MECHANISMS OF THE ROSETTA HIGH GAIN ANTENNA

by
Carlos Pereira
HTS AG
Wallisellen, Switzerland
Tel. +41-1-839-1254
Fax. +41-1-839-1200
mail to: carlos.pereira@htszh.ch

ABSTRACT

This paper describes the antenna pointing mechanism (APM) and the hold down and release mechanism (HRM) used in the high gain antenna of the ROSETTA mission.

The hold down and release mechanism consists of three units which compensate the tolerance mismatch between antenna and spacecraft through incorporation of potting rings. Given that the activation mode is pyrotechnic, release shock is a major concern and is minimised through integration of shock absorbers which allow stroking of the separation nuts.

The antenna pointing mechanism is a dual drive (azimuth over elevation) unit which allows controlled rotation of the antenna. The drive units incorporate spring loaded end stops to prevent the antenna from hitting the spacecraft, and optical encoders which register the *absolute* position of the antenna.

The pointing and the hold down mechanisms of the ROSETTA antenna are fully qualified and will withstand the high launch loads of the Ariane-5 and the environmental demands of deep space operation.

INTRODUCTION

The ROSETTA space probe is a ten year rendezvous mission to the comet Wirtanen and a cornerstone in the exploration of the solar system. The mission will be launched by an Ariane-5 platform in January 2003. One Mars and two Earth gravity assists will be used to gain the orbital energy which is needed in order to rendezvous with the comet.

The high gain antenna is the main link between this spacecraft and earth based receptors and is capable of transmitting data in both X (8.40-8.44 GHz) and S bands (2.11-2.12 GHz). It is a ribbed carbon fibre sandwich structure steered in its deployed configuration by the APM and secured by three HRM fixations during ground operations and the launch phase.

THE HOLD DOWN AND RELEASE MECHANISM (HRM)

The HRM has two main functions:

- Maintain the antenna in its stowed configuration during ground operations and launch
- Release the antenna after the spacecraft separates from its launch vehicle

The hold down and release mechanism consists of three units, two of which are mounted on tripods and a smaller unit, so-called short HRM, interfacing directly with the spacecraft (Figure 1).

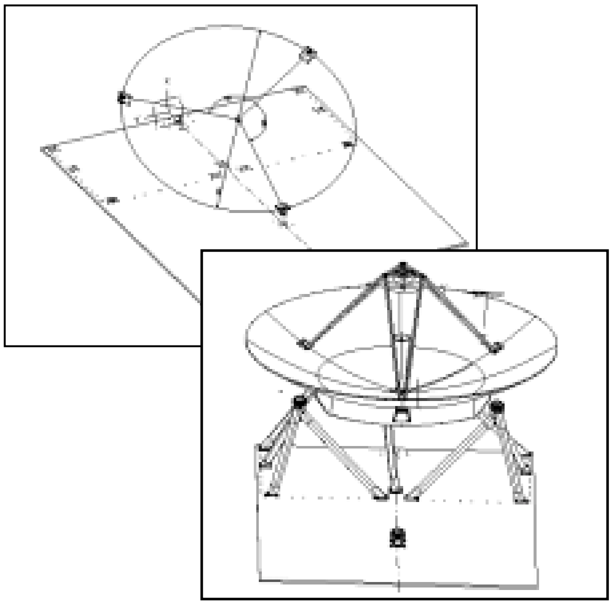

Figure 1 - Hold Down and Release Mechanisms: Antenna and Spacecraft Locations

Due to the fixation of the antenna at three HRM points and at the APM it is over constrained with regards to tolerance compensation . The HRM units were therefore designed to compensate for the tolerance mismatch between antenna dimensions and the location of their fixation points to the spacecraft. This is achieved through integration of potting rings in the HRM housings (Figure 2).

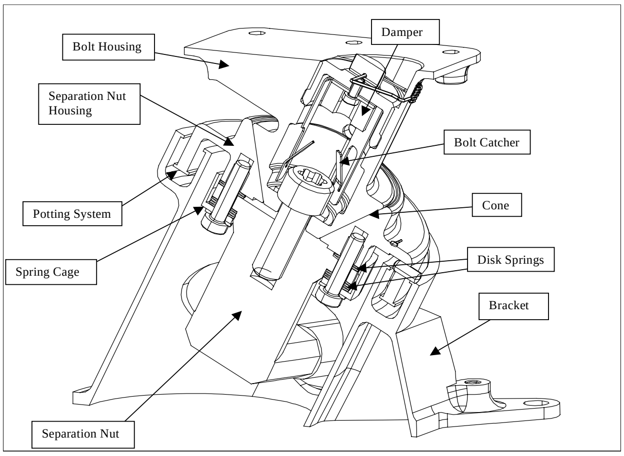

Figure 2 – Cross section of HRM

The chosen potting material is a low viscosity, two component epoxy resin which hardens at room temperature and meets the outgassing criteria of PSS-01-702 [1]. During integration the antenna is first lowered unto the HRMs and after fixing its position the potting resin is injected via 1 mm diameter canules. Once hardened the resin is stronger than the surrounding aluminium in the operating temperature range –40°C to 25°C. Figure 3 shows results of traction tests using a geometry representative of the potting channel. In all cases the aluminium yielded prior to resin failure.

