# E3000 High Power SADM Development

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## ABSTRACT

Astrium UK has been actively involved in the study, design, development, manufacture and test of Solar Array Drive Mechanisms (SADMs) and Bearing and Power Transfer Assemblies (BAPTAs) since the early 1970s having delivered 105 of these mechanisms to 22 spacecraft programs. As a result Astrium UK has accumulated in excess of 700 years of failure free SADM operation in-orbit. During that period power transfer requirements have grown steadily from below 1kW to 9.9kW and beyond. With this increase in power handling capability comes the associated problem of handling and dissipating the heat being generated within the SADM. The Eurostar 2000 family of SADMs were designed to handle up to 5.6kW for the E2000 family of spacecraft but the High Power SADM was conceived to meet the needs of the much bigger Eurostar 3000 family of spacecraft that could potentially grow to 15kW.

Keywords: **Astrium, High Power SADM, slip ring assembly, communication satellite, blind mate, Power Signal Slip-ring assembly, Solar Array Drive Mechanism, Eurostar 2000, Eurostar 3000.**

## 1 BACKGROUND INFORMATION

As mentioned in the abstract above the principal requirement for the E3000 SADM is to transfer 9.9kW from the solar array to the spacecraft structure. The E2000 SADM used a pancake configuration arranged in modules so that additional channels could be added to meet increasing power transfer requirements as the E2000 spacecraft design progressed. For the E3000 SADM initial analysis showed that a pancake configuration resulted in a design that would get very hot and problems would therefore be encountered in finding non-metallic materials that would satisfy the requirement. Having decided on a cylindrical slip-ring configuration the next decision was to identify a supplier as well as the material combination for the slip-rings and the brush wires. The other main design decision was that the SADM assembly should consist of a small number of modules that were to be individually procured and then assembled and tested at Stevenage. To this end the design of SADM was broken down into 4 modules as follows: PSSR – Power Signal Slip Ring assy, SMG – Stepper Motor Gearbox, Baseplate assy and Potentiometer. All these assemblies/parts were to be individually procured as finished items for final assembly at Stevenage. The other main driver was that the SADM should be ‘plug ‘n play’. This would mean that the SADM could be offered up to the spacecraft sidewalls and then blind mated to the array of connectors mounted within the spacecraft interior.

## 2 QUALIFICATION PROGRAMME

### 2.1 Design Selection Process

Having selected a configuration for the slip ring assembly the next major task was to decide on the material technology to be employed for transferring the power across the rotary interface. The E2000 SADMs utilised a silver loaded $MoS_2$ brush tip sliding on a gold plated ring for the material combination of the sliding interface. This technology was being replaced throughout the market by gold-on-gold technology and it was decided to follow this trend after some detailed investigations. A combination of gold alloy brush wires and gold plated slip rings was selected for the design and a European supplier with an existing record in this field was chosen to provide the PSSR. The design that subsequently evolved consists of 36 x 11 Amp power and return tracks combined with 34 x 0.5 Amp signal tracks. The shaft of the PSSR is profiled to allow the wires to be fed up to the individual slip rings from the solar array. The number of array side wires has been increased for the higher power version of the SADM under development that is capable of handling 15kW. On the spacecraft side of the PSSR an increased number of brush wires were required on each power and return track to ensure that the power could be efficiently transferred to the spacecraft bus without allowing excessive hot spots to develop under the failure condition of a broken wire. The total number of power and signal wires combined mean a total of 7 blind mate connectors are provided on the spacecraft side to provide the connection to the spacecraft bus.

With the PSSR configured and the maximum outside diameter of the SADM defined by size of the available hole within the Ywall of the spacecraft, the remainder of the components were integrated onto a baseplate to provide the means of rotating the PSSR. The chosen actuator for the SADM consists of a reduction gearbox driven by redundant stepper motors. The total output torque capability of this assembly, the SMG, is 17 Nm, which is sufficient to provide the required margin over the friction within the PSSR and the remainder of the SADM. A ring gear and pinion arrangement provides a gear reduction between the output of the SMG and the PSSR.

Within the assembly Lead Ion plating was chosen as the lubricant for the PSSR and main ring gear bearings and also for the pinion gear/main ring gear combination.

A potentiometer on the end of the PSSR shaft provides direct readout of the shaft rotational position. The final configuration of the SADM can be seen in figure 1.

