To boldly go where no Sunsensor has gone before. part 2

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Abstract: During the AIA small satellite symposium in 2017 Lens R&D presented the progress on environmental tests performed on the BiSon74-ET-RH extended temperature Sunsensor. Now Lens R&D is taking this type of product a step further in frame of an ESA GSTP program which is to lead to two different types of fully ESA qualified Sunsensors. Being small enough to fit on almost any satellite and fully optimised for volume production through the use of a dedicated pick and place machine dubbed the *MAMA* tool (Mechanical Automated Membrane Aligner), the BiSon64-ET and BiSon64-ET-B Sunsensors are expected to become Sunsensors that can be universally applied.

The last process optimisation that could be profitably performed was the membrane alignment which is now fully automated by using the MAMA tool. This not only leads to a higher non-calibrated accuracy but also to a higher repeatability in production and consequently yield.

Furthermore, lengthy discussion with ESA on quality control and associated costs have led to a qualification program which is tailored to volume production and a combination of the ESA-ECSS-Q-ST-10-03 equipment qualification and ESA-ECSS-E-60-05 quality control for hybrid circuits specifications.

The presentation will focus on the design and development of the MAMA tool, the qualification process and qualification status of the development of the BiSon64-ET and BiSon64-ET-B Sunsensors and the associated pigtail cables. The pigtails are an addition to the program to ensure availability of pigtails able to match the sun sensors extended temperature and radiation hardness without any issues. These pigtails will be flown along with 20 sensors on the ESA Proba-3 mission.

1. INTRODUCTION

Lens R&D has developed, built and tested *Sunsensors* (in frame of an ESA Artes 5.2 contract) that exhibit an unprecedented operating temperature range. A combination of ceramic injection moulding and careful material engineering has led to sensors that have shown to be able to operate over a temperature range spanning -125°C to +125°C.

Figure 1: BiSon74-ET-RH

The titanium housing, 2mm sapphire window (and diodes that have been tested up to 1.1Mrad and 10^{16} 1MeV electrons) of the Bison74-ET-RH (figure 1) provided 3mm Aluminium equivalent circumferential radiation shielding. This, together with the extended temperature range, leads to sensors that are capable of surviving even the most demanding environments.

The test program (reported on in part 1 of this paper) showed a good survivability of the sensor, except for some issues with the epoxy glues. Consequently, new glues had to be found matching the extended temperature range. Another issue encountered was the fact that the laser cutting process of the thick membrane presented some issues with respect to laser damage on the coating. Together with the fact that a smaller FOV was better for most applications, this has led to a redesign of the Bison74-ET-RH to the BiSon64-ET. Thus, sensor has a thinner membrane, but in the meantime, it was realized that the tested 10^{16} 1MeV electron withstanding capability would allow to operate the sensors for hundreds of years in any selected orbit, even without the thick membrane.

2. EXTENDED TEMPERATURE SUNSENSOR DEVELOPMENTS

Further development and full qualification of the Bison64-ET was initiated in frame of an ESA GSTP program. There still was one critical issue to be solved, the extreme demand on accuracies for the membranes, mainly in relation to the laser cutting process of the sapphire wafers. A solution was found in a change to the sensors assembly strategy had to be revised: to change the high accuracies on dimensions of the (opto-mechanical) components to a more accurate monitoring and control system during assembly. This finally led to the development of the Mechanical Automated Membrane Aligner tool (MAMA tool in short).

Figure 2: MAMA tool

This production tool will be used to actively align the membrane with respect to the sensor and basically consists of a X/Y/Z translation stage setup with a vacuum gripping system and a Sun-simulator.

The membrane and semi-finished Sunsensor are both placed on a special holder which can be translated in the X and Y direction and kept in place by means of vacuum. The Sunsensor is then connected to the readout electronic and after placing the membrane in the nominal pick-up position, the door is closed.