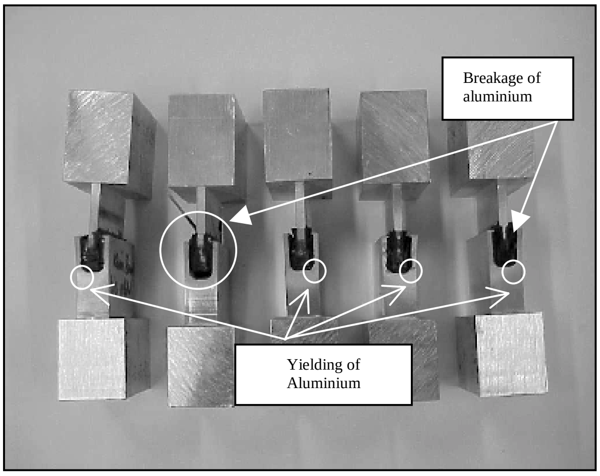

Figure 3 – Test Results at -80°C

Deployment of the antenna in space is performed via pyrotechnic release of the single attachment bolts. To this end redundant equivalent NASA standard initiators (NSI) are used.

The shock levels upon release of the highly pretensioned bolts exceed the shock threshold of the instruments harboured in the ROSETTA spacecraft.

In order to resolve this situation tests were performed using a dummy HRM. These tests indicated that the highest shock component occurred upon release of the bolt but prior to bolt contact with the upper housing. (Figure 4)

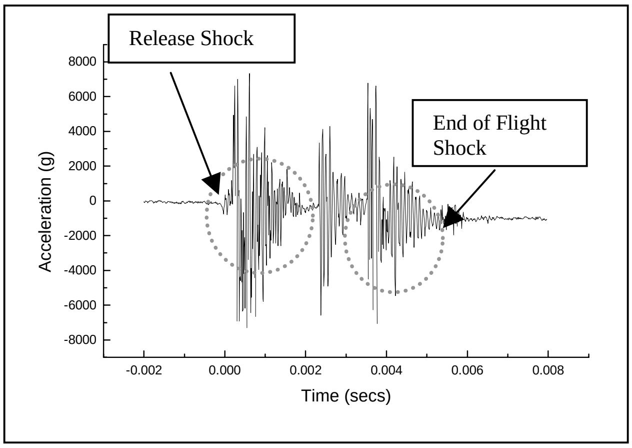

Figure 4 – Shock Response without Damping

The shock on the antenna is minimised by using an aluminium honeycomb damper. Its efficiency in reducing shock levels can be seen by comparing the preceding figure with figure 5 below.

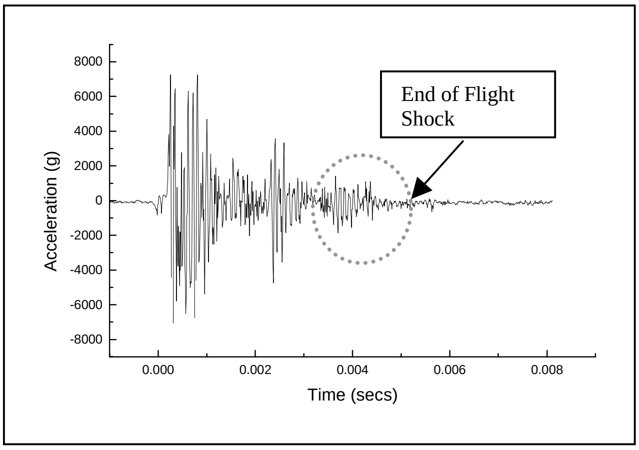

Figure 5 – Shock Dampened by Usage of Honeycombs

Reducing the shock at the spacecraft interface proved to be more difficult due to the short distance and high stiffness of the short HRM unit. Figure 6 indicates the possible areas for implementation of shock counter-measures.

