# Hybrids Acceptance Tools for the CMS Phase Two Tracker Upgrade

*Topical Workshop on Electronics for Particle Physics – Sep 2021*


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More than 50,000 hybrids will be manufactured for the Phase Two Upgrade of the Outer Tracker of CMS.

There are in total **five types of hybrids**, that will be combined to form two different modules, the 2-Strip (2S) module and the Pixel-Strip (PS) module.

To support the manufacturing of these hybrids, a complete test system has been developed.

- More information on the hybrids is available on dedicated talks:
  - **Front-end hybrid designs for the CMS Phase-2 Upgrade towards the production phase**  
    - Mark Istvan Kovacs  
  - **Power, Readout and Service Hybrids for the CMS Phase-2 Upgrade**  
    - Angelos Zografos
Quality control plan for the hybrids production

Hybrid produced

Passive Thermal Cycling

Cold Functional Test

Visual Inspection

Functional Test during Thermal Cycling

Long Term Thermal Cycling

Module Assembly

First screening

ACCEPTED

ACCEPTED

ACCEPTED

ACCEPTED

Second screening

During production only a fraction of the hybrids are tested

Validation of batch status

CERN

Contractors

Collaborating institutes

+35°C to -35°C (x5)

At -35°C

Reliability testing
Requirements for the test system:

- High throughput.
- Scalable system.
- Common for all hybrid types.

Structure of the test system:

- Multiplexing test system
  - Testing multiple hybrids during one test run.
- Base: multiplexing ‘backplane’ designed to fit in a standardized crate (IEC 60297-3-101 standard).
- Four plug-in cards can be connected to the backplane.
  - Power and data lines are multiplexed to one card at a time.
  - Hybrid-specific plug-in cards (‘test cards’).
Structure of the test system:

- Three backplanes can be assembled into one standardized crate, being able to host 12 test cards.
- The planned setup consists of three of these multiplexing crates, which allows for 36 hybrids to be tested per run.
- The multiplexing crate is connected to:
  - A µTCA FC7 FPGA to act as the backend and interface with the hybrid.
  - The PC running the tests, which controls the FC7 and test card features.
The backplanes in detail

- The backplanes are responsible for multiplexing 50 × LVDS, 1 × USB and 8 × LVCMOS signals between the test cards containing the hybrids under test and a computer and FC7 as well as distributing power (3V3, M3V3, Test_Voltage).

- Use of both FMC connectors in the FC7: L8 and L12.

- Signal bandwidth up to 2 GHz for the LVDS lines.
The backplanes in detail

- Level 1 multiplexers
- Card select and card present logic
- Backplane interconnection connectors
- USB and power connectors
- Reverse polarity protection
- Buffers, only enabled when backplane is selected
- Plug-in card slots
- Power good logic
- Address selection DIP switch
- Level 2 and 3 multiplexers
Test cards for the Pixel Strip Module

- PS Front-End Hybrid (PS-FEH) Test Card.
- PS Read-Out Hybrid (PS-ROH) Test Card.
- PS Power Hybrid (PS-POH) Test Card.

Test cards for the 2 Strip Module

- 2S Front-End Hybrid (2S-FEH) Test Card
  *(Designed at Bristol University).*
  
- 2S Service Hybrid (2S-SEH) Test Card
  *(Designed at RWTH Aachen University).*
2S-FEH Test Card

2S-FEH Tested parameters

- Digital I/O lines of ASICs.
  - I2C lines, CLK & Reset lines, FCMD lines, CIC and CBC OUT lines.
- CBC analog input lines.
- Tested to find opens/shorts.
- Hybrid performance at different voltages, current consumption and temperature during operation.

2S-SEH Test Card

- More details on the test system and test card for the Service Hybrid of the 2S Module can be found on this poster:
  Test system for the Service Hybrid of the 2S Module for the CMS Phase-2 Outer Tracker Upgrade
  Alexander Josef Pauls (RWTH Aachen University)
Test system hardware: test cards

Test cards for the Pixel Strip Module

- PS Front-End Hybrid (PS-FEH) Test Card.
- PS Read-Out Hybrid (PS-ROH) Test Card.
- PS Power Hybrid (PS-POH) Test Card.

