Validation and Test Results of the 2.5D Technology for Pancake Slip Rings

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Abstract

A slip ring assembly project has been performed to demonstrate that in future space mechanisms a slip ring assembly based on 2.5D printed circuit board (PCB) technology can replace the currently used risky and costly design. Four units with 2.5D technology have been manufactured, assembled and tested for an ESA ARTES 5.2 project to validate this technology at a level of TRL5.

The 2.5D PCB technology slip rings have undergone all the mechanical and environmental tests without showing any degradation. During the TVAC test, some lines have shown high dynamic resistance performance. After investigation, it was confirmed that this degradation (noise) was linked to a contamination problem.

The same level (even better) of performance is achieved with this type of technology compared to the standard one.

2.5D Slip Ring Definition and Validation

The data and power transfer within space mechanisms, such as a Solar Array Drive Mechanism (SADM), is in principle ensured by a contact technology. These components known as slip rings are of two types: cylindrical and pancake. The pancake slip ring concept is the one discussed in this paper. The pancake solution is made of electrical conducting tracks arranged on a flat disk as concentric rings centered on the rotating shaft (Fig. 1). The planetary configuration allows optimization of weight, volume and electrical features of the circuits.

The 2.5D PCB slip ring is a planetary slip ring composed of two sub-assemblies:

- The stator assembly, the fixed part of the slip ring.
- The rotor assembly, the rotating part of the slip ring.

The contact between the stator and rotor is ensured by wire brushes, soldered on the stator side on a PCB and preloaded to be in contact with the track during the whole life time.

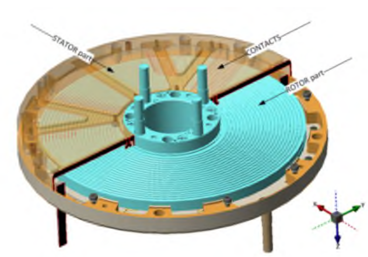

Figure 1. 2.5D slip ring overview

The main challenge of the project was to manufacture the rotor sub-assembly in only one part (PCB technology) to remove all the operations of gluing, machining, potting and soldering that increases the manufacturing activities. Therefore, the novelties of this innovative technology are:

- To apply a thickness layer of pure copper up to 500 µm based on PCB technology, this in order to manufacture a groove for brush guidance.
- To apply a hard gold plating on the tracks (according to a space-qualified RUAG process)
- To obtain the insulation barriers between tracks during PCB manufacturing operations
- To create a guidance groove in each track during PCB manufacturing operations
- To have a thermal drain inside the PCB to dissipate as much as possible the heat at the interface
- To choose the better candidate between different possibilities for the insulating barrier material

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In addition, special attention was focused on the stator sub-assembly to simplify the integration phase. A dedicated stator PCB was designed to improve the thermal dissipation of the slip ring and reduce the variation of current distribution into the wire brushes. The main modifications are showed in Figure 2 and Figure 3.