When the door is closed, the Z stage comes down and picks up the membrane. As a second step the membrane is lifted up and the sensor is positioned under the membrane at the nominal position. When nominally positioned, the membrane is lowered to the appropriate height above the sensor and the solar simulator is activated. The final positioning of the X,Y stage is then controlled in such a way that the membrane is positioned exactly centred above the photodiodes quadrant. When properly positioned, the Z-stage lowers the membrane to its mounting surface on the sensor and the already applied UV curable glue is cured by switching on the integrated UV light sources. After the UV-curing process the membrane cannot shift with respect to the diodes anymore and the sensor assembly process can be completed by thermally post curing the glue.

In this way, the product can not only be produced with very high repeatability, but also the Zenith error will be significantly reduced, thus increasing the non-calibrated accuracy.

As an additional verification step after the initial assembly it is possible to turn on the Sun simulator again to see if the membrane has shifted during the curing process so as to verify the accuracy of assembly even before the sensors are fully cured and calibrated.

This method was used to optimise the assembly and curing process and proved very valuable in improving the overall performance of the MAMA tool. A first set of sensors have been produced at Lens R&D and the first results were very promising.

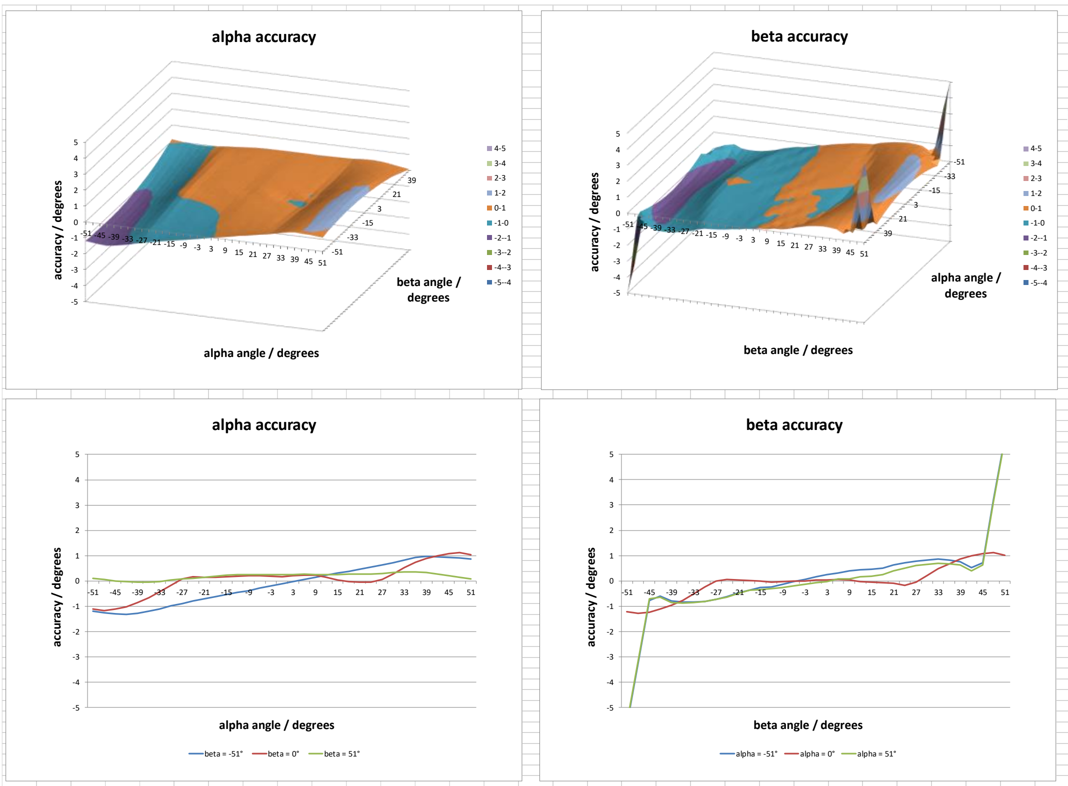

Figure 3 non-calibrated accuracy of first sensor assembled.

As Figure 3 shows, the non-calibrated accuracy at room temperature has improved from some 2.5° to less than 1.3° at the extremities of the field of view. For a very first attempt this is a very good result for which it can be noted that especially the error at Zenith has been significantly reduced. (even though for this particular sensor a small offset in alpha is still present.

