Strip sensor performance in prototype modules built for ATLAS ITk

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Abstract

More than 80 ATLAS ITk prototype strip modules were built with ATLAS12 sensors [1-2]. They were tested with electrical readout on the per-channel basis. In general, an excellent performance was observed, consistent with previous ASIC-level and sensor-level tests. However, the lessons learned included two phenomena important for the future phases of the project. First was the need to store and test the modules in a dry environment due to humidity sensitivity of the sensors. The second was an observation of high noise region for some modules. About 2.5% of modules were affected.

The high noise regions were tested further in several ways, including monitoring the performance as a function of time and bias voltage. Additionally, direct sensor-level tests were performed on the affected channels. The inter-strip resistance and bias resistance tests showed low values, indicating a temporary loss of the inter-strip isolation. A subsequent recovery of the noise performance was observed. We present the test details, an analysis of how the inter-strip isolation affects the module noise, and relationship with sensor-level quality control tests.

INTRODUCTION

Modules (Figure 1) typically exhibit good electrical performance [3]. The ambient humidity for both module testing and storage affected the breakdown voltage (Figure 2). When kept dry, the sensors had good performance throughout the assembly steps (Figure 3). Further humidity sensitivity studies are shown in submission by Javier Fernandez-Tejero *et al*, "Humidity Sensitivity of Large Area Silicon Sensors: Study and Mitigation" (Tuesday afternoon)

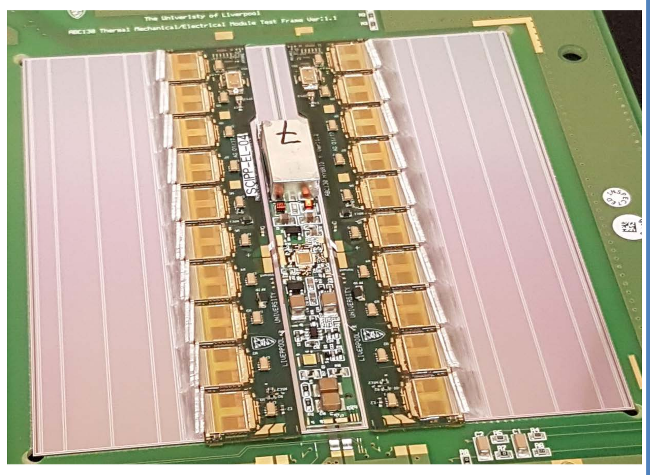


Figure 1 A module with ATLAS12 sensor

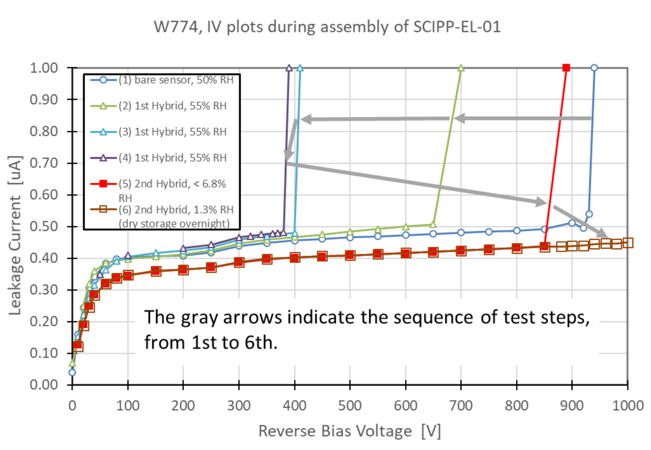


Figure 2 Breakdown evolution at different assembly steps and humidity levels.

