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Grounding and shielding strategy, validation and testing for the ITk Pixel Outer Barrel Detector of the ATLAS experiment

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Abstract: Robust grounding and shielding are critical to ensure the required detector performance of the upgraded tracking detector of the ATLAS experiment at the HL-LHC. This report presents the grounding and shielding strategy developed to avoid ground loops, enhance common-mode noise rejection, and maintain shielding integrity for the silicon pixel modules of the so-called Inner Tracker. Results from electromagnetic compatibility testing of the first multi-module structure are reported. Noise sensitivity to injected electric and magnetic fields under realistic conditions is quantified. Furthermore, the grounding and shielding verification method and overall strategy for detector integration, including the use of the so-called Ground Fault Monitor system, are discussed.

Keywords: Detector grounding; Particle tracking detectors (Solid-state detectors); Instrumental noise; Pixelated detectors and associated VLSI electronics

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Contents

1 Introduction

The current tracking detector of the ATLAS experiment [1] will be upgraded for operation at the HL-LHC. A new all-silicon tracker is being built, consisting of a Strip and a Pixel detector. The so-called Inner Tracker (ITk) will have a five-layer Pixel detector with 7 m^2 of p-type silicon sensors, corresponding to around 10000 modules. These are installed on carbon structures and connected with services for powering, control and readout. One section, the central outer three layers of the detector, has the modules installed on a flat section, on so-called longerons, and an inclined section, so-called inclined half-rings (see section 2). The grounding and shielding strategy is instrumental in reaching the noise occupancy at the required minimum in-time threshold (900 e^-) [2]. A description of the strategy, is shown in section 3 for the ITk Pixel Outer Barrel. Measurement results to determine its integrity are presented in section 4. The concept, which was developed to test aspects of the grounding and shielding during the integration of the Outer Barrel is explained in section 5.

2 System description

The ITk Pixel Outer Barrel consists of silicon pixel modules, which are glued with an electrically isolating adhesive onto cells made of a pyrolitic graphite tile and an aluminium graphite cooling block. These units, module cells, are attached with titanium screws onto carbon structures. They serve as mechanical support and have non-magnetic, titanium cooling pipes to provide cooling to the module cells [3]. A schematic of a longeron can be seen on the left in figure 1. The mechanical components of the carbon support structures (longerons and inclined half-rings) are connected electrically with a low-ohmic connection. The individual modules are powered in serial powering (SP) chains of up to 14 modules. They are connected with pigtails to flex-rigid PCBs (the PP0s). These route power, monitoring, and data lines. Type-1 services (cables) extend these lines to power supplies and optoboards which translate the data lines from electrical to optical signals outside of the active detector volume. A photo of a pre-series longeron is shown on the right in figure 1. The silicon modules are facing downwards.

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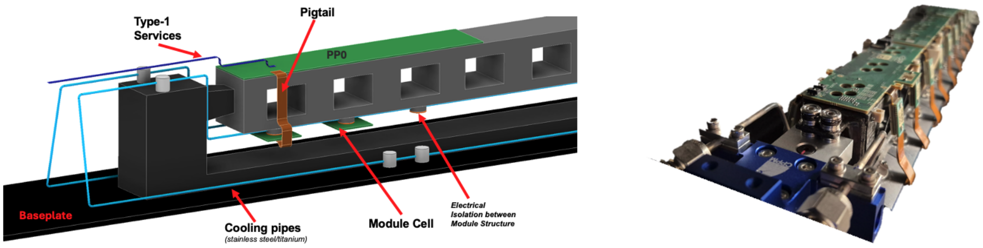

Figure 1. Schematic of longeron of the ITk Pixel Outer Barrel (left). Photo of longeron of the detector pre-series.

3 Elements of grounding and shielding strategy

The grounding and shielding concept of the ITk has the following key elements and is defined in an ATLAS internal document. There is a Faraday cage around the Pixel detector. Cables crossing the Faraday cage have common-mode filters to ground. When filtering is not possible, shields are employed in cables even inside the ITk volume. Each detector sub-system is electrically isolated. There is a single DC connection to ground (GND) and a star-like architecture is required for each sub-system. This avoids ground loops. Moreover, the power supplies have floating outputs. Figure 2 describes how the grounding and shielding concept of the ITk is deployed in the Outer Barrel. The modules and on-detector services (pigtails, PP0s) are electrically isolated from the carbon support structures and cooling pipes, as indicated in the figure with violette lines. Each module along an SP-chain is AC coupled to the ground of the last module in the chain (PP0 ground). The detector electronics are connected to the ITk reference ground in DC solely through the shields of the type-1 data cables that are serving each PP0. Finally, all the electrically conductive cooling and structural infrastructure is connected separately to the ITk reference ground.

