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Detectors for High Count Rate Measurements with a Compensation for MPPC Gain Dependence on Temperature

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Multi Pixel Photon Counter (MPPC) is one of devices called silicon photomultiplier (SiPM). It is characterized by a fast response time, high gain coefficient, high photon detection efficiency resulting in good energy resolution, low voltage operation, resistance to mechanical shocks, compactness and immunity to a magnetic field. A MPPC gain is temperature dependent, so it is necessary to use a device which allows to maintain a constant value of a MPPC gain.

We report on two devices designed at the National Centre for Nuclear Research (NCBJ): FilterBox@NCBJ and MTCD@NCBJ to be used at the Joint European Torus (JET) during high count rate measurements.

The experiments at JET during D-T campaigns will be performed in harsh radiation conditions, especially at high rates up to ~1 Mcps and at relatively high gamma-ray energy about a few MeV. Devices designed to replace existing detector at JET have to fit to available space and must use cabling installed almost 20~years ago. The device should be user-friendly and easy operated by both engineers and physicists. It is worth to notice that in case of a completely new system, some new designed elements could be optimized in comparison with a presented solution.

A device for real-time temperature monitoring and MPPC gain stabilization was designed and produced at NCBJ, necessary due to a very strong voltage-temperature dependence characteristic for MPPC.

In Fig. 1, the overall scheme of electronics for the upgraded system is shown.

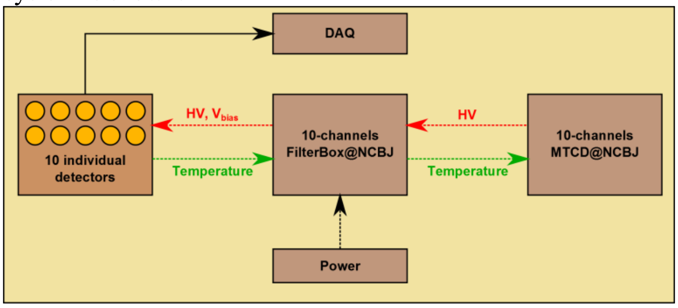

Fig. 1. Overall scheme of a detector system for the upgraded JET Gamma-ray Camera. HV denotes a bias voltage for MPPC, LV - power supply for both temperature sensor and active elements.

The most important requirements for electronics could be summarized as follows:

- setting of MPPC bias voltage,
- integrated temperature sensor,
- integrated power supply MAX1932,
- advanced power supply closed loop control.

A detector system consists of a set of individual capsules with a scintillator and a dedicated printed circuit board (PCB). On each PCB, a temperature sensor is mounted. The TSIC 506F sensor is characterized by an outstanding accuracy of ±0.1K, an excellent long-term stability and a very low current consumption of 30 μA during operation. The MPPCs, type S13361-3050NE-04 from Hamamatsu, were used.

An active system based on a transimpedance amplifier (TIA) was designed for MPPC signal read-out to obtain a signal characterized by a high output amplitude with low time-constant. TIA is mounted on the same PCB described above.

In Fig. 2 a detailed schematic of TIA is shown. All results presented in this paper were obtained with the same experimental conditons and a CAEN Desktop Digitizer DT5730 was used for data acquisition.

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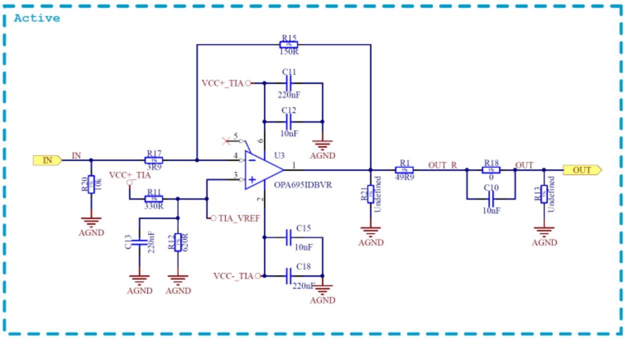

Fig. 2. Detailed schematic of TIA.

Information on temperature values is sent from a capsule to the FilterBox@NCBJ, based on a Microsemi ProAsic3 FPGA.

In Fig. 3 a photo of FilterBox@NCBJ is presented.

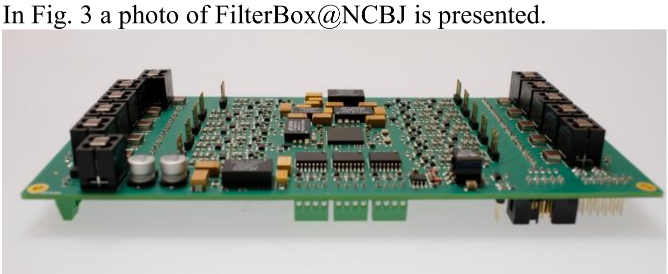
Fig. 3 FilterBox@NCBJ.

