THE TOTEM ON-LINE RADIATION MONITORING SYSTEM

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Abstract

The TOTEM detectors together with their related readout electronics are located in LHC and CMS areas where high radiation levels are expected. The Ionizing Dose and the particle Fluence are thus monitored during TOTEM operation and made available on-line through the Detector Control System. A total of 36 sensors are installed in TOTEM. The one located in the Roman Pot stations, along the LHC tunnel, sit more than 300m far from their readout electronics. This characteristic makes the system described in this paper unique with respect to the one of the other LHC experiments.

INTRODUCTION

The TOTEM experiment will measure the total *pp* (proton-proton) cross section and study elastic scattering and diffractive dissociation at the LHC [1]. TOTEM consists of three sub-detectors: the Roman Pot (RP) Silicon Detectors, located in the LHC tunnel near the Interaction Point 5 (IP5) and two inelastic telescopes, T1 and T2, located in the CMS end-cap regions.

The RP is a special beam pipe insertion which allows bringing the Silicon Detectors very close to the LHC beam. Four RP stations are symmetrically installed in the LHC tunnel at 147m and 220m from IP5. Each station is made of two units separated by a few meters and equipped with one horizontal and two vertical Pots. The telescope closest to the interaction point (T1) consists of Cathode Strip Chambers (CSC), while the second one (T2), makes use of Gas Electron Multipliers (GEM). All these detectors, together with their front-end electronics, are located in areas where high radiation levels are expected.

Table 1: Radiation Levels in TOTEM Sub-detectors

Detectors Locations	**TID (kGy/year)**	**1-MeV eq. Fluence (cm^{-2} y^{-1})**
RP 147m Si Detectors	10	$> 1\times10^{13}$
RP 147m Motherboard	5	7.5×10^{12}
T1	15	1.5×10^{13}
T2	10	1.5×10^{15}

In this paper we present the design and the functionalities of the on-line TOTEM RADiation MONitoring (RADMON) system that aims to measure, in real-time during operation, the Total Ionising Dose (TID) and the 1-MeV equivalent particle fluence (Φ_{eq}) at various locations of the experiment.

Measurements of TID and Φ_{eq} are needed to evaluate the radiation-induced changes in the performance of the detectors, to survey the radiation damage on the front-end electronics and to verify the Monte Carlo simulations. Moreover this system can help to detect anomalous increases of radiation levels that may arise from accidental radiation burst such as beam losses or unstable beams. This set of information can finally be used to better plan the TOTEM operation scenario.

Totem Radiation Levels

According to the simulation studies performed for the RP stations at 147m [2], Table 1 summarizes the radiation levels expected for the Silicon Detectors and in the location where the RP front-end electronics (the Motherboard) sits. For the 220m stations a decrease of a factor 10 in the tabulated values is expected. The quoted simulation refers to a nominal LHC luminosity of 10^{34} $cm^{-2}s^{-1}$ assuming an LHC operation time of $1.5x10^7$sec/year.

The radiation levels in the T1 & T2 regions, given in Table 1, have been instead simulated in the context of the CMS experiment at nominal LHC luminosity [3].

HARDWARE AND SYSTEM LAYOUT

Integrated Sensor Carrier (ISC)

The basic unit of the RADMON system is the Integrated Sensor Carrier (ISC) that host radiation sensors connected to the readout electronics (located in the CMS underground service cavern -USC55-) via long signal

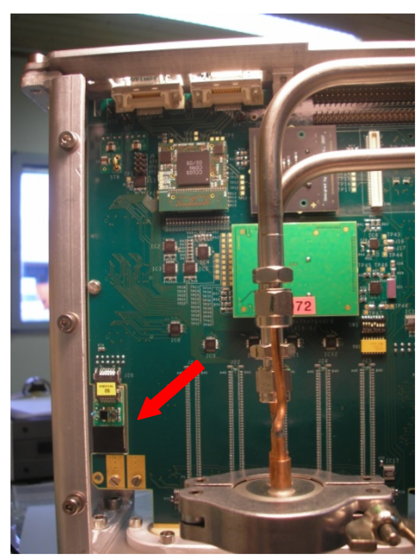

Figure 1: RADMON ISC installed in a RP motherboard.

