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Characterizing Powerboard Noise in ITk Strip Modules through Magnetic Triggering Tests

Summer Student Project Report

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Abstract

Silicon strip detectors for the ATLAS Inner Tracker (ITk) are subject to 2 MHz electromagnetic noise emitted by the DC/DC converter on each module. The magnetic triggering method is used at UBC to investigate this noise. The method involves picking up the 2 MHz signal with a coil and triggering on it for time-precise noise measurements. This report presents recent improvements made to the UBC cleanroom magnetic triggering setup and new Python scripts developed for data handling and visualization.

1 Introduction and Background

1.1 ATLAS Upgrades

The High Luminosity LHC (HL-LHC) upgrade is scheduled for 2026-2029 during the LHC's third Long Shutdown (LS3). Tighter beams will result in up to 140 proton collisions per bunch crossing [2] compared to the current maximum of 60, and the LHC experiments will also need upgrades to process and record data at higher rates.

The ATLAS experiment will see the complete replacement of the Inner Detector with the Inner Tracker (ITk). ITk will be composed entirely of silicon pixel detectors and silicon strip detectors, which will provide improved tracking resolution. The strip detector modules will be produced around the world and need to pass quality control tests. This work focuses on magnetic triggering tests of LS-type silicon strip detectors and the scripts developed for this.

1.2 Silicon Strip Modules

A silicon strip detector is a thin silicon wafer, sandwiched between a backing electrode held at high voltage and arrays ("streams") of long electrodes ("strips" or "channels") on top. On LS (Long Strip) modules, the strips are 48.3 mm long and spaced 75.5 µm apart. [4] On each LS-type module, there are two streams, referred to as stream 0 and stream 1. Due to space restrictions, the hybrid containing the modules' powerboard and data handling ATLAS Binary Chips (ABC's) is glued directly on top of stream 0.

A charged particle passing through the silicon layer introduces charge/hole pairs that drift toward the respective electrodes, causing a small burst of current and voltage drop in the corresponding channel. An ABC digitizes the signal as a binary 1 ("hit") if the voltage is over a certain threshold, 0 otherwise.

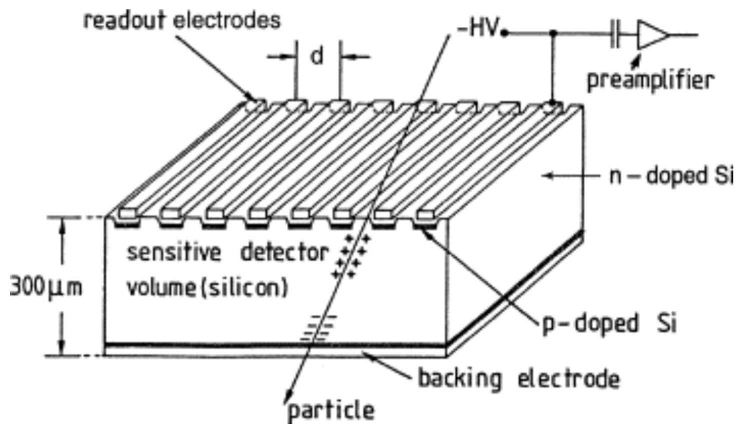

Figure 1: Diagram of operation of silicon strip module.

As of 2022, the modules are in preproduction and prototypes with varying designs, particularly in the powerboard and converter, are being studied at testing institutions. Eventually, around 1000 end-cap modules will be produced in western Canada. [3] End-cap modules are more complex and are destined for the ends of the barrel-shaped ITk. They differ from barrel modules such as LS in that they can have up to four streams, and strips that are at small angles to each other to form segments of the endcap's concentric circle layout. UBC is currently qualifying testing procedures on LS modules and will eventually test production endcap modules made in western Canada before shipment and installation.

1.3 Module Tests

To perform a noise occupancy test, the module is powered in a controlled and isolated testing box and all channels are repeatedly sampled. The noise occupancy for each channel is the fraction of samples that are hits. The voltage threshold is chosen so that the overall noise occupancy is around 50%. The noise occupancy quantifies the background noise in the module for some threshold, and the signal-to-noise ratio (SNR) of the modules can be calculated once subsequent tests are performed with test charges injected.