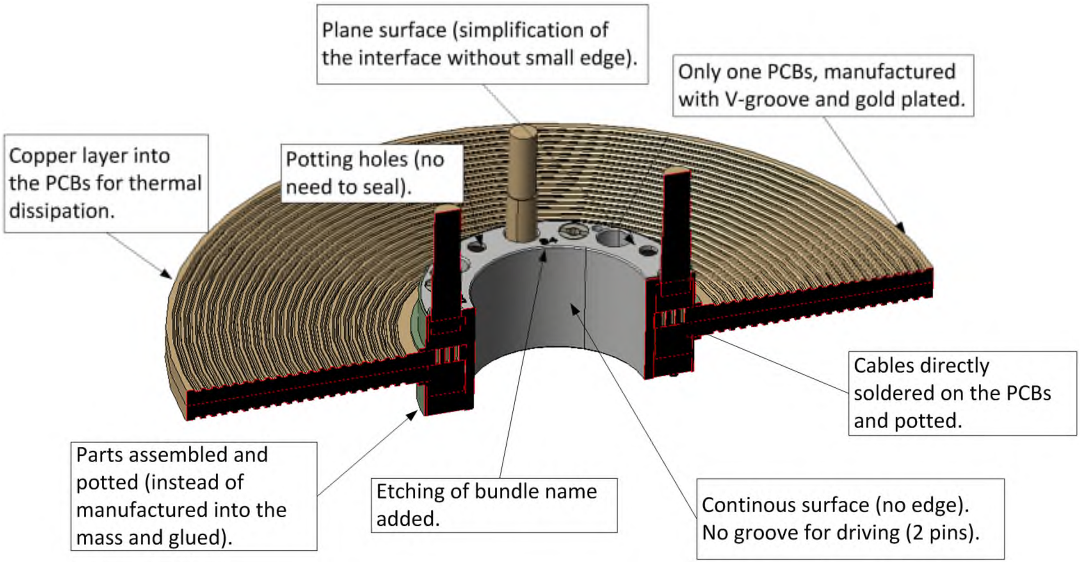

Figure 2. Rotor sub-assembly improvement

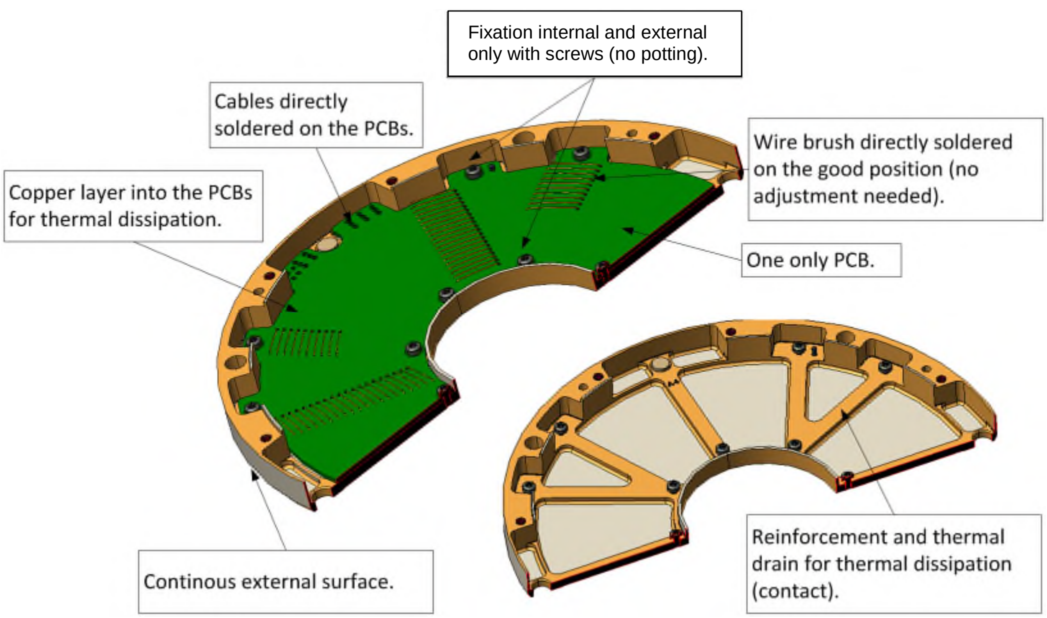

Figure 3. Stator sub-assembly improvement

The main benefits due to these improvements are:

- Reduction of manufacturing process time (no gluing, no adjustment of wire brushes, direct soldering) by about 50%
- Better reliability (controlled processes)
- High thermal dissipation on both sides (rotor and stator)
- Better current repartition into the wire brush (decrease of creep effect)
- Possibility to be modular

The electrical configuration of one module of a 2.5D slip ring consists of 20 power lines designed for 5.4 A and 20 signal lines designed for 1.1 A. This allows transfer of a total current of about 130 A (forward and return). For two modules in parallel, the transferred current can be doubled.

All steps performed during assembly have been verified and the process was validated. The final sub-assembly and assembly pictures are shown in Figure 4.

