Antenna Deployment Mechanism for the Cubesat Xatcobeo. Lessons, Evolution and Final Design

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Abstract

This paper aims to explain the whole development process that has been undertaken over the past few years including the problems encountered and the solutions adopted in what was to become the final design of an antenna deployment system for the Xatcobeo picosatellite. This mechanism was first presented at the 40th Aerospace Mechanism Symposia. At that time, we presented an evolved version of our antenna deployment mechanism, with many conclusions and lesson learned. However, only now can we present the final version of this mechanism with all the development problems, solutions and conclusions reached as well as the lessons learned over 3 years of work.

Introduction

In the paper published for the 40th AMS we explained the mechanism's general operation. This included how the antenna retention system, the burning system, and the opening detection all worked. Although, in general terms, none of these features has been changed to any great extent, they are all different in some way from what we described then. This is due to the many problems we came across and the way their solutions have led to changes in all the device's parts.

<u>Modifications</u>
This article will analyze in detail all the changes the design has undergone throughout the development period. Namely:

- The dimensions of some of the parts on the main piece (sub-chassis)
- The sub-chassis design
- New attachments
- The materials used
- The retention wire burning circuit. Two resistance types
- Retention wire tying
- Power Voltage
- Thermo-vacuum test

Also, totally new features will be explained that have been developed since the first article, such as:

- Electrical interface
- Mechanical interface
- Design of the RBF. PEM nut
- New part for resistance support
- Thermal interface between the sub-chassis, the new support part, the resistance and the shielding panel
- Calculations for avoiding the appearance of ESD following ECSS standards
- Compliance with the standard for outgassing values
- Final integration process and envelopes. Problems with dimensions and assembly.
- Modification of the margin with the enveloping film
- Qualification Tests

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Mechanism Background

This deployment mechanism is based on one main part, called the sub-chassis, which is designed to be built from a polymer using fast prototyping. All the elements needed for the mechanism's operation are installed onto this piece. This includes the antenna enveloping film, the burning resistance, and the opening detection switch. The sub-chassis can itself be installed in the shielding panel on one side of the Cubesat, which means that everything is easily inserted in a modular way.

Operation is very simple. The retention film is attached to the sub-chassis and allows the antennas to be folded and retained against the edge of the sub-chassis. Once the assembly is closed, a nylon wire passes through both the film and the antennas, and it is this that keeps everything folded away until the time for burning. At that moment, the burning resistance will cut the retention wire and the antennas will be deployed, leaving the retention film joined to the sub-chassis unable to detach itself.

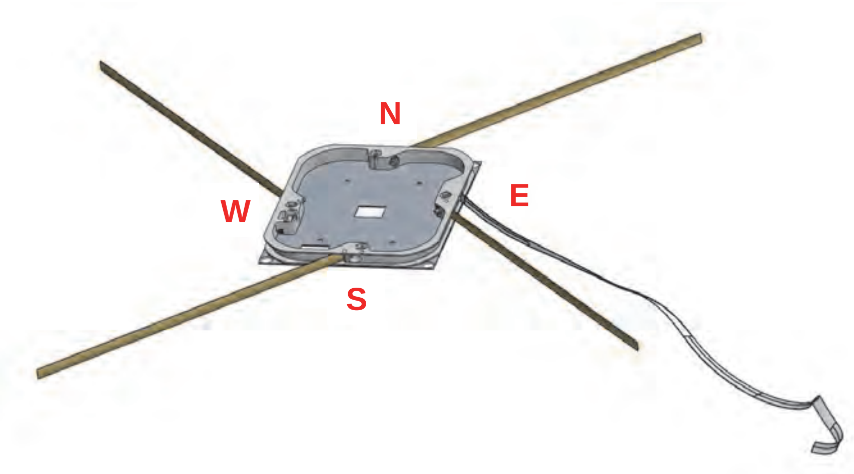

Figure 1. Final Deployment Mechanism

General view of the Mechanism

General operation is, as mentioned above, basically the same as before. The main difference lies in the fact that the enveloping film, instead of being fixed to the sub-chassis together with one of the antennas with which it was in direct contact, is now attached independently onto the sub-chassis. This way avoids problems related to the noise that could be produced on the antenna, but which requires a new nut and bolt to be included.

Furthermore, the enveloping film attachment moves from point S on the sub-chassis to point E. This is due to the fact that if it were attached at point S, the end of the antenna attached at point E would end beyond the retention point. The pressure from the retention wire would thus lead to this unpressed end opening towards the outside in such a way that it would exceed the limit given by the available envelope. In compensation, the film is roughly 80 mm longer. It needs to be perforated twice for the retention wire to pass through, which means its capacity for retention is much greater precisely because it passes twice over the retention point and none of the antenna's parts are left with no pressure against the sub-chassis.

Sub-chassis

The sub-chassis, as stated above is the cornerstone of this mechanism. Its special features allow it to be extremely light and act as the piece that enables the installation of all the other mechanism elements. This means it is of vital importance for endowing the assembly with modularity and simplicity.

Material and Manufacture
One of the main changes in this piece involves the material chosen to make it. In the previous article we had chosen polyamide 6 as the material and Selective Laser Sintering as the manufacturing method. During the development of this piece research into the properties of various polyamides led us to opt for polyamide 12 with fiberglass reinforcement. There were several reasons for this:

- The first reason is that PA12 is lighter than PA6 by about 10%, and absorbs less water. This was a step in the right direction which was to reduce the weight of the whole assembly as much as possible.
- The second is that the prototypes manufactured using SLS on PA12 with Fiberglass reinforcement were more precise than those made from PA6 with Fiberglass. This favored the correlation between the CAD model and the actual model. Bearing in mind that the attachment of the various parts onto the sub-chassis was based on a tight fit, it was very important to suitably meet this correlation. Moreover, this was also a way of improving repeated similarity between the different prototypes that were commissioned.