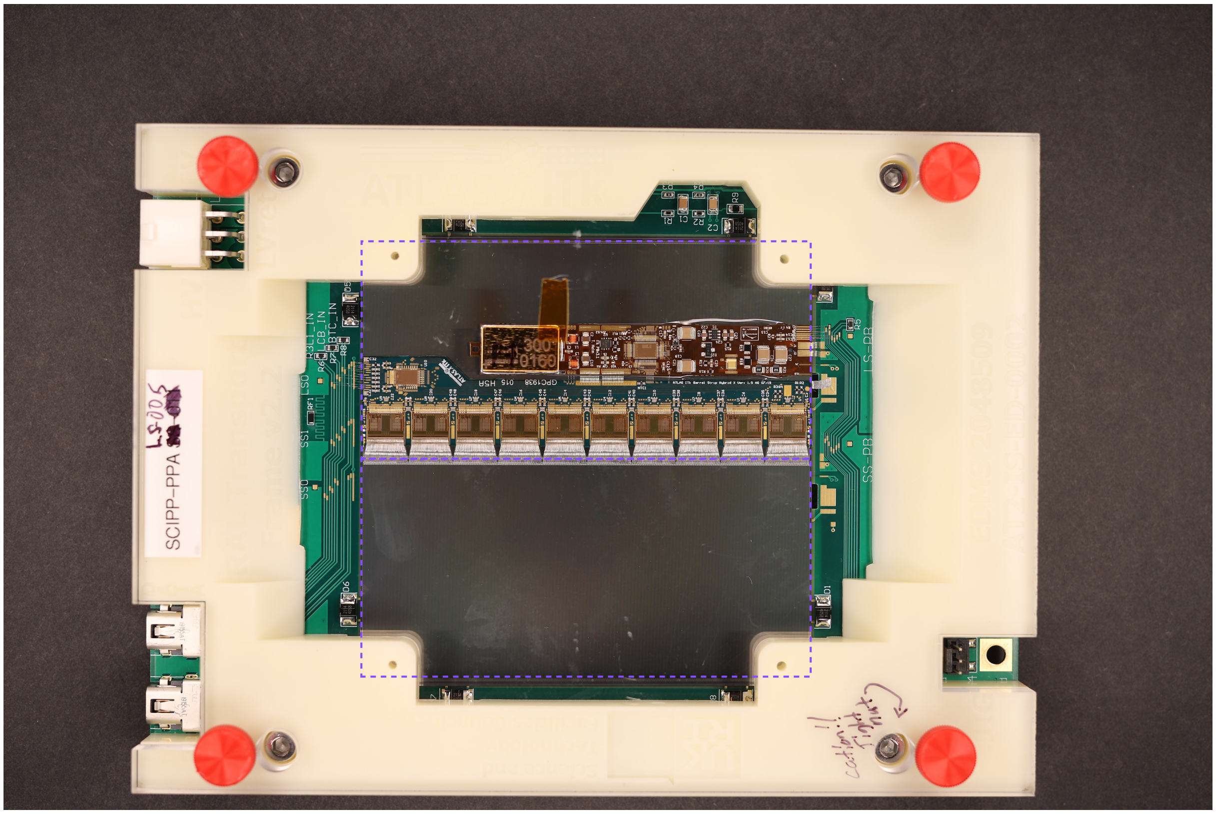

Figure 2: "PPA" module in protective transport case. Dashed lines enclose the two streams. The hybrid is attached to stream 0 on the upper half of the module and contains a row of ten ABC's as well as the DC/DC converter housed in the shield box.