Test cards for the 2 Strip Module

- 2S Front-End Hybrid (2S-FEH) Test Card
  *(Designed at Bristol University).*
- 2S Service Hybrid (2S-SEH) Test Card
  *(Designed at RWTH Aachen University).*

PS-FEH Test Card

**Tested parameters**
- Digital I/O lines of ASICs.
  - I2C lines, CLK & Reset lines, FCMD lines, **CIC IN and OUT lines, SSA OUT lines**.
- SSA analog input lines.
  - Tested to find opens/shorts.
- Hybrid performance at different voltages, voltage measurements at different probe points and current consumption during operation, temperatures.

The testing of the CIC IN and SSA OUT lines poses a problem:
To solve the incomplete data path problem, a test pattern is included in the design of the PS-FEH, which paired with a custom spring-loaded socket (POGO) allows access to the lines. Custom made POGO socket.
Test cards for the PS Module: PS-FEH

**PS-FEH Test Card**

- Pusher element forced by pivot lever
- Bottom pusher plate with spring washers
- Plastic hybrid pusher insert with inverted profile
- Hybrid POGO test socket
- Backplane connector

**Flex cable to connect the hybrid to the test card, with test-grade connectors. Different for right/left side.**
PS-FEH Test Card. Assembly

Steps to assemble a hybrid in the PS-FEH test card
PS-ROH Test Card.

Tested parameters
- Input and output lines of IpGBT.
  - CIC OUT, FCMD lines, I2C lines, CLK & Reset lines, IpGBT OUT.
- IpGBT functionality.
  - I2C masters, ADC.
- Hybrid performance at different voltages, voltage level at different probe points, current consumption and temperatures during operation.

Optical link testing
Two FC7s are needed to test the PS-ROH.
- One will test the electrical signals that go between the IpGBT and the front-end hybrids.
- The second one will test the optical links that go from the IpGBT (to the VTRx+) to the backend.

The VTRx+ will be a part of the test system.
Test cards for the PS Module: PS-POH

**Test Parameters**

- **Output voltage under current load for all outputs:**
  - No load → 120% nominal load
  - 6-12V input
  - 1mV accuracy for the measurement

- **Efficiency**
  - Min. load → 120% nominal load
  - 6-12V input
  - 1pp accuracy

- **Output Ripple**
  - Min. load → 120% nominal load
  - Stability check

- **Temperature**
  - Ambient
  - PCB
  - Cooling pad (underneath hybrid)
  - DUT → PTAT signal from bpol12

- **Setup time**
  - Power sequencing validation
  - 10us resolution

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**PS Power Hybrid with (left) and without (right) shield.**

**PS Power Hybrid test card functional diagram**
Test cards for the PS Module: PS-POH

V1 of the PS-POH Test Card.

CP2130 – USB to SPI bridge

PSPOH assembly on the test card.

μCU

24/09/2021
- Each hybrid type is tested using specific software and firmware.
  - Test procedure.
  - uTCA FC7 firmware.
  - Test card driver to control the test card functionalities.

- Test system is **transparent** to the user.
- The USB to SPI chip in the test cards has an identifying string that contains the **hybrid type** and the serial number of the card.
- The GUI & Test Manager selects the test procedures and FPGA firmware for each hybrid, based on the identifying string of the test card.
  - Different hybrid types can be tested in the same crate.
- The graphical tool presents the hybrid status to the user and uploads the test results to the CMS Database.

- The Graphical User Interface allows for the test system to be run by anyone.
- No need for experts travelling to the testing site.
- Increases the versatility of the test system.
The Graphical Tool running a test on three crates.
- Multiplexing test system that allows 12 hybrids per crate.
- 5 different test cards – one per hybrid type.
  - The test cards share some functionality between all of them:
    - Antenna circuitry for the analog channels testing in the FEHs.
    - USB to SPI bridge with test card identification.
    - Translation blocks.
- Single tool to manage the test run and bypass the complexity of the system.
- The test system has already been used to test around 380 hybrids during the prototyping phase, and the test cards and backplane designs have been verified.
- The production of the final version of the test system is ongoing, in preparation for the production testing of the hybrids.

<table>
<thead>
<tr>
<th>Hybrid type</th>
<th>Number of tested hybrids</th>
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<tbody>
<tr>
<td>2S-FEH</td>
<td>161</td>
</tr>
<tr>
<td>2S-SEH</td>
<td>28</td>
</tr>
<tr>
<td>PS-FEH</td>
<td>114</td>
</tr>
<tr>
<td>PS-ROH</td>
<td>59</td>
</tr>
<tr>
<td>PS-POH</td>
<td>19</td>
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Total n of hybrids tested with the system.
Thank you for you attention.

Any questions, suggestions?