The main functions of the FilterBox@NCBJ are:

1. to serve for all individual capsules in each part of the Gamma-ray camera,
2. to filter a bias voltage for MPPC in a capsule,
3. to power active elements, e.g., TIA and a temperature sensor, mounted on PCB. For each capsule, a separated DC linear voltage regulator is used to minimize noise and crosstalk between detectors,
4. to provide communication with the MTCD@NCBJ using three independent communication channels based on a RS485 standard. Via RS485 actual detector temperature values are read from FILTERBOX@NCBJ.

FilterBox@NCBJ is supplied from a dedicated low voltage laboratory power supply.

The firmware for the Microsemi ProAsic3 FPGA on FilterBox@NCBJ was designed in a VHDL language. It incorporates modules for reading a temperature from 10 sensors. The power supply for each temperature sensor can be switched on/off individually. Temperature readout is done continuously with a programmed frequency and temperature values are accessible by reading dedicated registers.

The MPPC Temperature Compensation Device (MTCD@NCBJ) is using a measured dependence of a breakdown voltage on temperature to maintain a constant value of the MPPC gain. The MPPC Temperature Compensation Device (MTCD@NCBJ) with integrated power supplies comprises two main parts: one is connected with 10 adjustable MPPC bias voltage channels for each individual capsule, the other one is used to determine an optimal value of a bias voltage which guarantees a constant gain. Each channel has its own isolated converter to eliminate ground loops, followed by a low-dropout regulator to minimize a ripple on output. Connections are protected against electrostatic discharges. All functions are controlled from a personal computer.

In Fig. 4 the MTCD@NCBJ board is shown.

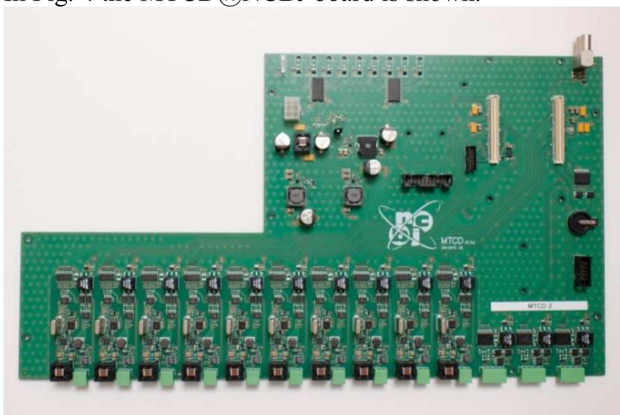
Fig. 4. MTCD@NCBJ with integrated power supplies.

Power supplies used in MTCD@NCBJ are characterized by an output voltage up to 80 V, filtering of the MPPC voltage and an option to limit current.

A development board MicroZed based on the Xilinx Zynq®-7000 was mounted in MTCD@NCBJ. A semiconductor device Zynq contains dual core ARM Cortex-A9 CPU with FPGA peripherals what allows to implement firmware both in HDL and high level language. A main algorithm was implemented in C language under Linux operating system to provide in an easy way a connection to MTCD@NCBJ via Ethernet or USB and investigation of an actual status of the device.

A control of 10 analog-to-digital (ADC) and 10 digital-to-analog (DAC) converters was implemented in VHDL. Modules allows to be controlled by CPU via standard AXI(AMBA) on chip interconnection.

PID (proportional–integral–derivative) regulator is applied to calculate a difference between actual and desirable voltage value. PID algorithm was implemented in C to control each high-voltage channel separately. A desirable value of a voltage is calculated based on temperature read from FilterBox@NCBJ.

In Fig. 5 a logic of MTCD@NCBJ is shown.

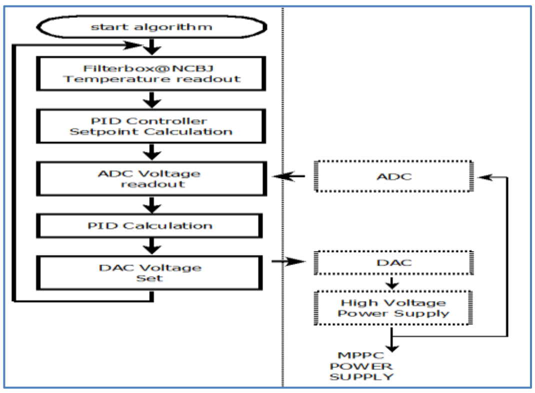

Fig. 5. Flow diagram of MTCD@NCBJ logic: *left*: CPU, *right*: programmable logic side in control program.

