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Construction of the CMS silicon strip tracker

Guido H. Dirkes[a,b,*], on behalf of the CMS Tracker Collaboration

[a] *Institut für Experimentelle Kernphysik, Universität Karlsruhe (TH), Germany*
[b] *CERN, Geneva, Switzerland*

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Abstract

In the last year the CMS experiment has constructed and integrated the largest ever build full Silicon Strip Tracker. The CMS Tracker collaboration set up a unique scheme of quality control to ensure the necessary high quality of all of the 15,148 modules and their super structures. The applied scheme of quality control revealed several problems, which escaped the initial R&D phase, ranging from corrosion effects on the silicon, capton and via problems on the front end hybrids up to aging conductive glue connections. An overview of the construction and qualification experience is given, discussing the major steps which result in the unique experimental device, which the CMS Tracker is currently commissioning.

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1. Layout of the CMS Tracker

The main goal of the Tracker is to guarantee an excellent track reconstruction with a good p_T resolution by providing a fine granularity and a global coverage of in average 24 minimum bias events per bunch crossing at design luminosity of $10^{34}\,cm^{-2}\,s^{-1}$. In total 10 barrel layers of silicon strip detectors are built around the interaction point giving an impact parameter resolution of $10-20\,\mu m$. The innermost layers are provided by the Tracker Inner Barrel (TIB) detector forming two double module layers[1] and two single module layers at radii ranging from 20 to 55 cm. Outside the Tracker Outer Barrel detector covers up to a radius of 110 cm, which consists itself of two double and four single module layers. In the forward direction the shorter TIB is closed by three Tracker Inner Disks (TID). Finally the barrel parts are extended by nine disks of the Tracker End-Caps (TEC) covering a forward tracking up to $\eta = 2.5$.

The basic units of the Tracker are the 15,148 modules, which assemble silicon sensors, pitch adapter and front end electronics on a carbon fiber/graphite frame (compare Fig. 1) coming in 29 different types. The strips pitch on the silicon sensors increases from inside to the outer parts, reflecting the fact that the occupancy drops with increasing radius. Inner layer modules are composed of a single 320 μm thick sensor, while the outer layers (starting from layer/ring five) are composed of two 500 μm thick sensors, compensating the additional length/noise by more signal.

All subdetectors consist of superstructures, which are split into a plus and minus end. Each of the four TIB layers is built of two half shells, the three TID disks are superstructures by themselves, TOB uses 688 rods[2] in its two barrels and the two TECs consist of 144 petals[3] each.

The Tracker silicon will be kept at $-10\,^{\circ}C$ in a dry Nitrogen environment to subdue electrical dark currents and to freeze out reverse annealing of the irradiated silicon sensors. The readout is analogue, interconnected by an optical fiber system. The readout chip (APV) is designed and produced in 0.25 μm CMOS technology. Detailed

*CERN, Geneva, Switzerland
E-mail address: dirkes@cern.ch

[1]Double module: two single sided sensor module mounted back to back with a stereo angle of 100 mrad.

[2]Rods are ladder like superstructures holding six or 12 modules.

[3]Petals are wedge shaped superstructures holding up to 28 modules.