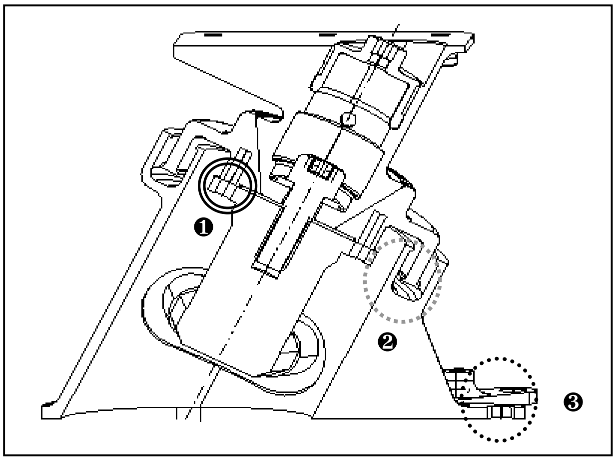

Figure 6 – Areas for Shock Countermeasures

The large area available in the potting region (❷ in Figure 6) makes it an ideal location for implementation of shock countermeasures. This region though lies directly in the load path between antenna and spacecraft. Given that shock damping generally implies a reduction in stiffness the use of a suitable elastomer in the potting area would lower shock levels but it would also compromise the performance of the HRM as restraint for the antenna and result in high loads to the antenna pointing mechanism drives. A similar reasoning applies to the spacecraft interface (❸ in Figure 6).

The only area which is not part of the load path is the separation nut to separation nut housing interface (❶ in figure 6) . It was decided to look into shock countermeasures in this area. The chosen solution consists of a double spring system held in place by a titanium M5 bolt. The principle of operation is shown in figure 7

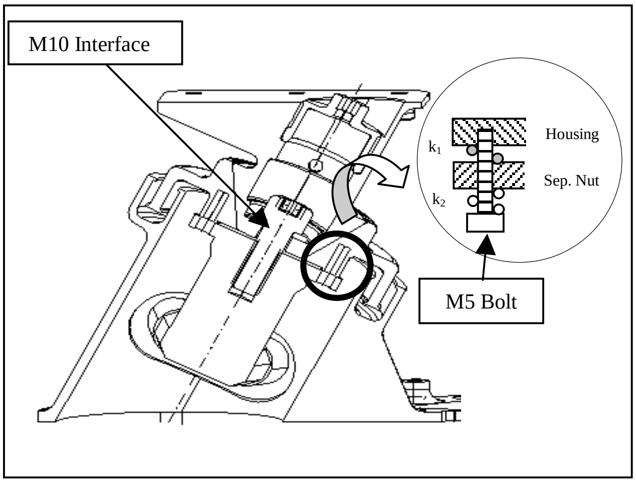

Figure 7 –Damping at Separation Nut Interface

Upon release of the central M10 interface bolt the separation nut recoils downward effectively reducing the cross sectional area for transmission of shock waves.

The damper system of figure 7 requires the definition of the two springs involved in shock reduction. Based on the calculated speed of the bolt a momentum balance on the unit indicates a maximum recoil speed of the separation nut of 1.1 m/s. Based on the available space two alternatives can be used to absorb energy:

- Elastomeric springs – such as Viton or Silicone O-rings
- Metal Disc Springs

Elastomeric springs are highly non-linear which results in very good dissipation in tension but a poor reduction factor in compression. The torque values required for the M5 bolt (> 2.5 N·m) would also lead to a compression set of the O-Ring with time. A further problem is that O-rings have a temperature dependent elastic constant and the damping mechanism must cover the deployment temperature range (-40 to +45°C) . In view of this it was decided to use disc springs and vary their thickness and stacking order to tune the spring constants for maximum energy absorption at each rebound (figure 8).

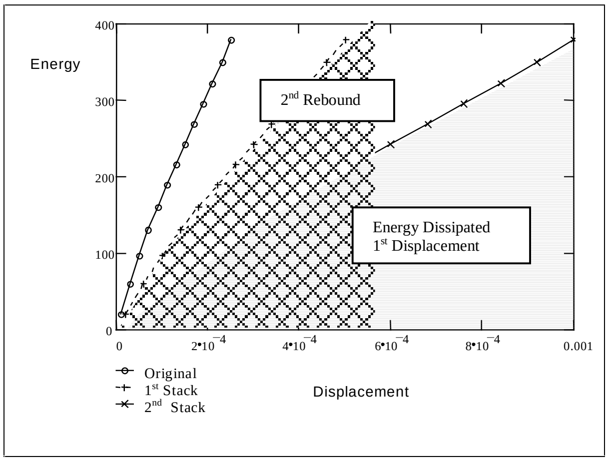

Figure 8 – Energy Absorption Curves of Damper

The performance of the damper and its repeatability can be seen in the Fourier transformed shock spectra. (Figure 9). The peak at A is reduced by a factor of 5 when compared to the undamped spectra as well as shifted towards higher frequencies. The overall effect is a reduction in shock levels of one order of magnitude (Figure 10).

