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The CMS Silicon Strip Tracker

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Abstract

The CMS strip tracker is the first large scale tracker entirely based on silicon detector technology. It consists of 198 m^2 of detector sensitive area instrumenting the inner region of the experiment with a pseudo-rapidity coverage of $|\eta| < 2.5$. This instrument, together with a silicon pixel system, is expected to perform robust tracking and detailed vertex reconstruction while embedded in the LHC high radiation and high luminosity environment. The project is in a well advanced construction phase: the detector module production is completed, the integration of the single components into large sub-detector units is underway and the full tracker commissioning is about to start.

In this paper, after a description of the tracker layout, detector modules production overview and a summary of the integration procedures for the inner barrel part of the tracker will be reported.

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1. Introduction

The CMS silicon strip tracker [1] is a complex detector whose dimensions can be clarified by a few numbers: 21 m^3 of instrumented volume, 15 148 silicon strip modules, 9 316 352 analogue readout channels, $-10\,^\circ$C sensor operating temperature, radiation fluence up to 1.6×10^{14} 1 MeV equiv. neutrons/cm^2 for an expected lifetime of about 10 years at the LHC. The realization of the tracker is based on the availability of high technology single components and their assembly into large sub-detector units. The excellent performances of the tracker basic elements should remain unaffected once they are installed in the highly complex final detector structure.

The silicon strip sensors used are single sided "p$^+$ on n" type, with metal over-hang implemented to obtain high breakdown voltages and $\langle 1\,0\,0 \rangle$ crystal orientation to minimize the surface radiation effects [2–4]. The silicon detector front-end chips [5] are realized in 0.25 μm CMOS technology: the thin gate oxide together with special layout techniques ensure their radiation tolerance [6]. The assembly of the detector modules has been carried out using automatic machines [7] with a high mechanical precision and reproducibility. The module quality has been monitored by extensive functional tests, performed also at realistic final working temperatures, which have characterized each single strip of the whole production set and spotted out problematic components.

2. The CMS Silicon Strip Tracker layout

The CMS Silicon Strip Tracker instruments the radial range, around the LHC interaction point, between 22 and 110 cm. The central region ($|z| < 110$ cm)[2] is split into an Inner Barrel (TIB), made of four detector layers, and an Outer Barrel (TOB), made of six detector layers. The TIB is shorter than the TOB, and is complemented by three Inner Disks per side (TID) each one made of three rings. The forward and backward regions $120\,\text{cm} < |z| < 280\,\text{cm}$ are covered by nine End-Cap (TEC) disks per side, each one made of seven rings. The two innermost layers of both TIB

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[2] z is the coordinate along the LHC beam axis.

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and TOB as well as rings number one, two and five of TEC and one and two of TID are realized with double-sided detector modules. A complete description of the Silicon Tracker layout can be found elsewhere [8]. The whole tracker region is embedded into the CMS 4 Tesla solenoidal magnetic field. Charged particle transverse momentum resolution of about 1.5% for central muon of 100 GeV/c is expected [9].

3. Detector modules

The detector module design has been kept as simple as possible to ease their mass production and integration. The sensor is glued on a carbon fibre support frame which also holds the front-end electronics hybrid. The readout chip pitch (44 μm) is matched to the sensor pitch via a glass substrate fanout circuit (pitch adapter). The hybrid circuit, which houses the front-end chips and ancillary electronics, is realized using kapton multilayer technology. Fig. 1 shows a single sided TIB detector module.

Detectors of the TIB, TID, and of the four innermost rings of the TEC have strip lengths of approximately 12 cm and pitches between 80 and 120 μm. These detectors are made of a single sensor 320 μm thick. In the outer part of the tracker (TOB and three outermost TEC rings) strip length and pitch are increased by about a factor of two with respect to the inner ones. In order to compensate for the noise increase due to the higher inter-strip capacitance (longer strips), a silicon thickness of 500 μm has been chosen for these larger detectors.

