PROCEEDINGS OF SCIENCE

The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade

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ATLAS is currently preparing for the HL-LHC, with an all-silicon Inner Tracker (ITk) that will replace the current Inner Detector. The ITk will feature a pixel detector surrounded by a strip detector, with the strip system consisting of 4 barrel layers and 6 endcap disks per side. After completion of final design reviews in key areas, such as Sensors, Modules, Front-End electronics and ASICs, a large scale prototyping program has been completed in all areas successfully. An overview of the Strip System is presented here, highlighting the final design choices of sensors, module designs and ASICs. In this article, results achieved during prototyping and the current status of production and pre-production on various detector components are summarized, with an emphasis on QA and QC procedures.

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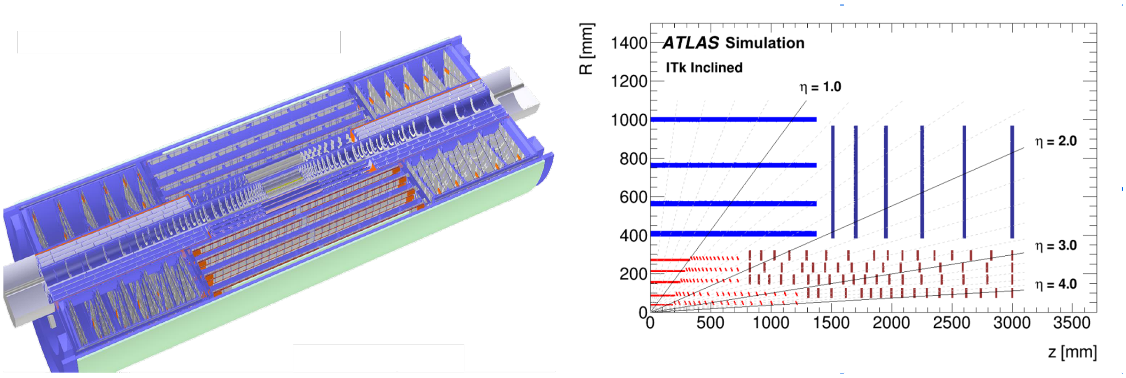

Figure 1: Schematic view of the ITk (left) and its layers (right). The strip layers are shown in blue. [3]

1. Introduction

ATLAS is one of the two multipurpose experiments located at the Large Hadron Collider at CERN [1]. Before the next LHC run, the collider will be upgraded to achieve higher particle multiplicities and enhance the potential for discoveries [2]. Following this upgrade, there will be up to 200 simultaneous proton-proton collisions at each collision point, the instantaneous luminosity will increase to 5–7.5$\times 10^{34}$ cm^{-2}s^{-1} and the integrated luminosity will reach 3000–4000 fb^{-1}. Due to more stringent requirements, and as the current ATLAS Inner Detector approaches the end of its operating life, it will need to be replaced. Unlike the Inner Detector, which had a gaseous part, the new ATLAS Inner Tracker (ITk) [3], depicted in Figure 1, will be fully silicon-based, moreover, with higher granularity and radiation hardness than the Inner Detector [4]. ITk will consist of two systems – pixel and strip. This contribution focuses on the production of the strip system components and the current status of this production.

2. Structure of the ITk strip subsystem

The strip system of the ITk consists of three parts: a barrel and two endcaps. There are two types of rectangular-shaped barrel modules, differenciated by the length of the strips. The two inner barrel layers are constructed using short-strip modules, while the two outer layers have long-strip modules. This design increases the granularity of the barrel closer to the beam axis. The modules are mounted on both sides of local support structures called staves. Every stave holds 28 modules and there are 392 staves in total in the barrel part.

The endcaps are placed on both sides of the barrel. They consist of six types of arc segment-shaped endcap modules, which are placed on both sides of local support structures called petals. Each endcap contains 192 petals, with each petal holding 12 modules. [3]

Staves and petals are low-mass carbon-fiber-based structures [5]. They are mechanically stable and precise, exhibit good thermal and electrical performance, and have titanium lines for CO_2 cooling. Schematic views of both structures and their layers are shown in Figure 2 together with a picture of a finished petal. Modules are mounted on both sides of the structures with up to 26 mrad rotation relative to their axes, allowing petals and staves to provide 3D information about passing particles.