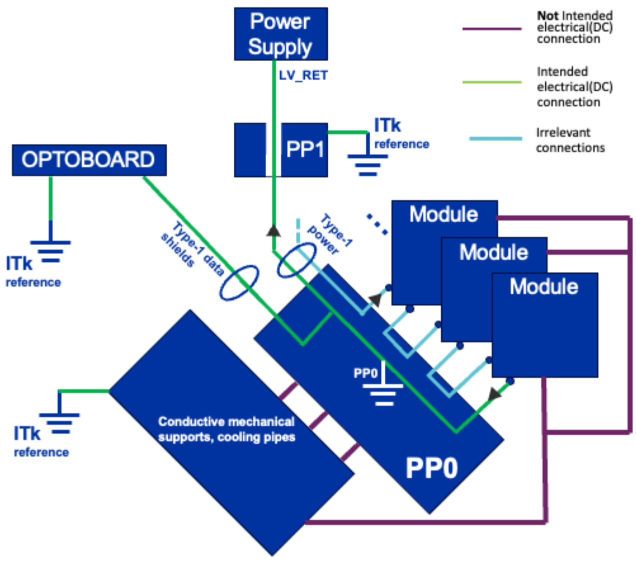

Figure 2. Schematic of the grounding and different connections in the ITk Pixel Outer Barrel.

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4 Electromagnetic Compatibility (EMC) validation of a multi-module support structure

The electromagnetic compatibility is validated using the first multi-module support structure of the Outer Barrel pre-production. It is a longeron with 18 silicon pixel modules. Both magnetic and electric fields are injected to determine the susceptibility of the longeron to them.

4.1 H-field injection tests and results

The deployed setup for H-field injection tests is shown on the left of figure 3. A bulk current injection probe [4] is mounted around the cooling pipe. Different levels and waveforms of currents are injected via a waveform generator [5] with 5 Ohm output impedance. By this, a current is injected along the pipe, and a magnetic field is generated close to the modules. E-field and H-field probes [6] are placed as close as possible to the longeron to monitor the injected fields and connected to an Electromagnetic Interference (EMI) receiver [7]. The settings and setup were optimized to inject the largest possible noise. An example of an H-field can be seen on the right of figure 3. The amplitude is much higher than expected during operation in the ATLAS experiment. The pixel modules are then operated, and their noise performance is captured. An exemplary result is the number of hits at a threshold like in operations, of one front-end chip of the module closest to the injection shown on the left of figure 4. No correlation with injected field magnitude or frequency is observed. Only a module which had issues

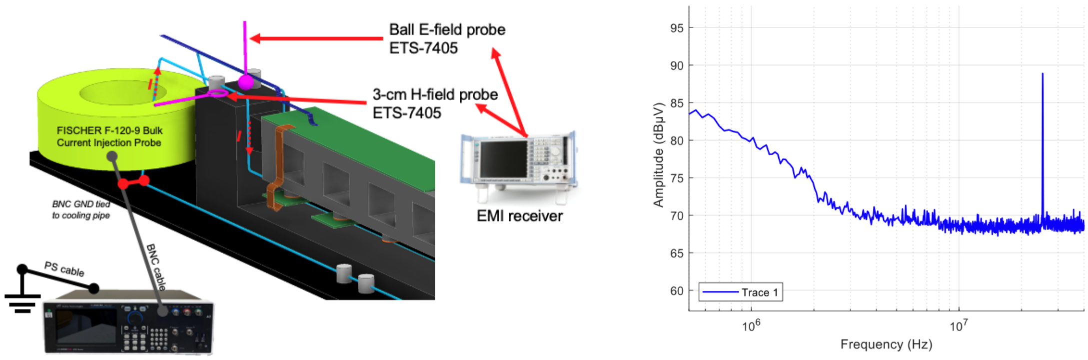

Figure 3. Schematic of setup to probe while injecting currents (left). Injected H-field at frequency of 25.3 MHz for a Sine wave injection with 20 V (right).

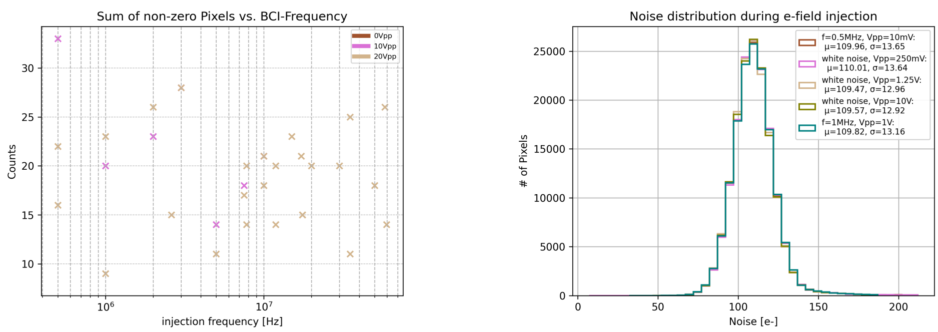

Figure 4. Number of total hits per front-end chip with a threshold like in operation of the detector for different injected frequencies (left) and noise measurement at different injection levels (right) for front-end 3 of the module closest to the injection point.