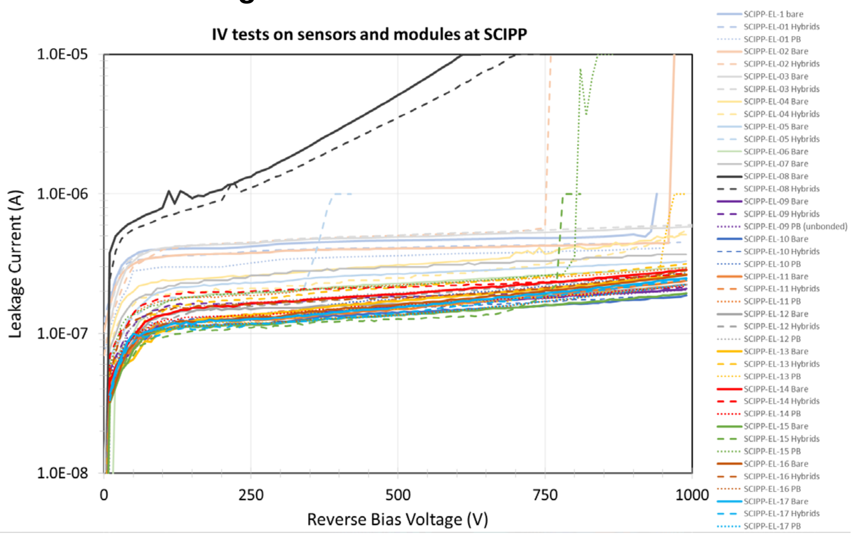


Figure 3 IV test for 17 modules kept in dry environment.

High noise occasions

There were 2 occasions, out of over 80 modules built, when there was a region of high noise exhibited. This region comprised about 35 strips out of 5120 total on this module type. This region seemed to pertain to the sensor performance:

- There was no correlation with the hybrid-level noise performance, or readout from a different strip row by alternating channels on the same ASIC (Figure 4).
- The noise level strongly depended on the bias voltage (Figure 5).
- The noise level changed over ~1 month time scale.

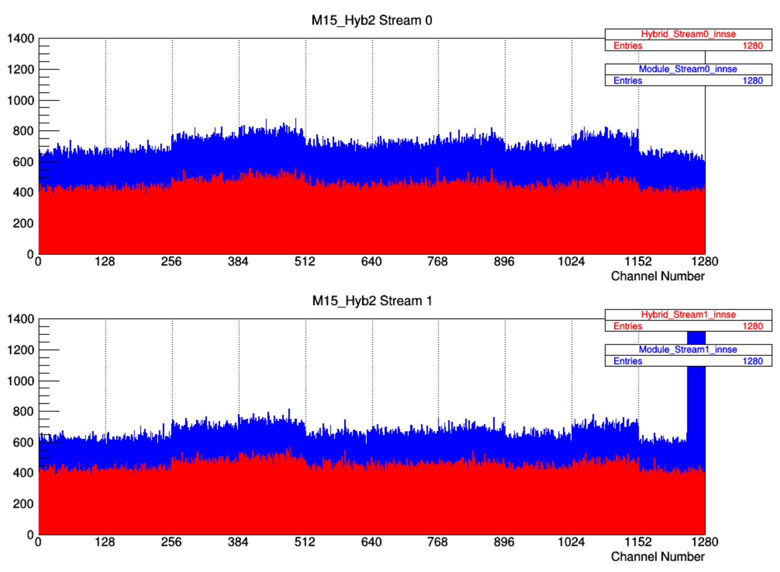
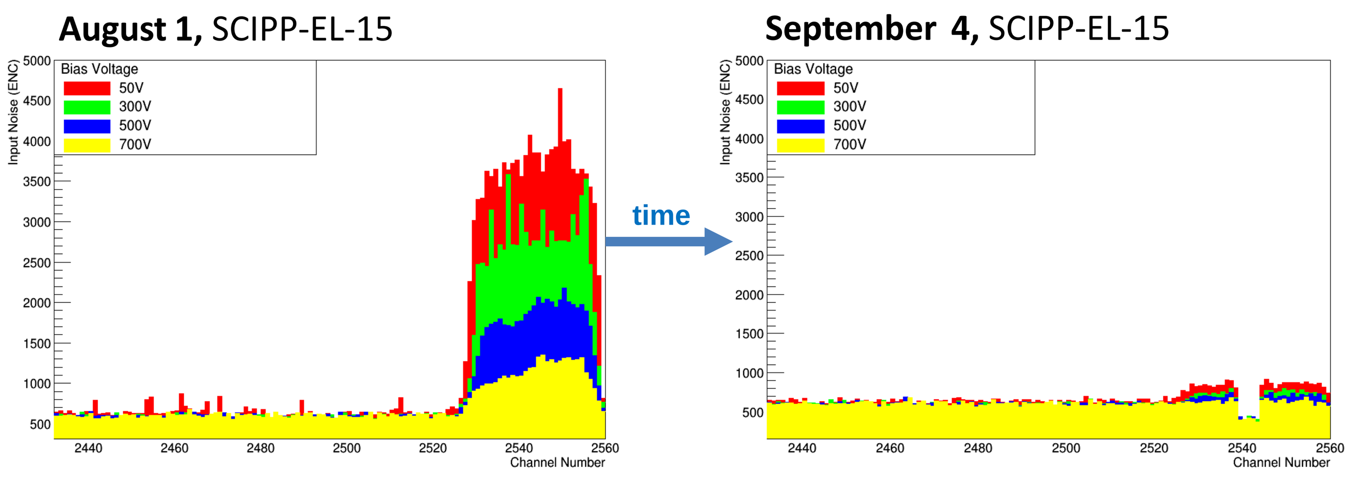


