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# How the discovery of Cold Noise delayed the production of ATLAS ITk strip tracker modules by a year

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The construction of the ATLAS strip tracker barrel will require the assembly of 12,000 barrel detector modules over the course of 3.5 years. In 2022, during the module pre-production phase, modules were found to display clusters of noisy channels outside required specifications when tested at operating temperatures (-40 °C), called "Cold Noise". Extensive investigations into the cause and mechanism of Cold Noise interrupted pre-production and occupied most barrel module assembly sites. This contribution presents an overview of the year-long investigations into Cold Noise, the final identification of the underlying mechanism and necessary changes for the transition to production.

## Summary (500 words)

Silicon strip sensor modules for the strip tracker barrel consist of a silicon strip sensor, one polyimide flex board controlling and monitoring voltage and current ("powerboard") and one or two kapton flexes with ten readout chips each ("hybrids"). For sufficient tracking performance, modules are required to have a noise occupancy < 1%, a hit efficiency > 99%, less than 2% bad channels and a signal-to-noise ratio of at least 10:1 at the end of life.

In 2022, pre-production barrel modules tested at operating temperature (-40°C) displayed clusters of very noisy channels, exceeding the specifications for acceptable module performance. Cold Noise was observed starting at temperatures between -20°C and -40°C, was observed to worsen or, occasionally, improve with repeated cycles; modules with nominally the same characteristics showed Cold Noise to different extent; some areas of modules were more likely to display Cold Noise than others. The statistical occurrence of Cold Noise complicated investigations into the unterlying issue, as modifications required the assembly of several modules in order to test their impact on module performance.

Over the course of the next twelve months, pre-production was halted, so that the limited number of pre-production components was available for investigations into the cause and mechanism of Cold Noise. In a project-wide effort, experts from all involved institutes investigated all aspects of modules that were potential causes of Cold Noise, which revealed individual parts of the overall cause:
- different glues with nominally identical properties led to different amounts of Cold Noise
- increasing the glue layer thickness reduced the observed amount of Cold Noise
- increasing the current drawn by the powerboard increased the extent of Cold Noise
- bypassing the powerboard for module operation (i.e. powering hybrids directly) eliminated Cold Noise
- adding mechanical stiffeners to the powerboard reduced Cold Noise
- adding various options for additional shielding did not impact Cold Noise
- Cold Noise is only observed for module channels located above a glue layer between hybrid and sensor
- the occurrence of Cold Noise shows a phase relationship with the switching frequency of the on-board DC-DC-converter's switching frequency
- inducing vibrations to the powerboard through a transducer produced a similar module noise pattern as Cold Noise.

In 2023, two major observations were made:
Laser vibrometer measurements on SMD components mounted on powerboards revealed that several capaci-

tors showed vibration at about 2 MHz with an amplitude of about 1 nm. These vibrations can couple into the silicon sensor through piezo-electric effects in the glue layer.
Cold Noise measurements of end-cap modules showed no Cold Noise in the production version of end-cap modules, despite utilising a nominally comparable component design that varied mostly in geometry.

The combination of both results provided enough information for a re-evaluation of the existing barrel module powerboard design and its adjustment for an improved noise performance.

For a more complete overview of the performed tests and results, please see the attached overview.

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