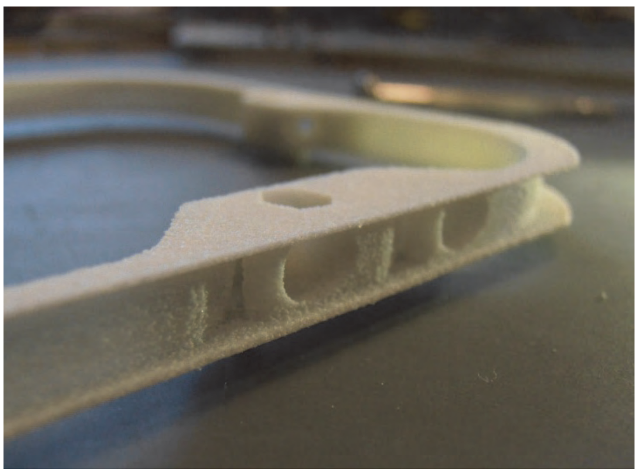

Figure 2. Sub-chassis detail. E point

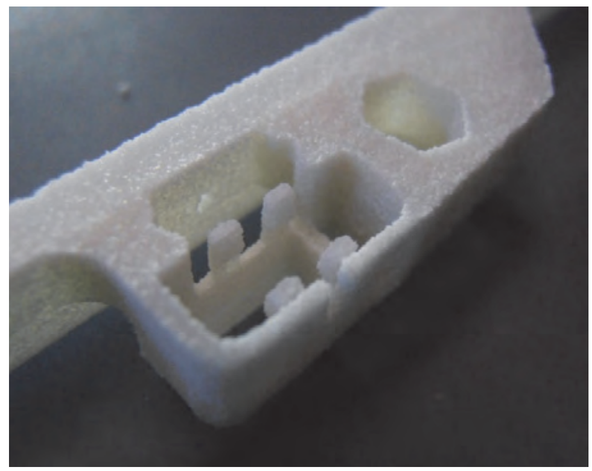

Figure 3. Burning receptacle. W point

Design and Dimensions
The changes made in the sub-chassis were aimed at solving problems arising during the development stage. Below we outline both the problems and the solutions in the design:

- Burning receptacle (resistance, switch, wire, tying system, increase of material in the area in order to insulate the resistance as much as possible and make the parts that are heat sensitive as massive as possible).
- New attachment for the film (equilibrium of the part, improvement in retention)
- Modification of the tabs (longer at the corners and narrower)
- The piece was reduced in width from 6.5 mm to 6.3 mm

Retention and Burning System

The previously published version of the system for burning and cutting the retention wire explained that a 0.125-W 9-Ω resistance had been chosen. The parameters used for dimensioning this resistance were early ones and the voltage for the power was later modified to 3.3 V. Once this value was accepted as the one which would produce the burn, a re-dimensioning of the resistance was begun to maintain the dimensions and nominal value of the power, i.e., the sought after resistance would be 0.125 W.

Test
In order to select the correct resistance from those available commercially, thermo-vacuum and room-temperature tests were carried out. The thermo-vacuum tests were redesigned until pressures even lower than those used earlier were achieved; a new vacuum pump was installed; the vacuum chamber and the

electrical connections were modified. This was all with the intention of achieving lower pressures, gaining greater control of temperature and eliminating losses in the vacuum chamber electrical connectors.

To reach the desired low temperatures, liquid nitrogen was used. To apply the liquid nitrogen indirectly, a system was designed comprising a bath of the liquid in a container within the vacuum chamber into which an oval-shaped piece of copper was dipped. While the lower part of the copper was submerged in the nitrogen, the upper part had the deployment mechanism bolted to it. The copper acted as a thermal conductor and the device's temperature was quickly reduced. Finally, a probe was installed in contact with the sub-chassis, as this is the part with the lowest heat conductivity and therefore the one that would be the slowest at changing temperature. The probe would thus provide the most reliable temperature reading for the parts that have a thermal balance inside the assembly. This is the atmosphere in which the device was enclosed and connected up in order to be fed power for the deployment to take place.

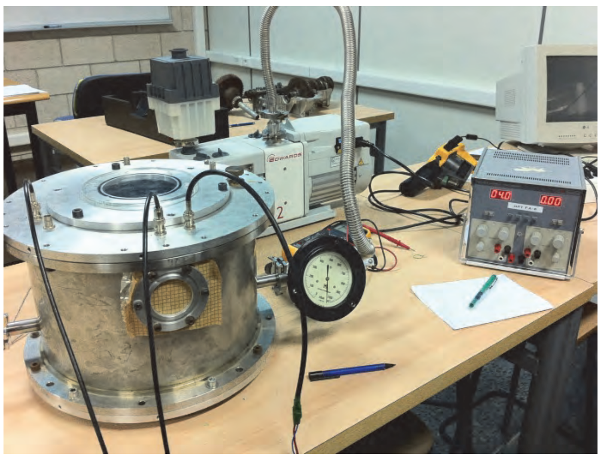

Figure 4. Thermo-vacuum chamber

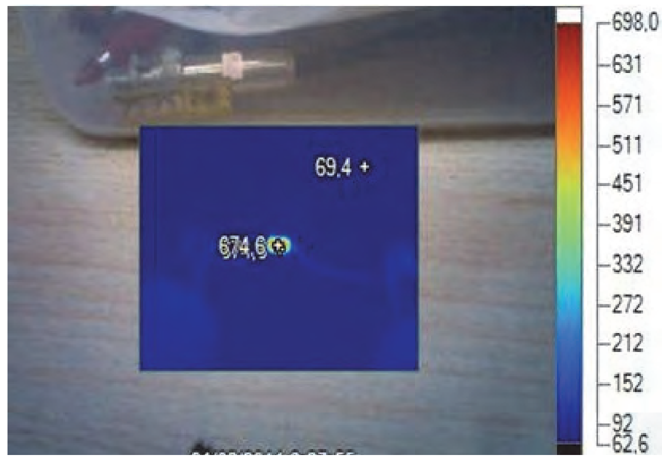

Figure 5. Thermal image of the resistance (ºF)

Besides this device, various tests were carried out on the wire burning at room temperature using a thermal camera for observation. With the combined results from thermal-vacuum and room-temperature tests, in which the same potential was burned and the same resistance used, the temperature value was found that the resistance must reach at room temperature in order to burn the retention wire in the thermal-vacuum atmosphere. This temperature is directly linked to an electrical power value needed, and it is thus simpler to select a resistance from commercially available values.