In the meantime, several additional sensors have been assembled with similar results and assembly procedure improvements have since been implemented. Over time it has become obvious that assembly down to the micrometre accuracy level is all but futile and various small contributors need to be carefully isolated, evaluated and mitigated in order to improve the assembly accuracy to beyond the initial level achieved.

One of the key parameters that need further investigation is the nominal field of view. The on-axis field of view is currently indicated to be 58° and a deviation from this field of view can be caused by different mechanical tolerances and variation on glue thicknesses for instance. For the moment all indications are that the actual field of view is slightly larger than the specified 58° and more like 58.5°. Although this is only a small variation, it does have a remarkable effect on the overall non-calibrated accuracy as can be seen in below figure.

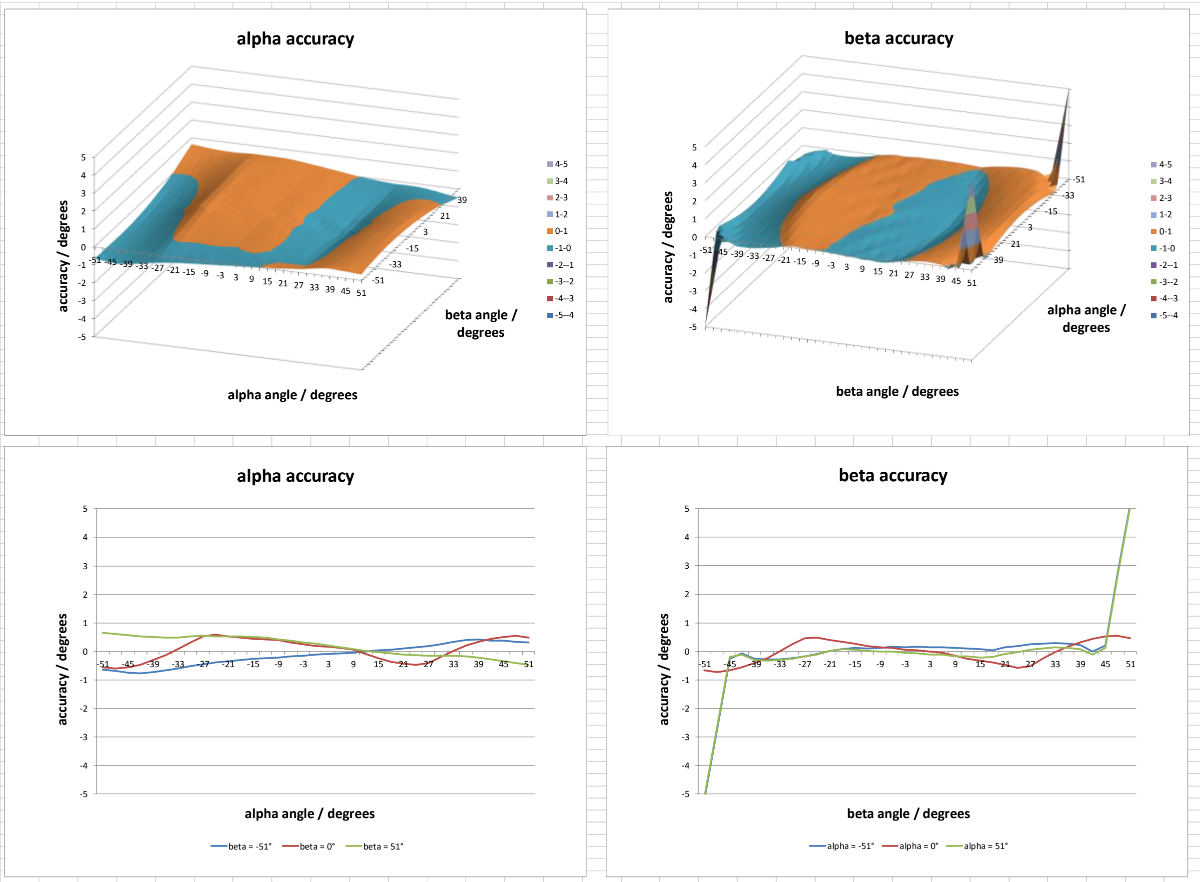

Figure 4 non-calibrated accuracy for 58.5° field of view.

