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Low power high dynamic range photomultiplier bases for the surface detectors of the Pierre Auger observatory

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Abstract

Design, tests and production methods of the photomultiplier bases for the surface detectors of the Pierre Auger Observatory are presented. The voltage divider is a purely resistive chain including a low consumption high voltage power supply. Two different output sensitivities have been obtained by using the anode and the last amplified dynode outputs. The charge ratio between the anode and the amplified dynode is around 32. The design ensures the stability of the gain and of the base line for events made of several pulses over a long time duration (up to 20 μs) and a total charge ranging from a few to 6×10^5 photoelectrons (typical value: a few thousands) with a peak photocathode current of up to 200 nA. The pre-production, test and mounting on photomultipliers of 200 bases has been carried out. The total production is 5000 pieces.

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Keywords: Photomultiplier base; High dynamic range; Low-power high voltage

1. Introduction

The surface detectors of the Pierre Auger Observatory [1] are designed to measure particle showers created by cosmic rays with energies of up to 10^{21} eV. The surface array is composed of 1600 Cherenkov 12 m^3 water tanks placed on a grid with a spacing of 1.5 km. The Cherenkov light emitted by the particles (mainly photons, electrons and muons) in the water tank is detected by three photomultiplier tubes (PMTs) placed on the top of each tank. The PMTs, the 230 mm diameter Photonis XP1805/PA1 [2], have been chosen after extensive tests [3]. They have to measure signals over a wide dynamic range of amplitude and charge because of the large variation of the particle density with the primary energy and the distance from the shower core. Since the surface detectors

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are supplied with solar cell batteries, the PMT bases have to fulfil stringent constraints on the power consumption. The installation has to be in operation for 20 years.

2. Requirements

Based on shower simulations [4], the typical signals of interest are made of several pulses over a duration of up to 20 μs with a total charge of thousands of photoelectrons. A good base line stability over this period is required by the readout electronics. The largest signals to be considered correspond to a peak photocathode current of around 200 nA, a 10–90% rise time of around 100 ns, a 90–10% fall time of around 500 ns, for a total charge of 6×10^5 photoelectrons. The minimal signals to be detected correspond to a few photoelectrons.

The standard operating gain of the PMT will be set to 2×10^5 and could be extended to 10^6. In order to cover the large dynamic range the measurements will be performed on two outputs with different gains (ratio of about 32 between the two channels). Simulations and measurements show that the best solution is to implement two outputs on the base: one from the anode, and the other one from an amplifier connected to the last dynode. The PMT cathodes are placed near the water and therefore the PMTs have to be supplied with a positive high voltage. The maximum high voltage is 2 kV and it has to be provided locally from a module powered with a +12 V DC. The total power budget for one PMT base and the associated high voltage power supply is limited to 500 mW.

The bases will face a high environmental stress: a high level of humidity, large thermal cycles. As a consequence, the bases will be plotted.

3. Design

The base design and the choice of the components is a tradeoff between the performances, the cost and the high reliability constraints [5]. Calculations and simulations on different base implementation techniques show that transistors are not necessary and that a resistive voltage divider is suitable for the required performances. The last stages of the divider are shown in Fig. 1. The large decoupling capacitances ensure the gain stability. The signal is read on the anode and picked on the last dynode. The last dynode signal is amplified by a two-stage amplifier using Analog Device AD8012 integrated circuits: an inverting stage which is a transimpedance amplifier, followed by a voltage amplifier.

Simulations were carried out to determine the lowest acceptable values for the capacitors to ensure the best gain stability. Each dynode stage was modeled by an ideal current source which characteristics was depending on the interdynode voltages. The gain variation was calculated during the pulse by the evolution of each interdynode

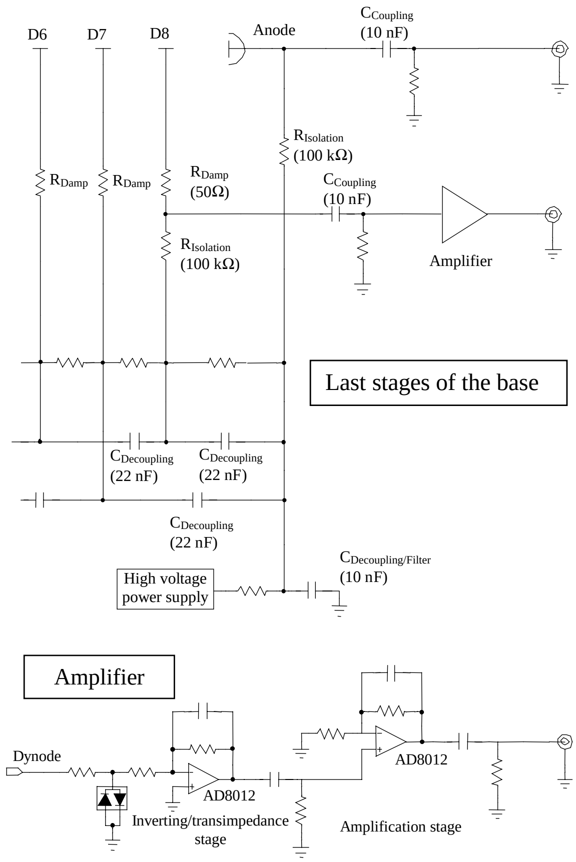

Fig. 1. Last stages of the base and amplifier structure.

voltage, according to the parameters given in the data sheets and the first measurements on the tubes. The gain stability was estimated to be better than 2.5% in the required working range. The gain evolution is shown in Fig. 2.