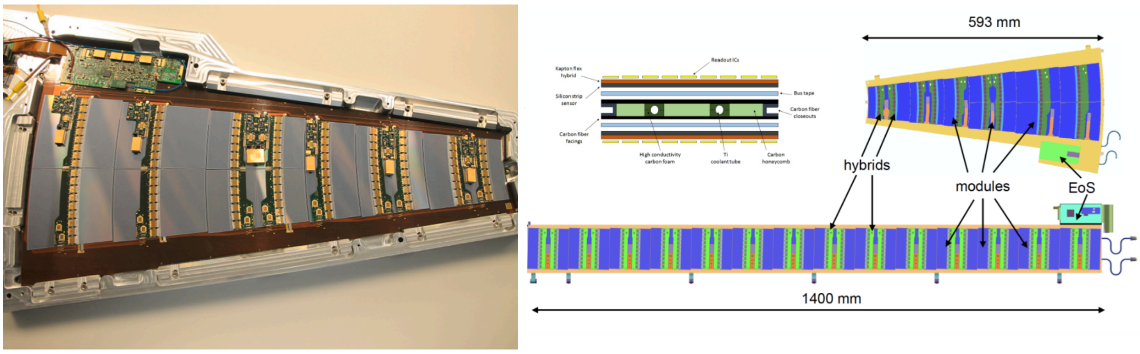

Figure 2: Left: a finished petal [5]. **Right:** Schematic view of petals and staves.

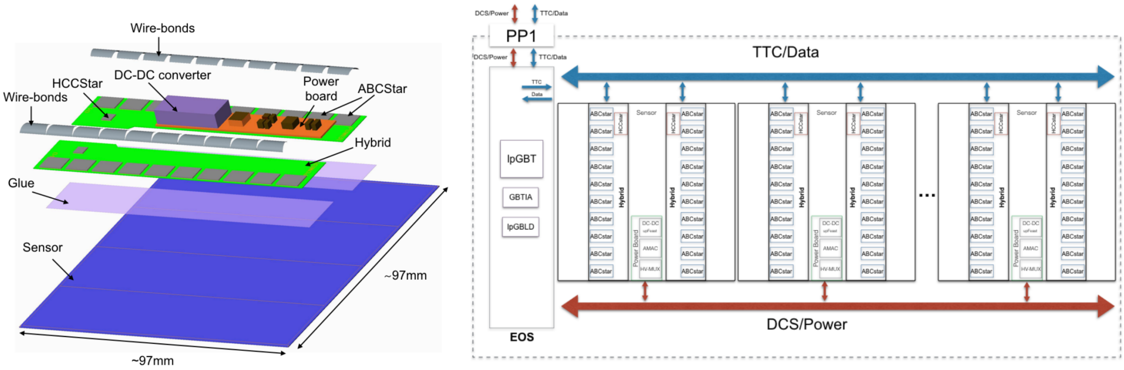

Figure 3: Left: schematic view of a strip module. The electronics are glued on top of a silicon sensor. **Right:** schematic view of a stave with mounted modules. The readout data is collected by the ABCStar chips and then packaged by the HCCStart chips and sent out of the module. The AMACStar chip controls the module operation and power. [3]

3. Module assembly

The assembly of the ITk strip modules involves gluing the electronics on top of a silicon sensor and then establishing an electrical connection using wire bonds. The sensors, manufactured by Hamamatsu Photonics on 6-inch wafers, come in eight different types: two for barrel modules and six for endcap modules. For the construction of the ITk n-in-p sensors are used, as they offer better speed and radiation hardness than p-in-n sensors, and can provide good signals even when partially depleted [6]. Currently, around 15,000 sensors have been received by the collaboration, amounting to approximately 71% of the total number required. The schematic view of a module is shown in Figure 3 on the left.

