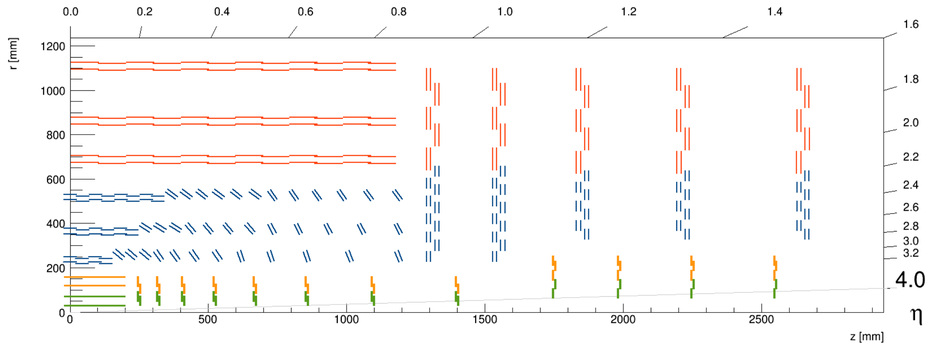
Visual Inspection of the CMS Phase-2 Outer Tracker hybrid electronics

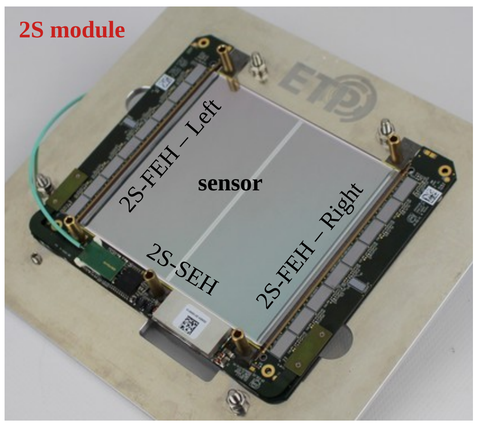
Krisztina Márton* on behalf of the CMS Tracker Group

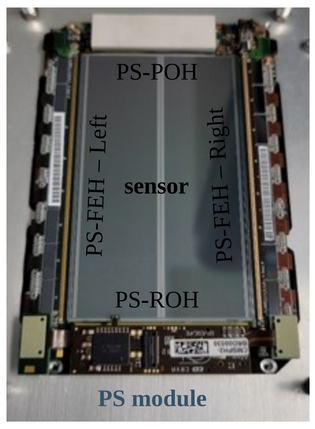
2022 November LHCC meeting, 29 November 2022, CERN

The Phase-2 Upgrade of the CMS Outer Tracker for the HL-LHC

- As preparation for the High Luminosity Large Hadron Collider (HL-LHC), CMS is going to replace its whole silicon tracking system during the next long shutdown (LS3).
- The upgraded Phase-2 Tracker detector is designed to have better radiation hardness, increased forward acceptance, higher granularity, and compatibility with higher data rates, to provide robust tracking performance through its whole lifetime (~10 years).
- The Outer Tracker (OT) will also contribute to the L1 trigger by identifying hit pairs (stubs) that carry position and directional information about tracks above a given p_T threshold.
- The Outer Tracker is built up from two types of modules: the 2S and the PS. They consist of two, closely spaced silicon sensors (strip - strip or macro-pixel - strip), which are wire-bonded to the front-end hybrid circuits. Each module is powered, controlled, and read out by its own service electronics.



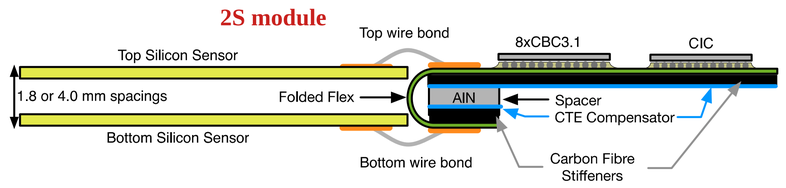


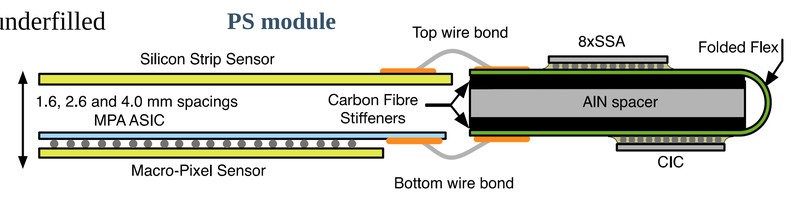


Hybrid electronics for the new OT modules

Front-end hybrids (FEH)

