Quality inspection aspects of hybrid prototypes for the CMS Outer Tracker upgrade at HL-LHC

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Abstract:
In the HL-LHC scenario, the CMS experiment will need to operate at up to 200 interactions per 25 ns beam crossing time and with up to 4000 fb⁻¹ of integrated luminosity. To achieve the physics goals the experiment needs to improve the tracking resolution and the ability to selectively trigger on specific physics events. The CMS Tracker upgrade requires designing a new detector to cope with HL-LHC scenario. The new Outer Tracker (OT) is based on two silicon modules (strip-strip and pixel-stripe). Each module type has a few types of high-density interconnect hybrid circuits which house the front-end and auxiliary electronics. Two sides of the sensors are wire-bonded to the front-end hybrids. For both module types, folded flexible circuits are used to enable wire-bonded connection from the sensor assemblies with various spacing. The poster introduces the technological choices for modules and hybrids and presents the quality inspection aspects of the first hybrid prototypes.

Motivation and requirements

- High Luminosity LHC upgrade:
  - Increase of pile-up to ~200
  - Peak Luminosity ~7.5x10³⁶ cm⁻² s⁻¹
  - Integrated luminosity of ~4000 fb⁻¹

CMS Tracker upgrade key features:
- High granularity to keep channels occupancy low
- Radiation hardness (Runway & total ionizing dose)
  - Innermost layers: 2.3 x 10¹⁰ cm⁻² & 1.2 Grad
  - Outer layers: 10¹⁰ cm⁻² & 100 Grad
- Low material budget for improving tracking performance in high pile-up scenario
- Contributes to trigger level 1 by using transverse momentum of tracks to reduce data volume

Tracker input to the Level 1 trigger

- Modular design allows for easy reconfiguration of different trigger scenarios
- Use of advanced electronics for improved trigger efficiency

Front-End Hybrids topologies

- 25 Module
  - 25-FE-Left
  - 25-FE-Right

- PS Module
  - PS-FE-Left
  - PS-FE-Right

- Silicon strip and macro-pixel sensors
  - 2 x 960 strips, 100 µm pitch
  - 32 x 960 macro-pixels, 1.5 mm x 100 µm
  - 45 cm² active area

- Two service hybrids
  - PS-PDH Power Hybrid based on BOPOL chips
  - PS-RDH Readout Hybrid based on the pGBT and the VTRx

Outer Tracker module designs

- Two parallel silicon strip sensors
  - 2 x 1016 strips, 90 µm pitch
  - 90 cm² active area

- Left and Right side 25-FEH front-end hybrids
  - Based on bump bonded CBC1.3m chips and CIMChips

- One 25-SEH service hybrid containing
  - DCC0.6 converters based on BOPOL chips
  - Optical readout based on the pGBT and the VTRx

- Silicon strip and macro-pixel sensors
  - 2 x 960 strips, 100 µm pitch
  - 32 x 960 macro-pixels, 1.5 mm x 100 µm
  - 45 cm² active area

- Left and Right side PS-FEH front-end hybrids
  - Based on bump bonded SSM7 and CIMChips, wire bonded to MaPSAA array

- Two service hybrids
  - PS-PDH Power Hybrid based on BOPOL chips
  - PS-RDH Readout Hybrid based on the pGBT and the VTRx

Hybrid visual quality control, mechanical measurement and thermal cycling tests

- Visual inspection targets using stereo microscopes with coaxial, ring and external lighting and consists in inspecting and evaluating:
  - Components soldering and placement quality
  - Alignment and adhesive quality of hybrids element as flex, stiffener and connectors
  - Evaluation cleanliness of circuit (incl. interior of connectors)
  - Bond pad quality (where applicable)

- Main reasons to include the visual inspection in the hybrid quality control plan:
  - The wire bondability is critical and if it fails, the module fails. The bondability depends on many, mostly mechanical and chemical issues, some of which can be detected visually and via measurement
  - The precision of the mechanical properties of these hybrids for module assembly has a much higher standard than in the past detector
  - The reliability (mechanical and electrical) is critical given the harsh environment and long lifetime required of these hybrids, thus electrical functionality is not sufficient

The acceptance of the hybrids requires passing electrical and functional tests that are carried out with a crate based on a multiplexing platform [Ref.: M. Kovacs, et al., PoS TWEPP2019 (2020) 062]

In addition, characterization and stress testing of a sample of 25-FEH prototypes are performed at nominal operating temperature of ~35°C
- Including thermal cycling between ~35°C and ~20°C
- Ensuring reliable performance at edge condition of what can be expected during the CMS Tracker operation/lifetime
- Test cycle:
  - Look for short and open loops
  - Inject stubs using noise and check that the check that the correct stubs are measured by the CBCAs (correlation plots)
  - Pipeline address test
  - Offset register test
  - Pipeline/Buffer RAM test
- Visual inspections performed before and after temperature cycling:
  - No indication of mechanical damage to flex hybrid from ~20 thermal cycles between 20°C and ~30°C

- Thanks to the visual inspection, electrical control and characterization made on the hybrid prototypes valuable inputs were provided to the contractors to finalize the design of the hybrids assessing aspects related to mechanical assembly and interconnection properties.
- The Hybrid project is overall on track and entering in the pre-production phase of the CMS Outer Tracker Upgrade project.