Development of a compact test board for silicon sensors IV/CV characterization

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To build a new CMS Phase II tracker system [1] in the framework of High Luminosity LHC (HL-LHC), more than ten thousand silicon strip modules have to be produced and tested. The modules in the new tracker will have to reliably work during 10 years under harsh irradiation conditions, as it will be impossible to replace a failing module once installed inside CMS. It means that reliable and rigorous testing of strip modules and its components becomes necessary. To sustain the production throughput we should be able to test several modules in parallel. For this reason a fast, reliable, scalable and cost effective production QC test bench has to be designed and implemented. For the CV and IV measurements of sensors and modules we are developing a low-cost (less than 500€) integrated electronic board which will be scaled up to ten channels to measure DUTs in parallel. In the current work the design of the IV/CV board and the calibration procedure to increase the accuracy of the current and capacitance measurements, for which a special calibration dipole board based on tight tolerance capacitors and resistors has been designed, as well as future development plans are described.

Introduction

The CMS detector (*Fig.1*) at CERN is a general-purpose experiment at the Large Hadron Collider (LHC). After High Luminosity upgrade an instantaneous luminosity will increase sevenfold to $7.5\cdot10^{34}$ $cm^{-2}s^{-1}$, corresponding to approximately 200 inelastic collisions per bunch-crossing (whereas the LHC runs resulted in up to 50 collisions). Along with that the radiation load on the tracker system will be increased.

In order to fully exploit the highly-demanding operating conditions and the delivered luminosity, CMS will need **a completely new Tracker detector**. The new Tracker will have also trigger capabilities.

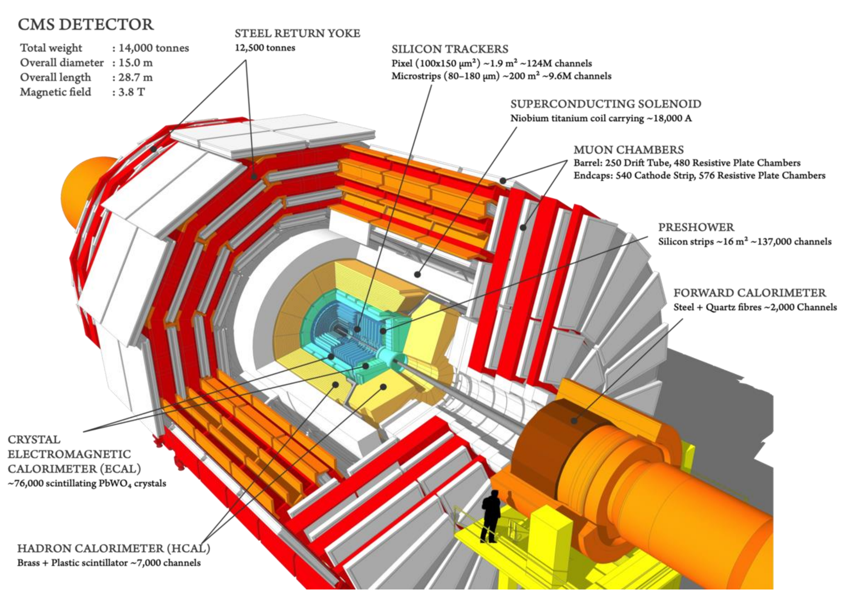


Fig. 1 - A schematic view of the CMS detector with all main components.

Motivation

The Belgium production center at the IIHE, contributing to this collective task, has decided to build about 2000 dual silicon strip modules (*Fig.2*) for one endcap of the outer silicon tracker. Integration centers in UCL (Belgium) and Lyon (France) will assemble those modules to form one endcap that will be later installed in the CMS detector at CERN.

