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THE DETECTOR CONTROL SYSTEM FOR THE ELECTROMAGNETIC CALORIMETER OF THE CMS EXPERIMENT AT THE LHC

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ABSTRACT

The purpose and layout of the detector control system for the CMS electromagnetic calorimeter (ECAL) are presented. The latest results from system prototype tests in the 2002-2004 ECAL testbeam programme, the current status of the system development and plans for its production, installation and commissioning are briefly discussed.

INTRODUCTION

The Compact Muon Solenoid (CMS) experiment is one of the two large multi-purpose detectors at CERN's Large Hadron Collider (LHC). CMS is presently under construction and shall be ready for data taking in 2007. The design concept of the CMS experiment guarantees full exploitation of the physics potential offered by the LHC, which will provide proton-proton collisions at an unprecedented centre-of-mass energy of 14000 GeV. One of the most accurate, distinctive and important detector systems of the CMS experiment is the high precision Electromagnetic Calorimeter (ECAL), consisting of 75848 Lead-Tungstate crystals, which will provide accurate energy measurements of electrons and photons and thus be essential in the search for new physics, in particular for the Higgs boson. A detailed description of ECAL can be found in [1] and of its current construction status in [2].

DESCRIPTION OF THE ECAL DETECTOR CONTROL SYSTEM

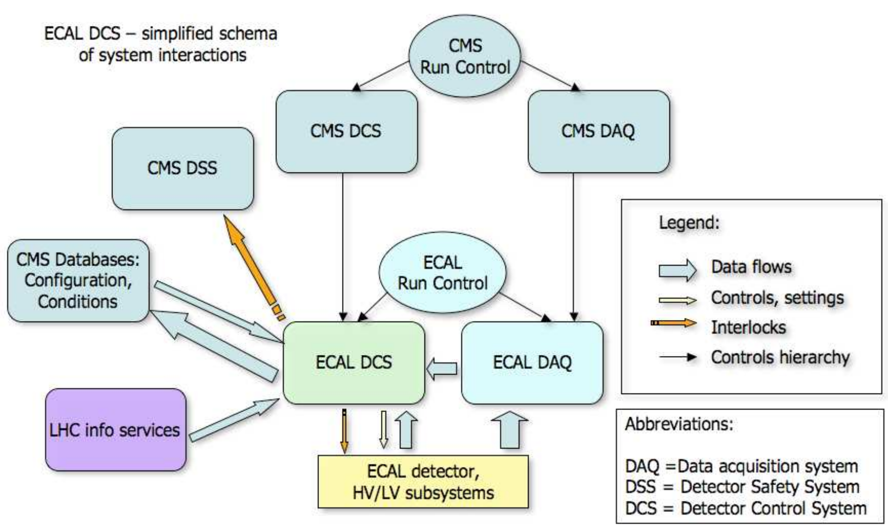

Figure 1: Connection of the ECAL DCS with other systems

DCS mission, functionality, challenges

The ECAL Detector Control System (DCS) should provide the monitoring of the detector conditions, of the on-detector electronics as well of all ECAL subsystems (High Voltage (HV) [3], Low Voltage (LV), cooling system, status of laser monitoring system). All these monitored data should be recorded and archived as part of the common CMS "conditions database". The DCS also has to provide early warnings about abnormal conditions, issue alarms, execute control actions and trigger hardwired interlocks to protect the detector and its electronics from severe damage. Regarding control functions, the DCS will switch on/off and ramp up/down the HV and LV, as well as set up their operational parameters. Overall CMS will have a hierarchical DCS tree. This tree is a software layer built on top of the experiment controls. Every detector integrates its controls in this tree-like structure. The CMS DCS Supervisor (Figure 1), which is connected to the CMS Run Control, will sit on top of the tree. In this way the ECAL DCS will be directly controlled by the CMS Supervisor. However, when ECAL runs separately (i.e. commissioning) its DCS is under control of an ECAL Run Control. The ECAL DCS also has connections to the CMS DSS (Detector Safety System).

The main challenges for the ECAL DCS are the large number of channels and parameters to monitor (~120'000 in total), high raw data rates (10 Mbytes/hour) and large data volumes to archive (1.5 Gbytes/month). Also, all of the DCS functionalities must be constantly available during the ECAL (CMS) run time and some functionality practically non-stop (24h/365d) during the whole CMS detector life time (more than ten years).