Figure 4 Input-referred noise vs channel number for a module with breakdown region. Red plot is for hybrid-level test. Blue plot is for module-level test.



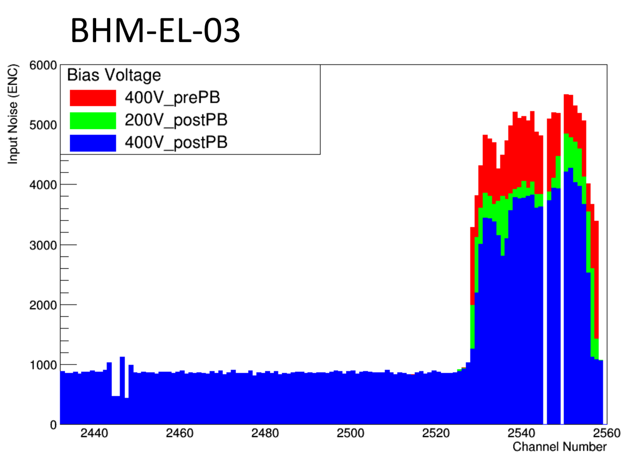


Figure 5 Zoom-in the noise plot at the region with high readout noise for two modules that had it. The top two plots are for the same module tested at different times. The 4 channels in the middle of the region had lower noise in the last test due to removed wirebonds.

Sensor Properties

On one of the modules we disconnected 4 channels in the middle of the high-noise region from the readout ASIC. The DC contact pads on these channels were wirebonded out to traces for electrical contact (Figure 6). Measurements of inter-strip resistance and effective bias resistance were performed in dry atmosphere (1-4% RH) at 15 C (Figures 7 and 8):

- Clearly the inter-strip resistance has a strong dependence on bias voltage.
- Single-probe bias resistance also depends on the bias voltage, likely influenced by the small R(int) to the neighbouring strips. The 3-probe bias resistance measurements (with neighbouring strips held at the same potential as the "central" strip) has a less strong dependence.