Thanks to these tests we detected that the resistances, on being subjected to much greater powers than the nominal ones, underwent deterioration and variation in their properties when the current was passed through them. This was helpful when determining the point at which the resistance was capable of burning the wire in the coldest environment and not destroy itself at room temperature. For this, the deterioration was related to the variation in the current flow by maintaining the power voltage constant over time. This fact can only be due to the variation in the resistance value over time due to the deterioration through overload. The graph in Figure 6 shows the results from observation of the resistance in a thermal-vacuum test at 3.3 V over more than a minute of burning, with two seconds of stop before the opening of the antennas

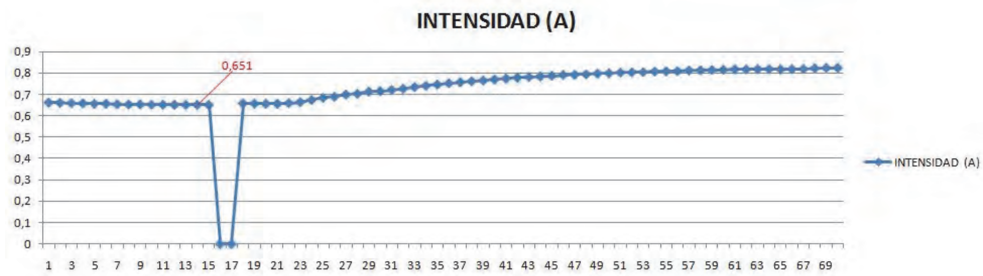

Figure 6. Monitored intensity during burning thermo-vacuum test

<u>Change of direction. New Burning Voltage</u>
Once the resistance was dimensioned to burn at 3.3 V, at a specific value of 5.6 Ω, changes were made to the project from outside our design process. The voltage supply was changed from being a set figure to one somewhere in the interval between 4 and 5 V. This not only caused a delay and meant the work done so far could not be applied in the Xatcobeo project, but it also posed a new problem for the task of guaranteeing correct resistance operation, which did not now have a fixed voltage value but instead had a rather wide range of values.

The challenge set by the new resistance values lay in guaranteeing that the selected resistance would burn the wire at the coldest temperature and with the lowest voltage (now 4 V), while at the same time ensuring that the resistance would not be destroyed at the highest voltage (5 V) and at the highest temperature, i.e., room temperature. Furthermore, the limitations still existed of using commercial values and consuming the least power possible.

One possible consideration was to select a resistance of 0.25 W, as it would then be possible to dissipate more power and, in theory, have more room for manoeuvre. Thus, two sub-chassis were designed independently, each one adapted to each resistance type. However, when the burning tests were carried out, it was observed that, the 0.25-W resistance was much more easily destroyed than the 0.125 W one contrary to what we had first thought. This meant this options had to be totally discarded and the tests became more centered on finding a suitable resistance at 0.125 W.

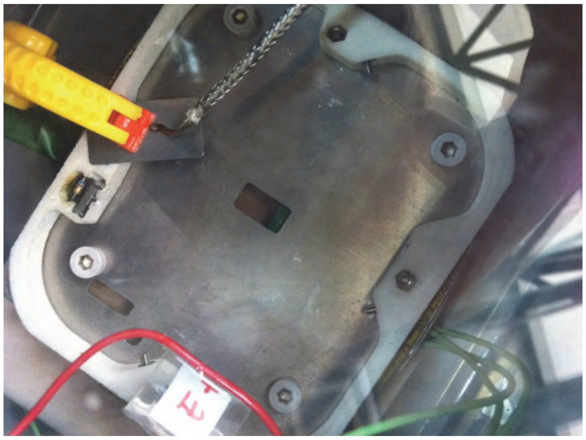

Figure 7. Burning thermo-vacuum test

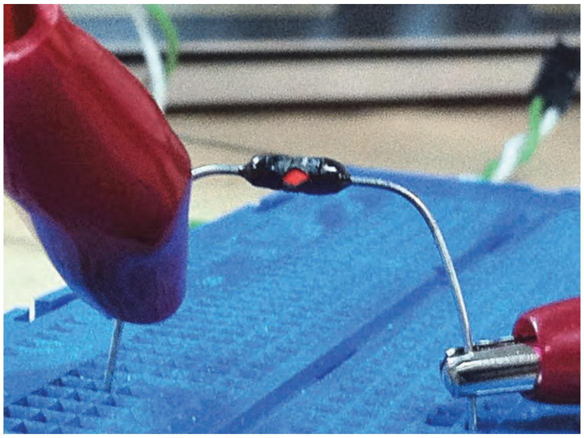

Figure 8. Destroying a 0.125W resistance

Thermo-vacuum tests were carried out at -100ºC using several resistance values to determine the wire burning. The burning tests consisted of a three-minute continual burn in order to check both that no damage was caused to the resistance and also the burning time at 4 V and 5 V. Observation was also made of the current variation produced by the deterioration of the resistance. In this way all possible effects were checked and operation was guaranteed in the face of much higher time values than the real ones for the burning cycle, which were set at 20 seconds by these tests and which double the burning time in the worst possible conditions.

