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The PS Front-End Hybrid High Voltage Filter Test System for the CMS Phase 2 Outer Tracker

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Abstract

As part of the CMS Phase 2 Outer Tracker upgrade, a test card has been developed to test the sensor high voltage bias filters present in the Front End Hybrids (FEH) of Pixel-Strip (PS) modules. The test card can test up to four hybrids at the same time. The test system measures voltage, current and resistance from each hybrid over time. A software test procedure was written to control the card and to perform data acquisition.

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ABSTRACT: As part of the CMS Phase 2 Outer Tracker upgrade, a test card has been developed to test the sensor high voltage bias filters present in the Front End Hybrids (FEH) of Pixel-Strip (PS) modules. The test card can test up to four hybrids at the same time. The test system measures voltage, current and resistance from each hybrid over time. A software test procedure was written to control the card and to perform data acquisition.

KEYWORDS: Hybrid circuit; Flexible circuit; High voltage measurement; Current measurement; Resistor measurement.

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1. Introduction

The CMS detector, including its tracking systems, will be upgraded in time for the High Luminosity phase of the LHC (HL-LHC). The Phase 2 Outer Tracker [1] will comprise two types of modules: 2S (Strip-Strip) modules which are instrumented with a pair of silicon strip sensors, and PS (Pixel-Strip) modules where one of the two sensors is pixelated. These modules must be fully tested and characterized before the assembly. Figure 1 shows the PS module.

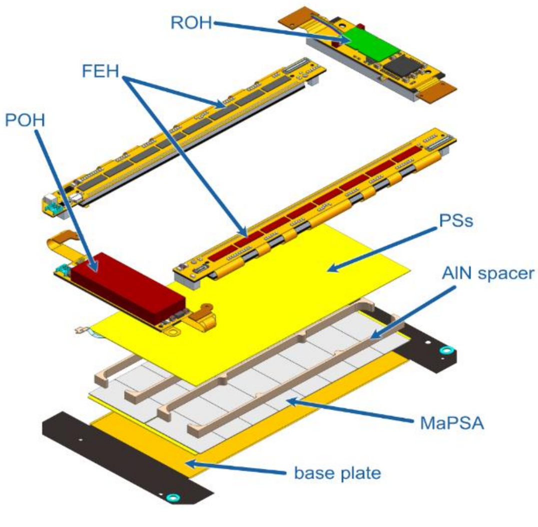

Figure 1: Diagram of PS module including Front End hybrid (FEH), Power hybrid (POH), Readout hybrid (ROH) and strip sensor (PSs).

The silicon sensor of the PS module needs to be biased at -800 V during operation. To achieve this, a high voltage (HV) bias filter is present on the right-hand front-end hybrid (FEH), referred to as the PS-FEH-R [2] and is the top-most FEH in Figure 1. This filter needs to be tested before module assembly to ensure that it works properly. There are three properties to be tested: continuity up to 1 kV, filter series resistance and capacitor leakage current. The filter is shown on Figure 2.

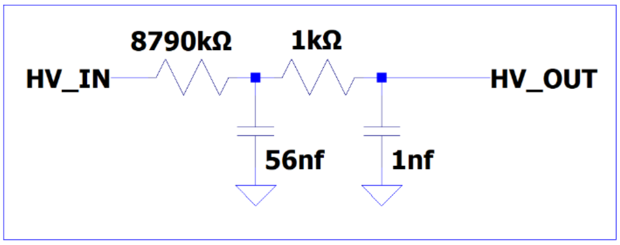

Figure 2: PS-FEH-R high voltage filter with HV input on the left and HV output on the right.

The circuits are tested in a climatic chamber at a temperature of -40 °C to simulate nominal operating conditions and the temperature is monitored by the test card using an integrated temperature sensor. The test card can perform the tests on up to four hybrids as shown on Figure 3.

