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A Serially Powered ATLAS Strip Tracker Stavelet with Improved Referencing Connections

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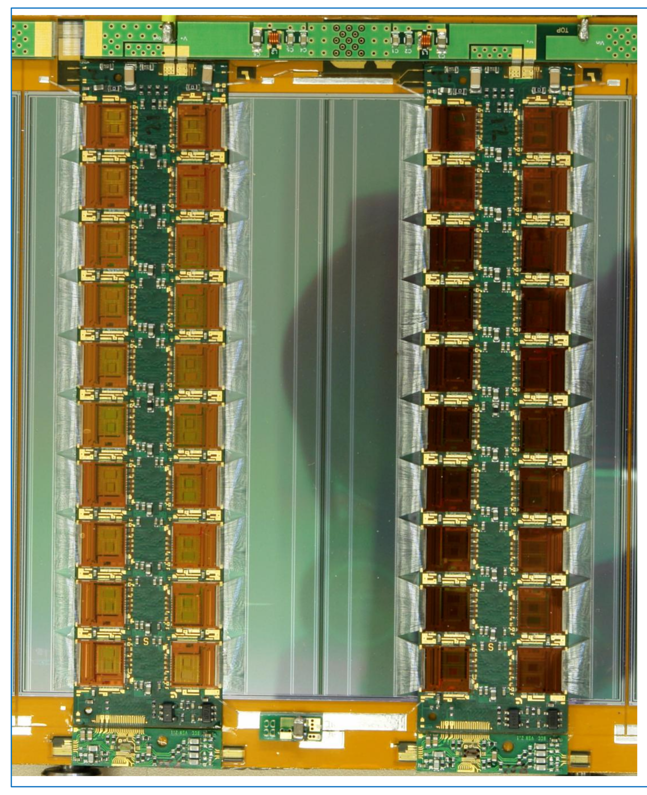
Introduction

The present ATLAS SCT (semiconductor tracker) comprises 4088 silicon microstrip detector modules, each powered by its own independent low and high voltage power supply channels. Given the requirements of the upgraded inner tracker needed for ATLAS running at HL-LHC, with over 10,000 detector modules in the short strip region alone, it becomes increasingly difficult to justify the retention of independent powering both in terms of system efficiency and overall cost. Therefore two alternative powering schemes are under active consideration within our community, namely Serial Powering and on-detector DC-DC conversion.

For the upgraded detector, it is natural to integrate groups of modules into intermediate scale structures, known as "staves". A stave functions both as a thermal-mechanical core, to precisely support and cool the modules, and as a "backplane" through which digital signals, power, and detector bias can be distributed to modules. A stave is also a convenient unit for which to implement the serial or DC-DC powering infrastructure. For the purpose of prototyping, we have chosen to study 1/3 length staves, referred to as "stavelets", each comprising four short strip modules.



- One Sensor
  - n-in-p, 10cm * 10cm approx
  - 4 columns of ~2.5cm strips
  - Originally one, later two backplane connections
- Two Kapton Hybrids
  - Glued directly to sensor for minimal mass
- Each Hybrid has
  - 20 ABCN-25 ASICs arranged in 2 columns
  - Integrated SP shunt control circuitry
- ABCN-25 ASIC
  - Binary architecture: 128 channels of trimmable preamplifier/discriminator, pipeline and control logic
  - LDO to produce 2.2V analogue power from 2.5V digital
  - Dual (redundant) shunt transistors
- Expected Operating Threshold
  - 0.7fC

Figure 1: The Short Strip Stave Module

Early Results

Studies from a serially powered stavelet were first presented at TWEPP 2010. The stavelet was built in a "Chain of Hybrids" configuration, meaning that the two hybrids on each sensor sit at different DC potentials with respect to the system ground. As a consequence of this, only one hybrid may be DC referenced to the sensor: the other must be AC referenced. Initially found to have good ENC noise performance, this stavelet was later found to exhibit unacceptable noise occupancy at certain points during the readout cycle. A small voltage dip correlated with receipt of the trigger signal was found to be feeding back into the front end, making clean operation at 0.7fC threshold impossible.

Studies of a companion stavelet built using STV-10 DC-DC converters (provided by the CERN group) were presented at TWEPP 2011, concluding that a "star" configuration of the power feed and return was essential to decouple each module from external noise currents.

To obtain the best noise performance it was also necessary to add a second backplane connection to each module and to tie the ground planes of each sensor's two hybrids together as closely as possible. This was achieved by means of multiple bond wires placed between each hybrid's ground plane and the aluminium foil located under each sensor: originally intended to shield the sensors from LVDS signals routed underneath, these aluminium foils were now serving as a **referencing plane**. The connection between the inner edges of each hybrid pair, having the lowest inductance route, were found to be especially important. After modification, the DC-DC stavelet had acceptable noise occupancy at all points of the readout cycle, at and below the expected 0.7fC operating threshold. For further details, including an explanation of the Double Trigger Noise Test method, please see reference 1.