Furthermore, numerous tests were carried out of the burning in a vacuum, at room temperature, and at the highest voltage in the range, in order to guarantee that the worst conditions for thermal dissipation, the highest temperature and the maximum power value did not destroy or serious damage the resistance. Burning was also for a continuous three-minute period, and some tests were even carried out at up to 15 minutes non-stop without destroying the resistance, although there was some relatively major deterioration after this time.

All the testing and dimensioning work led to a resistance of 6.8 Ω and 0.125 W being selected, thanks to which burning was produced in 2-3 seconds at room temperature and 6-9 seconds at -70ºC.

Retention system. Remodelling

In the 2010 article we described the retention system as a film joined to the sub-chassis and sharing an attachment point with one of the antennas, namely antenna S. The material chosen was a polyvinyl acetate, which had the optimum mechanical properties but not the best electrical ones as its surface resistivity was too high and so posed an ESD risk.

This was one of the main problems, along with the one mentioned above concerning the attachment of the film to antenna S, which had one serious inconvenience in that the antenna attached at point E is not completely pressed against the sub-chassis as it finishes its run along the side several centimetres beyond the burning receptacle, where the retention knot is tied. The local pressure applied by the knot deformed the antenna and made its end cross over the limit of the envelope allowed on the deployment device and go beyond the Cubesat rail.

There was a third problem linked directly to the film attachment. This time with the antenna's shared attachment. The radio-communication and IT engineering group discovered that the film, on being in direct contact with the antenna and unearthed, would introduce a great deal of noise into the signal, which meant measures had to be taken and changes made.

To solve the first of these problems we decided a change of material was needed. So we began to look for a polymer that would keep the lightness but also guarantee suitable antenna insulation, be dissipative, and, furthermore, have mechanical and thermal properties that were similar to the excellent ones of the polyvinyl acetate.

We chose a commercially available polymeric film and carried out thermo-vacuum deployment tests with it. The results were excellent, for, despite being thinner than the acetate, it complied with the mechanical needs for correct antenna retention operation.

In order to ensure correct surface resistivity, and even though we knew the material was catalogued as being anti-ESD, we decided to make the calculation needed to demonstrate that, in effect, the chosen film met the electrical requirements. We decided to use document ECSS as a reference, which states that in the worst case it should bear an electric potential of 100V between extreme and basis. Also the current density through the film should not exceed 10 nA/cm^2 in order to avoid ESD risk.

Independent attachment of the enveloping film

The independent attachment of the retention film is one of the greatest changes the sub-chassis underwent due to the above. For this there was a possibility of creating a new fixing point in any free area of the sub-chassis. Many options were considered, such as locating the attachment point in the free area just below the burning receptacle on the sub-chassis corners or on a prolongation of one of the antenna attachments.

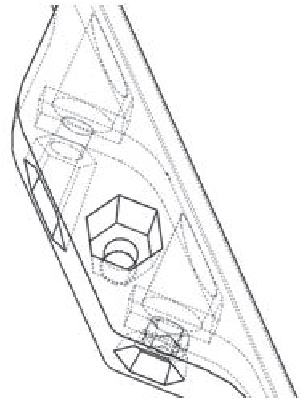

Figure 9. Independent fixation

We finally chose the last option which included a shift of the attachment point from antenna S to E. This led to improved antenna E retention and to the sub-chassis' center of gravity moving towards the geometric center of the piece because a practically perfect anti-symmetric piece was attained by this change.

Retention wire and mechanical interface with the Switch

In the mechanism presented in 2010, the detection switch was used to know the state of the antennas after each period of supply to the burning resistance. This meant that the retention wire pressed the switch tab and thus indicated that the antennas were folded. The loss of tension allowed the switch tab to lift and indicate that the antennas were open when the wire was cut.

Mechanically, the wire had to go through (in order, from the outside of the sub-chassis ring towards its inside) the enveloping film, and the antennas, the sub-chassis' outer wall, and pass over the resistance, close the switch, pass through the inner wall of the receptacle and be tied in a hole located a few millimetres away from the line of the wire.

A problem arose in the hole through which the wire had to pass in the internal wall of the burning receptacle. In some of the tests the tab was not able to open as a result of the trajectory curve that the retention wire had to follow. In order to solve this, the hole had to be designed above its previous position, although this compromised both the wall's integrity and the ease of tying as it made it difficult to achieve the tension needed to keep the antennas tied up.

This was achieved by introducing a second hole and tie attachment in such a way that the wire was tied between the two holes with no possibility for it to turn either before or after the burning. This detail increased the tension attained when tying and security, and also improved the wire's behavior in our search for prefect switch operation.

Figure 10. Burning receptacle

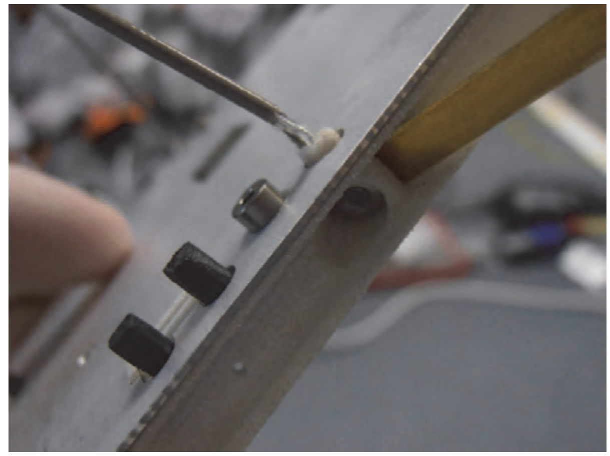

Figure 11. Detail of the interface between resistance support, sub-chassis and shielding

Resistance support piece

After many trials burning the retention wire, and bearing in mind that the order of events made it possible to produce successive burns in the case that the switch did not open after the burn, it was decided to test successive burns carried out on the same resistance, the same sub-chassis, and with the same assembly.