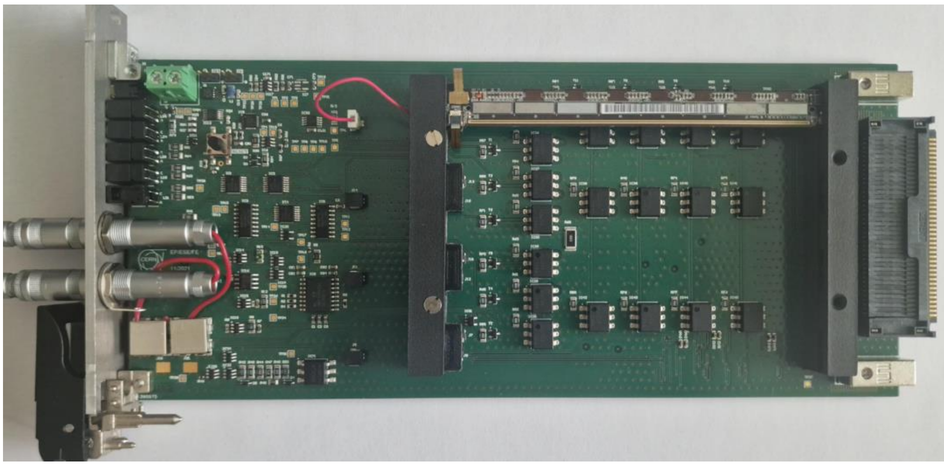

Figure 3: PS-FEH-R-HV test card with HV LEMO connectors on the left side, there is one hybrid placed on the test card, the switches are placed below the hybrids.

2. High voltage routing

The high voltage is routed to the hybrids through the test cards. A single HV power supply from ISEG is being used to power a crate containing 12 test cards at once. This crate can multiplex the measurements and so reduce the number of cooling cycles. To decrease the cabling complexity, we are using a daisy-chained design for HV with LEMO connectors.

For safety reasons, the high voltage traces are routed on inner layers of the PCB and exposed pads are shielded with a metallic screening box connected to ground. In addition, the embedded switching solution must provide a commutation up to 1 kV. We chose solid state relays (SSR) to provide a galvanic isolation between the command and the output. The selected SSR is rated up to 1.5 kV at 20 mA in both directions.

3. Readout interfaces

To read out the test card, there are two multiplexed USB ports; the first one for normal in-crate operations and the second one for standalone operations. A USB to SPI bridge is used to communicate with a 12 bit ADC and the temperature sensor. Figure 4 shows an overview of the interfaces.

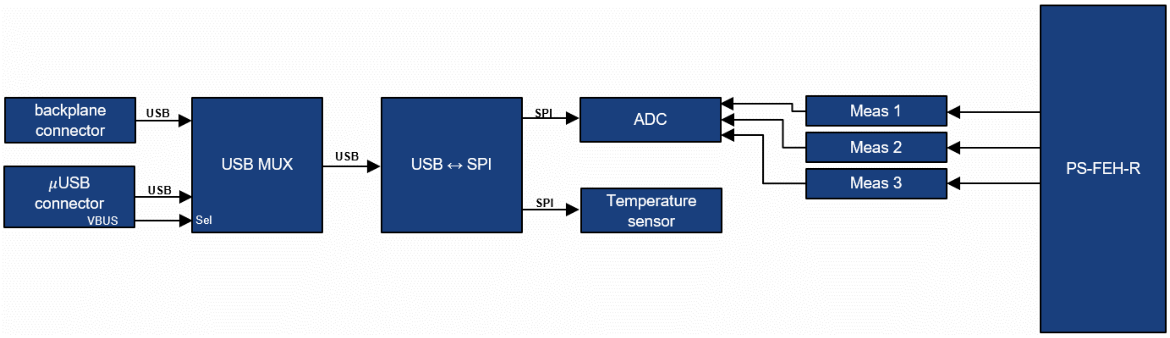

Figure 4: Readout interface overview with three measurement functions: voltage continuity, leakage current and resistance.

4. Hybrid integration

To maintain the hybrids on the test card, a mechanical support was designed and printed with carbon-fibre loaded plastic to protect the circuits against electrostatic discharge. Figure 3 shows the mechanical socket assembly with one of the four hybrids plugged in.
The hybrids are connected to the test card with flexible circuit jumpers fitted with FPC connectors and a wire cable. Figure 5 shows the two flexible designs.

