PROCEEDINGS OF SCIENCE

Temperature studies of Pixel-Strip Detector Modules for the Upgrade of the CMS Outer Tracker using a Burn-In Setup

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The high-luminosity upgrade of the LHC will result in an increase of the typical instantaneous luminosity by a factor of about four. In order to cope with the new conditions, such as higher levels of radiation damage, larger pileup, and higher data load, the CMS detector will require substantial upgrades. As part of this upgrade program, the entire silicon tracking detector will be replaced. The basic elements of the new CMS Outer Tracker (OT) are p_T modules containing silicon sensors, which implement a mechanism to contribute to the Level-1 trigger system. The modules have to operate at low temperatures (-35°C) to mitigate the increase in the leakage current resulting from exposure to high radiation levels.

In addition to thorough quality control, a burn-in procedure is needed to ensure the functionality of each OT module at the operating temperature, both during long-term operation and after temperature cycles.

For this purpose, a burn-in system is being commissioned at DESY. This setup will perform thermal cycles from room temperature down to the operation temperature and conduct essential tests to ensure good performance of the modules. For the validation of this setup, the thermal contact for a Pixel-Strip (PS) module under power as well as there internal temperature distribution have been studied.

In this contribution, the burn-in setup as well as the temperature studies of a prototype of a PS module will be presented.

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1. The Outer Tracker of the CMS Phase-2 tracker

The High-Luminosity Large Hadron Collider (HL-LHC [1]) will reach instantaneous peak luminosities up to $7.5 \times 10^{34}\,\mathrm{cm}^2\mathrm{s}^{-1}$. This will allow us to collect integrated luminosties of the order of $300\,\mathrm{fb}^{-1}$ per year and up to $3000\,\mathrm{fb}^{-1}$ during the HL-LHC projected lifetime of ten years. The HL-LHC is expected to run at a centre-of-mass energy of 14 TeV and with a bunch spacing of 25 ns. To cope with this very challenging scenario, substantial upgrades will be made to the CMS detector [2]. These include increased radiation tolerance to handle elevated radiation levels (reaching up to $1.1 \times 10^{15}\,\mathrm{n}_{eq} \times \mathrm{cm}^{-2}$ in the Outer Tracker (OT)), finer detector granularity to mitigate occupancy issues resulting from increased pileup, and improved trigger capabilities to manage the anticipated higher rates (750 kHz). This upgrade is referred to as the CMS Phase-2 Upgrade.

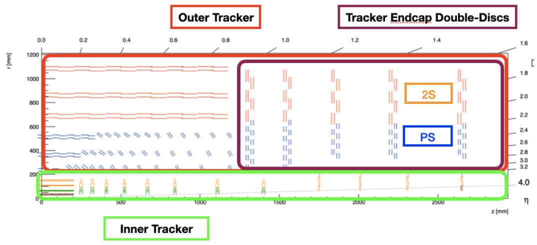
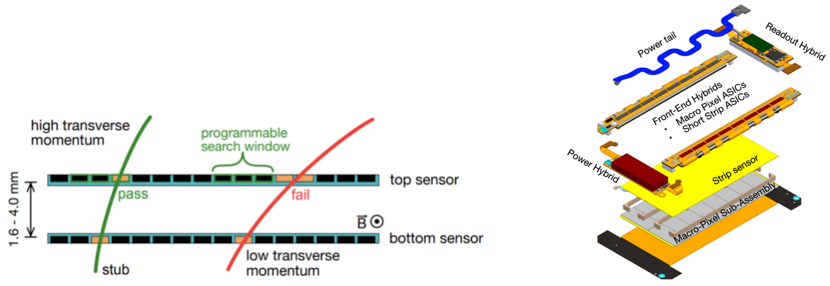


Figure 1: Sketch of one quarter of the Phase-2 CMS tracking system in r-z view [3].

The Outer Tracker is populated with on-board transverse momentum (p_T) modules, which provide inputs to the L1 trigger. The p_T module concept relies on a strong magnetic field and a stack of two closely spaced silicon sensors read out by common front-end electronics. Two versions of p_T modules have been realized: modules with two strip sensors (2S modules) and modules with a strip sensor and a macro-pixel sensor (PS modules). A longitudinal view of one quarter of the new detector layout is shown in Fig. 1. The red box shows the Outer Tracker where the blue and orange lines represent the PS and 2S modules, respectively. In addition, a maroon box is placed around the endcap region. The Outer Tracker consists of six barrel layers and five endcap double-discs per endcap. Modules located at a given radius are mounted alternatingly on the two sides of one disc, with overlap in ϕ, forming a hermetic ring. Consecutive rings along r are mounted on the two double discs, hence also achieving radial overlap.