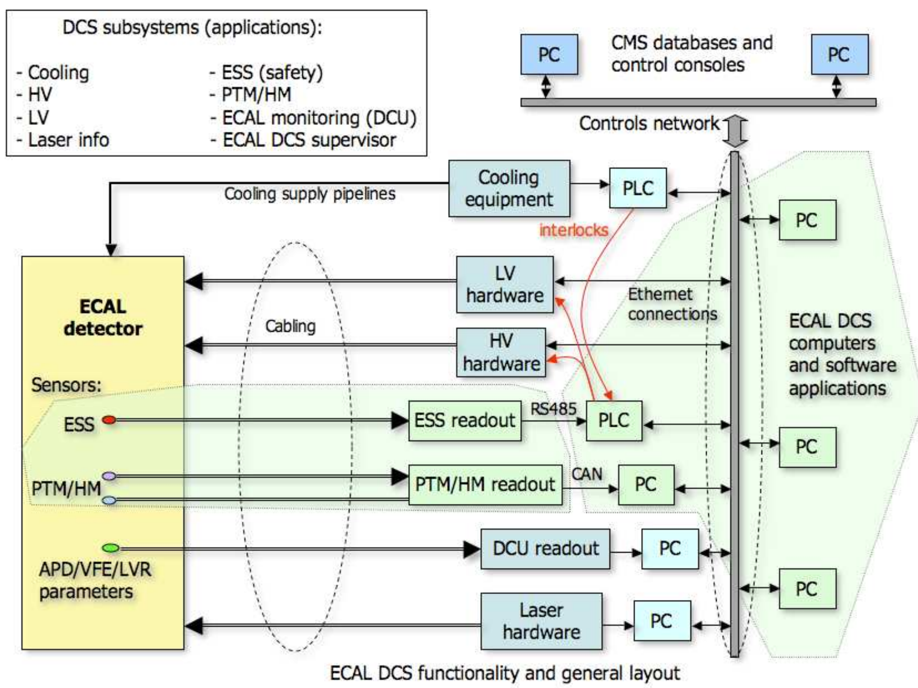

Figure 2: Layout and functionalities of the CMS ECAL detector control system. The acronyms are defined in the following sections.

Part of the DCS functionality (Figure 2) is implemented as software applications running on dedicated DCS computers, such as the HV, LV, cooling and laser monitoring systems. These applications communicate to "intelligent" hardware or embedded computers, typically using industry standard network or fieldbus connections. Specific detector parameters are collected by dedicated ASICs (Detector Control Units, DCUs) on the Very Front End (VFE) electronics and read out via the control rings of the data acquisition (DAQ) system, before being transferred to the DCS and the databases. These parameters are: temperatures near the photo-detectors (Avalanche Photo-Diodes (APDs), Vacuum Photo-Triodes (VPTs)) and on the VFE printed circuit boards, dark currents of the APDs and the voltage output values on the low voltage regulators (LVRs).

Some of the DCS functionalities are implemented via dedicated hardware (sensors, readout electronics, communications etc). These are the ECAL Safety System (ESS) and the ECAL Precision Temperature and Humidity Monitoring (PTM/HM). In these cases further specific challenges are added to those mentioned above: their sensors must be reliable and capable to operate accurately in high radiation (up to 10^{14} neutrons/cm^2 of total flux over the CMS life cycle) and magnetic fields (4 Tesla). These sensors are not foreseen to be replaceable and even accessible, so they must maintain their parameters stable during the whole period of the CMS operation. In addition, the readout electronics must be radiation tolerant, since it will be placed in the CMS cavern, and designed in such a way that the long cable paths (50-100m) will not cause a deterioration of the measurement precision. In the following these systems are described in more detail.

Precision temperature and humidity monitoring (PTM/HM)

Preliminary estimates in the CMS ECAL Technical Design Report (TDR) [1] showed that the ECAL VFE and FE electronics will dissipate approximately 2.9 W of thermal power per channel or 5 kW of thermal power per supermodule (SM). At the same time, the strong temperature dependence of the crystal light-yield implies the need for a thermal stability at 18°C to within 0.1°C over an inter-calibration period. This temperature stability is also required for a stable APD response. Such a thermal stability will be provided by a dedicated water cooling system and monitored by the Precision Temperature Monitoring (PTM). Because of the stringent requirements the relative measurement precision should be at least 0.01^0C. The temperature map is obtained with sensors mounted on both sides of the crystal volume, as well as with immersion temperature probes in the water-cooling pipes. In total there are 10 sensors per supermodule. NTC thermistors (100kΩ) from Betatherm were chosen as temperature sensors.