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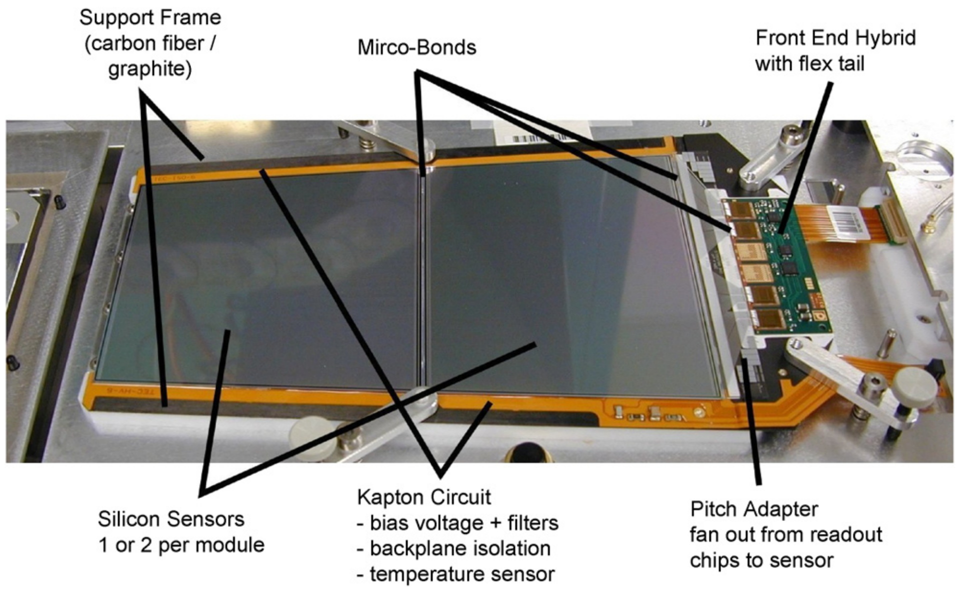

Fig. 1. A CMS Tracker module consists of six main parts: one or two silicon sensors mounted on a Kapton circuity resting on a carbon fiber/graphite frame. The readout chips on the front end hybrid are connected via a pitch adapter by micro-bonds to the strips.

descriptions are found in Refs. [1,2]. A thorough description of the design strategies to ensure a radiation hard Tracker is given in Refs. [3].

2. Construction of the Tracker

Building 15,148 modules means, that the Tracker had to launch an industrial like production reflecting the different abilities of the participating institutes. A direct consequence is a largely scattered production calling for an unique quality assurance and control program, which revealed weak spots in each component used.

For the silicon sensor testing several papers give a precise overview of the measurements done and actions taken [4,5]. Mainly the problems found are due to too high flat band voltages, too high bulk resistances or too low inter strip resistances [7] and a tendency of some sensors to suffer from corrosion [6]. Furthermore scratches cause a significant number of devices to be rejected, where everything from bad handling to misadjusted machines in the production lines were found to be the reason for the scratches.

For the front end hybrids several options were tested, before the final layout was settled. The first approach with thick film on ceramics suffered mainly from the connection of the Kapton cable to the hybrid and from the fact, that control chips came as non-packaged dies. Intermediate designs based on a flex rigid PCB gave electrically good results, especially as we also changed to encapsulated control chips. Unfortunately the substrates were not flat enough and therefore not adequate for automatic production. Finally a four layer Kapton substrate laminated onto ceramic was chosen. Nevertheless even the final layout needed an additional iteration in design, as we found its vias to be instable under thermal stress, which is critical as several vias are without redundancy due to space limitations on the hybrids. Together with the producer we identified a cleaning step during the processing to be responsible for the problem: it was etching away also part of the glue between the Kapton layers. Therefore we introduced an additional Kapton/glue layer, reduced the thickness of the glue layers and increased the via diameter from 100 to 120 μm (compare Fig. 2). Nevertheless about 2500 hybrids were affected.

For the Kapton cables separating the carbon fiber frame from the sensors backplane and distributing the bias voltage we faced a problem of poor solder pad metallisation, where the upper part of the Ni-layer was brittle, which caused bad contacts especially after thermal cycles. We reproduced the Kapton cables and improved the quality control by adding 20 thermal shock cycles ranging from −40 to +85 °C with final retest.

Shipping of modules between the US production centers and CERN revealed another weak spot. Vibration of the silicon sensors during the transport weakened the pull strength of the mirco-bonds or even ripped them off completely. Therefore, the stiffness of the modules were increased by adding ceramic stiffeners for TEC modules or by applying a Sylgard glue strip from below in case of TOB modules.

Mirco-bonds were also affected, when we found burn marks at the edge of the n^+ protection ring below the connection of the bias return between two sensors. Here we found bad bonding parameter causing a bond loop, which was less than 100 μm above the n^+ ring structures. This caused sparks between the bond wire and the n^+ ring, as the latter is on the bias voltage of up to 500 V.