1.4 Synchronous Noise Source

The powerboard of each module contains a DC/DC converter to convert the 11V power supply to the 1.5V used by the ABC chips. The coil and circuitry of the converter emits electromagnetic noise due to the presence of a current switching at 2 MHz. [1] Though contained in a Faraday cage consisting of a gold-plated aluminum box and a copper layer in the board structure, significant B fields still leak through. The presence of the field introduces a time-dependent component to the module's noise, particularly in the row located under the hybrid. The hypothesis is that the B field accelerates the charge carriers, modulating the strength of the current burst and causing false and missed hits.

1.5 Magnetic Triggering Test

Previous module testing was performed without synchronization to the converter switching, and saw only a time-averaged noise in each channel. The magnetic triggering test involves positioning a simple pickup coil above the converter and connecting it to an oscilloscope. By triggering on the received signal and applying a small delay, data taking can be synchronized to measure the noise occupancy at different phases of the 2 MHz signal. The noise occupancy is then normalized to the asynchronous values.

2 Progress

2.1 Test Environment Improvements at UBC

The first half of the project focused on improving the existing testing setup in the UBC cleanroom. Trials of different pickup coils and filters, including off-the shelf components, settled on a combination that showed a high quality 2 MHz signal. This improves the trigger accuracy from 40 ns to 10-12 ns, making it possible to trigger reliably at the LHC's bunch crossing frequency of 25 ns. Reliable triggers also vastly increased the data collection rate, reducing the time to run a full test from over 24 hours to as little as 3.

As the Hennings building at UBC lacks a central dry air system, humidity is a constant challenge in Vancouver's wet climate. The use of bottled dry air for the testing box is expensive and labour-intensive, but was successfully cut back. Among the strategies implemented were reducing the circulating air volume of the testing box with foam blocks and improving wire port seals. Both required creative maneuvering of the power, data, coolant, and air lines to maintain structural integrity and prevent interference.

2.2 Python library

The tests are run with ITSDAQ software and output a large number of ROOT files recording the hits counted in each channel.

The Python scripts developed for this project serves two main purposes: to convert the data into a compact form that is easy to process and to produce plots to visualize the module performance. The `file_access.py` script extracts the data for each stream from all the ROOT files and stores it as a single .npy format array. Reading and transferring the data is much faster in this form. It also occupies 25-30 times less disk space and makes it much simpler to use NumPy's powerful array analysis tools. The `plotter.py` script performs data analysis and produces the types of plots shown below.

3 Results

Tests were mainly performed on three different prototype modules produced at the Santa Cruz Institute of Particle Physics (SCIPP), nicknamed "PPA", "Frank 1", and "Frank 2". These plots show their results from top to bottom.

3.1 Noise Occupancy Waterfall

The noise signature of a module depends on its exact configuration, particularly the orientation of the coil (Figure 3). Frank 1 shows an invasive noise pattern affecting both streams strongly but homogeneously, modulating the occupancy by greater than a factor of 2. PPA and Frank 2 show similar noise that mainly affects the physical location of the converter above strips 600-950 of stream 0.