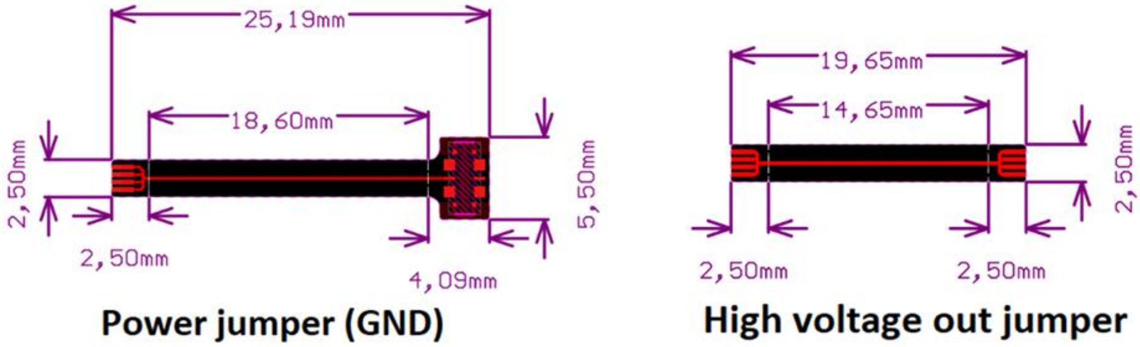

Figure 5: Jumper circuit designs.

5. Measurements

All the measurements on the hybrids are performed by the test card ADC. The continuity test uses a voltage divider with $\frac{1}{1001}$ gain to reduce the voltage to a readable value for the ADC. In addition, a follower operational amplifier is used to ensure that the current is high enough for the ADC to read the voltage.

The current measurement is performed using a current to voltage converter called a trans-impedance amplifier circuit [3] (TIA) and the resulting voltage is read by the ADC. The range of this measurement is ±350 nA. For the series resistance measurement, there is a constant current flowing through the filter and the ADC is reads the voltage across it.

6. State machine

An embedded state machine on the PCB ensures that the current source used for the series resistance measurement is isolated from the high voltage and that the capacitors are discharged. Figure 6 represents the state machine diagram.

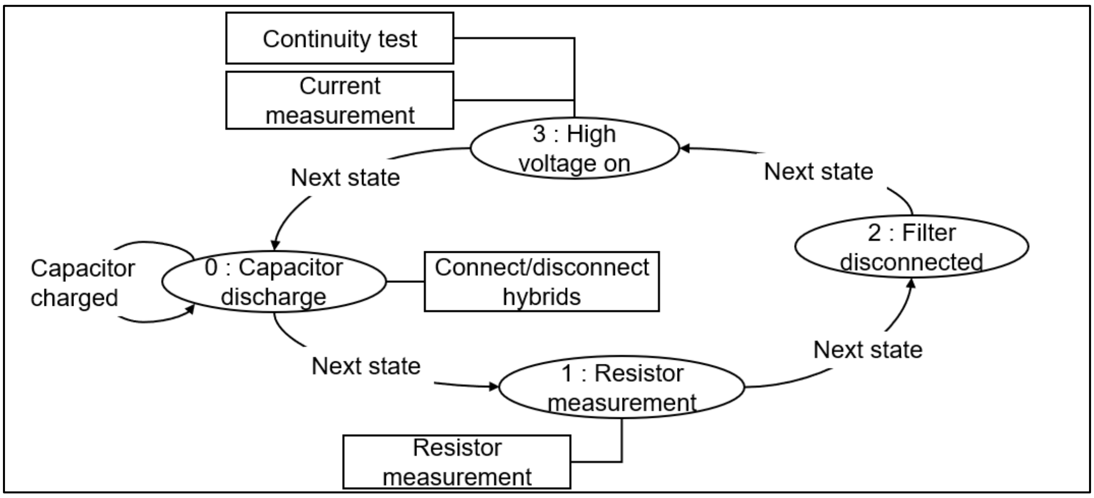

Figure 6: Embedded state machine with the four different states.

The initial state discharges the filter capacitors through a resistor to move safely to the next measurement state. When the capacitors are fully discharged and the next command is received from the USB, it goes into *State 1,* then the resistor measurement can be performed.