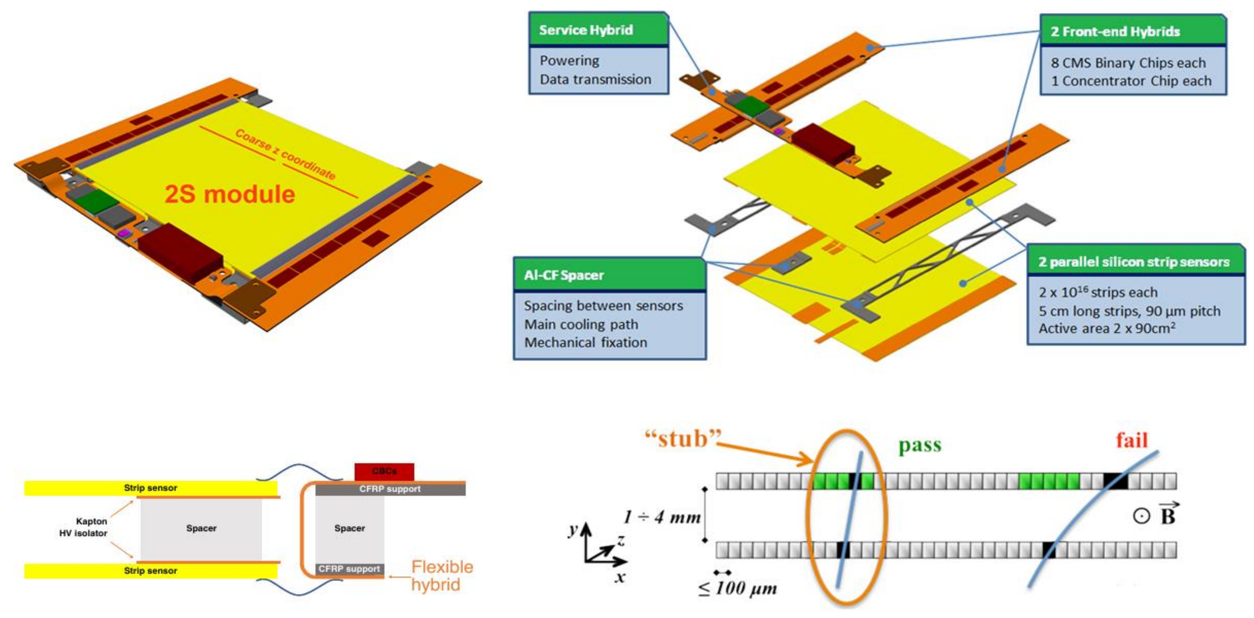


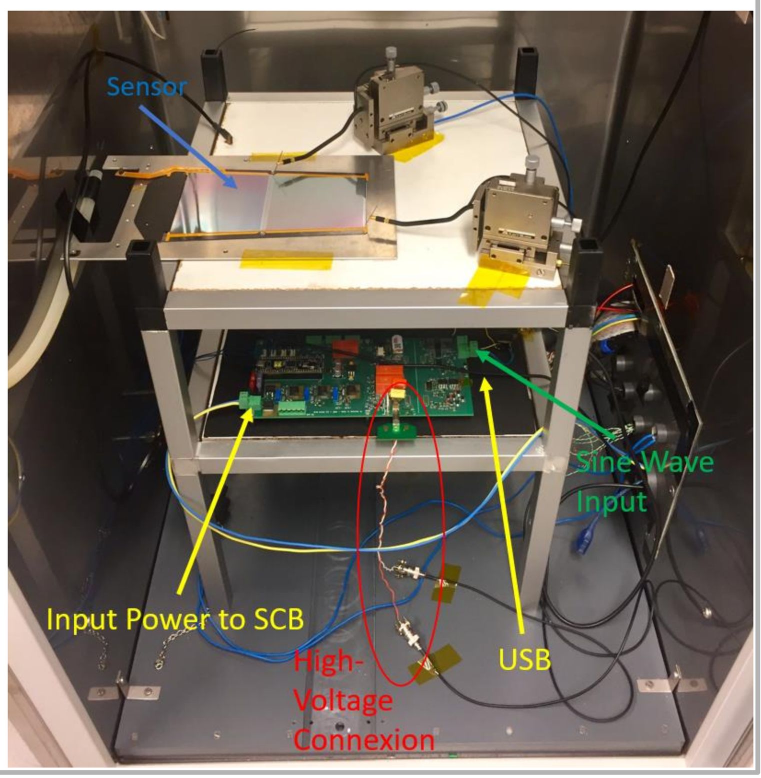
Fig. 2 - Layout of the CMS 2S silicon modules and principle of track selection.

There are numerous tests to be done for the quality control (QC) of them: hybrid functional tests, sensor test including visual inspection and **IV/CV measurements**, module functional tests, etc.

Below is a non-exhaustive list of requirements to the setup and modules related to the IV/CV tests:

- Relative Humidity: < 10%
- Voltage: up to **1000 V**, step of 5 V
- Current resolution: **1 nA**
- CV curve frequency: **1 kHz**;
- Breakdown voltage V_{break}: > 800 V
- Acceptance current limits: I_{600V} < **7.25 μA**, $I_{800V} < 2.5 \cdot I_{600V}$
- Full depletion voltage V_{fd}: < 350 V (at 290 μm thickness)
- Equivalent sensor capacitance: ~ **3.28 nF**

Fig. 3 – A picture of the experimental setup based on the prototype of the developing IV/CV board. The sensor is connected to the measurement instrument via KarlSuss micro-meter probes. The board 12 V power supply and function generator used to generate the sine waves are placed outside the industrial fridge.