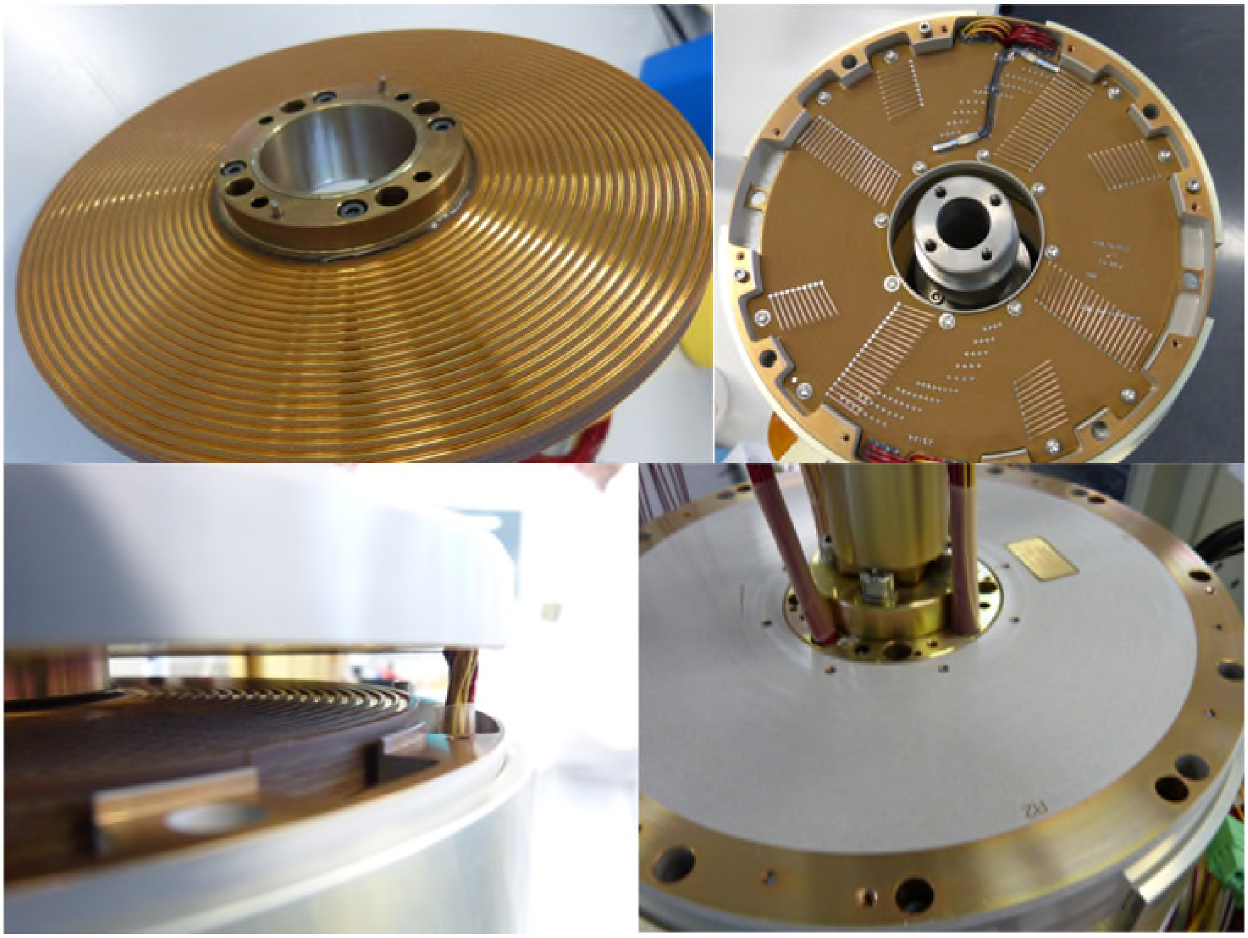

Figure 4. Sub-assembly and assembly pictures

Four units have then been tested according to the test sequence shown in Figure 5.