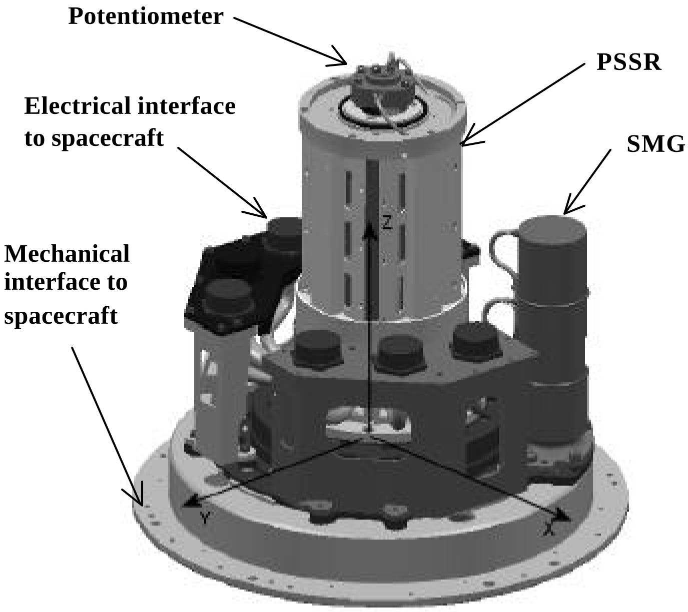


Figure 1: E3000 SADM showing the arrangement of the piece parts on the spacecraft side.

### 2.2 Design Analysis

Design analysis of the SADM consisted of the normal thermal and stress/strength analysis against the predefined launch and operational environments. Initially the thermal environment was defined by a simple set of boundary conditions. These however have evolved to become a very complex set of conditions, resulting in a complex test set up to simulate the environment. Other analysis included Radiation analysis, FMECA and WCA. The stress analysis was performed using a mixture of FEM models and hand calculations. The thermal analysis was performed using a combination of ESATAN and Ideas analysis for the thermo-elastic distortion analysis.

***Thermal Analysis***

As mentioned above the thermal performance of the SADM proved to be the design driver for the whole SADM design and in particular how heat was conducted to the 2 principal heat sinks; the solar array and the spacecraft structure. Radiation is also a principal means for the transfer of heat energy to the spacecraft structure and early on in the test programme it was identified that additional radiative surfaces were required to reduce the internal temperature of the PSSR shaft and brush blocks.

Detailed models were built up of the brush blocks in order to determine the maximum temperatures being developed within these units and ensure that the post cure temperature of the resin structure was not being exceeded. See figure 2, 3 below.

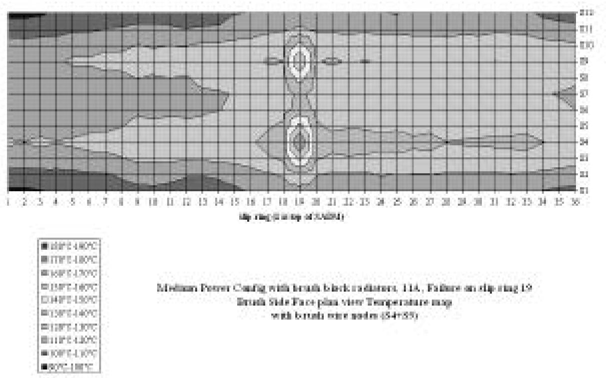

Figure 2: Thermal map along the brush block

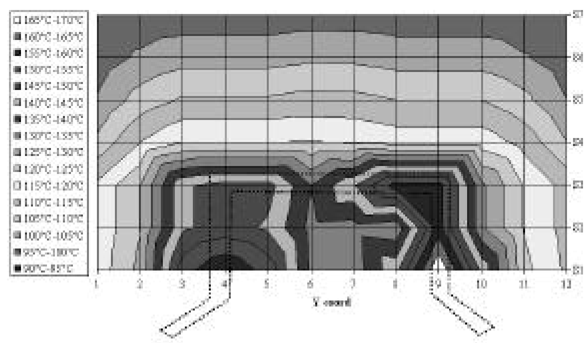

Figure 3: Thermal map of brush block cross section

From these detailed models predictions where able to be made about the regions of maximum possible temperatures and to tune the design to reduce the temperature in these regions to within the capability of the material properties.

***Thermo-elastic Distortion Analysis***

As mentioned above the PSSR design is based upon 'gold-on-gold' technology, consisting of gold alloy brush wires running on gold plated slip rings. The conflicting requirements of low brush wire resistance, dictating larger diameter wires, and low stiffness, dictating small diameter wires, were solved by very carefully selecting the brush wire diameter and the preload. A very fine line had to be driven between as low a preload as possible to minimise friction and as compliaint a system as possible to eliminate the effects of thermo-elastic distortion and the possible loss of contact at temperature extremes. IDEAS was used to model the PSSR in detail and predict the minimum preload that could be tolerated to ensure continuous contact across the predicted operating temperature range. See figure 4 below.