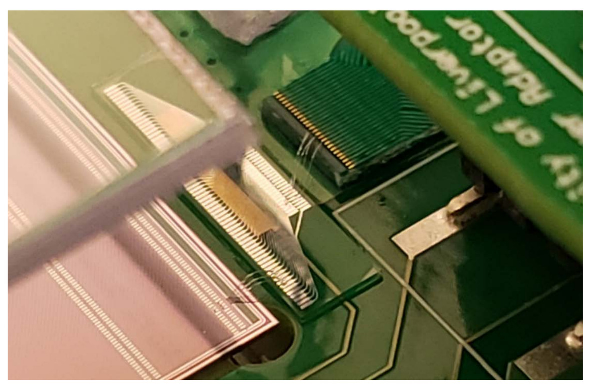


Figure 6 Wirebonded connections for 4 test channels in the high-noise region.

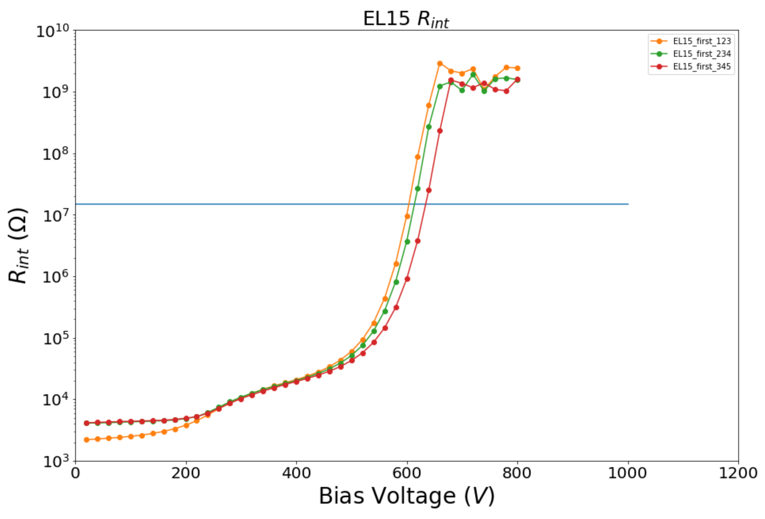


Figure 7 Inter-strip resistance measurements as a function of bias voltage for the 4 test channels

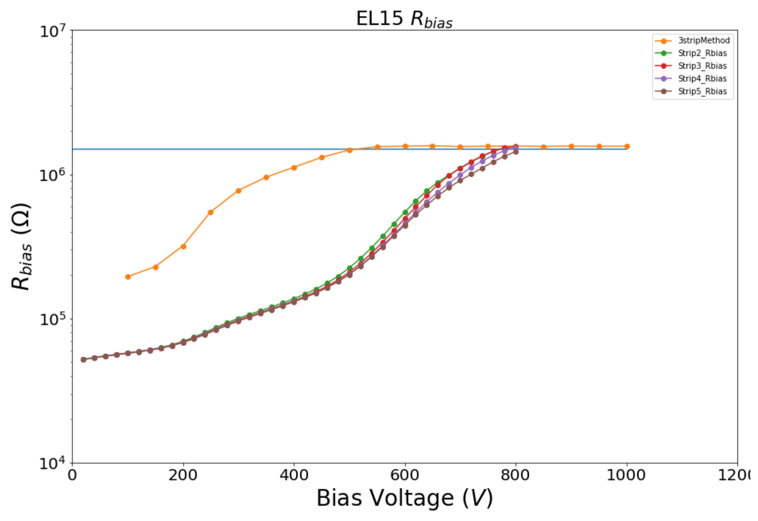
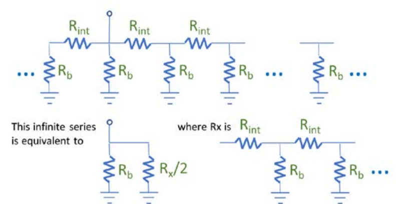


Figure 8 Inter-strip resistance measurements as a function of bias voltage for the 4 test channels

Relation with the module noise

Effective R(bias) will be less than the true value of bias resistor when R(int) is not large [4]

$$R(bias,eff) = \frac{R(bias)*Rx/2}{R(bias)+Rx/2}\ , Rx = 0.5*\left(R(int)+\sqrt{R(int)R(int)^2+4*R(int)*R(bias)}\right)$$



This will increase the module noise due to the parallel resistance term [5]:

$$Q(Rbias,eff) \propto \sqrt{4kT\tau/R(bias,eff)}$$

However, Z_{in}(amp) < 1 kΩ , therefore the R(int) is a "parallel" resistor by itself (Figure 9). The noise estimate in this case is even larger (Figure 10). It's qualitatively consistent with the data (Figure 11).

