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Front-end hybrid designs for the CMS Phase-2 Upgrade towards the production phase

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Sixteen thousand 2S front-end hybrids and twelve thousand PS front-end hybrids will be produced for the CMS Tracker Phase-2 Upgrade. The hybrids consist of flip-chips, passives and mechanical components mounted on a flexible substrate, laminated onto carbon-fibre stiffeners with thermal expansion compensators. In the prototyping phase, several critical issues have been solved to manufacture these complex circuits. Final designs are now reaching readiness for the full-scale production. High-density circuit design practices, lessons learned during the prototyping phase and different improvements for manufacturability will be presented in this contribution.

Summary (500 words)

Ten front-end hybrid variants for the Compact Muon Solenoid (CMS) Tracker Phase-2 Upgrade for the High-Luminosity Large Hadron Collider (HL-LHC) are currently under development. The upgraded Tracker is based on two main types of modules, the strip-strip (2S) and the pixel-strip (PS). The 2S modules contain two parallel strip sensors of (10 × 10) cm2 and two front-end hybrids connected to a service hybrid. The PS modules contain a strip sensor and a macro-pixel sensor of (5 × 10) cm2 and two front-end hybrids connected to a power and a readout hybrid. These modules require state of the art High Density Interconnect (HDI) front-end hybrids assembled with fine pitch flip-chip front-end ASICs, connectors and passives.

All front-end hybrids are using a four-layer build-up topology with micro-vias with copper filled laser drills ranging from 25-50 µm diameter, captured by a pad of 110 µm. These vias are used as via-in-pad to fan-out the 250 µm and 270 µm pitch ASICs on the 2S and PS front-end hybrids respectively. The minimal track width and spacing is 45 µm in the critical routing areas.

The 2S-FEH has more than 6500 interconnections implemented with more than 18000 µvias on 33 cm2, while the PS-FEH has more than 5000 interconnections implemented with 15000 µvias on 24 cm2. The extremely small feature sizes and very high routing density used in these circuits, represent the leading edge of the Printed Circuit Board (PCB) manufacturing technology.

The hybrids are reinforced with carbon fibre laminates with very high stiffness and thermal conductivity. These laminates, due to the cyanate-esther resin system, are highly sensitive to moisture and their Thermal Expansion Coefficient (CTE) is very different from the Hybrids'CTE. Because of this, the usage of carbon fibre stiffeners is bringing additional complexity into the design, handling and manufacturing of these circuits.

The materials used for the circuit fabrication and assembly processes need to be radiation tolerant and of minimum mass to fulfil the tight material requirements of the CMS Tracker. These constraints further challenge the Hybrid manufacturers.

In order to enable and simplify testing of these circuits, the designs implement features as connectors with test-grade mating parts, test points, alignment holes etc. Therefore, the test system has been designed in parallel with the hybrids, so both sides could be adapted appropriately.

The assembled modules from these circuits have been mechanically and functionally validated. Beam tests and functional tests demonstrated the correct operation and compatibility of these hybrids.

In the first part of the contribution, the PS and 2S module baseline designs and the constraints imposed to the hybrids will be introduced. After the introduction, the circuit designs will be presented with emphasis on HDI design techniques, improvements for manufacturability and reliability along with features related to testing. The difficulties related to the usage of the carbon fibre stiffeners along with the adopted processing solutions will be presented. Finally, the modifications and adjustments introduced for the production scale designs will be explained.

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