The result was that the resistance withstood all the successive burns perfectly well, without too much deterioration and without putting the retention wire's burning capability at risk. However, the heating up of the conductors in the resistance itself, together with the force applied by the tightened wire in contact with the resistance, produced a process similar to hot wire cutting on the part of the sub-chassis used for holding the resistance in the correct position.

This was a risk when several successive burns were needed to burn the retention wire. That is why a part was designed to substitute that part of the sub-chassis. This part holds the resistance in an unchanging position regardless of how many burns are used.

A material was sought that could withstand high temperatures of around 300ºC, would comply with values for outgassing, and would, in addition, present no ESD problems, i.e., one that was electro-dissipative without being conductive. The resistance could then be supported directly by it. The solution is a technical polymer made of PEEK, graphite and carbon fiber, which is also machinable and can thus be easily manufactured.

Finally the sub-chassis was redesigned to make this piece fit the lower part, where it is inserted, in such a way that the sub-chassis attachment itself was used for this piece. In this way we avoided adhesives or new mechanical joints and kept the assembly light. It also avoided the inclusion of new elements in the burning receptacle area, which was already congested.

Outgassing and ESD

All the compounds making up the device must be selected so that the outgassing values do not exceed 1% in the TML and 0.1% in the CVCM. These values are demanded by the ECSS standard.

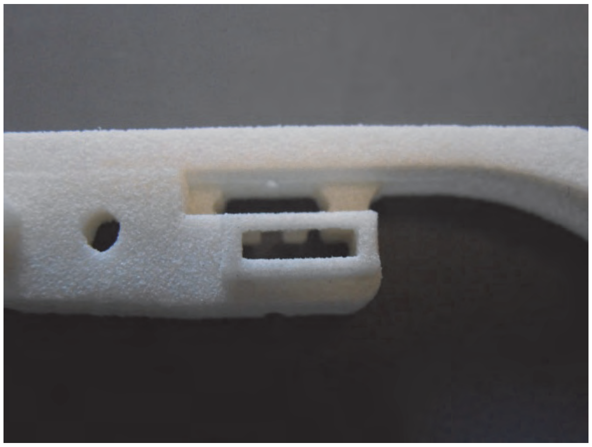

Figure 12. Sub-chassis

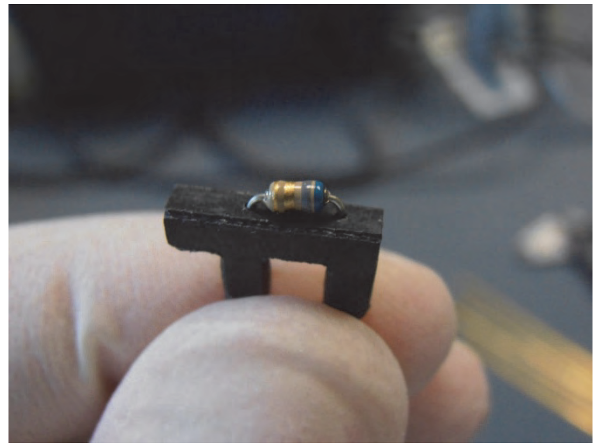

Figure 13. Resistance support

This is not a problem when working with metals, as no conventional metals have appreciable outgassing values, which means that there is no problem when working with aluminum, steel or titanium. However, when polymers are used it becomes more complicated to comply with the outgassing values demanded by the standard. It is often impossible in practice for the suppliers of finished parts to give outgassing values as they are parameters for very specific applications.

As this is considered to be a low-cost research project, we do not work with suppliers from the aerospace industry as they are far too expensive. Which means that obtaining the outgassing values for the polymers we work with has been complicated. We have already analysed the case of the polyamide, which, due to it containing fiberglass and being manufactured using laser sintering, has values below the limits according to the ESTEC/544 (QM/3958) reference test from 2004.

PEEK with Graphite and Carbon Fiber is an extremely expensive product, which in our case does not have major repercussions on the project given that the piece we use is very small. Here are the outgassing values for this compound:

Total Mass Loss (TML) [%]	0.16	ESA, ESA PSS-01-702
Collected Volatile Condensable Material (CVCM) [%]	0.00	ESA, ESA PSS-01-702

As for the dissipative film, it can be seen to be a conflictive element for several reasons, but above all because of the ESD risk. Regardless of this, it also had to comply with the outgassing parameters. Below are the values.

Total Mass Loss (TML) [%]	0.32	ASTM E-595
Collected Volatile Condensable Material (CVCM) [%]	0.00	ASTM E-595

The other elements on the device are metals such as Ti6Al4V for the mechanical attachment, or aluminum for the shielding, which do not cause problems with regards outgassing.

<u>ESD</u>

Much has been said about the way in which the device retains the folded antennas by using a polymeric enveloping film, and also about the sub-chassis structure that acts as the support for all the device's elements. Both share the same feature of being made out of polymeric materials, which not only reduces weight but also acts as electrical insulation at the same time.

Initially, this feature seems to be nothing but advantageous, but when the space environment is analysed it can be seen that there are several serious drawbacks, some of which we have already mentioned. These include steep temperature gradients, expansion forces, heat build-ups due to the lack of convection in heat transmission equations, and, in addition to others not mentioned here, the risk of electrostatic discharges (ESDs) appearing due to the high doses of ionized plasma that exist in the space environment.

After analysing the needs and requirements set out in the ECSS-E-ST-20-06C standard, we selected a commercially available electro-dissipative film. This is Polyethylene terephthalate (PET) sheeting with an aluminized face with anti-corrosive primer.

We decided to check whether this material was apt for our specific application. ESA experts in ESD were consulted and by combining their advice with the standards we made a series of calculations that show the material to be completely valid for the working environment it will have in space, even in the worst case.

The first hurdle is the unit in which surface resistivity is and the calculation of the electro-dissipative film 's total resistance. The characteristics film gives a value of 6.81 e10 Ω/Square, which is the unit used to differentiate resistances of surface resistivities.