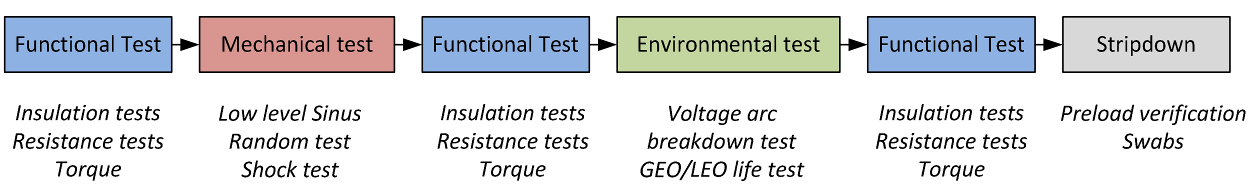

Figure 5. Qualification test sequence

The 2.5D slip rings performed all the mechanical and environmental tests without showing any degradation. Some lines were detected out of specification in terms of dynamic resistance performance during the environmental tests. After an investigation, it was confirmed that the identified noise was linked to contamination during integration. It has been assessed that a potential contamination occurred onto the slip rings rotors while cycling them into the oven. (Rotors were positioned into the oven as described in Figure 6).

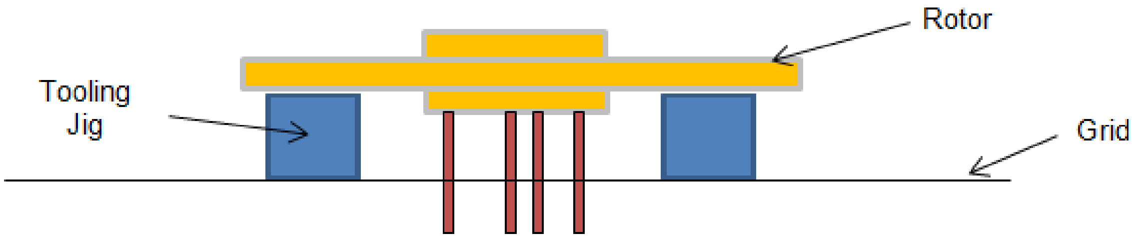

Figure 6. Rotor sketch assembly into the oven

The investigation showed that the tooling jigs the rotor rests onto into the oven have the exact same shape as the one observed on the rotor. Some Kapton® tape residue was present on the jigs and the assumption is made that contamination occurred at this stage. Kapton® tape glue has evaporated onto the rotor track during the temperature cycling. The rotor clearly exhibits a discoloration as depicted in Figure 7.