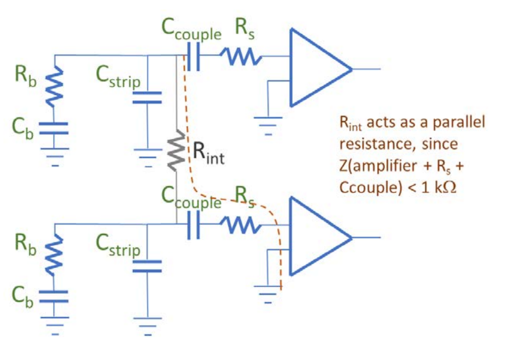


Figure 9 R(int) as a "parallel" resistance for module noise

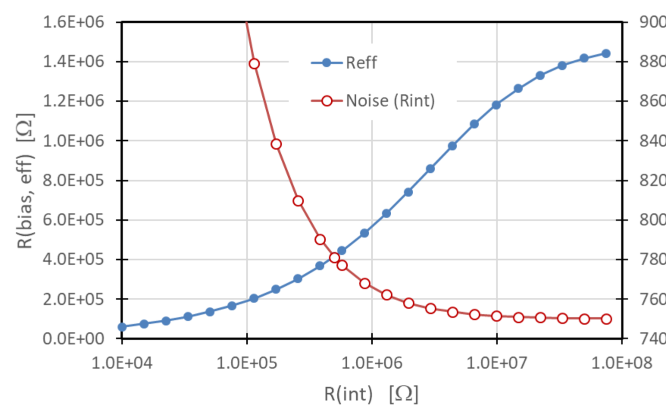


Figure 10 Effective bias resistance and strip noise as a function of R(int).

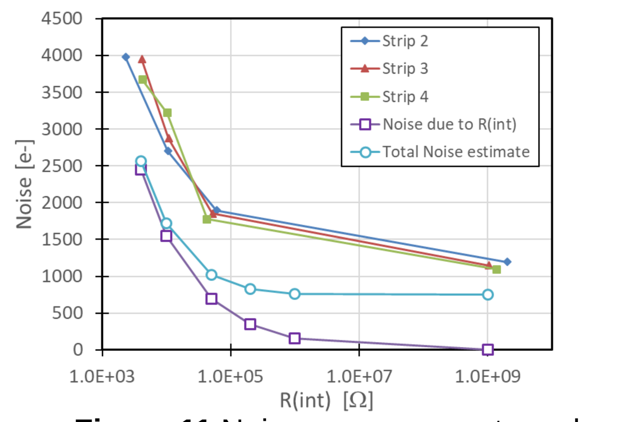


Figure 11 Noise measurements and estimates a function of R(int).

Wafer-level tests

The ATLAS12 sensors used for these two modules were previously tested on a probe station at the per-strip level. The R(bias) measurements at that time showed stable values inconsistent with the low resistances indicative of the large noise observations. However, there was a test performed on a different wafer, which indicated qualitatively similar features:

- A region with small bias resistance (Figure 12)
- Bias voltage dependence of the resistance (Figure 13)
- Eventual change of the resistance value to the nominal 1.5 MΩ