First, we had to calculate the film 's total resistance:

$$R = \frac{\rho \cdot l}{w \cdot t}$$

Where ρ is the surface resistivity, l the length of the strip, w its width and t its thickness.

$$R = \frac{6.81\ \mathrm{e}10 \cdot 500}{4{,}5 \cdot 0{,}0508}$$

$$R = 1{,}4895\ \mathrm{e}14\ \Omega$$

As mentioned, the standard gives a current density limit of J =10 nA/cm^2 and, in order to avoid electrostatic discharges in inverse voltage gradients (e.g. between a dielectric and a conductor at a greater negative potential), a maximum potential difference (V) is established between dielectric and adjacent conductor exposed to the vacuum of +100 V. Furthermore, when A is the area exposed in cm^2, we know that:

$$R = \frac{V}{J \cdot A}$$

$$R = \frac{100}{1\ \mathrm{e} - 8 \cdot 50 \cdot 4{,}5} = 4{,}44\ \mathrm{e} + 08\ \Omega$$

That is, for our case:

$$R \geq 4{,}44\ \mathrm{e} + 08\ \Omega$$

If we reverse this reasoning and take R as data to calculate the current density resulting from using the resistance:

$$J = \frac{V}{R \cdot A} = \frac{100}{1{,}4895\ \mathrm{e} + 14 \cdot 50 \cdot 4{,}5} = 2{,}98385\ \mathrm{e} - 14\ \mathrm{A/cm^2} \ll\ 1\ \mathrm{e} - 8\ \mathrm{A/cm^2}$$

According to what is established in the standard, this value cannot exceed 1e-8 A/cm^2 (28 ECSS-E-ST-20-06C page 28). Thus we demonstrated that the material is fit for purpose in space, as it easily meets the requirements of the standard.

Mechanical, Electrical and Thermal Interfaces

Before describing the final design and its features, we would like to explain all the interfaces found on the device as we believe it is important to know about them in order to understand the characteristics of the design.

This project is characterised by the number of factors that must be taken into account during the design and dimensioning tasks. The wish to make a system with such strict requirements and objectives, one which is also totally modular and independent from the structure itself, means that there are numerous conditioning factors caused by local conflicts between the various elements in the assembly. We have decided to call these conflicts “interfaces”, of which there are three kinds:

- Mechanical Interfaces. These are all the relationships, contacts, and dependences of the distinct parts in the device that are mechanical in nature.
  - The most obvious ones are those generated between the deployment device and the shielding onto which it is installed, and that between the shielding and the frame. The latter is the simplest and consists of 4 countersunk M3 drill holes, whereas the former is the most complex of all the faces of the Xatcobeo, the reasons for which are given below:
    - Attachment of the sub-chassis. There are 4 holes through which the bolts should pass to attach the sub-chassis to the shielding. These are M2 pass through holes.
    - Antenna connection. One of the most conflictive points on the assembly and easily the one that took up the most design, verification and redesign time during the whole project.
  - At this point is the mechanical interface between the sub-chassis and the shielding, formed by 4 holes through which a part of the polymeric piece can pass towards the inside of the satellite.
  - There is a further mechanical interface between the connection cable and the holding bolt for the antenna, which had to be taken into account so that the traction from bolt tightening did not break the conection wire.
  - Between the connection cable and the insulation protruding from the sub-chassis. This protruding piece is designed to fit the coaxial's inner insulation and thus eliminate mechanical stresses on the conection wire.
  - Between the cable's coaxial mesh and the joint between sub-chassis and shielding. This interface gave the integration problems described later.
  - Finally, there is a less noticeable interface made up by the sub-chassis and its parts that protrude towards the internal face of the satellite and the structure frame.
    - There are other mechanical interfaces that do not directly involve the deployment device but which take place in the shielding, such as the microHDMI connection and the RBF bolt.
  - The following mechanical interface is made up of the antennas and the shielding and that generated in the joint attachment of the antenna and polymeric enveloping film.
    - It is formed by the antenna itself, the bolt that enables attachment and the sub-chassis, with the antenna connection wire in the middle.
  - The interface between the polymeric film and the antennas. These can be divide into two, as follows:
    - Whilst the antennas are folded

        - Once the antennas have been deployed and the film is attached to the assembly and has free movement. Another reason for avoiding ESD and earthing it, should it make contact and discharge towards an antenna.
    - Mechanical interface between the resistance and the sub-chassis. The resistance must remain in a set position during the burning time, which means there is contact between both elements. This interface, furthermore, is designed so that its characteristics stop the resistance from becoming detached after burning, even if the power cables were to become loose for any reason.
    - Switch and sub-chassis. This is another of the interfaces that caused the most headaches throughout the project. It is very important that the switch be installed at the exact point it was designed for, because in this way the trajectory of the retention wire is correct and its aperture is guaranteed together with correct deployment measurement. There have been many modifications based on the results from tests and flight prototypes.
    - Nylon wire. The nylon wire is another of the more complicated interfaces as it is in contact with the enveloping film, the antennas, the outside of the sub-chassis, the resistance, the switch, the inside of the sub-chassis and, finally, with the sub-chassis again, when it goes through the tying holes.
    - Interface between the polymeric support piece for the resistance, the sub-chassis and the shielding. This piece should leave the resistance in the correct place and fit tightly in order to avoid vibrations or shifts of position.
    - Attachments. The use of different materials to make the device's parts means that expansion gradients can appear at the areas where there are mechanical conflicts between materials depending on the temperature changes produced during orbit. This takes on greater importance at the attachment points on the sub-chassis for the antennas, where there is contact between Polyamide 12 with fiberglass and the Titanium, Aluminium and Vanadium Alloy. Some play is needed in order to avoid polymer fault.
- Electrical Interfaces. All the electrical relationships between elements in the device are given in this section:
    - Burning resistance. The design must guarantee electrical separation between the power cables to the resistance and the metallic mass of the satellite that serves as its electrical mass. At the same time the electrical connection must be guaranteed between the resistance conductors and the power cables to the antenna board. In this case by soldering.
    - Switch. In the same way as for the resistance, the switch connections must be electrically insulated to ensure perfect measurement. As with the resistance, the connection must be guaranteed with the measurement cables in the switch. Soldering is also the solution here.
    - Antennas. It is clearly necessary to insulate the antennas from any electrical contact that may exist. This is a point had also previously been studied and included in the design of the sub-chassis itself, as can be seen in the tabs.
    - Connection of antennas and metallic mass. The bolt must keep the connection wire for each antenna in contact in order to ensure perfect data transmission. At the same time, the metallic mesh of the coaxial cable for antenna connection must be kept between the shielding and the sub-chassis, i.e., earthed at all times.
    - The dissipative layer of the sub-chassis and the shielding. To avoid ESD in the sub-chassis, it was decided to use dissipative paint on it and earth it in contact with the shielding by direct contact between the covering and the shielding.
- Thermal Interface. This interface is somewhat complicated given that in one small area 4 different materials are in contact, each with distinct conductivities, distinct fusion points and distinct responsibilities in the device; these are the resistance, the sub-chassis, the shielding and a piece that acts as the resistance support and is the sub-chassis' protection against high