Test setup: IV and CV measurement board and the Calibration dipole

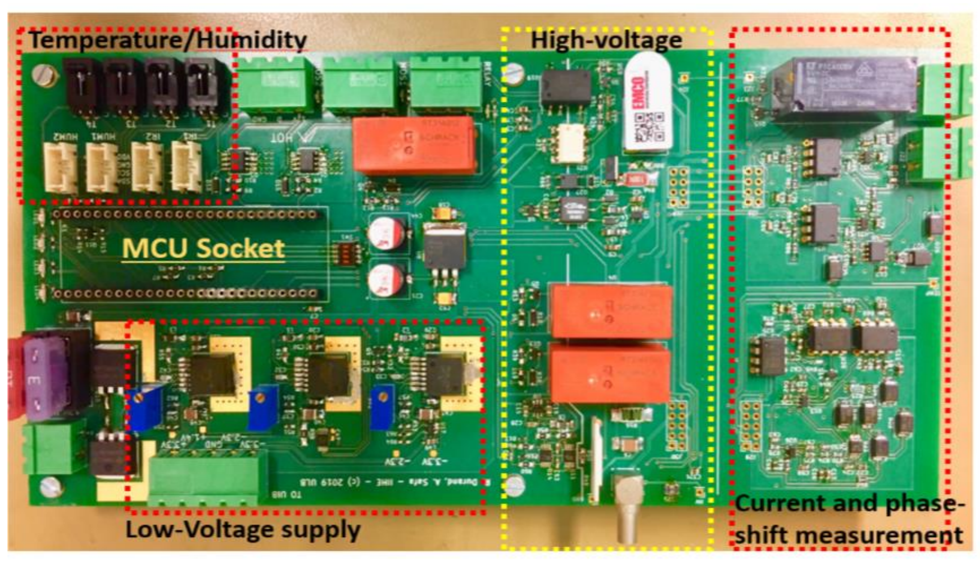


Fig. 4 - A prototype of the IV/CV board. Dimensions: 30 cm x 15 cm.

The features of the board:

- Generation of high reverse bias voltage up to 1 kV to deplete the silicon sensors. Maximum output ripple: 100 mV
- Measure of the reverse-bias leakage current (~ 4 nA) and the junction capacitance (1 - 100 nF ±1%)
- Low voltage supplies for front-end electronics found on modules
- Monitoring environmental data (temperature and humidity)
- External sine wave generator providing 250 mV, 1 kHz AC signal for CV measurements.
- The real-time communication of the measures to an external computer.

Comparison of the developed setup with a conventional solution for CV measurements:

Setup for CV measurements	Devices involved	Cost	Connectivity	Accuracy	Environmental sensors
RLC meter	RLC meter, HV source, HV decoupling box.	> 20 k€	GPIB + RS-232 + USB	0.1%	No: external RH+T sensors required
IV/CV board (baseline)	IV/CV board	< 500 €	USB	1%	Yes: (4 x RH and 4 x T ºC)
IV/CV board + cal. dipole	IV/CV board + cal. dipole	< 800 €	USB	<1%	Yes: (4 x RH and 4 x T ºC)

