NUCLEAR ELECTRONICS & COMPUTING

NEC'2011

Proceedings
of the XXIII International Symposium

Joint Institute for Nuclear Research

NUCLEAR ELECTRONICS & COMPUTING

XXIII International Symposium
Varna, Bulgaria, September 12-19, 2011

Proceedings of the Symposium

NEC'2011

ЯДЕРНАЯ ЭЛЕКТРОНИКА И КОМПЬЮТИНГ

XXIII Международный симпозиум
Варна, Болгария, 12-19 сентября 2011 г.

Труды симпозиума

Дубна 2011

CONTENTS

Solar panels as possible optical detectors for cosmic rays

L. Tsankov[1], G. Mitev[2], M. Mitev[3]
[1] *University of Sofia, Bulgaria*
[2] *Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Bulgaria*
[3] *Technical University, Sofia, Bulgaria*

Photovoltaic cells have relatively high sensitivity to visible light and are available as large area panels at a reasonable price. Their potential use as air Cherenkov detectors for the extended atmospheric showers, caused by high energy cosmic rays, is very attractive.

In this paper we make an evaluation of different types of photovoltaic (PV) cells. Assemblies of several cells are studied, both connected in series and in parallel, aiming for the increase of the sensitive area, performance improvement etc. We propose a schematic for optimal separation of the fast component of the detector system signal. The threshold sensitivity of the different configurations is estimated and their ability to detect very high energy cosmic rays is discussed.

Introduction

In 1936 the Austrian physicist V.F. Hess (1883 – 1964) receives the Nobel Prize for Physics for the discovery of the cosmic rays. Ever since, the largest and most expensive research complexes that have been built, have been dedicated to the registration and measurement of the primary and secondary cosmic radiation parameters. For that purpose there have been conducted many observation tests with blimps and artificial Earth satellites. Many underground and surface observatories (at sea level and high-mountain), with detector area sometimes reaching 100 km^2, have been built [1, 2].

Most frequently during observation of extensive air showers (EAS) in surface stations can be registered the muon component, using groups of organic plastic photo-scintillation detectors (PSDs), whose output signals are passed on to fast coincidence circuits [1, 3]. They allow for very precise definition of the moment of the event occurrence but offer more limited capabilities for defining the energy parameters of the registered event. Rarely, liquid (most often water) Cherenkov detectors are used.

Another popular method is the detection of the Cherenkov radiation caused in the atmosphere by the primary high-energy charged particles (at 30 – 60 km altitude), or by the secondary products of the EAS. Photomultiplier tubes (PMTs), placed in the focus of the optical system, are used for detectors.

The rapid evolution of the photovoltaic (PV) cells in the last decade made them accessible at low prices. Their high efficiency and the possibility for construction of systems with significant area, allows for their use in Air Cherenkov detectors [5, 6].

The purpose of this work is to evaluate the possibilities of PV-cell based detector systems to distinguish between the short light pulses of the Cherenkov radiation and the slow component arising from background light.

This imposes the need to look into new schematic solutions for the signal acquisition and shaping and the evaluation of their usability as components of Air Cherenkov detectors of EAS. It is necessary to define whether the sensor is capable of reacting to short light flux (the duration of the Cherenkov radiation is under 1 μs) and what is the minimum threshold for light impulse value (represented in number of photons in the interval) that can be registered with the corresponding detector.

Review

1. Particularities and limitations

The use of PVs in such nontrivial mode leads to the following characteristic particularities and problems, which should be considered during the development of the design of the signal acquisition and shaping circuit:

1. The detector's output signal comes from the charge generated in the detector volume, not the output voltage or current;
2. The mean output current arising from the background light (twilight, full moon, urban area light etc.) can be some orders of magnitude higher than the signal level;
3. PVs have significant capacitance (10-50 nF/cm^2), exceeding the capacitance of the semiconductor detectors, used for ionized emissions detection, manyfold.

In order to achieve large detector surface, for detectors constructed by PVs, exist two approaches – parallel or sequential connection of the cells. Both methods are equivalent in relation to the volume of the occurring charges. When n elements are connected in parallel the equivalent capacitance of the PV cell is n-times greater, while – connected in series – it is respectively n-times smaller. Obviously, having the PV cells sequentially connected is preferred for obtaining larger signal with the same generated charge.