3.2 Stripwise Fourier Analysis

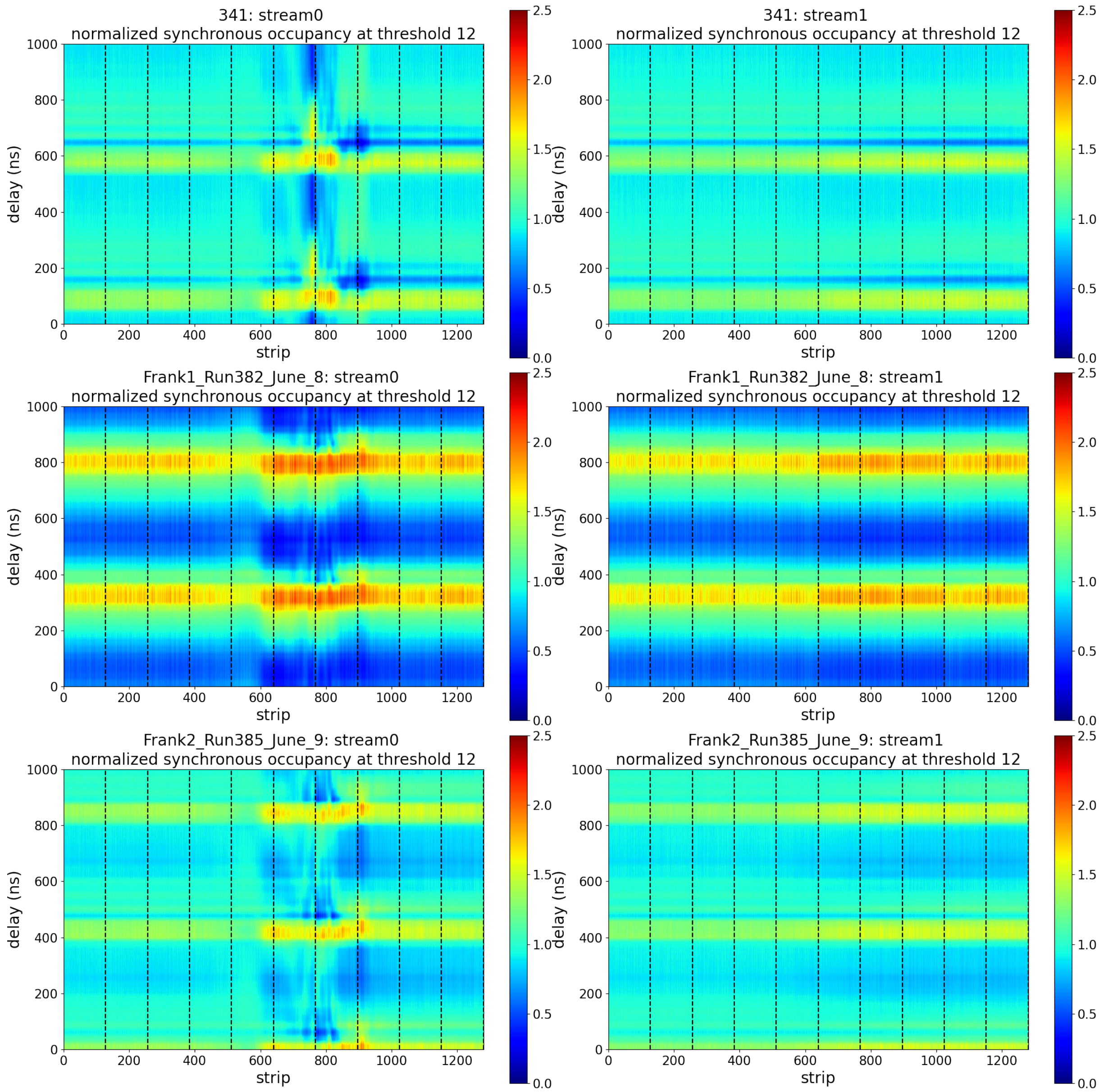

Figure 3: The normalized noise occupancy for each module is shown on these waterfall plots spanning two full cycles of the 2 MHz signal. The time resolution is 25ns. Stream 0 is on the left and stream 1 on the right.