1.1 PS modules

A schematic representation of the concept is shown in Fig. 2a. As charged particles traverse the module, they generate hits in both the top and bottom sensors of the stack, with the spatial displacement of these hits depending on the particle's transverse momentum. These hits are subsequently processed by the common front-end electronics. The hit from the bottom sensor (seed layer) is then correlated with the one from the top sensor (correlation layer) within a programmable search window. When these hits fall within this defined window, they are combined to create a stub (short track segment), facilitating the rejection of low transverse momentum particles, as illustrated by the green channels defining the accepted stubs, while particles with low p_T values are excluded from further consideration, as illustrated by the red-coloured track.



(a) p_T module concept **(b)** PS module

Figure 2: Illustration of the transverse momentum discrimination concept (a). Exploded view of a PS module (b) [3].

The PS module consists of a so-called bare module corresponding to a stack of two silicon sensors placed on a support plate and surrounded by dedicated hybrid electronic circuits. The sensor stack consists of a silicon strip sensor, shown in yellow in Fig. 2b, and a macro-pixel sensor, shown in grey. The sixteen Macro-Pixel ASICs (MPAs) that are bump-bonded to pixels on the macro-pixel sensor face the silicon strip sensor. The eight Short Strip ASICs (SSAs) are show in grey and red on each of the Front-End Hybrid (FEH). The module is complemented by one Readout Hybrid (ROH) and one Power Hybrid (POH). As far as data transmission and control is concerned, the ROH hosts the CERN low-power Gigabit Transceiver (lpGBT) ASIC in charge of controlling MPAs and SSAs, and packing data received from the FEH. The lpGBT is complemented by a Versatile Link Transceiver Plus (VTRx+) module used for the bidirectional optical data transmission between the module and the back-end system. Finally, to provide power to the front-end electronic components, the POH integrates two CERN bPOL chips used for DC-DC conversion and power distribution.

2. Burn-in test

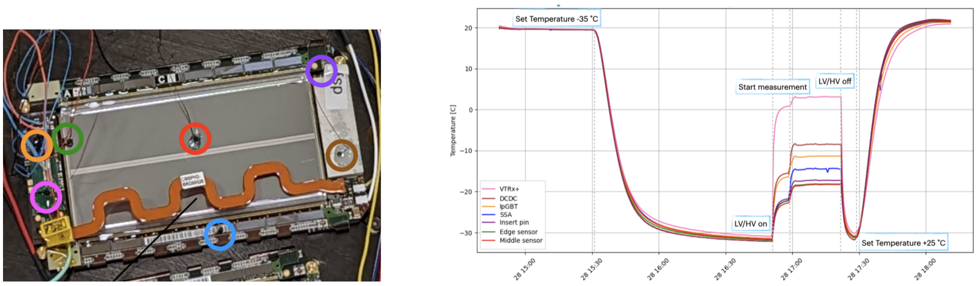
During the assembly of the modules, several tests must be performed to certify that the module is appropriate for integration. This procedure is known as module qualification, and the last test is an electrical burn-in of the assembled module while under power. This test is carried out aiming to ensure functionality at the operating temperature (-35 °C) in addition to at room temperature. Long-term operation must be ensured as well, since the lifetime of the CMS Tracker is expected to be at least 10 years. Finally, correct functionality of modules after warmup and cooldown cycles must be ensured. This setup performs thermal cycles from room temperature to operating temperature (5 or 6 cycles in the span of 24 hours). As part of each cycle, I-V measurements and noise measurements are performed.

2.1 System overview

The burn-in setup consists on a commercial refrigerator, acting as a passive cooling unit, that allows the system to have a controlled temperature and humidity conditions and provide a dark environment for the modules. Inside the refrigerator a carrier plate support is installed to place the modules inside (10 modules in parallel), as well as the temperature and dew point sensors. The cooling pipes connect the refrigerator with the chiller, which is used to perform the temperature cycles. The refrigerator is provided with a dry air supply to control the humidity inside, as well as a magnetic interlock to ensure that the unit is not opened during a measurement. The Controller Board, designed by FNAL, controls the magnetic interlock and the readout of the temperature and dew point sensors. In addition, the CAEN power supplies are installed in a rack and used to provide voltage to the modules. The readout system consists on an FC7 (FPGA-based circuit board) that performs the noise scans. All this is controlled with the OtSDAQ software developed by FNAL.