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initially in a subset of pixels showed an increase in the number of hits and sensitivity at low frequencies below 2 MHz. The observed immunity of the pixel detector against the H-field injection is also supported by the short analog channel nodes in pixel detectors. An Ansys Siwave 2D-simulation [8] is run to investigate it further. The geometry of the longeron is implemented and it shows that AC currents don't propagate in the multi-module structure beyond the first few modules. The design of the longeron is effective at high frequencies at providing paths for currents away from the modules.

4.2 E-field injection tests and results

E-field injection tests are conducted by connecting the waveform generator to the cooling pipe, as depicted on the left of figure 5. Broadband white noise is injected, and threshold scans are run on the modules at room temperature and fully depleted. The result for one of the front-end chips is shown on the right of figure 4. It shows the mean noise for different magnitudes of injected E-fields. The graphs are similar for the baseline and noise injection cases. There is no effect on the module noise found. The measurements are stopped at an injection level which results in instabilities of the power supply of the modules, which is indicative of the magnitude of the injection achieved. The observed immunity to E-field injection can be explained by the shielding of the analog nodes in the stack-up of the pixel modules, as sketched on the right of figure 5.

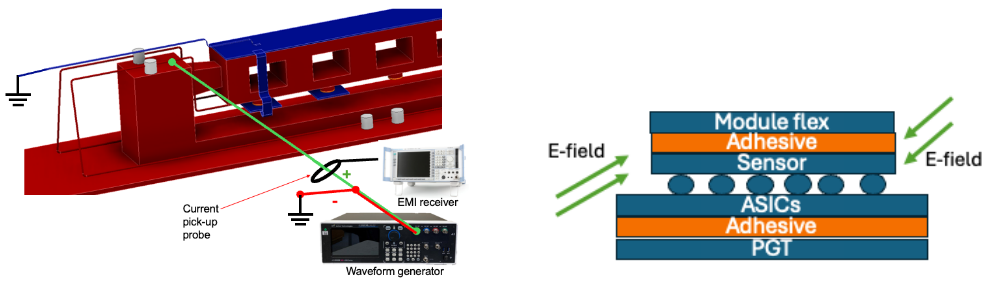

Figure 5. Schematic of test setup for E-field injection test (left). Schematic of module stack-up. Green arrows indicate the E-field injection (right).

5 Electromagnetic compatibility testing during integration

Faults on the grounding and shielding strategy implementation will not necessarily appear through simple functional testing. There is therefore a dedicated device foreseen to monitor the grounding connections during integration of the Outer Barrel. Failure modes could be damaged cables' jackets causing shorts between shields and carbon fiber structures, shorts between power cables' return and these structures, or other unintended connections to the ITk GND. The so-called ground fault monitor (GFM) is designed to detect such failure modes [9]. It is connected during the integration of the detector and measures if there is a current flowing between the carbon structures and GND. In the case of a current flowing, it issues an alarm signal. This is schematically shown in figure 6. The integration tool design was optimised, foreseeing the usage of the GFM. The sensitivity of the device was modelled and optimized by placing a resistor of 10 Ohm between the monitored detector structure and ITk GND. The sensitivity of the system would then be of the order of 1 kOhm.

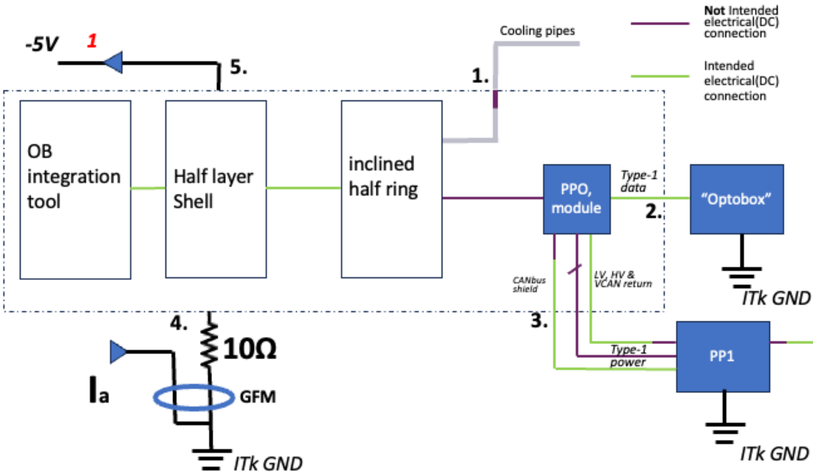

Figure 6. Schematic of integration tool and application of ground fault monitor during integration of the detector.

6 Conclusions

The grounding and shielding strategy of the ITk Pixel Detector guided the designs of all the components. The first multi-module support structure of the ITk Pixel Outer Barrel, was studied in terms of sensitivity to injected H-field or E-field noise. The results showed concrete immunity to the injections and expected noise behaviour in all cases. The grounding and shielding strategy will be tested continuously during the production stages of the detector, deploying a specific device, the GFM. Its application is optimized, and shorts of the level of 1 kOhm are expected to be detected.

Acknowledgments

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