Introduction

- CMS, the Tracker and LHC
  - Introduction
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  - Effects of radiation damage on sensors and electronics
- The Environmental systems for the CMS Tracker
  - Cooling and slow controls
  - Monitoring in a physicist’s world
- The “Fast” controls
  - Architecture and redundancy schemes
  - The CCU: Communications and Control Unit
  - The FEC: Front-End Controller
  - The DCU: Detector
- Putting it all together with SCADA
The CMS Detector

A Prototype of the Control System for the CMS Tracker Front-End
Piero Giorgio Verdini - C.E.R.N. and I.N.F.N. Pisa
The CMS Tracker

- In order to resolve the particles coming from proton-proton interactions at LHC and to measure their trajectory and thus their momentum, the CMS Tracker employs Silicon microstrip devices equipped with an ASIC that acts as preamplifier, shaper, analogue memory and multiplexer. While most planes measure the r-phi coordinate and the z coordinate is only bonded by the module granularity, some planes are equipped with double modules, capable of measuring the coordinate along the z axis.

- Radiation damage to the Silicon sensors has been studied, and the sensor geometry optimized to maximize the lifetime of the detector. In order to minimize the diffusion of carrier capture centers in the Silicon lattice, it has been chosen to operate at a nominal sensor temperature of -10 °C. This offers the additional benefit of vastly reducing the dark currents.

- In the design of the readout electronics the dual requirements of radiation hardness and ability to compensate for the effects of accrued damage both to itself and to the sensors by providing programmability of the relevant internal bias settings have resulted in highly versatile front-ends.
The CMS Tracker Radiation Environment

Charged hadron fluences (per cm²) in the CMS Tracker.

E>100 keV neutron fluences (per cm²) in the CMS Tracker.

Values correspond to the nominal integrated luminosity for ten years of operation.
The effects of radiation damage

Predicted evolution of the depletion voltage with time for the innermost Barrel layer, for two different initial bulk resistivities.

The dotted line corresponds to the nominal fluence for 10 years of operation. The solid line corresponds to a hypothetical “50% worse” scenario.

Predicted evolution of the leakage current for the most irradiated detectors.
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Monitoring Systems (1)

- The CMS Tracker must be kept and operated throughout its lifetime (expected to be about 10 LHC years) at -10 °C. The main reason for low temperature operation is the prevention of reverse annealing and thermal runaway phenomena. However, this entails the need to monitor and control the temperature and the relative humidity over the Tracker volume.
- The total power dissipated inside the Tracker when in full operation will be approximately 30 kW by the electronics and 50 kW on the Aluminum cables. The potential for disaster is obvious.
- There is a clear need for a temperature control system, to modify the Tracker power state (On/Standby/Off) as a consequence of temperature changes. In case of problems with the cooling system, the Tracker Control system must set the Tracker in the Off state by interlocking the power supplies according to a predefined sequence, in order to avoid damaging the Tracker.
Monitoring systems (2)

- However, this is not enough. Given the complex structure of the Tracker itself, a much more detailed measurement of the temperature distribution within the Tracker volume is needed to properly set the thresholds for the interlock intervention.
- The current plans foresee a control system that will act on the Tracker interlock on the basis of the information of a limited number of temperature and relative humidity sensors (~500 in total).
- In order to monitor the temperature distributions when the Tracker is running, a system with a very high granularity, composed of ~30,000 thermistors read by an ASIC directly assembled on the individual Tracker modules, is being designed.
- An additional monitoring system, with reduced granularity but aimed to be operable even when the front-end electronics are switched off, and based on the same thermistor and ASIC combination, is also under study. It is envisaged to interface additional humidity sensors to this system.
Thermistor tests

Initial results with the nominal calibration constants were not exceedingly promising:

the plot shows the difference between the reconstructed temperature and the value measured with a calibrated, precision 4-wire Pt100 sensor read-out by a dedicate PLC.

The relevant formulae used in converting from the ADC readout to temperature are Ohm’s Law and the NTC Resistance Temperature Characteristic Formula:

1. \( V = R(T) \times I_{bias} \)

2. \( R(T) = R(T0) \times e^{b \times (1/T - 1/T0)} \)

One can easily see that not only do the two values of temperature differ, but that their difference is not centered around zero, which suggests that the bias current \( I_{bias} \) is not set exactly to the nominal value.
More Thermistor tests

Fitting the R vs. T measurements improves the picture, but isn’t quite satisfactory yet over the [-25..0] °C range. Refitting only over the “region of interest” yields a very encouraging result, even with the expected degradation.
A physicist’s view of environmental monitoring
Relative Humidity Monitoring
Temperature Monitoring
Front-End Readout and Control Architecture

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Architecture for Redundancy

CCUM-1  CCUM-2  CCUM-3  CCUM-4

Primary

Secondary
CCU: Communications and Control Unit

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PMC FEC Prototype
DCU Specifications

- I²C standard protocol for the I/O interface (already used Tracker-wide);
- Single supply voltage $V_{DD} = +2.5$ V (already available for front-ends);
- 40 MHz LVDS clock (already available for front-ends);
- ADC specifications:
  - 8 channels (1 hard-wired to internal temperature sensor)
  - 12 bit resolution, no missing codes
  - conversion time < 1ms
  - input range: GND < $V_{in}$ < $V_{DD}$
- Temperature sensor specifications:
  - resolution: 0.5 °C in the operating temperature range of -50 to +50 °C
- 10 mA and 20 mA current sources
- Power Consumption < 50 mW
- Die Size: 2 mm x 2 mm
### SCADA: alarms and HVs

#### Table: Alarms

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<th>Srh</th>
<th>Proc</th>
<th>Time</th>
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<th>alert text</th>
<th>Direct</th>
<th>Value</th>
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</tr>
</tbody>
</table>

#### Diagram: SCADA Interface

- **Channel**: Channel 1, Module 1
- **Settings**:
  - Configuration: Normal
  - Time range: Current
  - Alert status: All
- **Monitoring**:
  - Vmon: 0
  - Imon: 0.001

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SCADA and FEC/CCU downloads

- A “Run Controller” has been implemented in the SCADA framework, to synchronize the actions of all the control and readout computers;
- The FEC supervisor program, which runs in a Java Virtual Machine on a Linux PC, has also been interfaced to an Oracle database for the retrieval of chip parameters from permanent storage and journaling/logging of the various settings for each run;

- Please see P. Gras’s talk on “Frontend electronics configuration system for CMS” for details.