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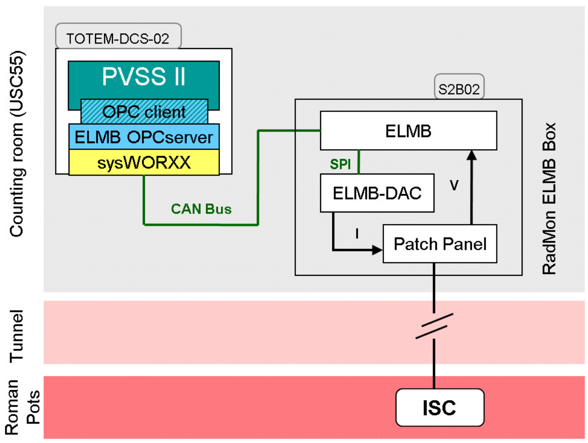

Figure 2: RADMON hardware overview diagram.

cables. The ISC Printed Circuit Board (PCB) used in TOTEM is configured with two RadFET (REM 250 and LAAS 1600) sensors for TID measurements, two *p-i-n* diodes (BPW34 and CMRP) to monitor the Φ_{eq}, and one temperature probe (NTC) [4]. The different sensor types provide the required sensitivity and dynamic range to the system for its operation over the experiment lifetime. The four radiation sensors and the NTC share a common Retour Line (RL) connection. This enables the electrical readout of a full ISC over 6-wires.

Each of the 24 RP Silicon Detectors is equipped with one RADMON ISC located on the RP Motherboard as shown in Fig. 1. Other 12 ISCs are distributed over the T1 and T2 telescopes. For T1, the 8 ISCs are hosted in dedicated PCBs mounted on the CSC planes; while T2 is equipped with 4 ISCs located on the front-end PCB that read the signals from the GEM chambers.

Readout Chain Overview

The TOTEM RADMON read-out is based on Embedded Local Monitor Boards (ELMBs) and ELMB-DACs. This approach, already adopted and tested by the ATLAS experiment [5], simplifies the integration of the RADMON sensors in the Detector Control System (DCS) and makes it compatible with the existent JCOP DCS structure agreed by all the LHC experiments.

As shown in the Hardware Overview Diagram (Fig. 2), the ELMB, communicates over the CAN bus with a PC of the DCS running the SCADA software (PVSS II). Each ELMB hosts 64 12-bit ADC channels (0-4.5 V) with a conversion frequency ranging from 2 to 100 Hz.

To power the RADMON sensors during the readout sequence, ELMB-DAC boards are connected to the Serial Protocol Interface (SPI) of the ELMB. The 16 channels, 12-bit DAC-module allows the ELMB to drive currents. In the RADMON configuration, two ELMB-DAC boards can be connected simultaneously and controlled by one ELMB.

The output current delivered by the DAC module ranges from 0 to 20 mA, while the maximum output voltage is set by the supply voltage and is limited to 30V due to power dissipation constraints of some DAC components. This maximum voltage drop allowed on DAC channels becomes therefore the main limiting factor in the ELMB-based RADMON readout. Nevertheless the 30V voltage span is sufficient to cover the TID and Φ_{eq} expected during TOTEM operation (see Table 1).

RadFETs and *p-i-n* diodes have to be readout with currents ranging between hundreds of μA and 1 mA. The ELMB-DAC feeds current to the sensors and the voltage drop that generates between its contacts is measured with the ELMB. Since the range of the ELMB ADC is up to 4.5V, differential voltage attenuators (1:10) are used. The attenuator circuits are hosted on a dedicated Patch Panel (PP) board.

The NTC temperature sensor mounted on each ISC is instead directly connected to the 2.5V reference voltage output on the ELMB, in series with a 1MΩ resistor located also on the PP board. The corresponding voltage is then read out via one available ADC channel.

Finally, to monitor the current flowing through each sensor being read out, in the PP board the common Return Line (RL) is connected to ground over a 100Ω resistor. The small voltage drop on this resistor, being proportional to the current flowing on the RL, is thus measured by one dedicated ADC channel.

During radiation exposure, the RADMON sensors must have the terminal shorted to ground. For this reason a series of switches (JFET transistors) are also installed on the PP board and are opened by applying a voltage from DAC before starting the readout procedure. In the "normal close" position the JFETs short the sensor terminals. Enabling the corresponding DAC channels, all the switch present on the same PP board simultaneously open enabling the readout of all ISCs connected to the PP board.

Integration in the DCS Infrastructure

The RADMON PP board is the key element that joins the current source (ELMB-DAC) with the voltage reader

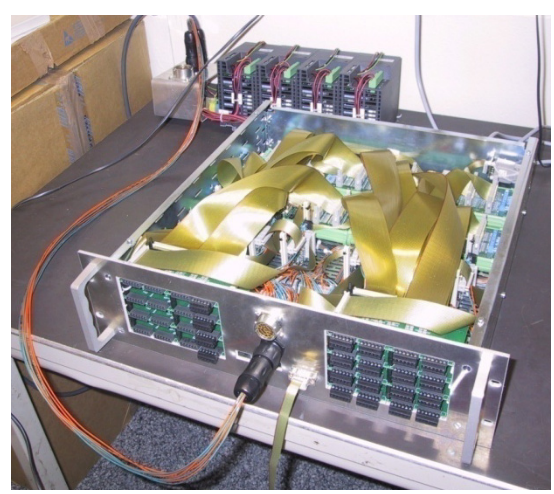

Figure 3: ELMB RADMON "Box" for the RP Silicon Detectors.