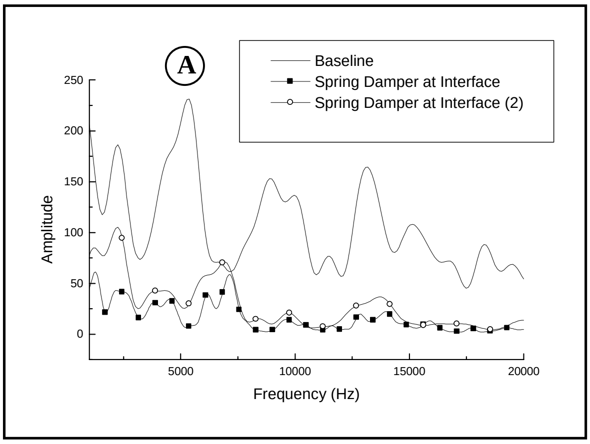

Figure 9 – Fourier Transform of Shock Spectra

Once integrated into the antenna assembly the shock damping mechanism was subject to vibration and its performance verified. Figure 10 shows the performance after vibration in comparison to the baseline (undamped) performance. The release shock spectra is shown in figure 11.

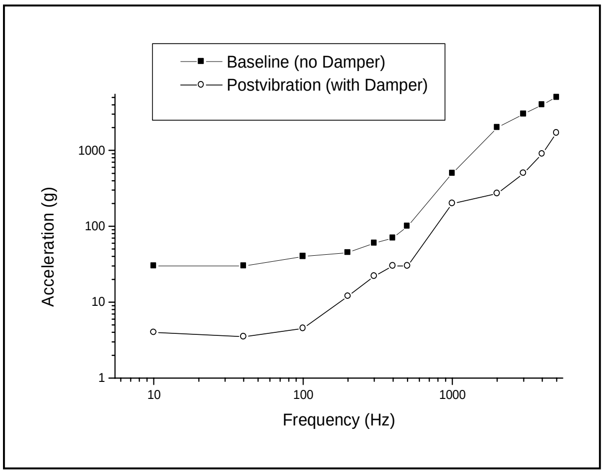

Figure 10 – Shock Performance Improvements

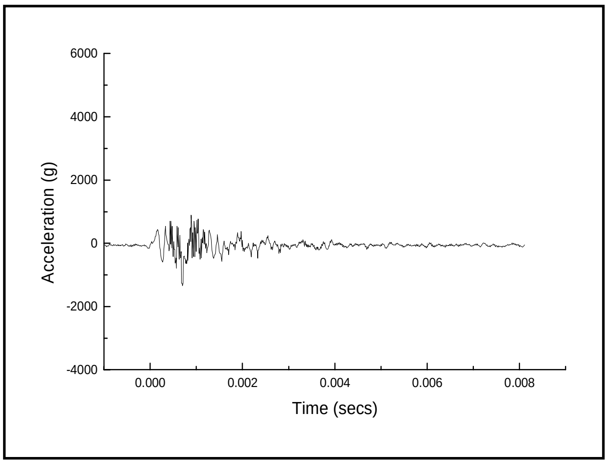

Figure 11 – Release Shock Spectra

Once the separation nut is activated the M10 fixation bolt is released. It flies towards the bolt catcher unit integrated onto the antenna. Contact shock is minimised through use of a honeycomb damper and the bolt is restrained by a spring integrated in the upper housing (Figure 12)

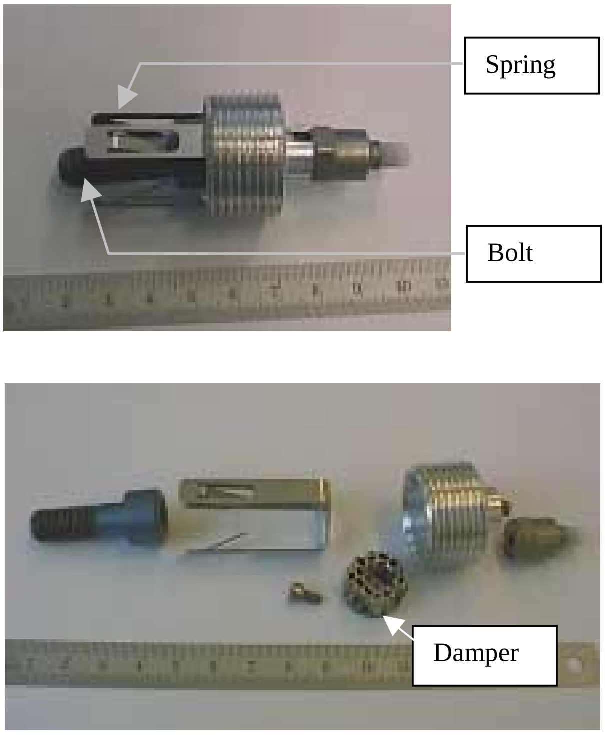

Figure 12 – Bolt Catcher Mechanism after firing (above and exploded view)

The separating interfaces meet at a 35° cone angle and are coated using NPI-425 (Figure 13). This is a polyimide-Sb_2O_3-MoS_2 solid lubricant coating with a friction coefficient of 0.01 and high abrasion resistance. This avoids lock-in and guarantees frictionless deployment under the thermal environment of the mission.