All Silicon Strip Sensors are of single sided type. Double sided detectors are realized simply gluing back to back two independent single sided modules (“R-Phi” and “Stereo”). To obtain a coarser but adequate resolution on the longitudinal coordinate the “Stereo” module has the sensor tilted of 100 mrad with respect to the “R-Phi” one. The “Stereo” sensor and electronics are identical to the “R-Phi” ones, the only difference being in the support mechanics and pitch adapters.

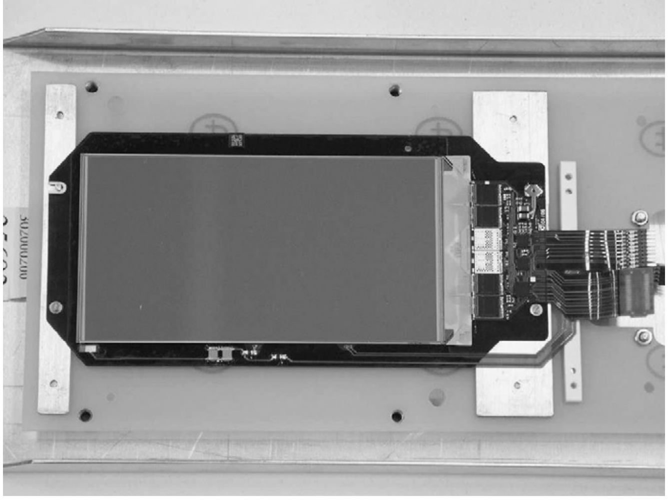
Fig. 1. A TIB single sided module fixed on its transportation cradle.

4. Tracker electronics

The signals coming from each strip are processed by front-end readout chips (APV25 [5]) mounted on a multilayer kapton hybrid circuit. The APV25 is a 128 channel chip built in radiation hard 0.25 μm CMOS technology. Each channel consists of a preamplifier coupled to a shaping amplifier which produces a 50 ns CR–RC pulse shape. The shaper output of each channel is sampled at 40 MHz into a 192 cell deep pipeline. The pipeline depth allows a programmable level 1 trigger latency of up to 4 μs, with 32 locations reserved for buffering events awaiting readout. Each pipeline channel is read out by an analogue circuitry which can operate in one of two modes. In peak mode only one sample per channel is read (timed to be at the peak of the analogue pulse shape). In deconvolution mode [10] three samples are sequentially read and the output is a weighted sum of all three. The deconvolution operation results in a re-shaping of the analogue pulse shape to one that peaks at 25 ns and returns rapidly to the baseline. This operating mode is particularly important for correct bunch crossing identification during the high luminosity running phase of the LHC. A unity gain inverter, which also reduces the common mode noise contribution, is included between the preamp and shaper and it can be switched in or out.

On receiving a positive level 1 trigger decision the APV25 sends out serially, at 20 MHz rate, the 128 analogue signals together with information about the pipeline address and the chip error status; signals coming from two APV25 are interlaced together on a differential line by a Multiplexer chip which is located on the hybrid circuit too. The electrical signals are then converted to optical ones in dedicated Analog-Opto Hybrids (AOH) few centimeters away from the detector, and transmitted to the counting room by means of multi-mode optical fibres [11], where they are digitized [12]. The LHC 40 MHz clock, which drives the APV25 sampling, is synchronized at the single module level by means of a PLL (phase lock loop) chip. In this way a particle signal can be correctly sampled at its maximum regardless of the module position with respect to the LHC interaction point and of the different clock line delays. The entire readout chain is able to sustain a level 1 trigger rate of about 100 KHz. The functional parameters of the devices located inside the tracker can be downloaded from outside using the I^2C standard communication protocol.

5. Module production and test

The different module components (silicon sensor, support frame, front-end hybrid with pitch adapter and HV bias circuit) are glued together using automatic assembly machines. After gluing, the modules are shipped to the bonding and test centres where they are micro bonded using industrial wire bonding machines. The quality of this operation is monitored measuring, on a sampling base, the bond pull strength.