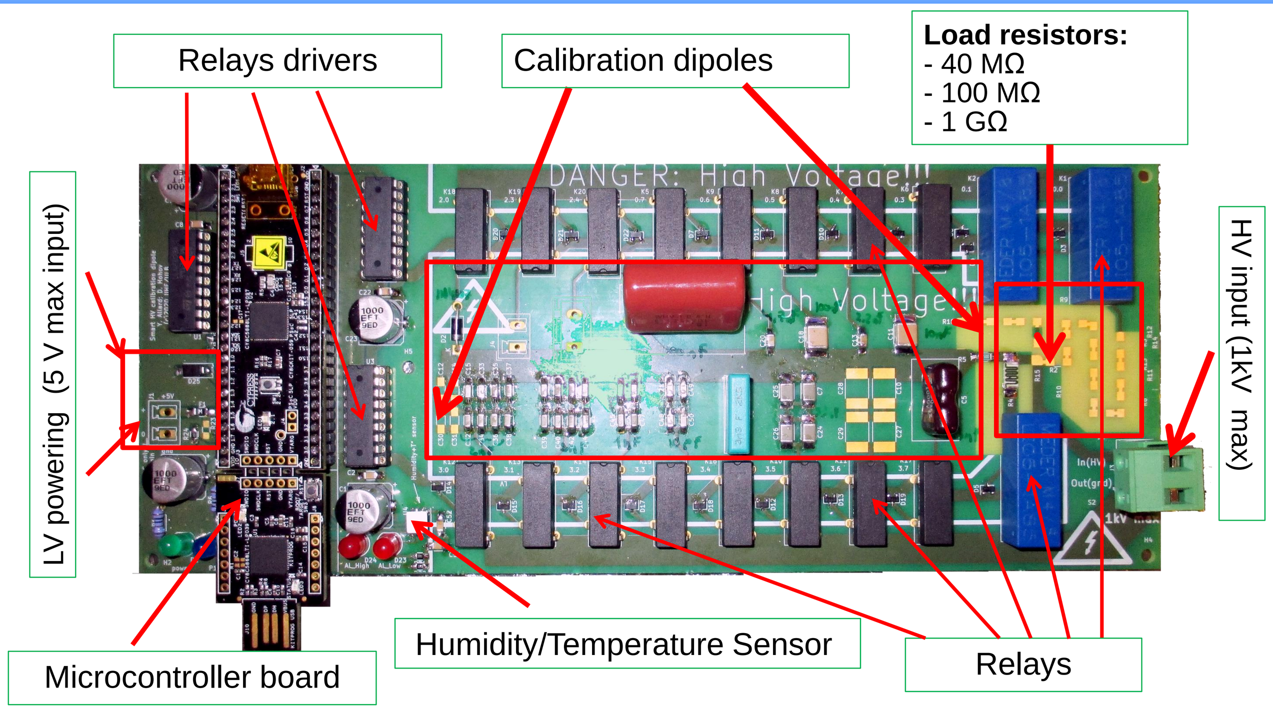


Fig. 5 – A picture of the calibration dipole PCB

- ✓ Capacitors organized in serial and parallel to decrease capacitance changes and withstand HV.
- ✓ Capacitors of better stability for ceramic types (U2J and C0G).
- ✓ Dual sided PCB; Dimensions: 27 cm x 10 cm;
- ✓ Price: PCB (70 €) + components (250 €).
- ✓ Calibrated with a RLC meter.
- ✓ Tight tolerance resistors (0.1% and better)resistors to precisely explore full range of leakage currents.
- ✓ Firmware and software to switch the combination of dipoles and monitor **RH** and **T ºC** for tests.

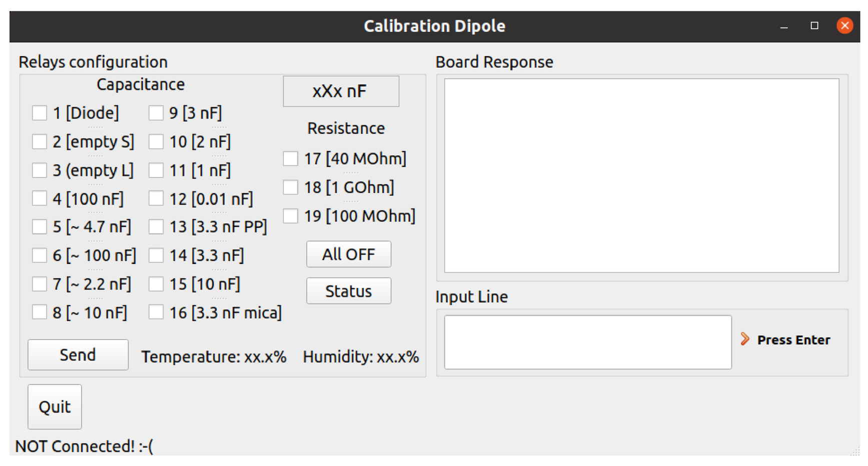


Fig.6 - A software to control the calibration dipole board. Calibration dipoles are listed.

Results

A phase-0 sensor have been measured to validate the system [2]. Three C-V and I-V curves have been measured. The measurements have been conducted at room temperature.

Measurement time 20 min per sensor. Signal processing is done within the interface software. The software core is written in C++ and the graphical user interface is written in Python.