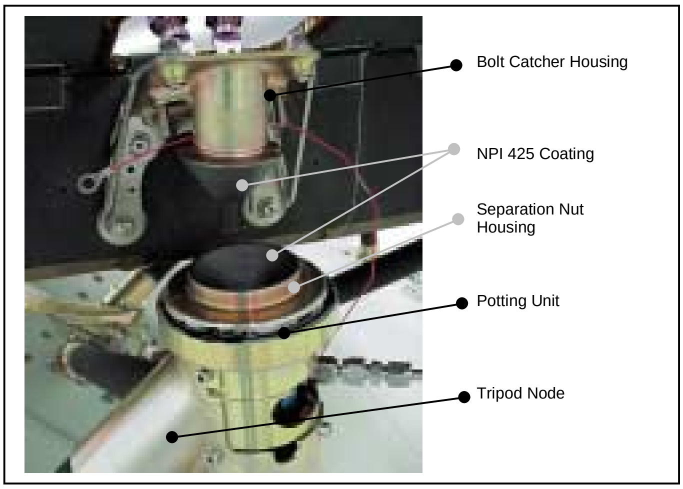

Figure 13 – Tripod mounted HRM unit

The hold down and release mechanisms of the ROSETTA high gain antenna have been designed to allow release of the antenna by ground crews and permit access to all their components. Figure 14 shows the exchange of tripod mounted separation nuts by removal of the potting unit.

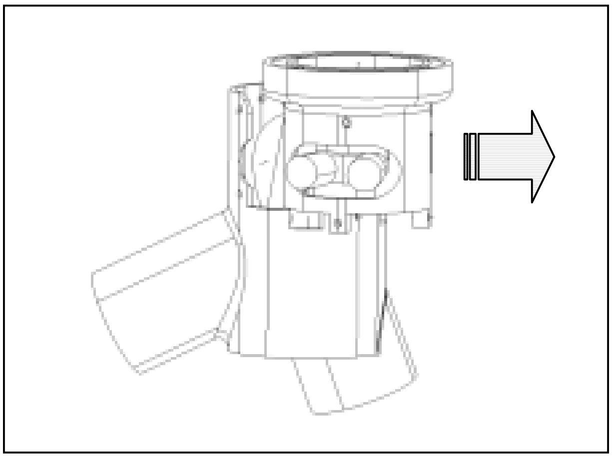

Figure 14 - Removal of potting unit of tripod HRM

Once the release of the antenna takes place the antenna pointing mechanism steers the antenna from its stowed configuration to its operational configuration.

THE ANTENNA POINTING MECHANISM (APM)

The main functions of the APM are:

- allow accurate and stable pointing of the antenna dish through controlled rotation about azimuth and elevation axes

- route signals between the antenna and the spacecraft

The APM is mounted on a carbon fibre tripod and consists of three main components

- Drive units with cable drums
- Azimuth bracket
- RF Equipment

The APM has two drive units: elevation and azimuth. An analysis of power consumption during deployment and pointing modes resulted in the azimuth-over-elevation configuration. Each of the units (figure 15) integrates an actuator unit in its housing.

The actuator unit consists of a 6 pole two phase redundantly wound stepper motor, with the permanent magnets on the rotor. It has an integrated planetary gearhead (reduction 1:200) which engages in a crown wheel.

The outer end of the output shaft is supported by an additional ball bearing to increase radial stiffness thus allowing the pointing accuracy targets to be met.

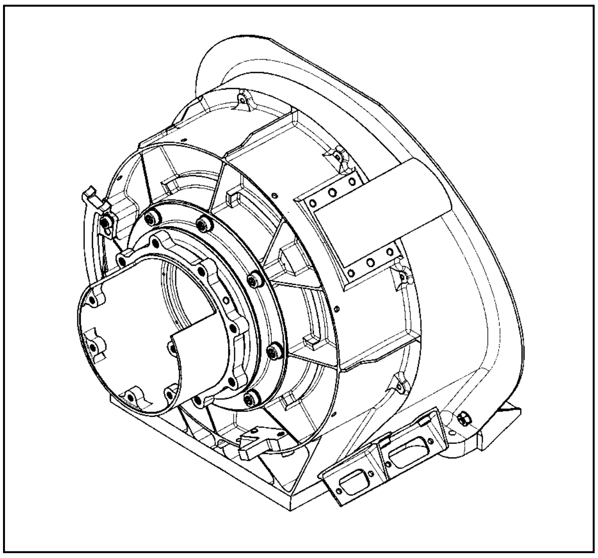

Figure 15 – Elevation Drive Housing

An anti backlash mechanism in the form of a spring loaded secondary pinion is integrated in the output shaft of the actuator (Figure 16). The actuator drives an inertia of 32 kg·m^2 with a low power consumption (less than 6 W) at a speed of 2.5°/sec.

