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Optical and data acquisition system for the SPHERE-2 detector

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Abstract: A new method for high energy cosmic ray detection was suggested by A.E.Chudakov in 1972. According to this method a reflected from the snow surface Cherenkov light is observed by an optical camera lifted above the surface on the balloon. Optical system of the SPHERE-2 detector consists of 1500mm diameter spherical mirror and has 1sr view angle. Shmidt aperture diaphragm allows to reach 109 pixel optical resolution on the focal surface of the mirror. Electronic part of the detector consists of 109 pulse shape acquisition FADC channels with 25 ns steps. The dynamic range in each channel is equal to 10000 due to using of two 10-bit ADC. PMTs have 109 autoranging high-voltage power supplies that allow to set optimal PMT sensitivity according to the light conditions of measurements. Trigger system allows to separate on the PMTs mosaic light spot images of Cherenkov light reflected from the snow surface.

Inroduction

SPHERE-2 detector is appointed for high energy cosmic rays detection. The method used in the experiment was suggested by A.E.Chudakov [1] and was evolved in [2], [3], [4], [5]. The detector is lifted by tied balloon to the altitudes 1–3 km at night time and detects like a camera images of Cherenkov light spots produced by Extensive Air Showers (EAS) on the snow covered ground surface. At altitudes 1–3 km the apparetus can registrate EAS images of primary cosmic rays with energies 10–1000 PeV.

First successful measurements using this method with SPHERE-1 prototype detector took place in 2000 year. The prototype had only 19 PMTs in mosaic. The number of photons detected during $1.5\mu S$ and time moments of the pulse rising and the fallen (the relative thresholds) with step $30nS$ was registered for each photomultiplier. The experimental data processing showed that measured values are not enough for good EAS axis angle reconstruction. The simulation showed that for 2-3 degree exactness a detail pulse shape memorizing needs. By the reason the SPHERE-2 detector developing was started.

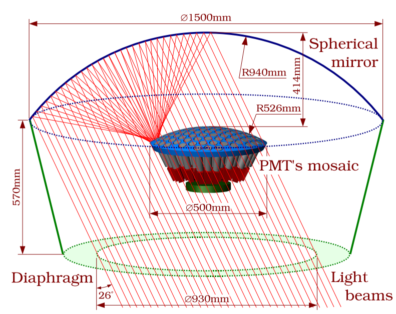

Figure 1: Optical scheme of SPHERE-2 detector (without mosaic shadow)

Optical part

The SPHERE-2 detector consist of a 1500 mm diameter and 940 mm curvature radius seven-segmet spherical mirror with the mosaic of 109 PMTs FEU-84-3 (Figure 1) on the mirror focal surface. PMTs have the hexagonal arrangement in the mosaic. Diameters of photocathode glass and of sensitive area are $33\ mm$ and $28\ mm$ accordingly. For optimal relation between optical resolution and visual angle the $930\ mm$ diaphragm is placed in front of the mirror. A spot diagramm produced by

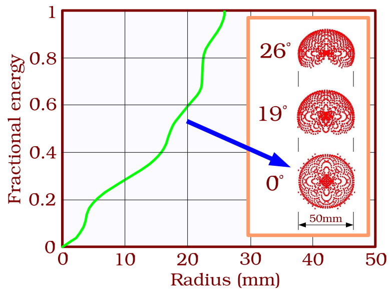

Figure 2: Optical spot (produced by paraxial beams) on mosaic surface with mosaic shadow

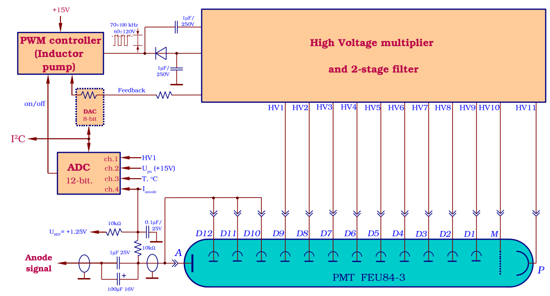

Figure 3: High voltage power supply for optical module

Figure 4: Optical module. PMT with High voltage power supply

paraxial beams (point source on snow surface) on mosaic surface shown on Figure 2. The full visual angle of the optical system is $52°$. Each PMT observe a $\sim 60\ m$ diameter surface area at the detector altitude 1 km and $\sim 180m$ at altitude 3 km.