A New Serially Powered Stavelet

We fed back the results of our previous studies into the design of a new bus tape which provides additional opportunities to make referencing connections between the hybrids. Another feature of the new design is that the mass of the reference plane under each sensor differs from location to location, with the base aluminium material having been etched away in various cross-hatch patterns. In each case a "hollow square" of solid material is left to facilitate referencing connections.

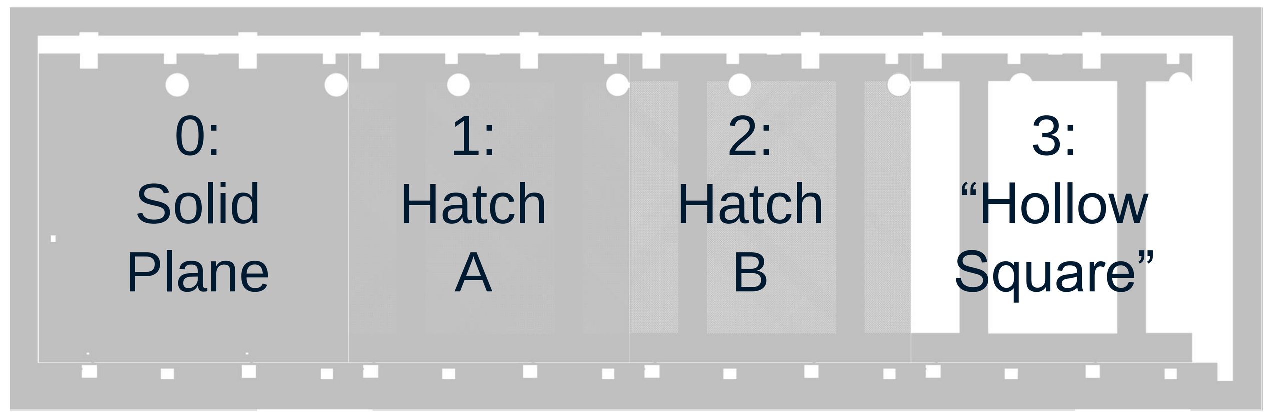


Figure 2: Material reductions in the referencing plane

The stavelet was configured in a "Chain of Modules" configuration which places the two hybrids on each sensor at the same DC potential, hence both hybrids of a module are DC referenced to the sensor. In addition, custom PCBs were made to implement a star power feed to each module. To simplify these boards, power protection circuitry was not included: this had been shown to work as part of the initial stavelet. Instead wires were added to each module's power feed such that each module could be individually powered to obtain reference results. After this the modules were linked to form a serially powered chain, initially by means of these copper wires and later by Aluminium wirebonds.

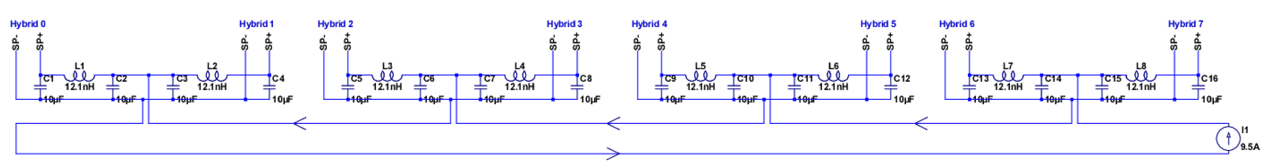


Figure 3: Schematic showing the "Chain of Modules" Star Power Feed

Results: Individually Powered

ENC performance was in agreement with results previously obtained for each module operated on a metal cooling block, once temperature differences were taken into account at approximately 1.5 ENC/degree.