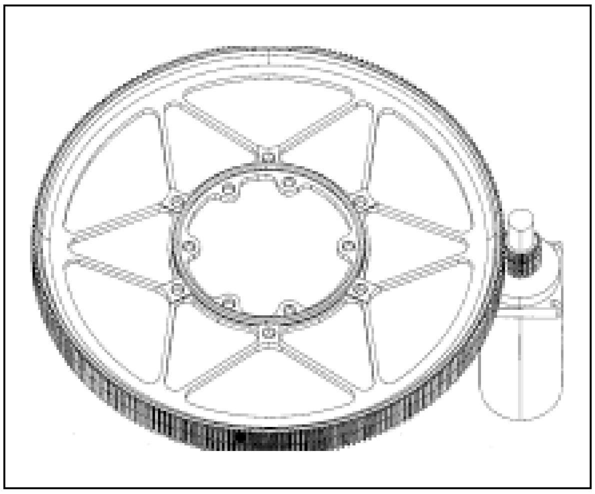

Figure 16 – Section showing crown wheel, motor and secondary pinions

A preloaded duplex angular contact ball bearing in back to back configuration ensures free rotation of the shaft in the gear housing. It is lubricated with Braycote™ 601 and has Fomblin™ Z25 impregnated phenol resin separators. The balls are TiC coated. A 16 bit optical encoder registers the absolute position of the shaft and on request submits this information to the electronic control unit located inside the spacecraft.

The shaft is hollow for the routing of the wave guide and the electrical harness. A cable wrap is attached to both housing and the revolving shaft. thus allowing the rotation of the drive unit to the extreme positions without imposing any torsion to the wire harness.

The azimuth bracket (Figure 17) is bolted to the shaft of the elevation drive unit allowing the azimuth drive to be guided from launch position (elevation -207°) to the extreme arc position (elevation +30°).

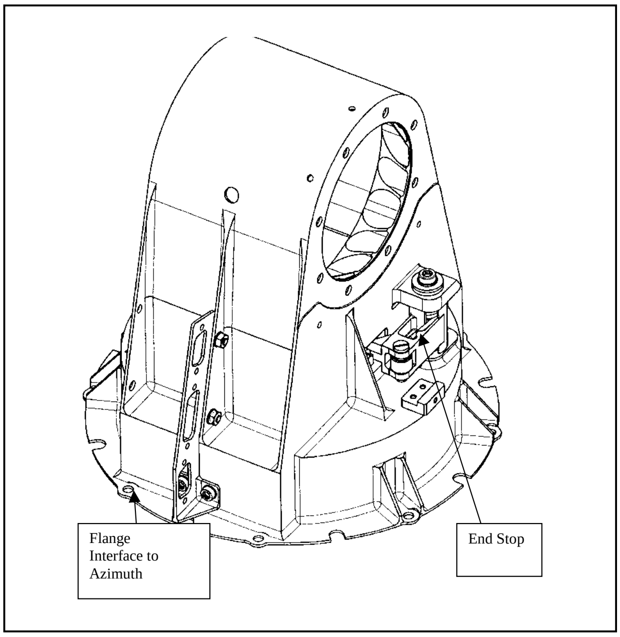

Figure 17– Azimuth Bracket

A spring loaded end stop automatically engages after the first antenna deployment (at –165°) (figure 18) and prevents the antenna from any accidental interference with the spacecraft. To override this end stop during ground handling, a lever has to be pushed back against the spring load of the end stop unit. Only then can the antenna be steered into its launch position. Figure 19 shows the antenna in its extreme positions.