4. High voltage power supply

The power supply module is a critical element for the base. It is supplied by +12 V. The total power absorption is less than 500 mW. The ripple is less than 2×10^{-5} full load, and the stability in temperature better than 10^{-4}/K. The output voltage is stable over changes in input voltage of up to 0.5 V. The voltage output is remotely set by a command voltage ranging from 0 to 2.5 V and is controlled by a monitoring output ranging from 0 to 5 V. The components are plotted and the module is protected by a metallic case connected to the ground to reduce electromagnetic emissions.

The power supply modules following the previous specifications were not commercially available. Prototypes were developed by several companies. Among them, ETL [6] and SDS [7] met the requirements with a satisfactory price. Fig. 3 shows the power absorption of those modules in comparison with the commercial ones. So far, 300 modules were produced and successfully tested.

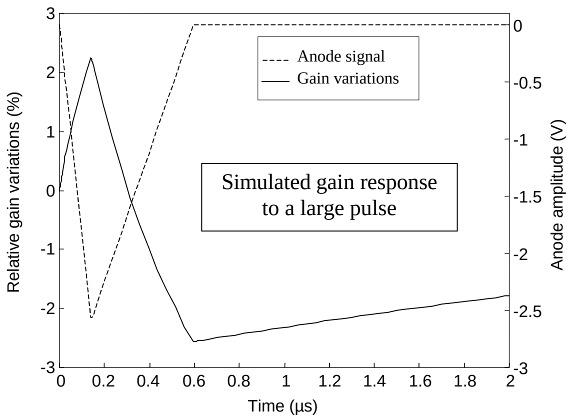

Fig. 2. Simulation of the gain evolution during the largest pulse to be considered. Plain trace: relative gain evolution. Dashed trace (scale on the right): simulated anode signal.

5. Results

The low noise design was validated by measuring the single electron response (see Fig. 4). The peak to valley ratio was compared with the one measured by the PMT vendor using a dedicated base for this kind of measurement. A good agreement was found between the two results: Fig. 4 shows a peak to valley ratio of 1.9 measured with the Auger base on a tube for which the vendor gives a value of 2.

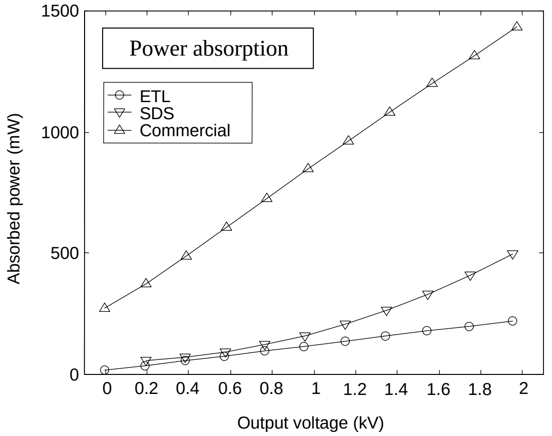

Fig. 3. Power absorption as a function of the output voltage for different power supply modules. The load used for the tests is 20 M Ω. The requested absorbed power is less than 500 mW.

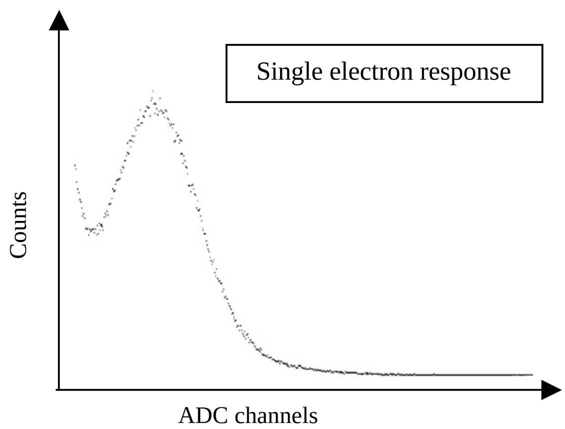

Fig. 4. Single electron response spectrum measured on the anode output with a spectroscopy chain (charge preamplifier, amplifier, and peak sensing ADC).

A second set of measurements was performed using the large time constant emission of a CsI(Tl) scintillator excited with a laser to test the behavior of the dynode output after the saturation of the amplifier. Fig. 5 shows the good correlation between the anode and the amplified dynode output, even after a saturation of the amplifier: the calculation of the correlation between the two curves starting between 0.4 and 2 μs gives 98%.