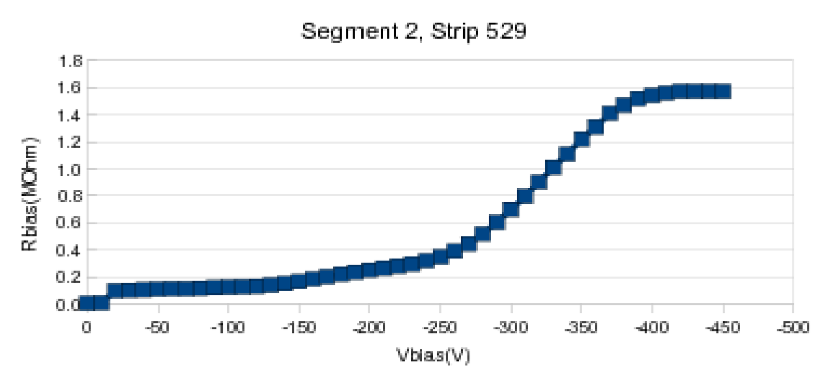


Figure 13 Effective R(bias) as a function of bias voltage for strip 529.

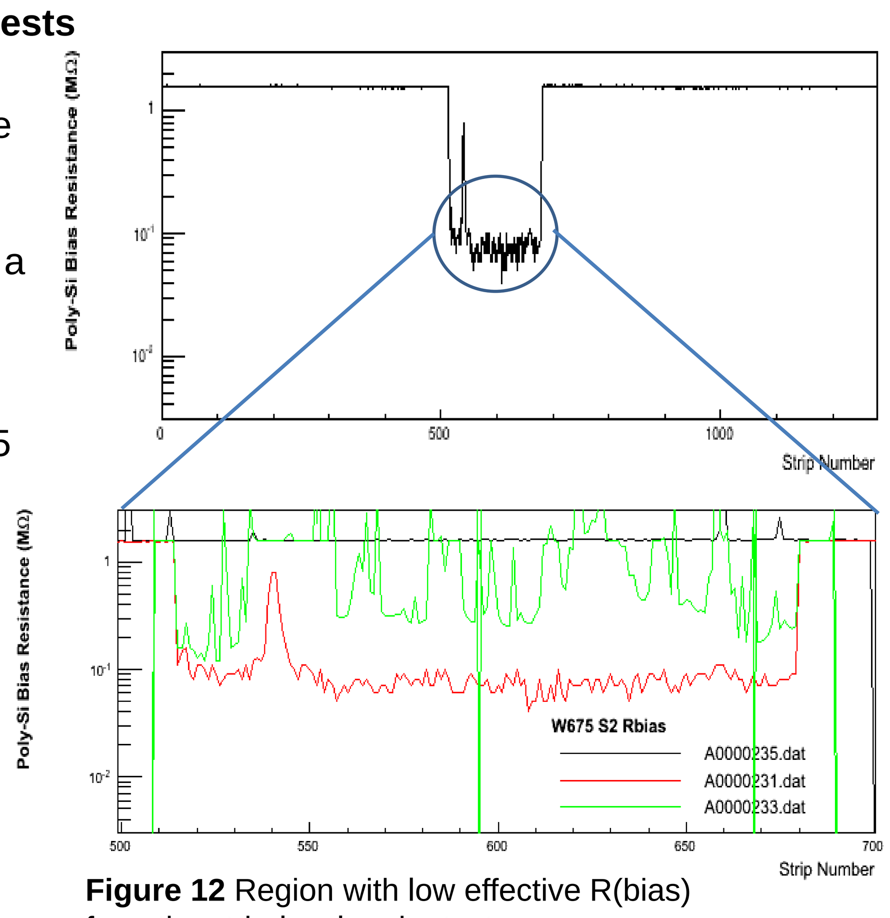


Figure 12 Region with low effective R(bias) from the strip-level probe tests.