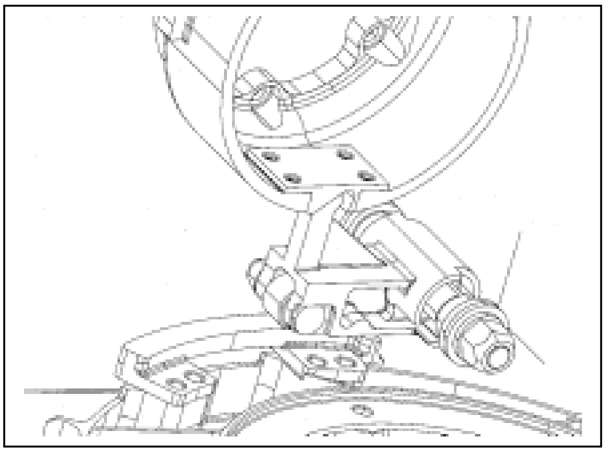

Figure 18 – End Stop Mechanism

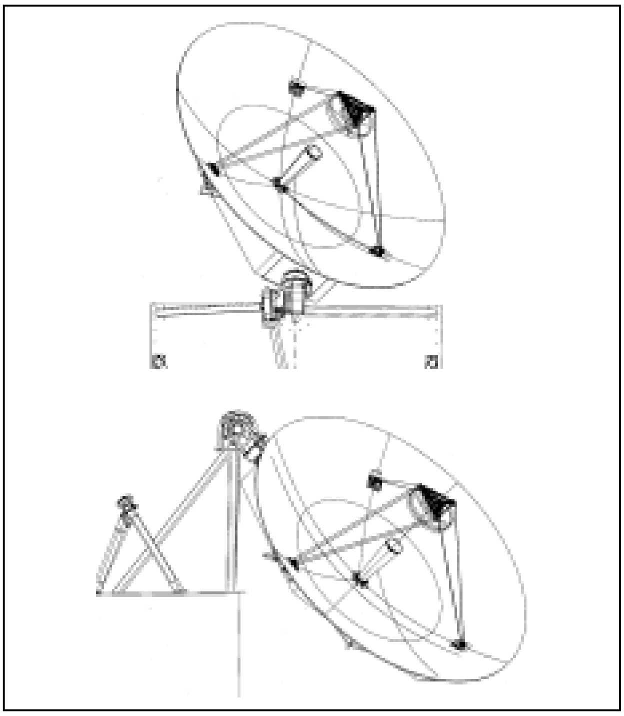

Figure 19 – Extreme Positions of Antenna

The azimuth drive (Figure 20) interfaces via six M6 bolts and insulating Vetronit™ washers to the antenna. The mechanical endstop for the azimuth drive is installed in the cable wrap and restricts the azimuth rotation to -260° to +80°. Figure 21 shows the APM

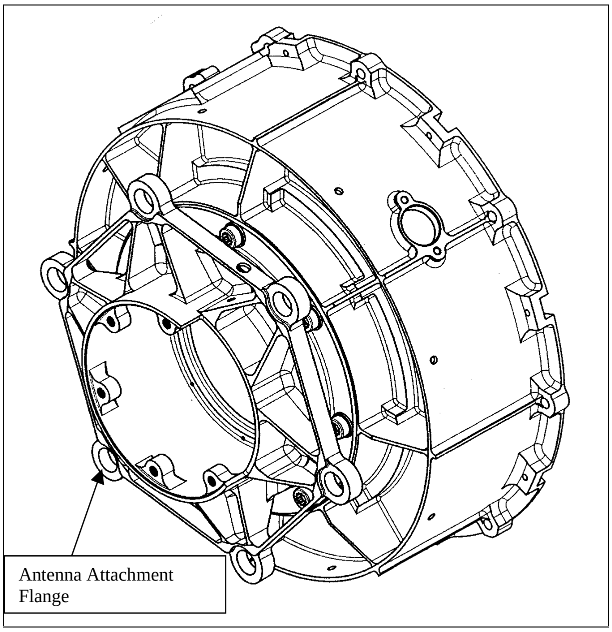

Figure 20 – Azimuth Drive Housing

Once deployed the antenna will be aimed at earth based receptors and begin broadcasting and receiving signals in both bands.

Figure 21 – Antenna Pointing Mechanism

The routing of signals is performed by waveguides in the X band and by coaxial cable in the S band. The waveguide consists of a rectangular channel guide and two rotary joints, one in each drive . The waveguide can be divided into three segments : the lower segment extends from the spacecraft sidewall to the elevation drive, the middle one connects the elevation rotary joint with the azimuth rotary joint and the upper segment extends from the azimuth rotary joint to the potter horn located in the centre of the high gain antenna. (Figure 22)

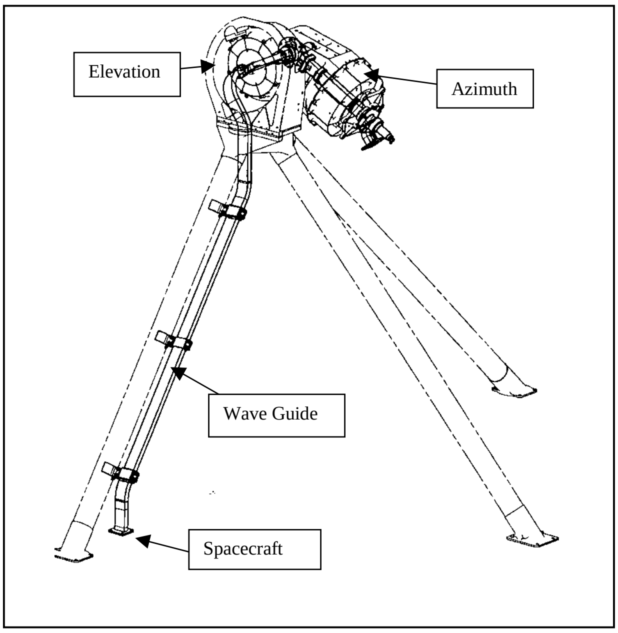

Figure 22 – Waveguide

The wave guide incorporates bellowed sections to allow for thermal expansion and to cope with the mechanical tolerances.