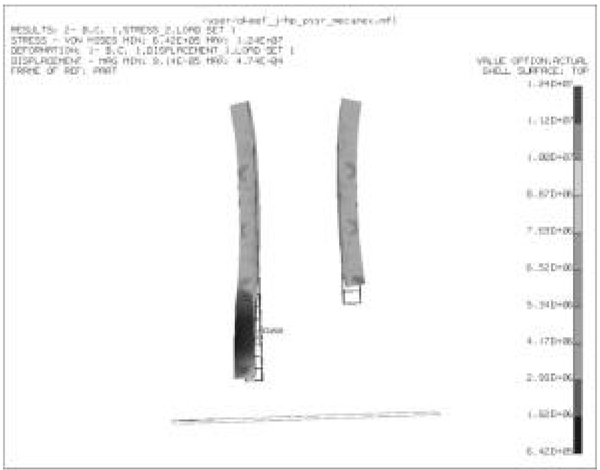

Figure 4: Thermo-elastic distortion Analysis using IDEAS

***Dynamic Performance Analysis***

Dynamic performance of the SADM driving the deployed array was simulated using SIMULINK and the command profile shown in figure 6 below. This model was used to size the SMG and also to define the design of the Inertia Simulation test rig that was to be used when the SADM was in the thermal vacuum chamber. The SADM is driven in micro-step mode consisting of 8 micro-steps in a 1 second period followed by a 7 second dwell after which the cycle is repeated. SIMULINK was used to predict that the deployed array would not be excited by the frequency of the command sequence and that the array and SADM would not couple together to oscillate uncontrollably. The same model was also used to model the effects of the damping coil on the electrical stiffness of the SMG and its performance in damping out the resonances within the SADM.

Simulating, in test, a very large inertia array with a very low natural frequency is also very difficult and again SIMULINK was brought into play to assist with the design of the inertia simulation rig for use when the SADM was in thermal vacuum.

Figure 5: Solar Array Simulator above Thermal Vacuum test chamber

The Solar Array Simulator consists of a large hexagonal ring suspended on a series of wires, 'merry-go-round' fashion with cross bracing wires to provide lateral stiffness. Obviously only the 1st modes can be simulated using such a test rig but the dynamic modelling was able to show that the higher order modes did not have an impact upon the SADM performance and could therefore be safely ignored.

### 2.3 Test Programme

The QM MP SADM test programme followed the traditional sequence of any space mechanism; vibration and thermal vacuum testing interspersed with performance checks. Static load/stiffness tests, shock and microvibration tests were also performed prior to the unit being placed on life test. The life test commenced in Jan 2003 and was designed to simulate 22.5 years of operation to provide a margin of 1.5 against an operational lifetime requirement of 15 years. Obviously it is not possible to undertake this test in real time and the test is being performed at accelerated rates to permit it to be completed in 4 months. A detailed assessment of the different lubrication regimes that exist with the SADM was undertaken prior to the start of the life test to ensure that the test was as representative as possible.

## 3 SUMMARY AND CONCLUSION

The E3000 MP SADM is currently approaching completion of its qualification test programme. The normal qualification test programme consisting of health checks interspersed with environmental survival and performance tests which have all be completed satisfactorily together with the shock test, static load and stiffness test and microvibration measurements.

The unit is currently approaching the end of its simulated 22.5 year life test programme having completed in thermal vacuum a total of 8400 revolutions at a variety of speeds from 90 revs/day to 1 rev/day and 135 eclipse events. Once the simulated life test is completed the principal remaining task is the post life test visual inspection of the 'Bought Out Finished' (BOF) items to look for signs of excessive wear. Qualification will be declared in the 3rd quarter of 2003.

## 4 FOOTNOTE

Once the life test and post life test inspection have been completed the E3000 MP SADM will have completed its qualification test programme and the unit will be deemed suitable for use on the E3000 spacecraft. Its first flight outing will be on the Intelsat 10-02 spacecraft, which is due for launch in 2003. In parallel with the qualification model programme 12 flight models have been delivered or are in the final stages of assembly and test. The flight model programme has been executed with very few problems and has benefited considerably from the continuity of production for this mechanism. A second batch of 12 units is on order and assembly of those will commence in the next few months.

In addition to the MP SADM Astrium are currently undertaking a HP SADM development programme. This will increase the SADM capacity to 15kW to meet the demands of the E3000LX spacecraft. This unit is expected to complete its test programme in the 4th quarter of 2004. For the same current rating running at a 100 volts the SADM is rated to support 30 KW.