A single chipset is used for all module types. The electronics boards hosting the readout electronics are called hybrids. The frontend chips for data readout are called ABCStar. The collected data is then processed by the HCCStar chips, which repackage the data per hybrid and transmit it out of the module. AMACStar chips manage module control and power. The schematic placement of chips on modules, as well as the data and power flows, is illustrated in Figure 3 on the right. After manufacturing, the chips are probed to ensure their functionality, then diced into individual pieces. At the next step, they are pre-irradiated to avoid a known phenomenon called

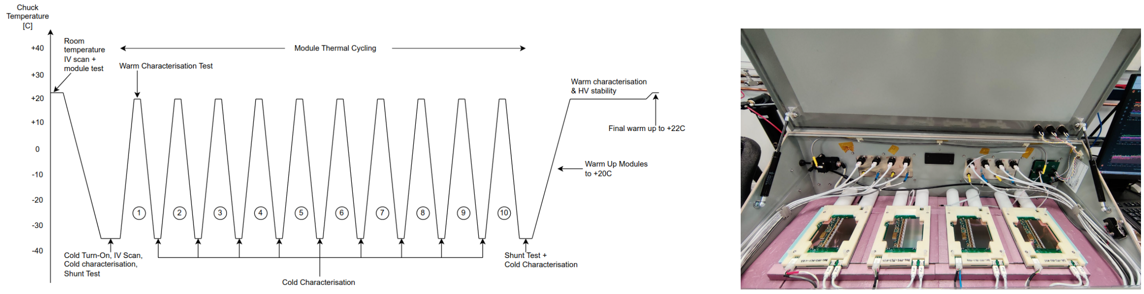

Figure 4: Left: schematic temperature plot of the thermal cycling procedure. The temperature varies between -35°C and +20°C 10 times and the module is tested electrically at each temperature. **Right:** the thermal cycling setup for barrel modules.

"TID bump" [7]. After a small dose of irradiation (~0.7 Mrad), the current of the chips peaks, and after more irradiation it reduces and stabilizes. Pre-irradiation of the chips positions the operating current of the chips past the bump. After pre-irradiation, the chips are distributed to the production sites.

Module building sites utilize dedicated tools for each module type to ensure that the modules meet required specifications. The tools are designed to accommodate various module geometries. The gluing of the components is a multi-step process. Chips are glued to the hybrid flexes with UV-curing glue, requiring dedicated compartments in the tools for UV lights. Glue is applied using stencils or programmable gluing robots, which dispense glue in a predefined pattern. The frontend wire bonds are a challenging aspect of the module building process. Advances in bonding techniques allow for angled wire bond placement, eliminating the need for an intermediate bond connections, necessary for straight bonds. Wire bonds are placed in four rows with each row over the previous one. This precise technique is now reliably proven [6].

4. Quality Assurance and Quality Control

Stringent Quality Assurance (QA) and Quality Control (QC) procedures are implemented to control the module production [8]. The IV characteristic of the silicone sensor is measured multiple times along the module production. Each component is tested individually before being incorporated into the final module. After the electronics are glued to the sensor, metrology is performed to ensure the module dimensions meet specifications. Following wire placement, the entire module undergoes a full electrical test to tune readout parameters and measure the noise levels. The most challenging part of the module QA/QC process is thermal cycling. It involves stress-testing the modules by cooling them down to the ITk operation temperature of -35°C and then warming back up to +20°C 10 times with electrical testing at each temperature. This aims to test the module's robustness and its ability to withstand the ITk operation. Special setups called *coldboxes* were designed and assembled for every ATLAS module site for this testing. Each coldbox can accomomodate several modules. A barrel coldbox and a schematic plot of the module temperature during thermal cycling are shown in Figure 4.

After thermal cycling, the modules are ready to become mounted on support structures – petals and staves. There are two approaches to module loading. Barrel modules are placed on staves with high precision manual tools, which makes it possible to load several modules at once. Endcap sites use automatic programmable setups, which load modules one by one. Both methods have high precision, ensuring that the final staves and petals meet requirements.

After loading, staves and petals undergo further tests before integration – their insertion into the global structures. Barrel integration will be done at CERN, while the two endcaps will be assembled at DESY and Nikhef. Dedicated tools for these processes are developed, and integration is ready to begin.

5. Conclusion

The construction of the ATLAS ITk is a complex task requiring effort from multiple institutions worldwide. Strict QA/QC procedures ensure that each module meets the required standards for successful operation. The production of the necessary components is currently ongoing.

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