A protection of overvoltage was implemented in a control part of a program to guarantee that detectors will not be destroyed by applying too high voltage.

The output voltage, determined by a 20-bits digital-analog converter (DAC1220E), is delivered through the buffer to the feedback loop of the HV switching regulator (MAX1932ETC+).

Measurements detailed:

- 20 mm×15 mm cylindrical $CeBr_3$ scintillator,
- MPPC type S13361-3050NE-04 from Hamamatsu,
- active system based on a transimpedance amplifier (TIA) to obtain a signal characterized by a high output amplitude with low time-constant,
- ^{137}Cs source emitting 661.7 keV gamma linne with an activity of 400 MBq.

Preliminary results are presented in Figs. 6 and 7 as well as in Table 1.

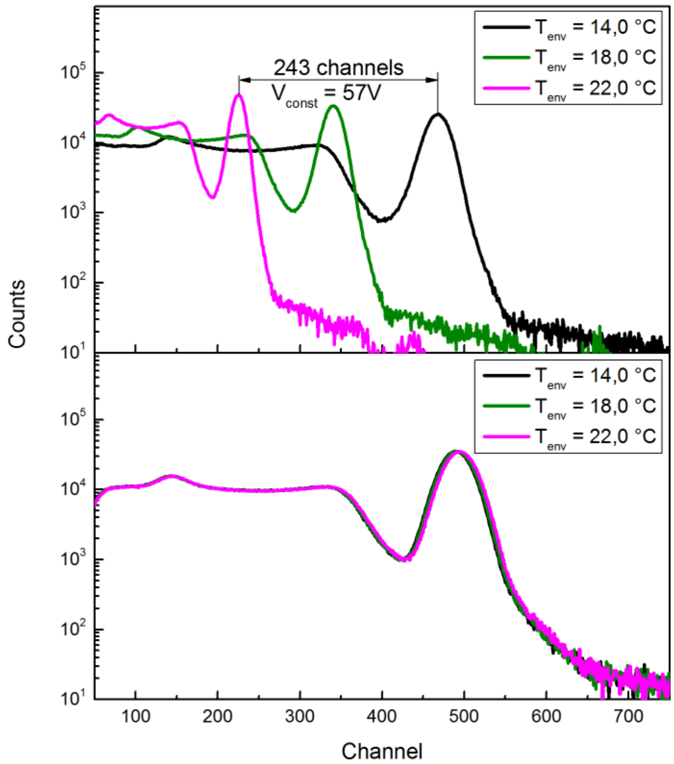

Fig. 6. Peak position as a function of MPPC temperature.
Upper: without MTCD@NCBJ.
Lower: with MTCD@NCBJ**.**

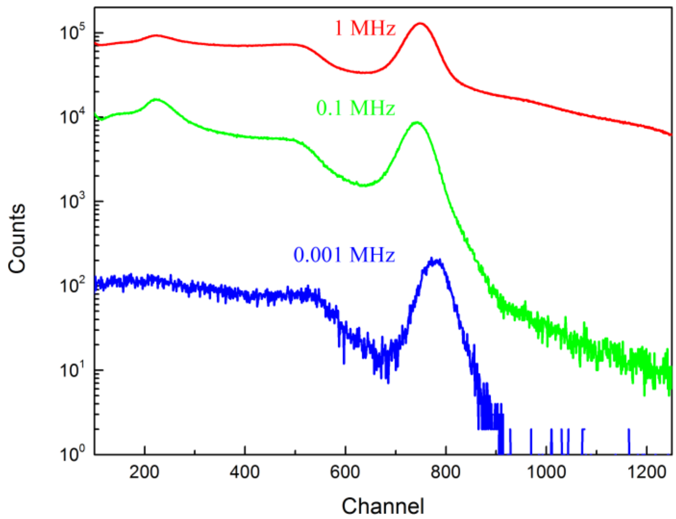

Fig. 7. Peak position as a function of count rate.

Table 1. Peak position and FWHM as a function of count rate.

Rate, Mcps	Peak position (PP), ch	$\Delta = \lvert PP-PP_{av}\rvert / PP_{av}$, %	FWHM, %
1	748	2.5	8.48
0.1	743	3.3	8.46
0.001	778	1.2	7.65

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