- 4-layer, high density flexible circuits, laminated to carbon-fibre stiffener
- folded back to allow wire-bonding to the top and bottom side sensors
- Al-N spacers to adjust the thickness of the hybrid to the module spacing
- CTE compensators to eliminate the bow (only needed for the 2S)
- custom ASIC readout chips, flip-chip soldered directly to the hybrid and underfilled
  - 8 CBC3 chips for the 2S and 8 SSA chips for the PS + 1 CIC for both





Service electronics

- responsible for powering, controlling, and data-transfer
- 2S module → everything is provided by the Service Hybrid (SEH)
- PS module → tasks are divided between the Power Hybrid (POH) and Read-out Hybrid (ROH)

Quality control of the OT hybrid electronics

- thorough testing procedure before module assembly
- QC in several steps at manufacturer and at collaborating institutes

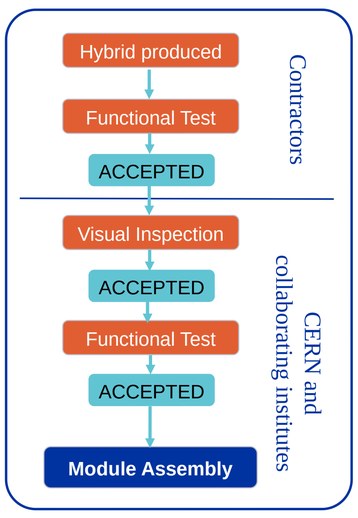
At the hybrids' manufacturer:

- optical inspection of the circuit + X-ray photos of the ASICs for soldering quality
- passive thermal cycling (from -35°C to +50°C)
- functional tests at -35°C and +40°C

At CMS institutes:

- visual inspection of the hybrids at CERN and at Wigner RCP (Budapest, Hungary)
- functional tests at CERN, Catania, and Genova

+ on sample bases: long term reliability tests at CERN and RWTH Aachen



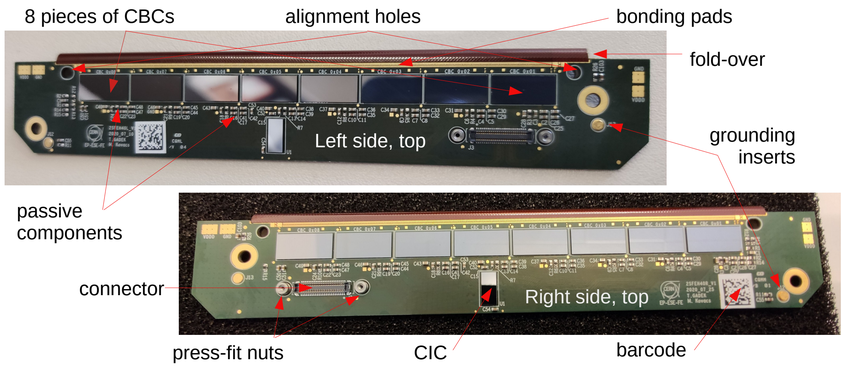
Infrastructure and environmental requirememts

Environmental control during hybrid handling to avoid damages and contamination:

- ISO7 clean room with laminar flow
- temperature and humidity control (20°C < T < 23°C, 35% < RH < 65%)
- protection against electro-static discharge: ESD surfaces, tools, and clothing

VI test facilities meeting these requirements have been set up at CERN and at Wigner RCP and equipped with:

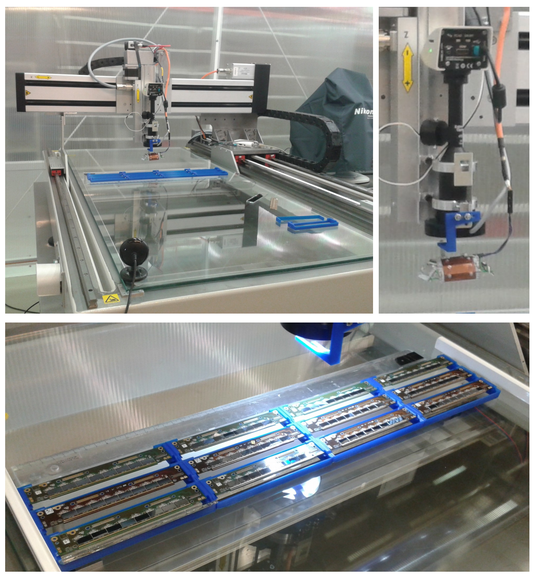
- stereo-microscopes with different lighting options, camera, and measurement software
- tools for measurements (digital scale, calipers, special jigs, etc)
- equipment for packaging



Importance of the Visual Inspection (VI)

VI will be performed on all of the circuits during production.