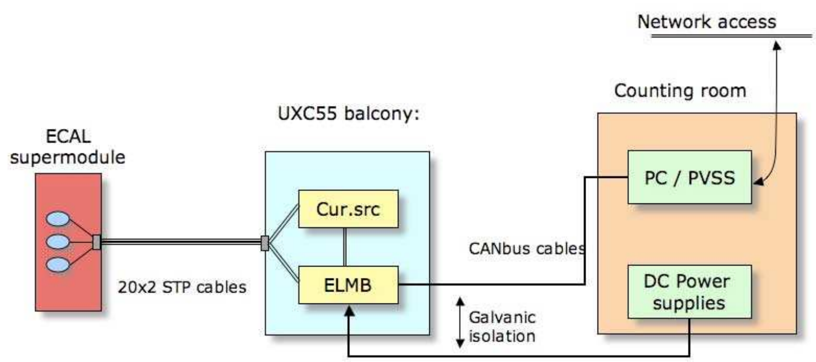

Figure 3: Layout of the PTM readout system

The PTM readout system is depicted in Figure 3. The sensor readout is performed using a four-wire scheme. On the balconies around the detector in the cavern (100m below surface) the readout stage is located, by using current sources for sensor excitation and the ATLAS ELMB (Embedded Local Monitor Board) [4] for multiplexing and digitization. This ELMB is a low-cost plug-on board used by LHC experiments for a range of different front-end control and monitoring tasks. The connection to a monitoring and data-recording PC is achieved via CAN-bus. The ELMB's, current sources and signal distributions will be integrated on specifically developed printed circuit boards.

An additional requirement for the ECAL DCS is the monitoring of the humidity level and the generation of software alarms in case of critical readings. There will be one humidity sensor per module, i.e. a total of about 200 sensors for the full ECAL. The UPS-600 humidity sensors, from Ohmic Instruments Co., will be used. These are rather cheap ceramic resistive-type sensors. The readout system is based on the same building blocks as the PTM readout.

ECAL safety system (ESS)

The purpose of the ESS is to monitor the temperature of the VFE and FE environment inside ECAL, to control the proper functioning of the cooling system and to automatically perform predefined safety actions and generate interlocks in case of any alarm situation. In short, it should fulfil the following requirements:

- Independent system for continuous monitoring and archiving of the VFE and FE environment temperature and the status of the water leakage detection system in the ECAL supermodules;
- Reliable hardwired interlocks with the HV and LV power supply systems;

- External interfaces with the cooling system for water temperature and water flow control;
- Prompt reaction on any external alarm or critical change of temperature inside the supermodules by issuing, in a proper time sequence, warnings and alarms to the HV and LV systems as well as to the Control Room (warnings and alarms via the controls software system);
- Maximum possible level of system robustness, safety and reliability.

The system has been designed as consisting of three interconnected layers: (a) the temperature conversion and channel multiplexing layer (*ESS FE Layer*); (b) the data acquisition, data processing and interlock generating layer, using a PLC system from Siemens (*ESS PLC Layer*); (c) the system monitoring and control layer (*ESS Application Layer*), with several external interfaces to the ECAL LV, HV and cooling systems. A functional layout of the system layers and its interconnections is presented in Figure 4. A detailed description of the ESS can be found in [5].