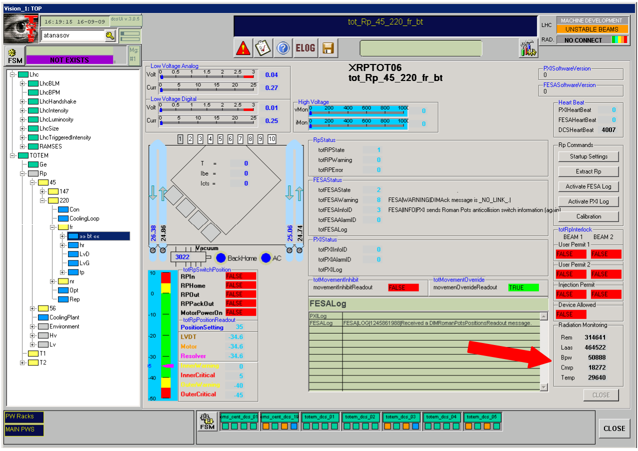

Figure 4: DCS Panel for the control of one RP Silicon Detector. The RADMON display is on the right corner.

(ELMB). Moreover, it hosts: voltage attenuators, various loads and the JFET switches. TOTEM designed its own PP board which couples to one ELMB and one ELMB-DAC and allows the readout of 3 ISCs. Since one ELMB can drive 2 DACs, a total of 4 ELMBs are needed for the readout of the RADMON sensors for the RP Silicon Detectors. Three more ELMBs are needed for the readout of the T1 & T2 sensors. All RADMON Hardware is assembled in a custom rack-mountable chassis: the ELMB RADMON "Box" [6]. Two of such boxes have been produced for TOTEM and are now installed in the rack dedicated to the DCS electronics in the USC55. The first box is dedicated to the RP Silicon Detectors (see Fig. 3), and the second one for the sensors in the T1&T2 Telescopes.

CONTROL SOFTWARE

The layout of the ISC (unique RL for all sensors on-board) imposes a sequential readout of the RADMON sensors connected to the same ELMB. A control library has been developed in PVSS to drive the switches and loop over the sensors with different currents and

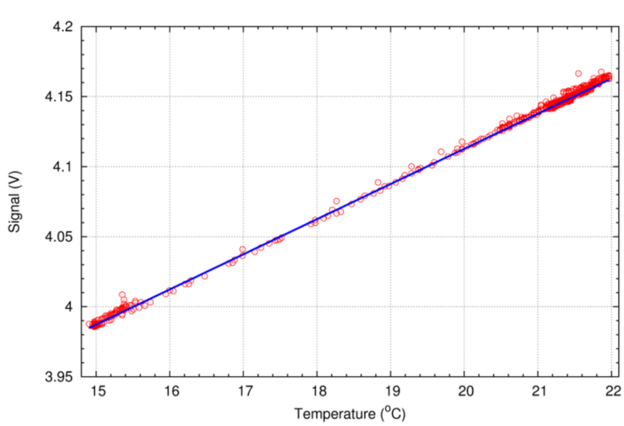

Figure 5: Temperature characteristic measured from one *p-i-n* diode (CMRP) installed in the LHC.

powering times. In order to match with the readout requirements (see details in Ref. [6]), the commands given to the hardware are sent over the CAN bus using SDO (Single Digital Objects) which allow sequential operations on demand.

The control script runs in background and updates the PVSS *DataPoints* which are displayed in the user interface as shown in Fig. 4. With the present version of the library the readout of one ELMB (e.g. 6 ISCs) is performed in about 1min.

SYSTEM PERFORMANCE

During the commissioning of the TOTEM RP Silicon Detectors installed in the LHC in 2009, it was possible to carry out a set of measurements which aimed to evaluate the performance of the system. Figure 5 shows, as example, the data for a CMRP *p-i-n* diode. The measured temperature coefficient (variation of the sensor's voltage as function of the temperature) of about 25mV/ºC match with the one measured for the same sensors with a laboratory test-bench [4].

Long term measurements were also performed in order to prove the stability and the repeatability of the voltage readout performed over the 300m long signal lines. This is the distance that separates the farthest TOTEM detectors (the RP Silicon Detectors that sits the LHC tunnel) to the ELMB system. In this readout conditions, the stability of the measured voltage has been determined to be better than 2mV. A similar result has been found by ATLAS testing the RADMON ELMB readout over much shorter signal lines [5].

Further performance measurements, to test the radiation response and the sensitivity of the whole TOTEM RADMON system, will be carried out in the initial period of LHC operation with proton beams.

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