- reliability of the hybrids is crucial due to the long operation time and extreme working conditions of the OT detector
  - → functional test can give information only on the current status
  - → VI can foresee long-term mechanical or electronical problems
- well-controlled fabrication and precise dimensions are necessary for module assembly
- quality and strength of the wire-bonds between the sensor and the FEHs depend on the properties of the bonding pads



Visual Inspection checklists

During the prototyping period, hybrids were produced and inspected from each type in several batches.

- main problems were identified, feedback to the manufacturer helped to improve the design and the fabrication process
- method of the testing procedure and checklists were developed

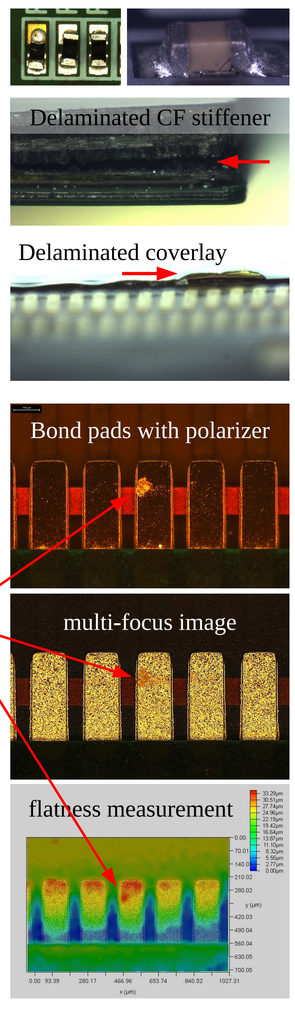
To be investigated with stereo-microscopes:

- soldering quality and component correctness
- cleanliness of alignment holes
- alignment and adhesive aspect of the layers
- fold-over accuracy
- cleanliness and damages of the circuit
- local and global flatness of the hybrid
- underfill quality around the ASICs
- placement of the grounding inserts
- conformal coating where needed
- bond pad quality (color, cleanliness, flatness, no damages)

Measurements (on sample base):

- weight
- dimensional measurements → length, width, thickness
- stretch of the circuit
- bonding pads row flatness

→ results of the VI and photos about the found problems are saved and uploaded to the database through a web application [3]



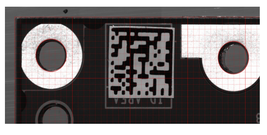
Large area optical scanner at Wigner RCP

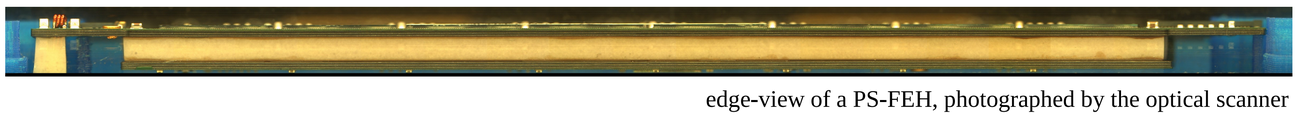
- 50cm x 90cm useful table size → place for ~100 hybrids
- 5 megapixel color camera, 5 micron resolution
- size of images: 12.2mm x 9.8mm
- LabView software controls the stepper motor and the camera
- different lighting settings are possible
- holders for each hybrid types were designed
  - → top and bottom sides of the hybrids in separate scans
  - → photos about the long edges with the use of a mirror

Measurements with the optical scanner

Hybrids that will be visually inspected at Wigner, are going to be photographed with the large area optical scanner.

1. photos are taken by the scanner with overlaps defined by the motor step size
2. picture of the whole hybrid is built up from the individual photos with an alignment matching the overlapping areas
3. hybrid type is identified based on "alignment dots" listed in a JSON file
4. calculate the rotation and position of the hybrid to define its own coordinate system
5. read and decode the barcode/datamatrix
6. type-specific processing, e.g. find and fit alignment holes
7. find and fit the bond pads
   - coordinate of the top left corner of each bond pad is measured and transformed to the hybrid's coordinate system
   - distance of neighboring pads, linearity and total length of the pad rows (stretch) can be measured for every hybrid
8. thickness and global flatness measurements on photos taken from the mirror about the edges





edge-view of a PS-FEH, photographed by the optical scanner

This poster

SCAN ME

References

1) The Phase-2 Upgrade of the CMS Tracker – Technical Design Report, CERN-LHCC- 2017-009, CMS-TDR-014
2) "Quality Inspection Aspects of Hybrid Prototypes for the CMS Outer Tracker Upgrade at HL-LHC", A. La Rosa et al., proceedings of TIPP 2021, arXiv:2112.14147
3) "Software Tools for Hybrid Quality Control for the CMS Phase-2 Outer Tracker Upgrade", talk by I. M. Dominguez at TWEPP 2022, CMS-CR-2022-193

This work is supported by NKFIH OTKA K124850.

* krisztina.marton@cern.ch, Wigner Research Centre for Physics (Budapest, Hungary)