2. Signal acquisition with PV cells

In [7] is shown that if the capacitance of the semiconductor detector doesn't change in a wide range, the signal acquisition with transimpedance, or charge sensitive amplifier give equivalent results. The presence of a significant offset current from the PVs makes the galvanic connection to the amplifier impossible. In [5] are reviewed the options given through the introduction of capacitive separation of the input, or the use of an isolation transformer.

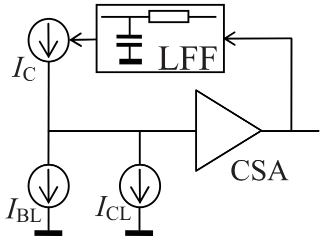


Fig. 1

Another possible solution is the compensation of the offset current. The PV cell output can be presented as a sum of two components (Fig. 1) – a slow one, due to the background light (I_{BL}), and a second one, fast changing short pulse, due to the Cherenkov light of EAS (I_{CL}). Our idea is to connect opposite the cell a current generator I_C, whose value is equal to the slow component and adaptively follows it. For the short pulse the high output resistance of the current generator I_C takes the role of a load, which guarantees the full collection of the charge in the detector volume, caused by the Cherenkov light.

3. Front-end-electronics schematic

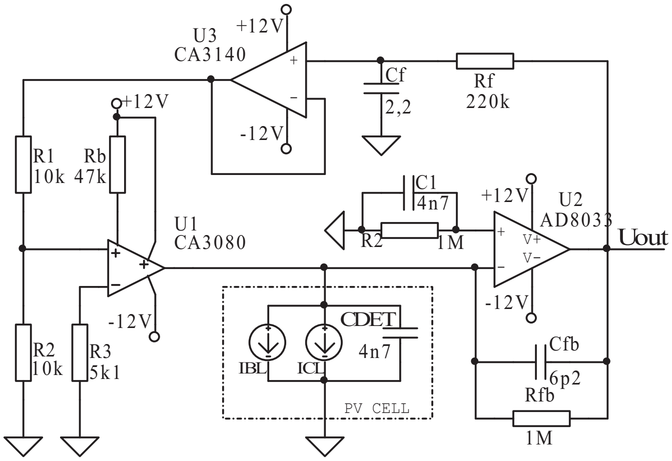


Fig. 2

The PV signal preamplifier is realized using AD8033 operational amplifier (Fig. 2). Depending on the Rfb/Cfb ratio, it works either as a transimpedance or as a charge sensitive preamplifier. That is illustrated by the form of the output signal on Fig. 3. That ratio influences the amplitude-frequency diagram of the amplifier (Fig. 4). An overcompensation is seen for Cfb < 5 pF, so the amplifier can lose stability. That can be seen both on the amplitude-frequency and output signal shape diagrams.