temperatures, not from the resistance but from the conductors located on both sides of it. Further details will be given in the section dealing with the burning resistance.

Integration of the Remove Before Flight

For the Remove Before Flight assembly, we had to bear in mind the great precision that had to be attained in the trigger position and, therefore, in the way this was guided towards the interior switch. It was decided that the best way to guide the trigger was by means of a threaded hole, and for the trigger to be a 16-mm long M2.5 bolt, as it had to close the switch at this distance until the RBF was removed.

In order to guide the bolt conveniently, one option was to use a single nut because the shielding is too thin for a hole to be threaded. However, the option to attach a nut using some kind of adhesive posed the problem of not being able to achieve suitable precision and of the bolt being likely to deviate with respect to the switch.

To solve this problem we resorted to a type of self-clinching nut called a PEM nut, which consists of a mechanical joint that uses pressure to embed itself thanks to the geometry of the nut itself. We designed an installation method which meant there could be no over pressure, and therefore no deformation of the shielding, using a simple installation tool for the nut and a small manual hydraulic press.

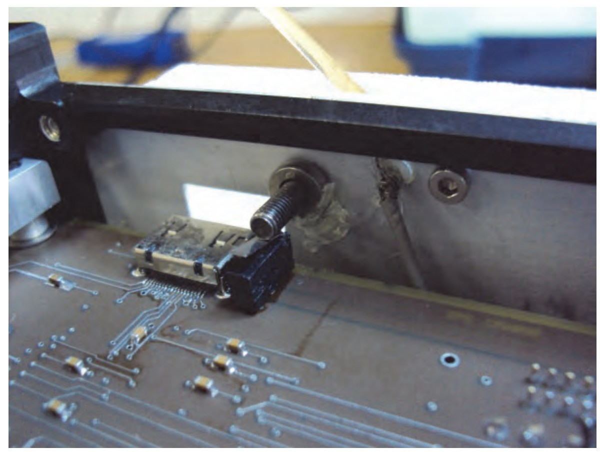

Figure 14. PEM nut for guiding the RBF

To check whether the nut would hold up after installation, several tests were carried out on a shielding that was identical to that for the flight. These consisted of severe mistreatment by means of heavy blows that destroyed the shielding. However, the PEM nut remained unmoved by all the knocks and accelerations that were produced. Finally, it is worth pointing out that in the vibration test (which was more professional and better monitored) that formed part of the Qualification tests, the PEM nut behaved perfectly and as expected.

Integration and Qualification

During the assembly tests for the mechanism, there were never any problems arising regarding the integration of the mechanism; nor were there any problems stemming from the mechanical interfaces. These tests had been carried out with a shielding that was identical to the one for flight, and the coaxial meshes of the connection cables for the antennas had been frayed to improve the coupling between cable, sub-chassis and shielding. However, the flight connection cables had been made in such a way that the coaxial mesh was compact, cylindrical and soldered. This led to the coupling between these three elements being highly unsatisfactory.

It must be said that the design had a margin of 0.2 mm with regards the limit for the envelope given in the Cubesat standard, set at 6.5mm. However, the pressure generated when the sub-chassis attachment bolts were tightened on the rolled up coaxial meshes produced a bending moment located at each of the four attachment points. This deformed the piece elastically to the point where the corners of the sub-chassis exceeded the available envelope dimensions by several millimetres.

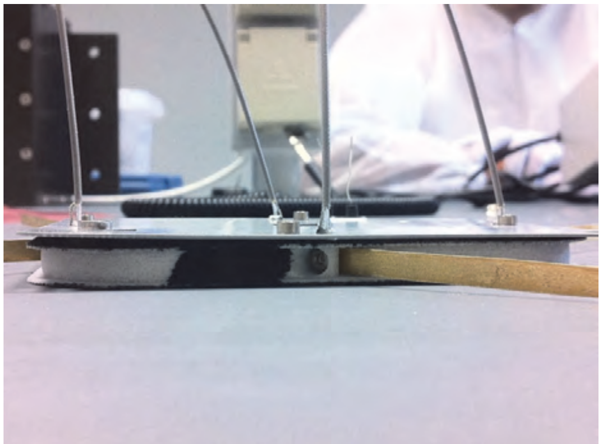

Figure 15. Integration problem with the coax

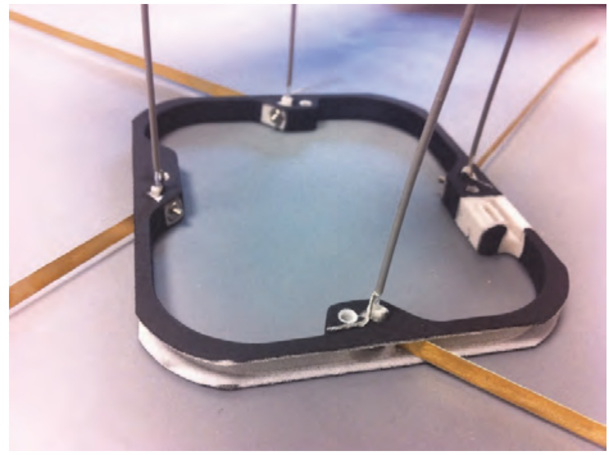

Figure 16. Coated Sub-chassis during the integration process

To solve this integration problem two measures were taken to avoid protrusion of the envelope.