Both Figure 3 and Figure 4 are based on exactly the same calibration data, only the field of view is changed from the 58° given in the ICD to 58.5°. Based on this change, the accuracy has improved from 1.3° to 0.7°. As the theoretical 58° doesn't take the actual glue thicknesses into account, statistical evidence might well prove that it is justified to change the nominal field of view to the above shown 58.5°, thus further increasing the non-calibrated accuracy.

The above data shows that the non-calibrated accuracy at room temperature by far exceeds anything seen on any current generation fine Sunsensor. Statistically proving this accuracy is valid for any sensor produced will take a very serious amount of labour and costs as a statistically significant number of sensors will have to be produced and calibrated before anything sensible can be said on things like measured 3σ error values or other confidence intervals. Despite this, it is very obvious from the acquired data that the performance to be expected in the future has been significantly increased with the commissioning of the MAMA tool.

Figure 5: BiSon64-ET and BiSon64-ET-B

All extended temperature Sunsensors (BiSon64-ET and the baffled version BiSon64-ET-B) will be assembled using this tool and assembly approach. While the ICD specifications, except for a slight increase in mass and dimensions of the baffle, have not changed, these products are drop-in replacements for the Bison64 sensors, however with a much wider temperature range.

The sensors will be qualified using a full ESA ESCC-E-10-03C test flow but it has been agreed upon with ESA that after the full qualification, the acceptance testing of FM units will be done through LAT2 lot acceptance testing according to ESCC-Q-60-05 (hybrid circuit qualification), to avoid costly and time-consuming acceptance tests.

3. TEST PROGRAM

In the meantime, several precursor tests on the selected glues have been performed, showing that the sensors with the updated glue selection are capable of surviving not only the severe temperature shock test performed by heating the parts up to +125°C and then dipping them in liquid nitrogen, but also 36.000 thermal cycles between -90°C and +95°C (which is equivalent to 7 years in LEO orbit). The maximum rate of change during the thermal cycling test–has been >15°C/min, which means the sensors are proven to be very resilient to temperature change

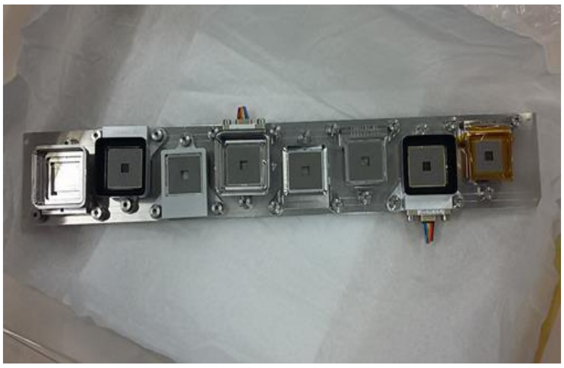

Figure 6: thermal cycling glue samples

The thermal cycling test was performed at ESTEC by putting the samples in the same thermal cycling tests as the solar panels for the LuxSpace ESAIL mission.

The qualification program currently running is largely in line with ECSS-E-ST-10-03 and shown in Figure 5.

An additional 10 thermal cycles test was added before vibration testing to mimic the loads provided by the on-ground thermal balance testing. This reduces the risk for the total test program, as it ensures that any failures in the bonds will be found early in the test program, avoiding costly retests to the largest extend possible.