3. Temperature studies

During the commissioning of the modules several studies have been performed for better understanding the temperature distribution within the module components. For this purpose, 7 thermistors have been attached to a PS module assembled at DESY, in different positions aiming to check the thermal homogeneity through the module, the thermal contact, and the hot spots. The thermistor positions can be seen in Fig. 3a: on top of the optical link module (VTRx+), located in the Readout Hybrid (in pink); on top of the DCDC converter in the Power Hybrid (red); on the low-power Gigabit Transceiver (lpGBT), located in the Readout Hybrid (orange); on one of the Front-End Hybrids (blue); next to one of the insert pins (purple); in the edge of the the Strip sensor, next to temperature sensor in the hybrid (green); and in the middle of the Strip sensor (red).



(a) Thermistors glued in PS module

(b) Temperature measurement

Figure 3: PS module with 7 thermistors (a); plot of the temperature as a function of time for the thermistors (b).

Fig. 3b shows the temperature measured for each thermistor as a function of time. From the plot one can see that the setup takes around 1 hour to cool down and 30 minutes to warm up, and the difference between the set temperature with the achieved temperature is around 3 °C. For a powered module the highest temperature is reached in the VTRx. The sensors located in the lpGBT and the DCDC converter also reach high temperature when powered and configured. This is because of a poor thermal contact with the carrier plate. A big increase when starting a measurement is observed in the Front-end hybrid owing to a localized power dissipation during configuration and readout. The two thermistors placed in the silicon sensor (green and red) show that the Strip sensor is cooled effectively both in the edges and in the center.

4. Noise studies

Noise is a key measure of the quality and performance of each individual front-end channel and it is used to optimize the design and operation of the module. For measuring the noise in the

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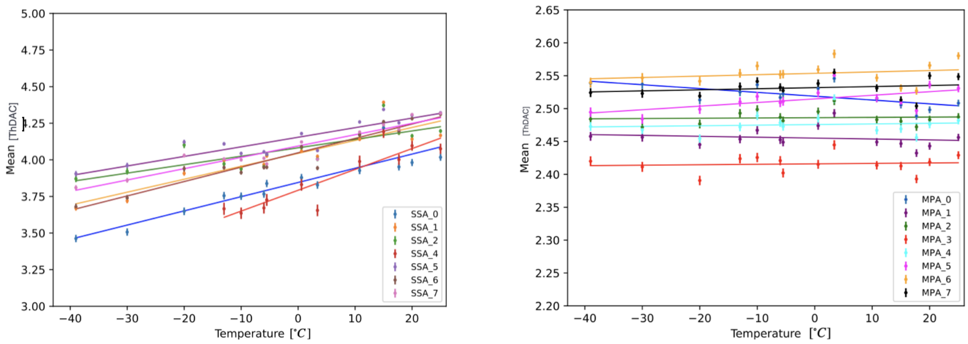
modules a so-called S-Curve (occupancy as a function of threshold) is performed, and for each channel the curve is fit using an error function:

$$f(x) = \frac{1}{2} erf(\frac{x-\mu}{\sqrt{2}\sigma}) \tag{1}$$

from where the pedestal (μ) and the front-end channel noise (σ) are extracted. The noise level targeted is around 4 ThDAC for strips, and between 2 and 3 ThDAC for macro-pixels. For this measurements the modules is biased at -300 V, with a dew point between -54°C and -58°C, and carrier plate temperatures ranging from 25 °C to -40°C.



(a) Short Strip ASICs (SSAs) **(b)** Macro-Pixel ASICs (MPAs)

Figure 4: Noise as a function of the temperature in the carrier plate for the SSAs (a) and the MPAs (b).

Fig. 4a shows the noise values for the different SSAs as a function as the temperature, while Fig. 4b shows the noise values for the MPAs. The noise decreases in the SSA with the temperature as expected, while in the MPA the noise remains constant, which is also expected.

5. Summary

The burn-in setup at DESY is usable but not yet fully automated. Temperature studies were performed showing good homogeneity with the power off and the expected behaviour with power on and performing a measurement. Noise measurements showed expected behaviour over a temperature range that includes the expected operating temperature.

References

[1] Z. Fernandez et al., *High-Luminosity Large Hadron Collider (HL-LHC): Technical design report*, 10.23731/CYRM-2020-0010

[2] CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST 3 (2008) S08004, 10.1088/1748-0221/3/08/S08004

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