Electronics

As the detector will operate on balloon and will be supplied by batteries there are same common requirements for the detector electronics; a) low power consumption and b) ability to work at temperatures down to $-40°C$.

High voltage power supply for PMT

High voltage (HV) power supply for PMT was elaborated especially for SPHERE-2 detector. As shown on Figure 3 the HV power supply have 11 negative high voltage outputs for direct connection to PMT dinode system. The scheme is based on Cockroft Walton multipliers with two stage filters for high and low frequencys. The filters allow decrease the electrical noise on PMT anode (with 50Ω load) to less then $0.1\ mV$. All outputs have high current load exclude PMT's modulator pin, which have high resistive devider connected with photocatode and first dinode outputs for better electron focusing.

HV power supply control is realized with two wire interface I^2C. Basic commands allow: 1) to switch on/off high voltage outputs, 2) to regulate all 11 output voltages including photocathode output from $-800V$ to $-1400V$ with step $2.5V$, 3) to measure anode current, input low voltage $(+15V)$, output high voltage on 9-dinode and temperature by means of the internal 4-channel 12-bit ADC (see Figure 3). Two HV power supplies can be connected in parallel to one I^2C port.

Power consumption of the HV power supply is less then $0.1W$ (if average PMT anode current is less then $100\mu A$). Input power supply voltage is set to $+15V$, but can be varied between $+12V$ and $+16V$. The maximum output current on HV1 (9-dinode) is $1mA$. Working temperature of the HV power supply is from $-40°C$ to $+85°C$.

HV power supply has small dimensions ($25 \times 25 \times 63mm$) and low electromagnetic noise that allows to mount it directly on PMT as it shown on Figure 4.

LPT port of on-board computer controls all 109 HV power supplies through especial commutator board located under PMTs mosaic. There are one CPLD XC95288XL-10PQ208I chip as a commutator and I^2C adaptor on 54 I^2C ports with 110 connectors on the commutator board. All connectors have a power supply filters for cross talk influence decreasing.

Flash ADC channels

Data acquisition system of the SPHERE-2 detector differ greatly from that of SPHERE-1 detector. A pulse profile is registered in each of 109 channels with $25nS$ time step. The 10-bit flash analog to digital converters (ADC) AD9203 are used for pulse shape measurements. The chip have a $75mW$ power consumption. The input signal is digitaling continuously during all measurement period. So it is possible to save anode pulse shape during last $12.8\mu S$. This time is larger then trigger system replay time, so there is no pulse shape information loss. The ”trigger ask” signal to trigger board appears in channell when sum of eight ADC’s conversions for a $200nS$ gate exceeds the presetted threshold level. This gate decreases energy spectrum threshold erosion and can be set in the range from $50nS$ to $400nS$. Also this gate allows to reject noise short anode signals from PMT light flashes in photocathode glass when a low energy particals goes through the glass.

Each channel have two ADC with preamplifiers attenuation coefficients -1 and -10, so dynamical range of channels is equai to 10000. In this range PMT *FEU–84–3* has a 20% nonlinearity of anode signal. Correction of the nonlinearity is considering during experimental data processing. The wide range allows to register lateral distribution function (LDF) on large distances from extensive air shower axis.

Digital part of flash ADC channels board on Figure 6 consists of four chips of programmable logic FPGA SpartanIII XC3S200-4TQ144I (one chip per four ADCs or per two channels). CPLD chip CoolRunner XCR3128XL-10TQ144I is used for communication to a SPHERE-2 computer through ISA bus.