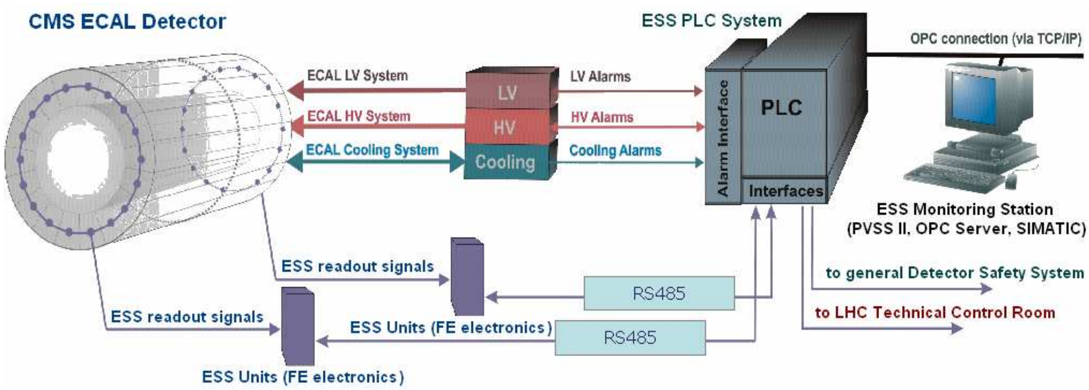

Figure 4: Layout of the ECAL safety system

Monitoring software

The CMS DCS software is based on the PVSSII SCADA package and the Joint Controls Project (JCOP) framework. The JCOP framework, implemented at CERN using PVSSII, provides tools to create control applications for hardware commonly used by the LHC experiments. This framework also includes a Finite State Machine (FSM) toolkit. The controls hierarchy and the partitioning rules are implemented in terms of this FSM toolkit. The ECAL FSM hierarchy consists of two trees, the detector (or control) tree and the hardware tree. Both trees connect to a common top node, where all the information is collected and commands for detector operation are available. The detector tree represents the structure of the detector partitions, i.e. the entire ECAL, barrel/endcap, supermodule. This FSM structure is implemented in the ECAL supervisory application (Figure 5). The smallest detector unit that can be controlled as a whole is the supermodule. At the supermodule level, each subsystem has its own hierarchy tree according to its internal structure, with a further split-up if appropriate, e.g. into modules and channels for the HV subsystem. In ECAL, all FSM commands concerning detector operation (including ramping the HV and LV) are propagated only in the detector tree. The second tree provides a view of the detector equipment, representing the hardware structure of the particular subsystems, e.g. crates, boards and channels for the various subsystems.

The states and commands in the hierarchy are designed in a concise way, thus only a few are available. Additional functionality for experts is provided either via dedicated expert panels or via the panels at the lowest level of the tree. Alarms from the lowest level devices are propagated up to the top of the tree.

TESTBEAM RESULTS

Several ECAL modules and supermodules have been extensively tested with electron and pion beams in the CERN H4 testbeam area. A detailed description of these tests, including the experimental setup and the performance of the cooling, HV and laser monitoring systems can be found in Ref. [6]. At this occasion various prototypes of the ECAL DCS subsystems have undergone extensive tests.

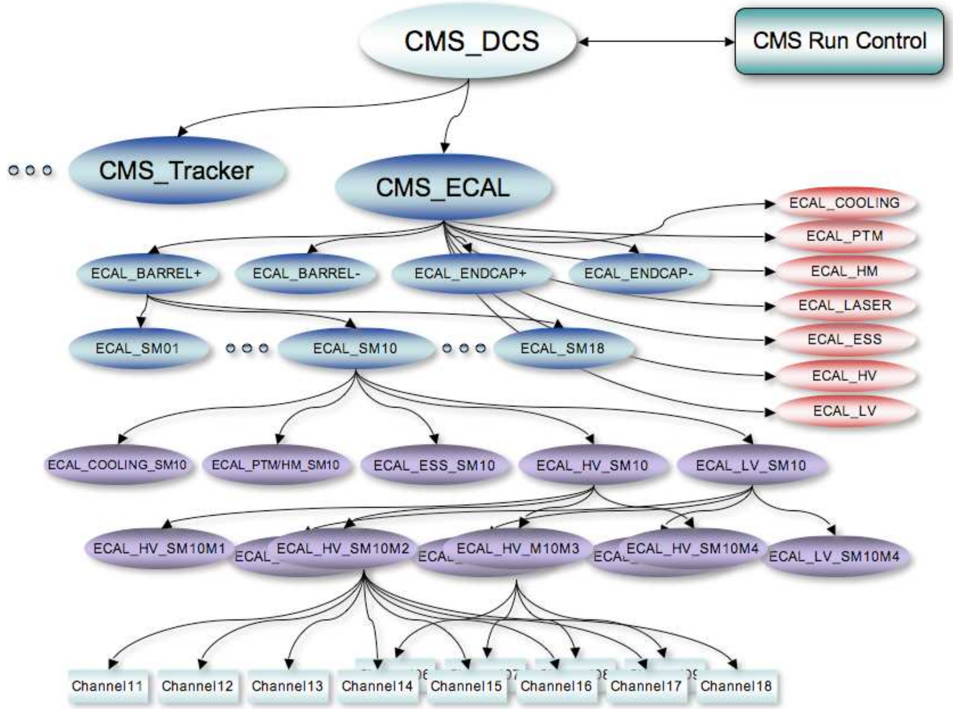

Figure 5: Structure of the FSM hierarchy tree of the CMS ECAL

In summer 2003 as well as in autumn 2004 a PTM/HM prototype setup was tested with the supermodules SM0, SM1 and SM10. Very satisfactory results have been obtained, with an achieved precision well within the requirements. Also the ESS showed good performance (cf. [5]) and generated automatically a ramping down of the HV and LV power supplies in a few occasions, triggered by problems with the water cooling system, thus protecting the hardware.