Further validations, were carried out during several months on an Auger tank installed in Orsay. There were 25 m of cable between each of the three tubes working and the control and measurement unit. The good signal-to-noise ratio is illustrated in Fig. 6 with one of the smallest signals of interest, the single muon trace. The gain stability of the base with the temperature was evaluated by measuring signals triggered by vertical muons (selected by the coincidence of scintillators placed above and under the tank) over a period of more than 60 h with a temperature amplitude greater than 20°C. The stability of the spectrum is shown in Fig. 7. The fluctuation of the average calculated by a sliding average over 2800 points (which corresponds to 2 h) is less than 2% around the mean.

6. Production

Due to a long operating time (20 years), a remote tank location, and a high environmental stress (humidity, large temperature variation), stringent assurance quality policies are necessary. This is reflected in the implementation and technological choices of the design: component rating, use of SMD packaging, use of non-electrolytic capacitors, reduction of the number of components. The connectors and stuffing methods were validated with the first production of 200 bases. An automated test bench was developed to test the power supplies before mounting on the base, as well as for the base after stuffing. These tests include the measurement of the voltages at each dynode to establish the relationship between the command voltage, the anode voltage, and the voltage monitoring output.

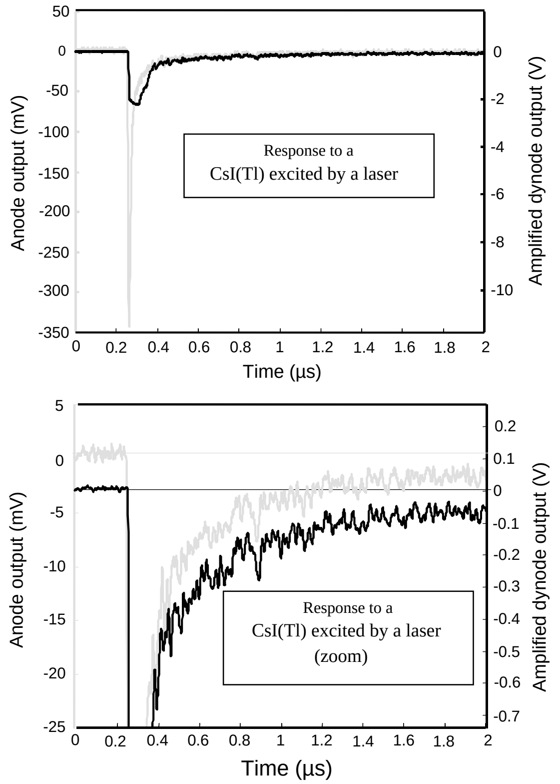

Fig. 5. Top: comparison of the anode (gray trace) and dynode (black trace, scale on the right) outputs in the case of a saturation of the dynode amplifier. The PMT gain is 2.5×10^5. The sampling rate is 2 GSPS. Bottom: same as the top curves with a sliding average over 5 points on the anode signal to reduce the effect of the oscilloscope digitization noise.

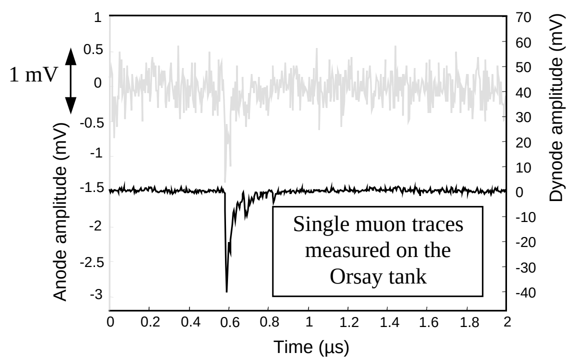

Fig. 6. Single muon signal measured on the Orsay tank with a digitizing oscilloscope. Top trace (in gray): anode output. Bottom trace (scale on the right): amplified dynode ouput. The oscilloscope was trigged by the coincidence between scintillators placed above and under the tank. The PMT gain is 2.5×10^5. The sampling rate is 2 GSPS.

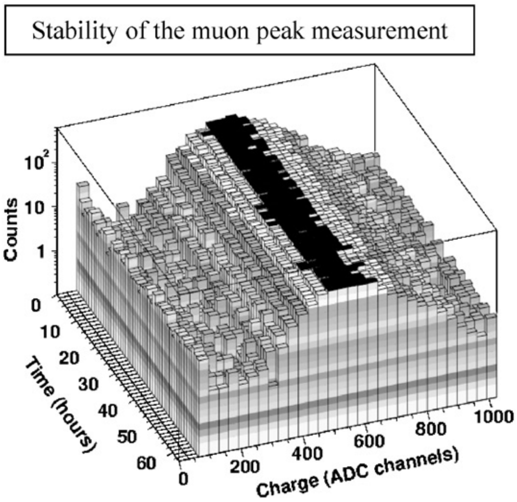

Fig. 7. Base stability in time measured in the Orsay tank. Evolution of the spectrum of vertical muons (charge measured on the amplified dynode output), detected by the coincidence of scintillators placed above and under the tank.

7. Conclusion

A resistive base including a low power high voltage module has been developed for the Pierre Auger observatory surface detectors. The high dynamic range is obtained by using the anode and the amplified last dynode output. The design was validated by tests in laboratory and in an Auger tank located in Orsay. The production methods have been validated by a preproduction of 200 pieces. The production of 5000 pieces is currently under way.

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