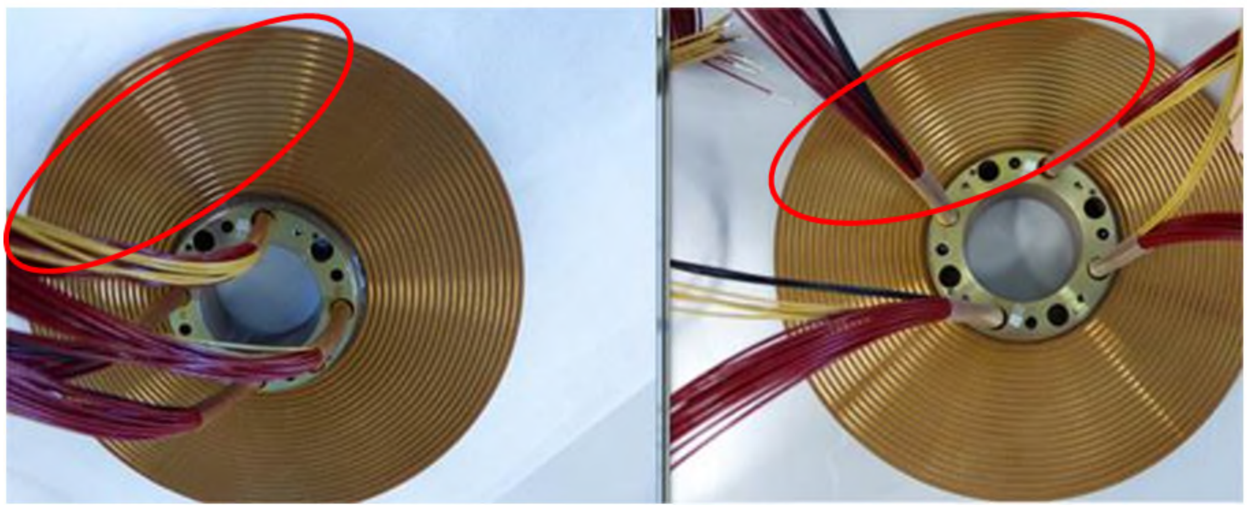

Figure 7. Discoloration on rotor track

Right after the tear down activity, a deep cleaning of the rotor was performed to verify any effect this could have on the resistance final results. Slip ring was re-assembled and tested after the cleaning and the new dynamic resistance test passed. The difference between the results at the end of the test sequence and after cleaning is shown in Figure 8 (resistance over one complete revolution on one track).

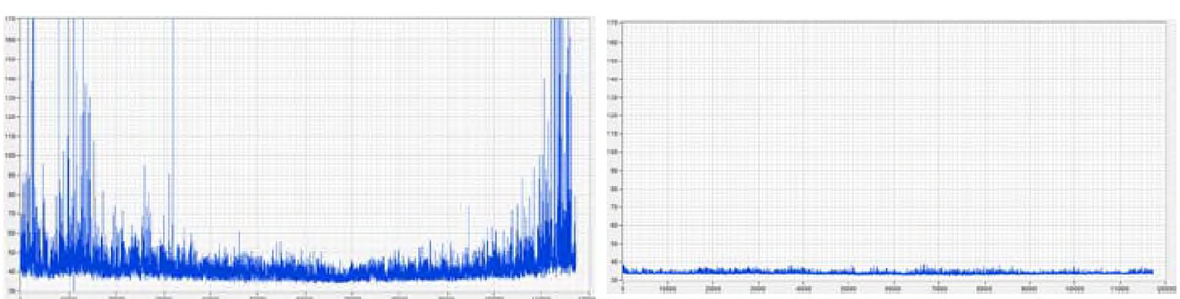

Figure 8. Noise before cleaning (left) and after (right)

The conclusion has been made that Kapton® glue on the track is the root cause of the deviation we found. Such contamination can generate noise and resistance test deviations.

The new rotor technology implemented in the 2.5D slip ring has demonstrated its performance in terms of:

- Insulation properties
- Resistance properties
- Mechanical properties
- Thermal behavior
- Wear (GEO and LEO applications)

In addition, this design has demonstrated its robustness with regards to the current capacity, by working without any damage with a current of 6.2 A on all the power lines during 24 hours at hot temperature.

The same level of performance is achieved with this type of technology compared to the standard one, see Figure 9.