The testbeam in autumn 2004 had for the first time a complete DCS software system for one supermodule running. This DCS software was distributed among three PC's. The system consisted of the applications for the supervisory system, PTM/HM, ESS, HV, LV, cooling (a specific application for the system used in the testbeam area) and laser monitoring. In the case of the latter an application has been developed in order to read the laser status via a DIM interface. In order to control the supermodule hardware, the DCS software system had all necessary commands implemented. In addition, alarms were issued and important values were archived using the internal PVSS archiving system. Screenshots of some application panels are presented in Figure 6. The HV system used in the testbeam included an import of preset values for the voltage settings of all supermodule channels. These values were stored and labelled in CSV (comma-separated values)-files, and were used for testing different APD gains. Further features of the HV system included: (a) data archiving into the PVSS archives with either a manual and/or a time-dependent export to a CSV-file; (b) voltage value based alarms; (c) information on the status of the connection to the OPC server and between OPC server and crate; (d) the possibility to set common values for all channels for voltage, current, ramping speed and trip time. Several communication problems between the HV/LV crates (both by CAEN) and the HV/LV applications were experienced. They occurred due to problems in the CAEN firmware and are now understood and solved.

CURRENT SYSTEM DEVELOPMENT AND PLANS

Currently, the focus of the DCS activities is on mass production of sensors and electronics, their integration into ECAL as well as the development of the final controls software. In particular, for the PTM/HM and ESS systems currently the sensors and probes are produced, calibrated and installed in the ECAL supermodules. In addition, their final readout electronics boards are close to their final design or already in production. The readout boards will be installed during 2006 in the CMS experimental cavern. A challenge for the ECAL DCS will be to support three running installations at the same time. First, there is the ECAL electronics integration centre, where supermodules are equipped with the VFE and FE electronics and fully tested. After these tests, the supermodules are moved to the CERN H4 testbeam area for calibration with cosmic muons or electrons (in 2006). This H4 area is the second location to be supported. Finally, at the beginning of 2006, the so-called CMS cosmics challenge will take place as part of the CMS magnet test at Point 5 (the CMS construction site). There for the first time a complete slice of CMS including almost all subdetectors will be read out, using (close to) final software. This represents a major milestone for the CMS DCS, its individual applications as well as for the communication of the various levels in the controls hierarchy, starting from the top CMS DCS level.

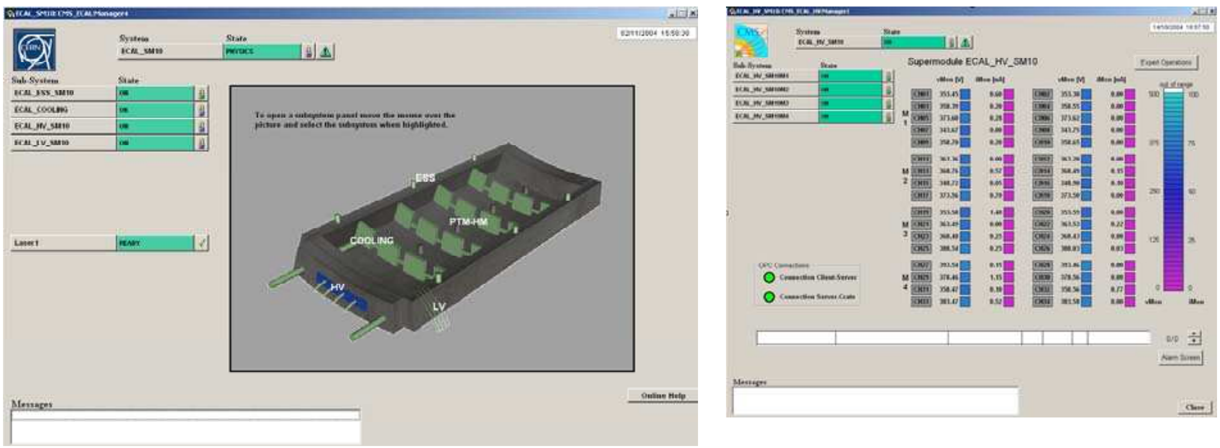

Figure 6: Screenshots of the supermodule panel of the supervisory (left) and the HV (right) application

Regarding the final ECAL DCS software development, practically all existing applications are currently updated or re-written, in order to account for the experience made so far, as well as to add further important features. These include the communication with the configuration and conditions databases (based on ORACLE) and the communication with the data acquisition system. The latter is needed in order to transfer overall system states as well as those data which are read out via the DAQ control links. With the current planning, the ECAL DCS will be ready for operation early in 2007.

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