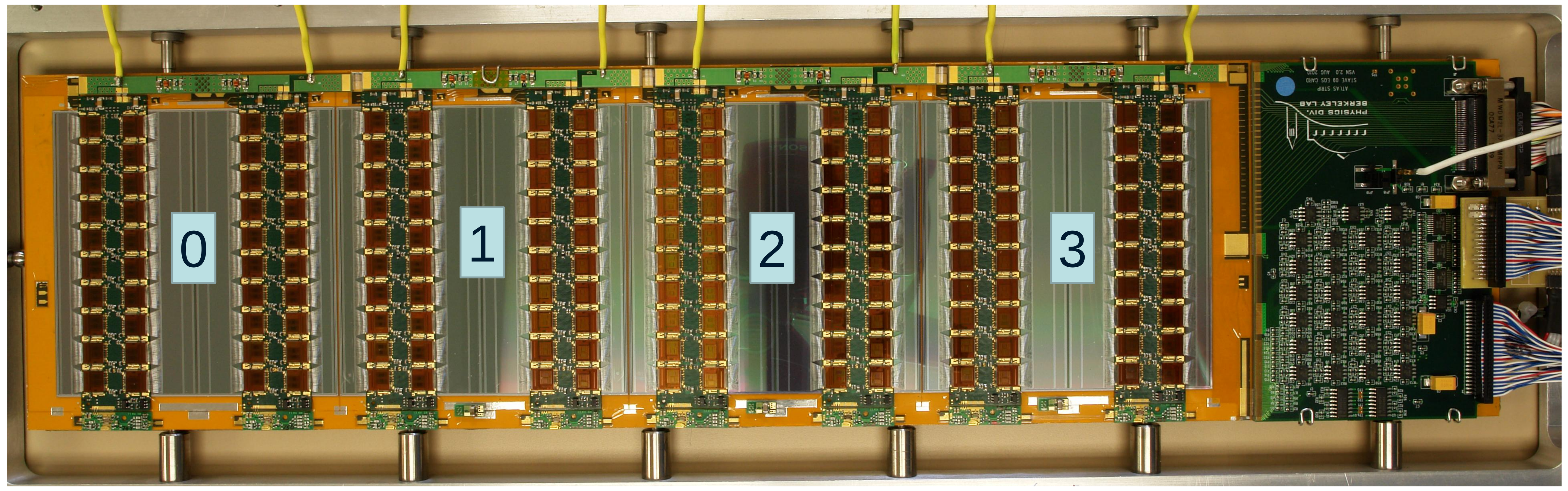


Figure 4: The Completed "Chain of Modules" Stavelet

One point to note is that module 0 was built using a hybrid from which the bottom shield layer had been omitted, giving rise to localised excess noise occupancy in column 3 due to the use of non-blind vias on certain LVDS lines. This has been corrected in later submissions of the design. With the exception of column 3, no module showed excess occupancy correlated with readout activity at the target operating threshold of 0.7fC, and occupancies at 0.5fC gave similar values to those previously recorded for the DC-DC stavelet as shown in Figure 5.

	DC-DC Stavelet	"Serially Powered" Chain of Modules Stavelet				
PSU	TSX1820P	TSX1820P				CPX400DP
ASIC Column	All Powered	Individually Powered	SP Wires (no caps)	SP Wires + CM caps	SP Bonds + CM caps	SP Bonds + CM caps
0	0	10	7	13	11	8
1	1	15	18	18	21	15
2	6	2	2	2	1	2
3	36	18237	18505	18603	18678	18707
4	18	0	0	0	0	0
5	5	0	0	0	0	1
6	12	3	4	4	2	1
7	38	2	5	2	2	2
8	12	0	11	0	0	2
9	2	0	1	0	0	1
10	4	0	17	0	1	0
11	9	3	35	1	0	3
12	0	8	609	4	10	8
13	0	9	640	7	11	7
14	0	11	1785	8	26	8
15	4	12	1770	19	43	15

Figure 5: Double Trigger Noise Occupancy at 0.5fC

Results: Serially Powered

Joining up the copper wires to form a Chain of Modules, ENC performance remained consistent with earlier tests, once temperature differences were taken into account. Initially a deterioration in noise occupancy correlated with readout activity was observed toward one end of the stavelet, which was attenuated by the addition of 10μF capacitors between each module's reference plane and system ground, routed by means of a the screen placed over the LVDS control lines which run along one edge of the bus tape. By such means the level of performance seen with the modules individually powered, one at a time, was recovered.

Finally the copper wiring between the modules was replaced by Aluminium wirebonds. A very small deterioration in double trigger noise occupancy was observed, but this was recovered by replacement of the power supply by a more modern model. The reasons for this remain under investigation. The results are tabulated in Figure 5.

Conclusions

The serially powered stavelet with "Chain of Modules" Star power feed works well, with observed ENC values within the range expected due to temperature variation between single module and chain configurations. Whilst a common mode signal develops along the stavelet, this was controlled by adding capacitors between the module reference planes and the (grounded) LVDS screen, bringing DTN occupancies down to the level observed during on-stavelet, single module reference studies. The lack of dependence of ENC or DTN results upon module location indicates that a solid or even hatched shield is not required, and that the "hollow square" is adequate for referencing purposes, however the impedance of this connection is critical and should be made by the shortest possible route.

We shall carry this knowledge forward to our future programme with (lower power) ASICs in 130nm technology.

References

1 Peter W Phillips, ATLAS Strip Tracker Stavelets, 2012_JINST_7_C02028

Acknowledgements

This work is presented on behalf of the ATLAS Strip Tracker Stave community, however special mention must be made of institutes providing the components used to make this stave. Thanks to Oxford for providing the bus tape; to Liverpool for assembling the stave core, providing modules and the "CofM Star" power PCB layout; to Cambridge for providing modules; to LBNL for the BCC and End of Stave (buffer) boards. Thanks also to Dave Lynn (BNL), Mitch Newcomer (Penn) and Ned Spencer (UCSC) for discussions on the subjects of grounding, shielding and referencing.

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