# Pressure monitoring system for the CMS muon chambers

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## *Abstract*

The CMS detector system of the LHC will use gas filled Drift Tube Chambers to detect muons. The gas pressure has to be kept at a constant level in the chambers and this level has to be monitored. Different versions of electronic boards (PADC) have been developed to regularly read out the pressure sensors and to send the pressure data to the Detector Control System (DCS) of CMS. This paper presents the functional description of the different PADC boards, the setup used for testing their radiation hardness and the results of the irradiation tests.

## I. INTRODUCTION

The Muon Detector System of the CMS detector at LHC will use gas filled Drift Tube (DT) Chambers detect the muons in the Barrel region. The drift velocity that is directly connected to the muon track measurement depends –among other parameters- on the gas pressure inside the chambers. Therefore the gas pressure has to be kept at a constant level and this level has to be monitored. The monitoring is also needed to have information about the performance of the gas sytem and detect any possible failure. Different solutions of this task have been studied and electronic boards (PADC) have been developed by the Aachen group to regularly read out the sensors and to send the pressure data to the Detector Control System (DCS).

Details of the gas pressure monitoring and pressure sensors are discussed in several papers like [1], [2].

The PADC boards will be connected to the Minicrate (a local interface between the DCS and the muon chamber related control units) using the same $I^2C$ bus which connects the Minicrate to the LED Driver boards of the Muon Barrel Alignment (MBA) system (see Figure 1). The Minicrate is supervised by the DCS through the slow control part.

PADC boards will be installed on each of the 240 pieces of Barrel Muon Chambers. The pressure monitoring electronics will operate in intense radiation environment; therefore, radiation hardness tests are of primary importance.

The irradiations were carried out at two different facilities. The proton irradiation was performed at the The Svedberg Laboratory in Uppsala, Sweden, while the neutron irradiation was done at ATOMKI (Debrecen, Hungary).

Special software was developed for testing the PADC boards during irradiation. A readout and data logging PC software was also prepared. During the radiation hardness tests the functions of the Minicrate were emulated by a USB – $I^2C$ intelligent media converter [3] developed by the Debrecen group at ATOMKI.

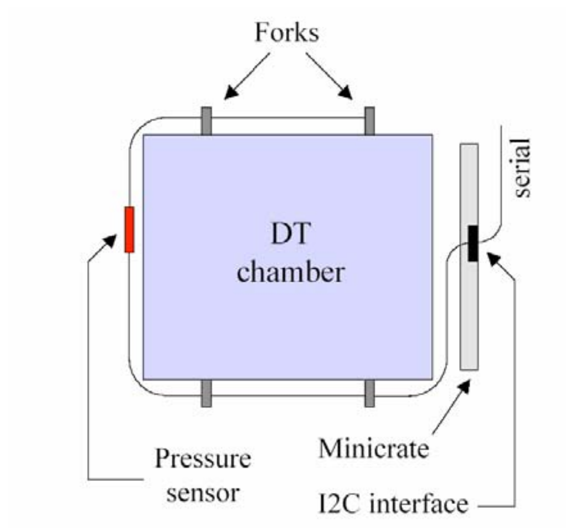


Figure 1: Schematical arrangement of the pressure monitoring electronics and MBA LED holders (Forks)

## II. EXPERIMENTAL TECHNIQUES

### *A. Description of devices tested*

To fulfill the above-mentioned requirements, two versions of the PADC board were developed. One version is based on ATMEL microcontrollers [4]. There are two processors on the board, one AT90S8535 main processor and one ATTINY26L processor for reconfiguration. Later the main processor was replaced by an ATMEGA8535. This board has local intelligence and can store the measured data autonomously for approximately 1 day in EEPROM on the board. This way the pressure history of the DT chambers can be analysed even when the DCS is unable to read the pressure values for some reason. The software of the main microcontroller can be reprogrammed through the $I^2C$ bus with the help of the ATTINY26L processor. This feature is useful if the software in the main processor gets damaged due to radiation or if replacement of pressure sensor is unavoidable. A look-up table is also stored for each pressure sensor to enable the conversion of the measured raw data to pressure values.

A much simpler version of the PADC board was also developed. This board lacks the more advanced features of the ATMEL microcontroller based board. It is based on a dedicated multi-channel ADC chip with $I^2C$ interface, MAX127 and MAX 1138 [5] were used (Figure 2). This board can only measure the actual pressure data, so if the storage of pressure data for a longer time is necessary, it has to be solved on a higher level (e.g. Minicrate). On the other hand, less complexity means less chance of failure due to radiation. Both versions of cards have opto-isolated $I^2C$ bus and an on-board power supply.

