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# Hybrid designs and kick-off production experience for the CMS Phase-2 Upgrade

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The CMS Tracker Phase-2 Upgrade requires the production of new sensor modules to cope with the requirements of the HL-LHC. The two main building blocks of the Outer Tracker are the Strip-Strip (2S) and Pixel-Strip (PS) modules. All-together 47520 hybrid circuits will be produced to construct 8000 2S and 5880 PS modules. The circuit designs for the mass production were fine tuned and the kick-off batches were manufactured. The presentation will focus on lessons learned from the prototyping stage, design optimization details for the mass production, test results and yield from the kick-off batches.

## Summary (500 words)

Two main module types were designed and prototyped for the Compact Muon Solenoid (CMS) Tracker Phase-2 Upgrade. The 2S modules are constructed from two co-planar strip sensors of (10 × 10) cm2, two front-end hybrids and a service hybrid. The PS modules are more complex, they consist of a strip and a macro pixelated-strip sensor of (5 × 10) cm2 assembled into a module with two front-end hybrids, a readout hybrid and a power hybrid. The PS readout hybrid ensures the communication with the back-end while the PS power hybrid hosts the DC-DC power converters and powers the electronics. In the 2S service hybrid these two functions are combined in the same circuit. The front-end hybrids are hosting the front-end readout ASICs and concentrator ASICs on both module types.

All circuits are based on a flexible substrate reinforced with carbon-fibre or FR4 stiffeners in the case of the PS power hybrid. The hybrids are using advanced High Density Interconnect (HDI) features such as micro-vias with copper filled laser drills ranging from 25-50 µm diameter, via capture pads of 110 µm diameter and track width and spacing of 45 µm in the critical routing areas. Flip-chip ASICs are bonded to the circuits without additional redistribution layers, therefore via-in-pad technology is used to fan out the 250 µm and 270 µm pitch bump arrays. In order to increase the reliability of the hybrids, high reliability design practices were used, such as staggered vias, teardrops and crosshatched metal structures.

The hybrids were prototyped extensively before launching their production. Various, mostly minor issues were discovered during this phase. In response to the discovered problems, design changes were implemented to improve the performance and the yield of the circuits for the production phase. Due to the high production quantities, even minor changes can reduce the cost of the hybrids significantly.

The 2S and PS front-end hybrids were fitted with noise reduction features and a new alignment design that improves the precision and the yield of the carbon fibre stiffener lamination process. The PS power hybrid and 2S service hybrid designs were modified to achieve lower noise injected into the sensor modules. In order to reduce the risk involved in the modifications, two versions were designed from each circuit, a split-plane version and a regular version. Simulations and system level analysis were made to compare the expected performance of the different designs. The PS readout hybrid was fitted with a light shield to reduce light emissions from the optical transceiver unit.

The presentation will introduce the different hybrid types, the challenges resolved during the prototyping phase and the utilized design techniques. The modifications carried-out on the different hybrid types and the reasons why they were required will be presented. The simulation results will be compared with measured performance for the 2S Service hybrid and PS power hybrid designs. The effectiveness of the modifications

such as the achieved noise reduction and yield increase will be presented alongside with the general yield numbers from the kick-off hybrid production.

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