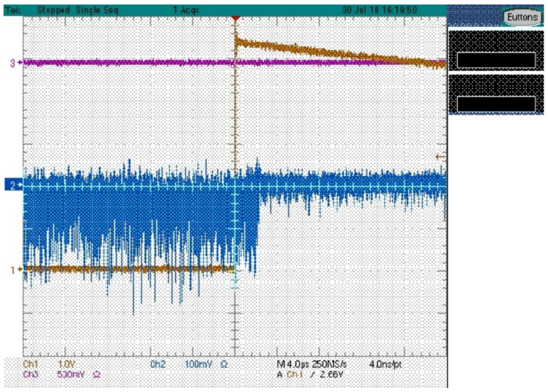

Figure 3: Oscilloscope showing the square pulses (yellow) to control the switch, and in blue the PMT anode pulses. One horizontal division is 4 μs.

6 Higher photon fluxes.

Lightnings, meteors, transient luminous events (TLE), or man made light (cities) could be very bright. During the JEM–EUSO mission we might expect to meet photon fluxes even 10^6 times higher than the background level (see Section 2). Some of them can last tens of milliseconds (i.e. long compared with GTU = 2.5 μs). As we still like to measure them, following method is applied.

When the light intensity is growing in 10 millisecond scale the HVPS should provide enough power to keep linearity of measurements up to about 200 times the background level. Laboratory measurements with calibrated light sources showed that our HVPS is capable to fulfil these conditions. However, when the light intensity rises above 100 times the background value, then we would reduce collection efficiency in the whole PDM by about 100 times, still going on with anode current measurements. When the intensity still rises by the next 100 times, we would reduce the efficiency in the PDM by another 100 times, and the next such step can be performed (see Figure 3). This reduction shall be fast (within 1-3 GTU) to secure the tubes against potential damages or wear by large currents or charges at last dynodes and anodes. However, we would still measure the anode current and the higher gain would be restored when light flux falls below the harmful level.

7 Fast reduction of MAPMT efficiency.

In the case of increase of photon flux about 100 times above the background level we would reduce the efficiency of pe collection on the first dynode D_1. We would apply new voltage on the cathode below the voltage on the first dynode D_1 keeping all other voltages unchanged, e.g. changing the cathode voltage from -900 V to -750 V, and keeping the D_1 voltage on the level -800 V. These would provide the opposite electric field and reduce the efficiency by about 100 times. The next 100 times efficiency reduction for M64 tubes requires cathode potential equal to 500 V, and with cathode grounded the efficiency would be still at the level about $3{\cdot}10^{-5}$.

In the M64 MAPMT the cathode and metal housing box are connected. Therefore the cathode capacitance of 36 photomultipliers (PDM) is large, about 1 nF. To change the electric potential of cathode by 500 V within one GTU (2.5 μs) requires a current of 0.3 A for that time, which is a large value.

We made a two way switch controlled by low voltage circuit which has galvanic isolation from the high voltage part. It works as a current source (this or other way) providing large nearly constant current during the GTU. It requires large capacitors (0.2 μF on high voltage) in the required step of HVPS. The switch takes about 4 mW while not switching.

8 Conclusions.

We made several prototype models of HVPS and high voltage gain switches which have been successfully tested in laboratory conditions with M64 photomultipliers. Still further tests will be performed in a process of preparing engineering models and then space qualified models.

Acknowledgement

This work was supported in part by the Polish-French collaboration COPIN-IN2P3 (09-135).

References

[1] T. Ebisuzaki, this conference, ID1628
[2] G. Medina–Tanco et al., this conference, ID0956
[3] F. Kajino et al., this conference, ID1216
[4] P. Bobik et al., this conference, ID0886
[5] S. Neumaier et al., NIM in Physics Research (1995) **A360**: 593-597