Each flash ADC channels board has individual secondary power supply. ISA bus voltage $+5V$ converts to four output voltages $+2.8V$, $-2.8V$, $+2.5V$ and $+1.2V$ used on the board. For positive voltages a MAX1556 step-down DC-DC converter chip with up to 97% efficiency and maximal current out to $1.2A$ is used. Total power consumption of the board is less then $2W$ on maximal

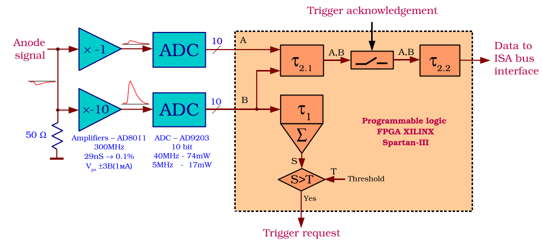

Figure 5: Block scheme of channel

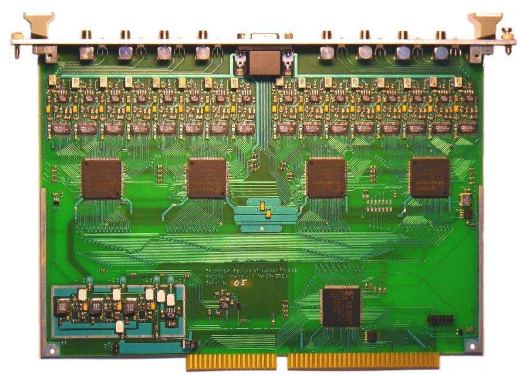

Figure 6: 8-channel FADC board

ADC’s conversion frequency $40MHz$. A sleep mode operation is provided when detector waits measurements start. In this mode all converters are turned off and power consumpition equals to $10mW$. Only CPLD chip works as a supervisor and continiously waits for a computer commands. Also there is possibility to measure temperature conditions by two sensors and power supply voltages by addition low power ADC.

Trigger

Trigger system recive up to 112 input ”trigger ask” signals from channels. The system is able to choose events, when few neighboring PMT channels give simultaneously signal according to a logical model. The logical model describs PMTs arrangement in mosaic. Trigger condition is an events when 3 (soft trigger) or 7 (hard trigger) neighboring PMTs give ”trigger ask” signals during $1\mu S$. The trigger board is based on one FPGA SpartanIII XC3S400-4PQ208I complex chip and ISA bus interface CoolRunner XCR3128XL-10TQ144I CPLD chip.

On-board computer and peripheral

On-board computer of SPHERE-2 detector consists of the low power half-size ISA-bus CPU industrial card PCA-6751 with Intel Pentium $266 MHz$ MMX processor with $128 MB$ memory, $256 MB$ CompactFlash card for OS Linux and $80 Gb$ HDD for experimental data. The board have expanded working temperature range from $-40°C$ to $+85°C$.

All electronics is mounted in 19" case with 21 slots of 6U high modules. Passive cross board PCA-6120 on 20 slots of ISA bus is used. ISA bus allows to transmit the experimental data from all 109 channels with $3\ Hz$ frequency. The real event frequency is $0.5\ Hz$. One event size is $170\ kB$, so one $10\ hour$ night information size is equal to $3\ GB$. This data is saved on hard disk and backuped on external USB flash disk.

There are two ways for wireless communication between SPHERE-2 detector and ground control center - GSM/GPRS modem and fast Wi/Fi connection.

The altitude and coordinates of SPHERE-2 detector are controlled by GPS Garmin 16 HVS through serial RS-232 port. GPS have a $1\mu S$ precise time PPS output to tie detected events to world time.

The total power consumption of SPHERE-2 detector is $50\ W$. The detector supplies by 80 Lithium Ion ICR18650 rechargeable batteries.

Conclusion

A new electronic equipment for SPHERE-2 detector was developed and tested. The detector allows to use new method of high energy cosmic rays registration. First measurements with SPHERE-2 detector is planned on 2008 March on snow covered Baikal's lake ice.

Acknowledgments

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