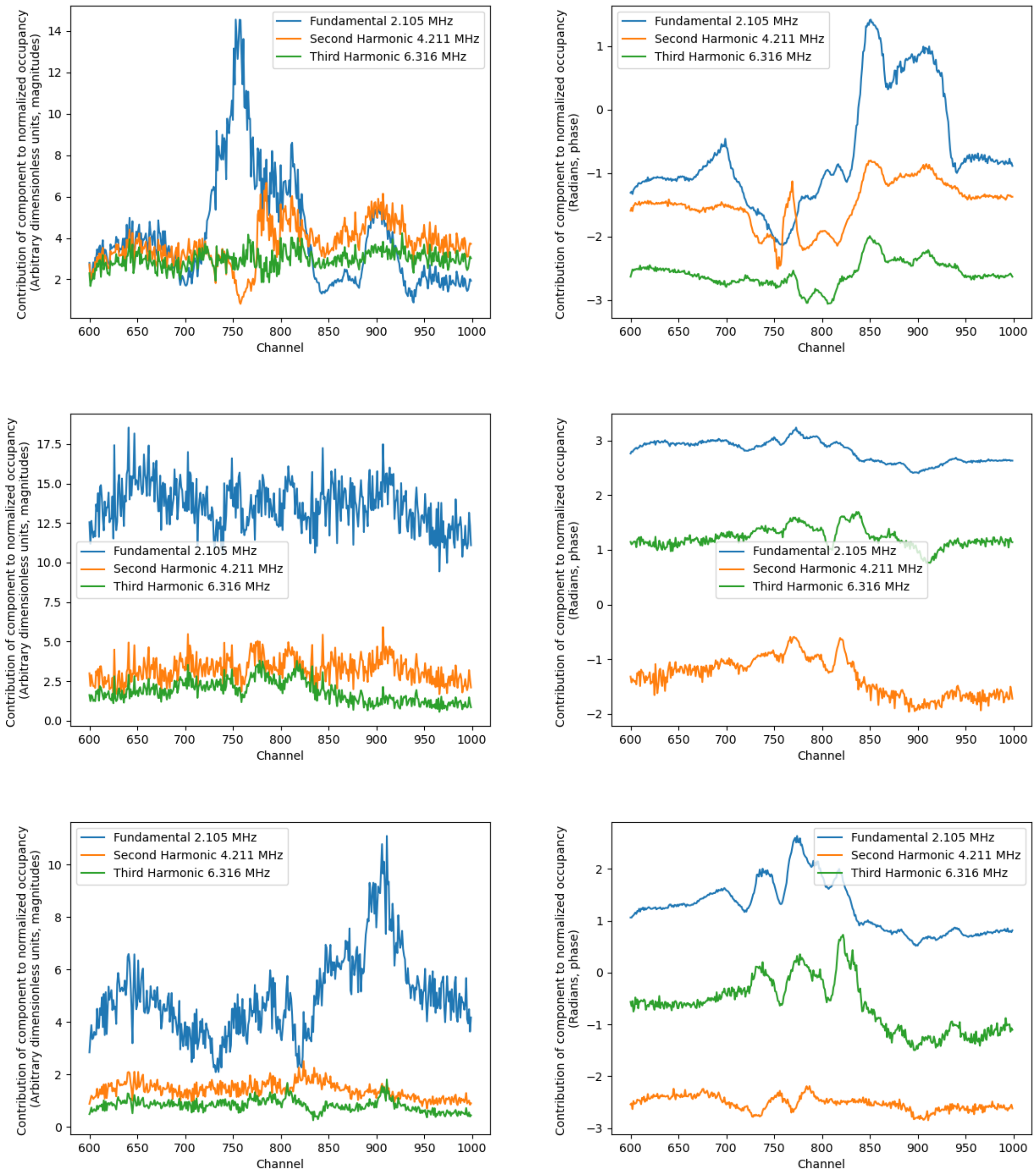

Figure 4: Fourier analysis of time-dependent noise in each module showing relative contributions from harmonics (left) and relative phase (right).

A Fourier transform is taken on the time series of each channel to show the relative contributions of the 2 MHz component and its second and fourth harmonics. The relative phase is also plotted. Again, each tested module configuration has a different signature (Figure 4). PPA shows a phase inversion around strip 800, a fundamental peak at strip 750 and a lesser peak at 900, and areas around strip 850 where the harmonics dominate over the fundamental. Frank 1 shows consistent harmonics and phase across the module, and Frank 2 shows a fundamental peak around strip 900 instead.

4 Conclusions and next steps

The magnetic triggering setup and the Python analysis library make it possible to plot module noise performance on different powerboard configurations in detail. The Fourier analysis in particular is likely very helpful to understanding the dynamics of the EM noise emitted by the converter. In the near future tests will also be performed on irradiated modules, at low temperatures (-35ºC), and on different module types having up to four streams. The Python library will be adapted to process the data from these tests. This information will inform the final design of the ITk silicon strip modules before they go into full production.

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