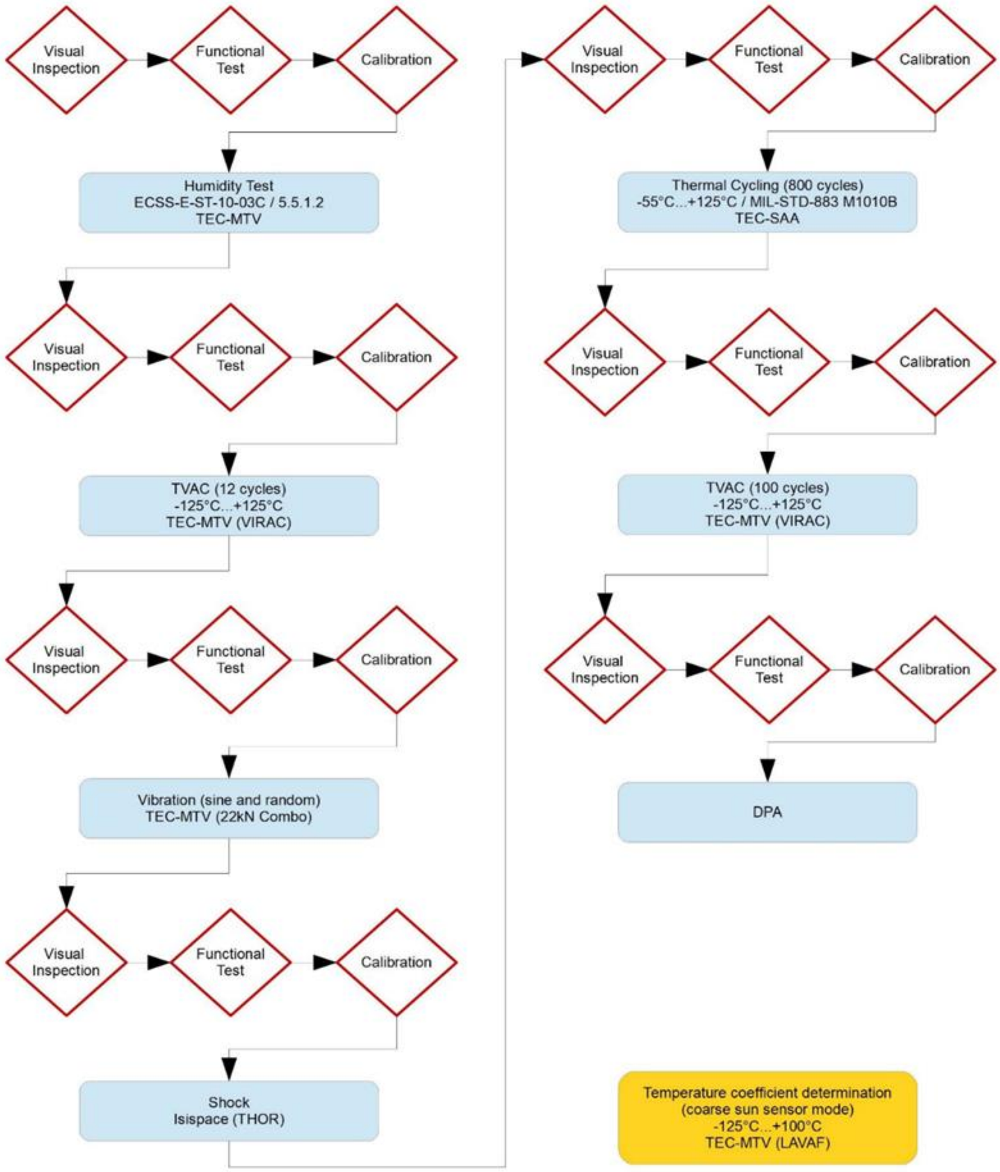

Figure 5: Bison64-ET Test Sequence

4. CONCLUSIONS

The earlier completed Artes 5.2 program in combination with the glue testing has shown that it is possible to produce *Sunsensors* that can withstand the large temperature excursions associated with direct solar panel mounting or interplanetary missions. The high radiation tolerance (240Mrad tested at diode level) and provided 1mm aluminium equivalent shielding will allow to use these sensors in high radiation environments. This combination qualifies the sensors for just about any mission conceivable. Flight standard sensors have been produced and are currently being put through a full qualification program. Upon completion of this qualification these sensors will have proven to be able to:

"boldly go where no Sunsensor has gone before."