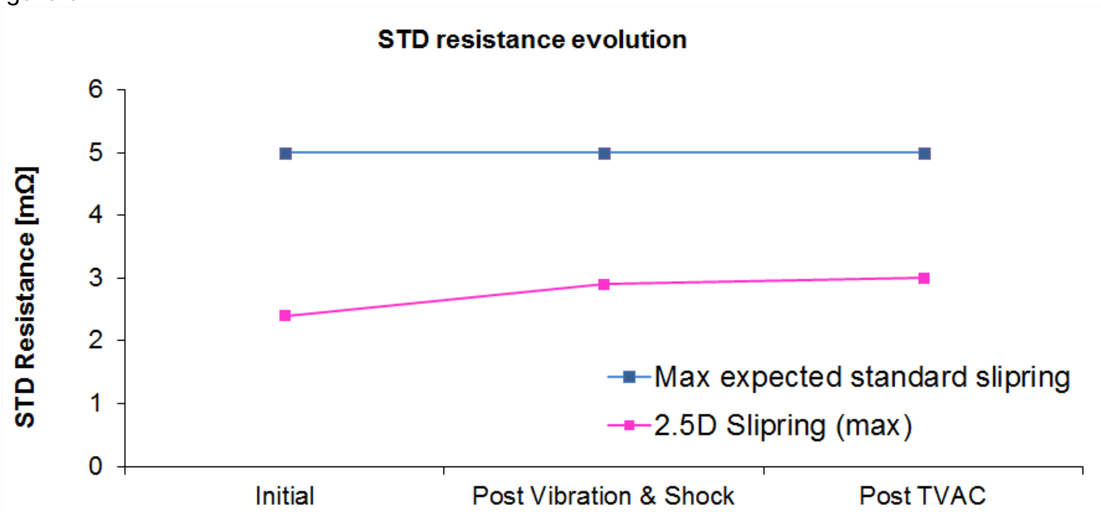

Figure 9. Standard deviation evolution

At the end of the validation test campaign, a tear down was performed on two units: SN001 that performed the GEO life test, and SN004 that performed the LEO life test (Fig. 10). The tear down confirmed that the wear present in the slip ring is nominal and that there is still enough gold on the track after the GEO and LEO life test.

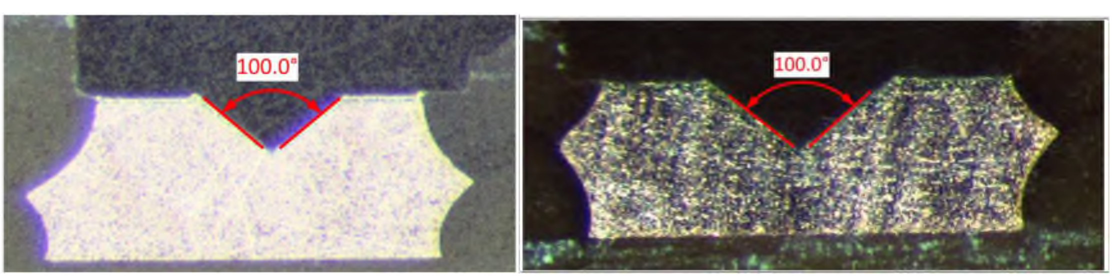

Figure 10. GEO life test (left), LEO life test (right)

In addition, the wear on the wire brushes is as usual and the wire brush preload verification has demonstrated that 99% of the wire brushes were in the expected range of preload at the end of the life test.

Conclusion

In conclusion, the 2.5D technology can be used to replace the standard costly and risky concept.

The perspective for further technical evolution is quite large. A great benefit with this kind of design is the modularity. The number of tracks, the electrical configuration, as well as the number of wire brushes can be modified to be in line with the customer specification.

Today, there are two technical limitations of this system:

- The stacking of only two modules
- The thermal aspect

For the stacking, some change in the design can be foreseen to have the possibility to stack an infinity of modules. The main change will be the output of the wires that shall go out on the external side of the stator, respectively on the internal side of the rotor.

For the thermal aspect, the result of additional tests has demonstrated that the system can survive additional current and power, but in a limited range. The temperature at a soldering location is only 10°C under the allowable temperature. This margin shall be kept for other applications.

From a commercial perspective, the 2.5D PCB technology activity is fully in-line with the development of new SADM and instrument applications and provides a competitive and technological advantage to our company. The optimization with an industrialization process is an undisputable advantage against other space slip ring manufacturers worldwide.

This innovative technology will not only improve the product reliability, the performance and the repeatability, but will also drastically decrease the procurement lead time. Indeed, with today's technology several uncompressible processes are needed leading to a final delivery time of twelve months for the two first modules. With the 2.5D PCB technology, the lead time will be reduced by at least a factor of two.

Furthermore, the competitiveness at a SADM level being more and more difficult worldwide, the cost of a slip ring is becoming one of the drivers in the SADM price. With the new 2.5D PCB technology, the final price of the product would be also reduced.

Finally, an important lesson learned was Kapton® tape with Kapton® glue shall not be used during the manufacturing, assembly, integration and test of a slip ring.