The *State 2* is here to ensure that the current source is fully disconnected before it goes to *State 3* and connects the high voltage to the filter to perform the continuity and current measurement. At any time, the state machine can be reset though the USB interface to get back to the initial state.

7. Software

A control class for the card was implemented in C++ to perform the connection and disconnection of the hybrids, read the active state of the system, request to change the state, and read the result of the measurements. The acceptance criteria for the tests are the following: for the continuity test the measured voltage should be within ±10 V of the one applied at the input, for the leakage current, the measured value should be less than 330 nA at 500 V; and the series resistance should be within ±1 % of the nominal value of 9870 Ω.

Another class was implemented to drive the high voltage power supply. It manages the communication with the power supply using Ethernet or the serial port, and it can set and measure the voltage and current.

8. Results

The tests were performed at ambient temperature. The voltage measured by the test card corresponds to the voltage applied at the filter input. The resistance measurement is temperature sensitive, and a correction factor applied to compensate for temperature was not found to be sufficiently accurate over a range of temperature. The measured resistance is within 3 % of the expected resistance.

In addition, a small voltage drop was observed across the SSR that should be corrected for by software. The test must be performed in the climatic chamber to verify the measurements under nominal operating conditions.

The leakage current test is performed following the datasheet conditions of the capacitors to compare the results at 500 V after 120 s, as the polarization in the dielectric needs finite time for the dipoles to redirect the actual charging current. The results shown on Figure 7 are 10 times better than the acceptance criteria based on calculation.

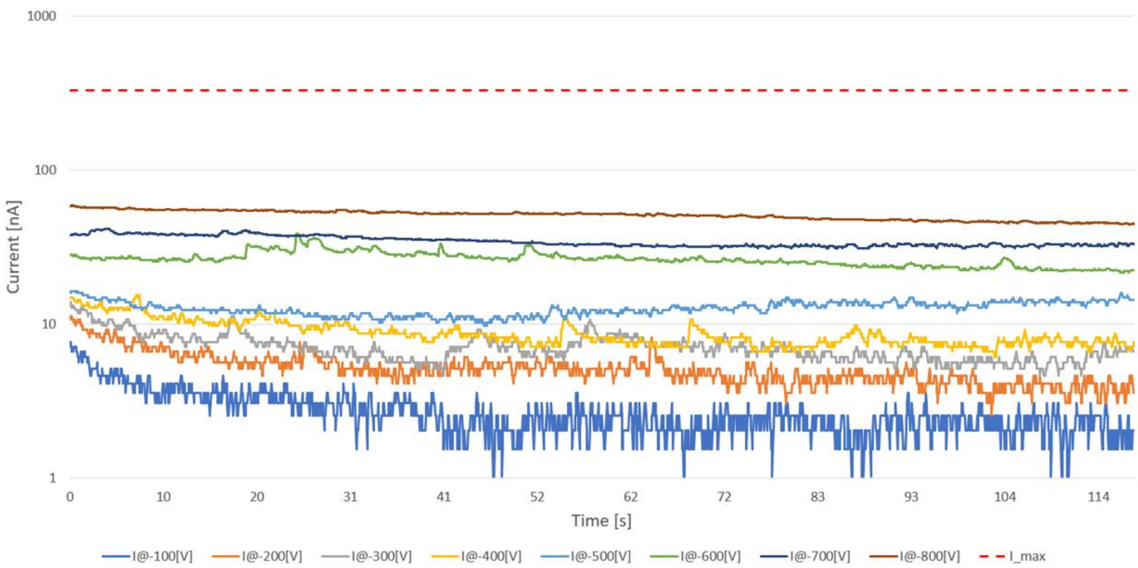

Figure 7: Leakage current from -100 V to -800 V, the red dashed line shows the acceptance criteria of 330 nA.

9. Summary

The test card is fully verified and can characterize 4 hybrids. A total of 80 boards will be produced and dispatched to the contractors. The results for the tested hybrid are in the expected range. The state machine is fully functional, and the state can be read by dedicated test system software, alongside measurements of temperature, resistance value, filter output voltage and leakage current.

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