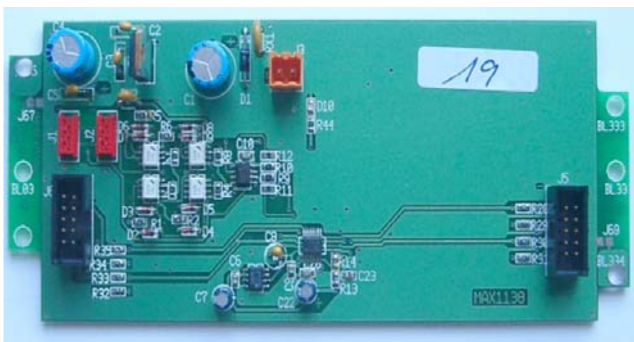


Figure 2: The PADC board with the MAX1138 ADC

### B. *Proton irradiation circumstances*

The plan for the irradiation tests was based on the CMS radiation requirements [6].

The proton irradiation was carried out at the The Svedberg Laboratory (TSL) in Uppsala in the Blue-Hall on the proton beam line “B” [7]. The existing facility at TSL is intended to be used for irradiation of electronic components and testing functionality of those in radiation (e.g. space) environments.

At the broad-proton-beam facility of TSL a single-scattering-foil technique has been adopted. The incident proton beam coming from the cyclotron is focused on a 1.5mm thick tantalum foil. The profile of the produced scattered beam is of gaussian shape. Then the scattered beam is collimated to a predefined width using a set of tantalum-graphite collimators. The beam exited from the beam tube to free air through a thin aluminium window. The irradiated components were placed on the proton test bench at 380 mm from the exit window. Three nominal beam energies were used: 50 MeV, 100 MeV and 180 MeV. Taking into account the energy losses in the Ta scatterer foil and in the Al end foil, 48 MeV, 95 MeV and 171 MeV protons impinged on the irradiated circuits, respectively.

The absolute fluence density of the beam was determined with an in-beam monitor consisting of a thin film breakdown counter. The operation of this detector is based on the $^{238}$U(p, fission) reaction with a cross section which has been approved as standard for protons. The detection sensitivity to protons is in the range $10^{-6}$-$10^{-7}$ pulses/proton/cm$^2$. This beam monitor was used to calibrate the detector system during the measurement.

A second monitor was installed to measure the relative proton fluence. It consists of a scintillation telescope placed at 45 degrees to the beam line viewing the scattered protons from the beam exit window.

### C. *Neutron irradiation circumstances*

The neutron irradiation was done at the p+Be neutron irradiation facility [8] at the MGC-20E cyclotron at ATOMKI (Debrecen, Hungary). Neutrons with a broad spectrum ($E_n$<20MeV, <$E_n$>=3.5MeV) were produced by bombarding a 3mm thick target with protons of 17 MeV. Neutrons emitted from the neutron source were inherently associated by gamma photons. The additional gamma doses were measured by the twin ionisation chamber method [9]. The gamma dose/neutron flux ratio depended on the irradiation circumstances. Typically it was in the range of (3-5)E-10 rad cm$^2$s/neutron. All irradiations and measurements were performed at room temperature.

### D. *Electronic test set-up and measurement*

The PADC module was fixed in front of the proton beam (Figure 3).

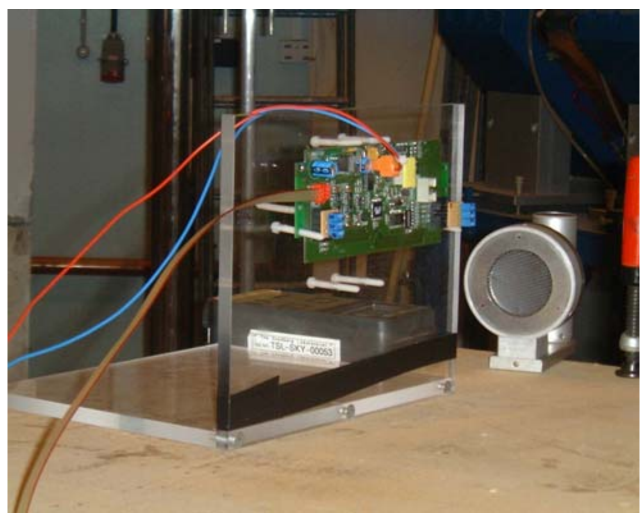

Figure 3: The PADC board

The input voltage (6V) was supplied by a laboratory power supply. The current consumption of the board was monitored during the measurement by a Metex M-3650D digital multi-meter. The serial port of this meter was connected to a concentrator which converted the serial bus to $I^2C$ bus. This $I^2C$ bus and the $I^2C$ bus of the PADC board were connected via a 20 m long cable to an “Optoisolated USB – $I^2C$ Bus Converter” produced by ATOMKI. The USB – $I^2C$ Bus Converter was placed outside the irradiation hall. A laptop PC with USB port was used to monitor the functions of the PADC board irradiated.