To allow rotation with a minimum of RF loss a rotary joint was placed in each drive. These joints have static outer flanges which interface to the waveguide and rotary central flanges, allowing stress free rotation about their longitudinal axis. Figure 23 shows the arrangement used. The S-band cable is mounted in piggy back configuration unto the X band .

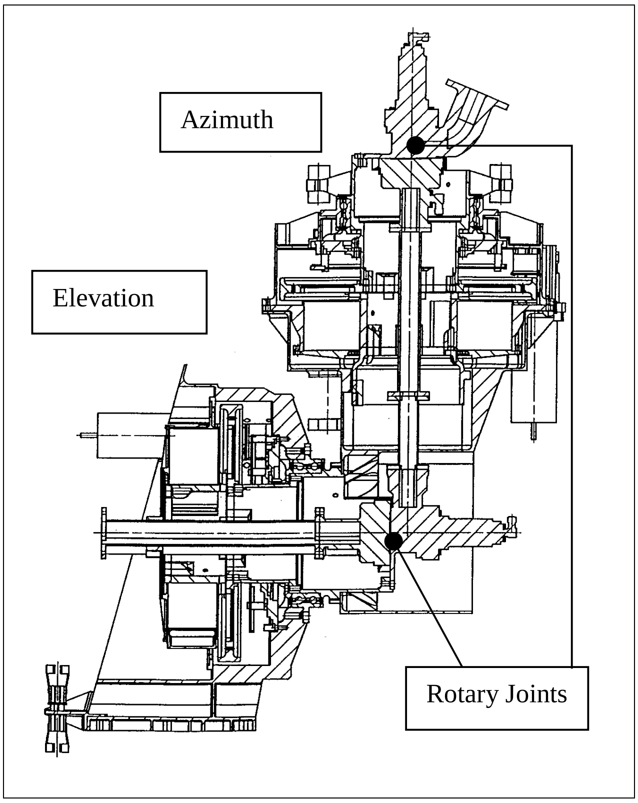

Figure 23 - Rotary Joint Arrangement

Following a comet implies exposing the APM and RF equipment to dust clouds. To prevent the ingress of dust into the sensitive systems of the APM, no access holes exist and gaps are kept to a minimum. The outer side of the bearings and the rotary joints are covered by close tolerance labyrinth seals.

MISSION REQUIREMENTS

The ROSETTA Mission environment requires compliance with the following requirements

- High shock and vibration resistance – Ariane 5 launch platform
- Low temperature performance: -50°C operating and -85°C in passive mode
- Low RF losses
- High pointing accuracy: better than 0.1°
- 15 year operation

The ROSETTA high gain antenna major assembly which includes the antenna , the hold down and release and the pointing mechanisms as well as control electronics and thermal insulation, has been extensively tested using a three model philosophy: a pre-qualification model was used for engineering design, a qualification model (Figure 24) was used to verify margins with respect to the mission parameters and a fully tested flight model (Figure 25) is currently undergoing final preparations before integration to the launch platform.

Figure 24 - Qualification Model mounted to the Satellite

The design, testing and production of optimised mechanisms for hold down, release and pointing of the antenna was performed within a three year period to meet the programmatic requirements of the mission with a very narrow two week launch window in 2003.

Achieving a fully qualified design within this ambitious timetable was possible given the high degree of collaboration with subcontractors such as Saab Ericsson Space, the antenna manufacturer , BAE Systems, the rotary joint manufacturer and ETEL, the electronic control supplier. The prime contractor and system integrator Astrium and the European Space Agency were involved in the design steps of the process and their assistance in resolving the technical issues proved to be invaluable.

Figure 25– Flight Model of The High Gain Antenna

The mechanisms developed in the framework of ROSETTA can be adapted to other missions and thus represent valuable off-the-shelf solutions which meet the demands of deep space operation.

REFERENCES

1. PSS-01-702 Issue 2 Thermal vacuum test for the screening of space materials (1994)

Vetronit™ is a trademark of Von Roll Isola Holding AG
Braycote™ is a Trademark of Castrol Inc.
Fomblin™ is a Trademark of Ausimont Inc.
NPI-425 is a product of National Process Industries Inc