Regions with low effective R(bias) were also found in strip-level tests of a subsequent prototype version, ATLAS17LS. Two sensors were afflicted by this phenomenon (Figure 14). In one case there was an improvement with time. For the other sensor, the low-resistance region expanded with time. ATLAS17LS design details are described in two contributions:

- Y. Unno et al, "ATLAS17LS - Large-format prototype silicon strip sensors for the long-strip barrel section of the ATLAS ITk strip detector"
- M. Ullan et al, "Design and Evaluation of Large Area Strip Sensor Prototypes for the ATLAS Inner Tracker Detector"

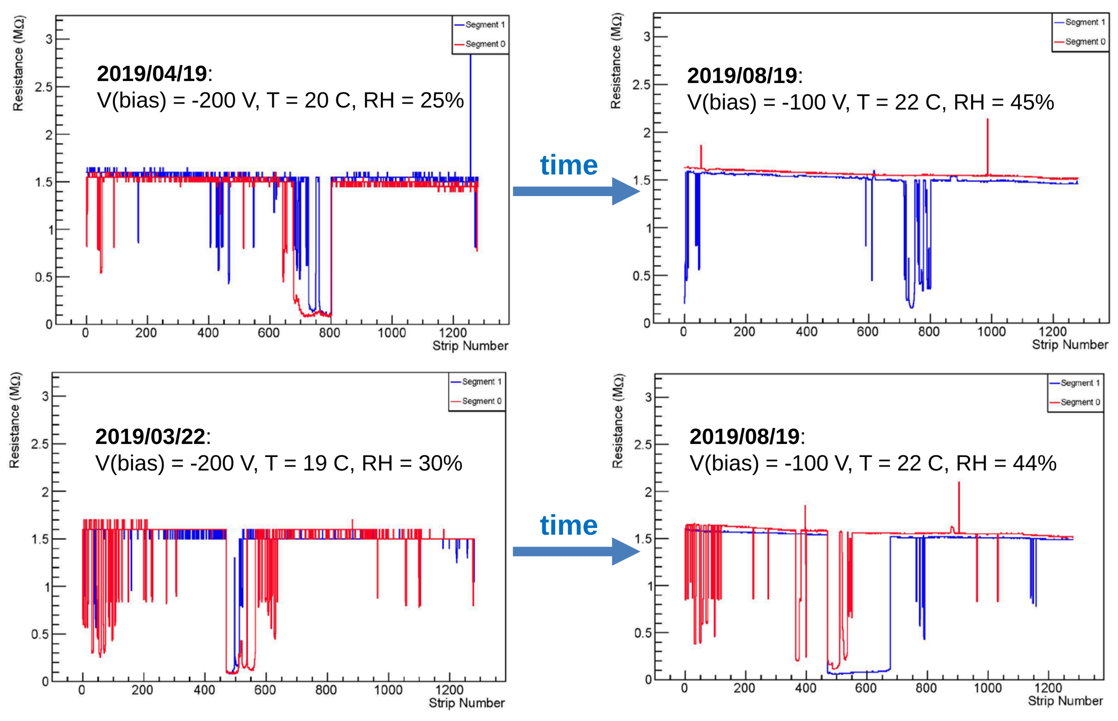


Figure 14 Change of low R(bias) regions with time on 2 ATLAS17LS sensors.

CONCLUSIONS

We have seen 2 high-noise observations on modules. They feature time and bias voltage dependence. Further investigation revealed:

- This is related to the temporary loss of inter-strip resistance
- Low R(int) leads to extra noise, likely as an extra "parallel resistance."

There are corroborating observations from strip-level probe tests:

- A case when a region with low R(bias) disappeared during strip-level probe tests of the sensor
- There are a couple of ATLAS17LS sensors with similar regions, that have signs of evolution.

References

1) Y. Unno *et al*, "Development of n+-in-p large-area silicon microstrip sensors for very high radiation environments – ATLAS12 design and initial results", NIM A 765 (2014) 80-90
2) L.B.A. Hommels *et al*, "Detailed studies of full-size ATLAS12 sensors", NIM A 831 (2016) 167-173
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4) A. Chilingarov, "Interstrip resistance measurement", RD50 technical note RD50-2009-01.
5) H. Spieler, "Semiconductor Detector Systems", Oxford University Press, 2005

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