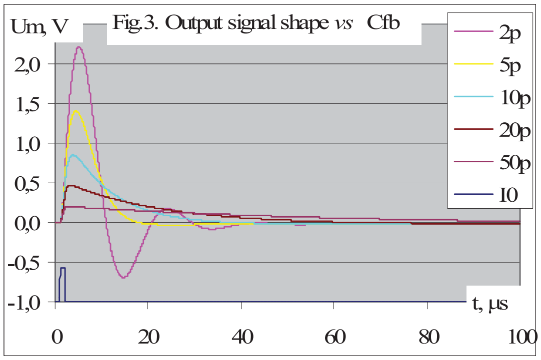


Fig. 3

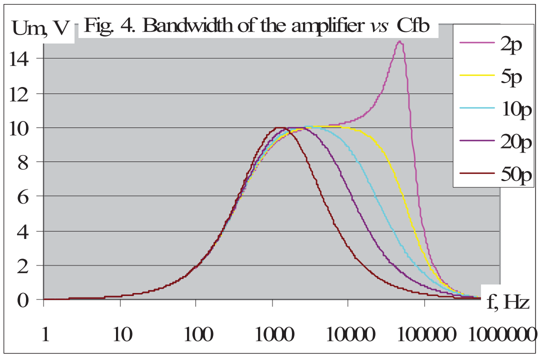


Fig. 4

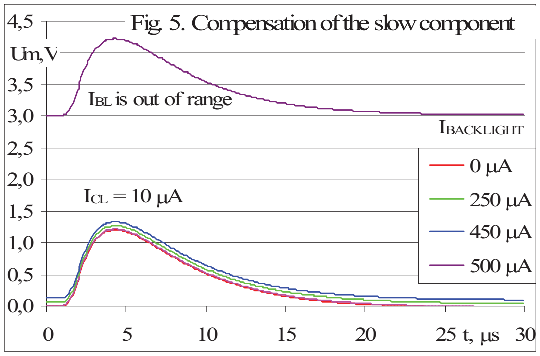


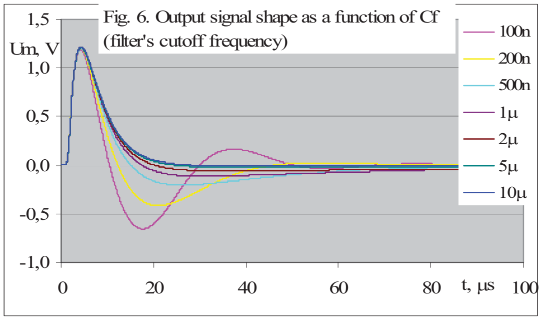
Fig. 5

An OTA CA3080 is used to compensate the background and the slow component of the PV current. Fig. 5 shows the device's performance for input pulses with duration 1 µs and amplitude 10 µA, while the slow component changes from 0 to 500 µA. It can be seen that the disturbance is successfully compensated up to 450 µA. We get an output signal with considerable amplitude without any significant offset.

That guarantees the schematic would work flawlessly in high background lighting conditions – e.g twilight, full moon or urban areas.

A first order low pass filter is implemented based on Rf and Cf, followed by a buffer amplifier CA3140. The signals with frequency lower than the cut-off frequency of the filter are fed to the input of the adjustable current generator and change its output value, compensating the low frequency background and noises. The high frequency signals (in this case caused by the short light pulses) can't get through the filter, the current generator keeps its value, corresponding to the mean value of the offset current of the PV cell. The high output resistance of the current generator guarantees the full collection of the charge, induced by the short light pulse. The influence of the notch frequency on the output is illustrated on Fig.6. It can be seen that the compensation circuit does not deteriorate the rise time and the output amplitude of the pulse – i.e. its operation doesn’t change the signal.

The output signal vs. the detector's capacitance is shown on Fig.7. It is seen that the amplifier might become unstable at high capacitance. This suggests the general rule when connecting PV cells into batteries - they should be connected in series in order to decrease the total capacitance. In our experiments this value was decreased to 7,2 nF and 3,6 nF for the different configurations.



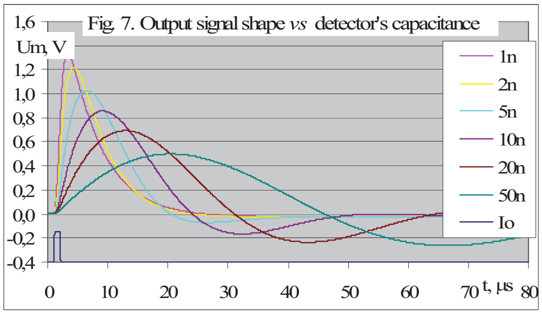


Fig. 6

4. Test SETUP

Our experimental setup (Fig. 8) uses a light pulse generator [8] with adjustable amplitude and duration of the signal, and interchangeable LEDs (red, green and blue). It is possible to set 15 different levels of the LED drive current either in continuous, or pulse mode. The light pulse length is step-adjustable in the rage between 50ns ÷ 250µs.

The PV output current is measured in continuous mode lighting, using highly sensitive digital microampermeter (6-Digit Multimeter Hameg 8112-3). That makes possible, by factoring-in the light pulse length, the calculation of the charge generated in the volume of the PV cell. The amplitude and the shape of the output pulses are monitored with a digital oscilloscope.