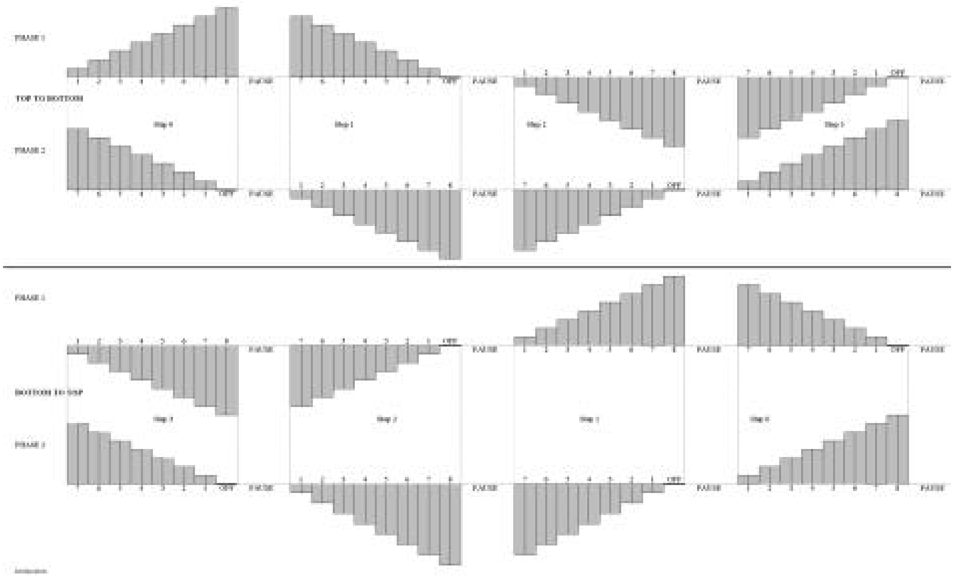

Figure 6: Command Profile for either Direction Of Rotatio n

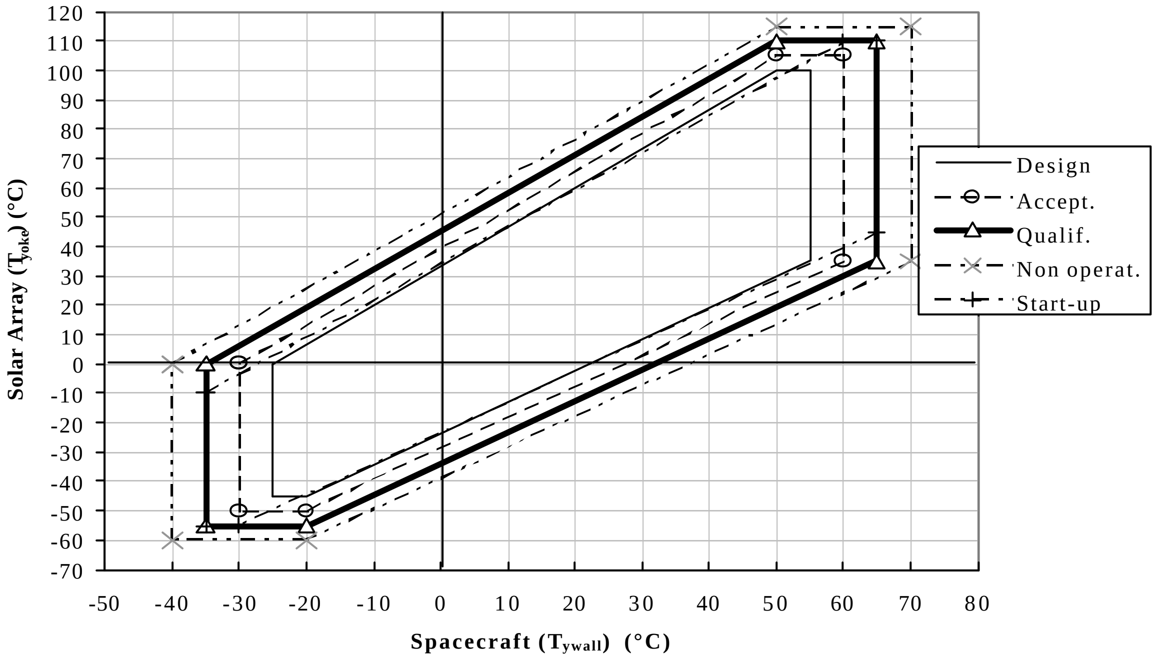


Figure 7: Thermal Performance envelope



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