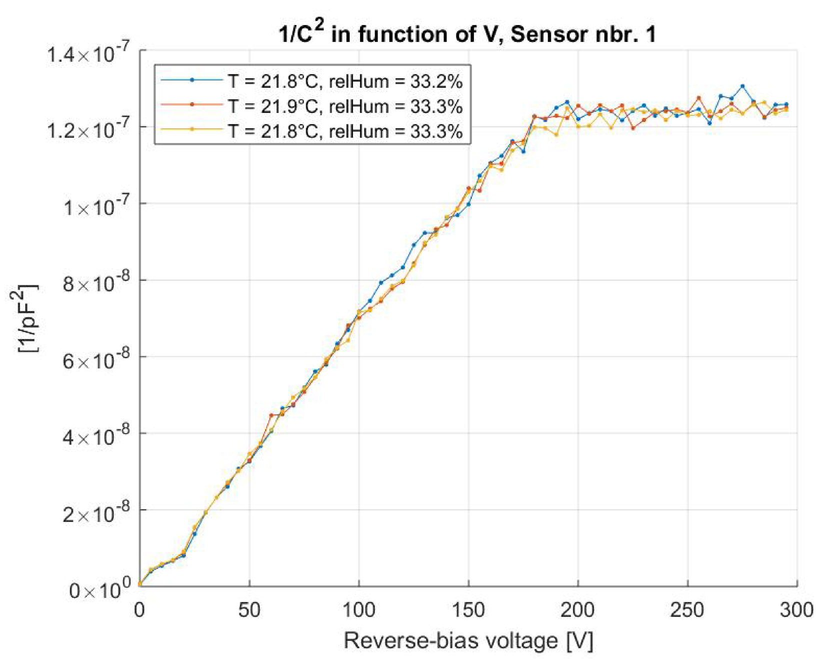


Fig. 7 – C-V curve of the phase-0 sensor. Full-depletion voltage: 177.8 V

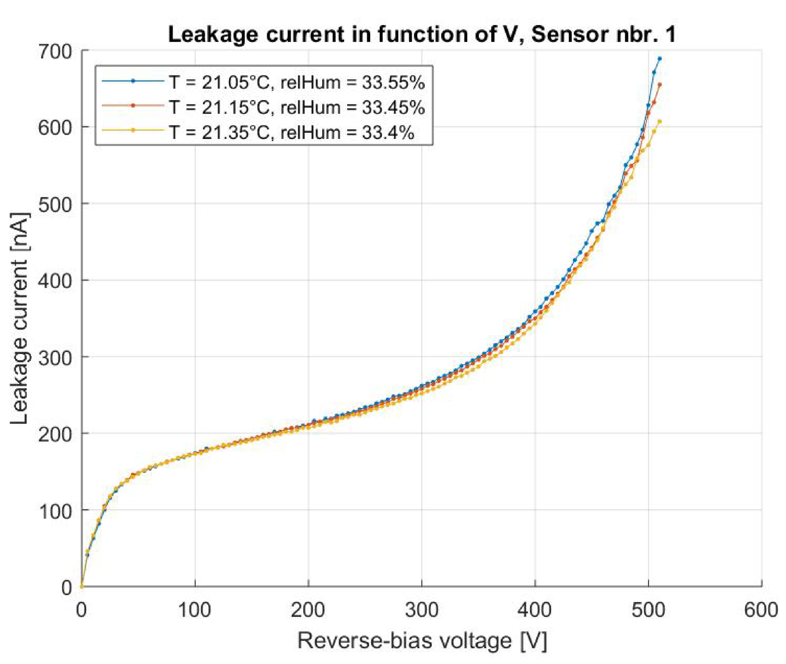


Fig. 8 – I-V curve of the phase-0 sensor.

Future plans

New IV/CV board revision:

- More reliable and accurate HV source.
- Capacitance computation and sine generator included onboard.
- 1% calibration of C measurements
- Better HV protection for sensors. Overcurrent protection with hardware and firmware sequences to safely handle faults.

- Software adaptation to existing production chain software and databases.
- Extending the setup to multichannel design.

Conclusions

- ➢ A compact "all-in-one" IV/CV measurement instrument has been designed and validated on silicon sensors.
  - ➢ Tailored to production chain requirements.
- ➢ Computer configurable calibration dipole for better IV/CV board calibration has been manufactured.
  - ➢ Crosschecked with a RLC meter.

Bibliography

[1] CMS Collaboration. "The Phase-2 Upgrade of the CMS Tracker Technical Design Report", CERN-LHCC-2017-009, CMS-TDR-014, 2017.

[2] Ali Safa. "Characterisation of the new tracker sensors for the CMS experiment at CERN". Master thesis (2019).

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