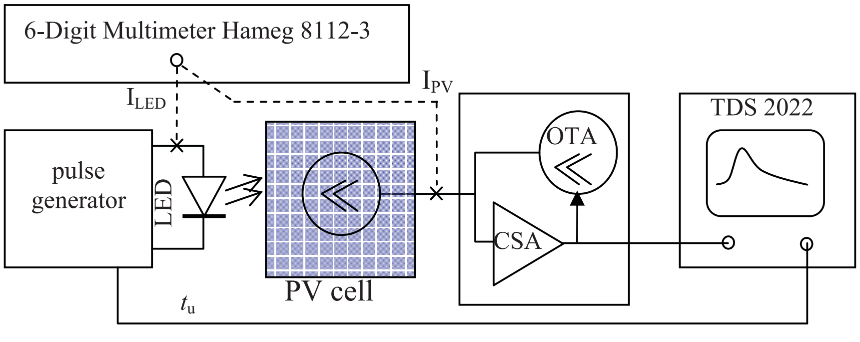


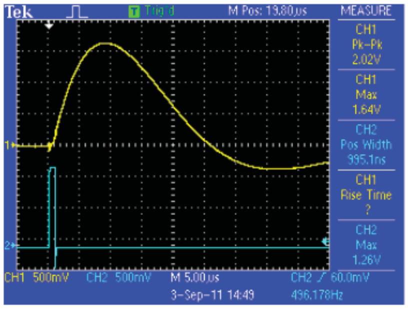
Fig. 8

Results

Series of measurements were conducted using commercially available PV panels, consisting of either 36 cells sized 60x15 mm (nominal output 5W at 12V), or 36 cells - 60x30 mm each (nominal output 10W at 12V). The PV cells are internally connected in series. Two of the smaller panels were also used connected in series as an aggregate panel. The shape of the output pulse is presented on the oscillogram (Fig. 9), together with the pulse lighting the LED. The experiments, carried out using slowly changing background light (e.g.

reflected luminescence light), have proven that the schematic successfully compensates these disturbances.

Fig. 10 shows the signal/noise (S/N) ratio for the three panel assemblies as a function of the signal (number of photoelectrons generated by the LED pulse (1µs) per m^2). The S/N ratio of 3 is reached at about10^8 pe/m^2, while the night sky is estimated to give about 10^{12} pe/m^2 (i.e. 10^6 pe/m^2 for the pulse duration).



TDS 2022 - 15:49:02 9/3/2011

Fig. 9

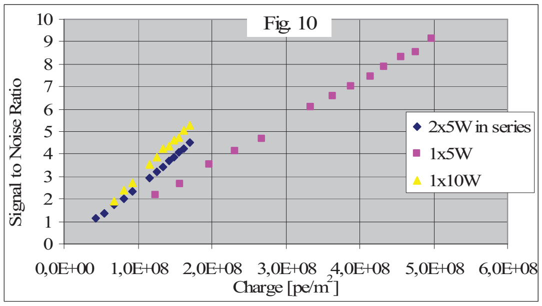


Fig. 10

Conclusion

The experimental results show that both the performance and the sensitivity of PV cells are sufficient to register the Cherenkov component of very high energy EAS. The compensation circuit for the slow component (due to the background light) allows to increase the observation period significantly - during the whole night, even at full moon, as well as performing observations in sites having poor astro climate.

Acknowledgement

The present research is supported by the Technical University - Sofia under Contract 112ПД051-3.

References

[1] P.K.F. Grieder. Cosmic rays at earth: researcher's reference manual and data book. ELSEVER. Amsterdamp, 2001, p. 1093.
[2] V.F. Sokurov. Physics of cosmic rays: cosmic radiation. Rostov/D.: Feniks, 2005 (in Russian).
[3] http://livni.jinr.ru
[4] V.S. Murzin. Introduction to Physics of Cosmic Rays. Moscow: Atomizdat, 1979 (in Russian).
[5] S. Cecchini et al. Solar panels as air Cherenkov detectors for extremely high energy cosmic rays. arXiv:hep-ex/0002023v1 (7 Feb 2000).
[6] D.B. Kieda. A new technique for the observation of EeV and ZeV cosmic rays. Astroparticle Physics 4, 1995, pp. 133-150.
[7] H. Spieler. Semiconductor detector systems. Oxford Press, 2005.
[8] G. Mitev, L. Tsankov, M. Mitev. Light Pulse Generator for Photon Sensor Analysis. Annual Journal of Electronics, ISSN 1313-1842, Vol. 4, N. 2, 2010, pp. 111-114.