The ADC inputs of the PADC boards were connected to a resistor network in order to make different voltage levels for each ADC channels.

In the case of the PADC board versions with the ATMEL processors, software was loaded to them, which read out the ADC channels and stored the data in the external EEPROM. The ATMEL processor sent the data through the $I^2C$ bus each time when the control SW running on the PC sent a request.

Control software written in JAVA was running on the PC connected to the $I^2C$ bus. It read out the ADC channel and the current consumption regularly, and it saved the values in a report file for further analysis and also plotted the values on the screen.

## III. RESULTS AND DISCUSSIONS

The results of the proton irradiation are summarised in Table 1.

Table 1: Result of proton irradiation of the PADC boards

| Proton energy (MeV) | Board | Nr. of protons ($p/cm^2$) | Total dose (krad) | Remarks |
|---|---|---|---|---|
| 171 | AT 90S8535 | **$3.0\times10^9$** | 0.18 | No SEU-s, 1 fatal error |
| 171 | AT 90S8535 | **$2.2\times10^9$** | 0.136 | 2 upsets |
| 171 | ATMEGA | **$2.2\times10^9$** | 0.136 | No upsets |
| 171 | MAX127 | **$2.2\times10^9$** | 0.136 | No upsets |
| 171 | MAX1138 | **$2.2\times10^9$** | 0.136 | No upsets |
| 94 | AT 90S8535 | **$3.56\times10^9$** | 0.367 | Latch up, no fatal errors |
| 94 | ATMEGA | **$3.56\times10^9$** | 0.364 | No upsets |
| 94 | MAX127 | **$3.56\times10^9$** | 0.367 | No upsets |
| 94 | MAX1138 | **$3.78\times10^9$** | 0.389 | No upsets |
| 48 | AT 90S8535 | **$5.73\times10^9$** | 0.945 | No upsets |
| 48 | ATMEGA | **$5.72\times10^9$** | 0.944 | No upsets |
| 48 | MAX127 | **$5.74\times10^9$** | 0.947 | No upsets |
| 48 | MAX1138 | **$5.76\times10^9$** | 0.95 | No upsets |

The PADC board with the ATMEL 90S8535 processor produced some errors during irradiation and one of them was fatal. The module stopped working after about 30% of the aimed number of protons. The ADC values could not be read and the processor did not answer the $I^2C$ commands. The current consumption increased up to more than 1.5 times of the initial value. After switching *OFF* and *ON* the power, the current consumption dropped below the initial, normal value. The ATMEL chip did not answer the $I^2C$ commands and it could not be read or reprogrammed by the programmer. At the same time, the $I^2C$ bus itself remained fully functioning. Until the processor stopped functioning, no errors were found, the current consumption was normal (Figure 4), the processor answered the $I^2C$ requests and the ADC values were stable. After replacing the board, the test could be continued, but further errors were encountered. These were not fatal but at one occasion the board had to be restarted to restore the normal operation.

On the other hand all the other modules worked perfectly, without any errors. During the proton irradiation, the modules accumulated more that 1.4 krad total dose.

All the boards were irradiated with neutrons, with a fluence of $1\times10^{11}$ $n/cm^2$. No permanent or temporary errors were detected, the current consumption was normal.

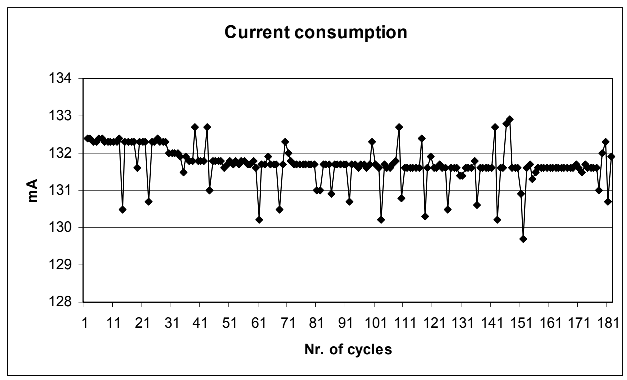


Figure 4: Total current consumption of the PADC card during irradiation

## IV. CONCLUSIONS

The PADC modules were irradiated by protons of different energies and with neutrons. The board with the ATMEL 90S8535 processor had several failures, but the other three boards performed well, so any of the latter modules can be chosen for production from the radiation point of view. The PADC board with the MAX 1138 chip was finally selected for the pressure monitoring application. The production of the boards is on the way.

## V. ACKNOWLEDGEMENTS

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