- It was decided to look at the way in which the coaxial meshes were integrate, that is, we undid the rolling and the soldering and frayed them all. The aim was to increase the contact surface (and therefore reduce local pressure) and reduce the thickness of the mesh, as both factors were producing the excess in dimensions.
- The sub-chassis had been designed at the limits of its possibilities, but thanks to the results of the material chosen and the manufacturing method turning out to be better than expected, we decided to reduce the thickness of the upper tab on the sub-chassis by 0.15 mm and the lower one by 0.05 mm, which gave us 0. 2mm of additional margin.

Both these actions combined resulted in the mechanism comfortable complying with the standard set for the film and all the measurement taken showed that the mechanism entered with a margin of at least 0.1 mm at any point on the design inside the envelope dimensions laid down.

Qualification Tests

The final step for the project was to carry out qualification tests on the satellite. We will focus here on those to do with the antenna deployment mechanism. These are the thermal-vacuum test and the vibration test.

Both tests were undertaken at the INTA facilities (Madrid) and had support from many members of the Xatcobeo project and INTA staff. The first was a complete simulation of the heat process during launch and orbit initiation, and a real-time simulation of orbital periods. During this test there was deployment of a duplicate of the antenna deployment mechanism, given that the main one was assembled on Xatcobeo. The results from the deployment were more than satisfactory.

With regards the vibration test, this was carried out at room temperature with a TEST-POD MkII, following a random profile as given in the reference document used as a guide in the tests. This reached up to 28g of acceleration. The test results were satisfactory as all the components in the deployment mechanism withstood the test with no shifts in their positions, no breaks, and no need to fine tune any part of the design. In short, there were no setbacks from the vibration test, which was the most ambitious one from the outset.

Conclusions

After almost three years of development, we have achieved a design that fulfils all the standards involved in the project. At the same time we have attained extreme lightness and great simplicity in operation and assembly. A great deal of the design's success lies in the use of polymers and the way their characteristics have been applied correctly after a process of testing, modification and verification.

Many of the problems and drawback found in the project have also stemmed from the use of these materials, and their use is an engineering risk when the aim is the search for extreme lightness. But thanks to this risk, a mechanism weighing in at only 13g has been completely validated even when faced with the most demanding tests.

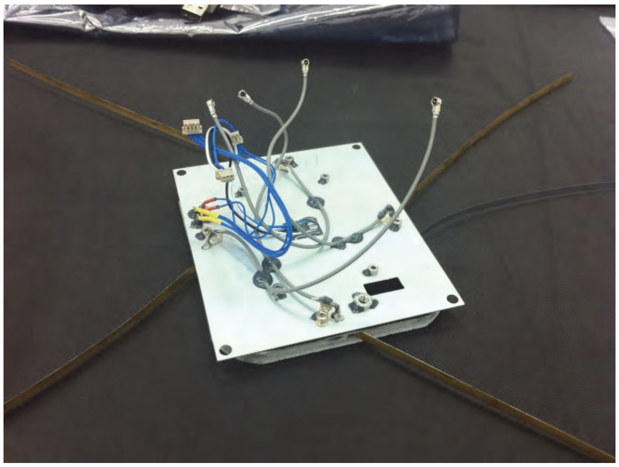

Figure 17. Rear side with the antennas deployed

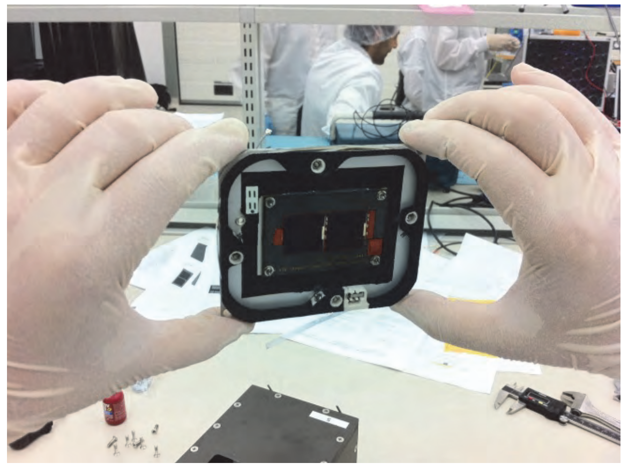

Figure 18. Front side with the antennas folded

We believe that the design process has sought validity within the characteristics decided upon for this mechanism in the face of all the important factors. Also the testing process has been exhaustive. The results have shown that the durability and reliability of not only the retention system but also the burning and detection system are all proven and guaranteed. The definitive test will soon take place when Xatcobeo is placed in orbit in the VEGA inaugural flight. However we are confident of the results shown by the mechanism in testing and of the reliability that the design has shown on the ground.

Given all that has been described in this and the previous article, we believe that using a combination of polymeric materials as a base and fast prototyping as a manufacturing method provides major advantages. These include the speed of the design process, the lightness of the assembly and the reduced cost of the project, and makes it possible to obtain feedback from flight parts at a reduced cost. It is also possible to overcome drawbacks stemming principally from the need for a direct correlation between the computer model and the manufactured item.

The final conclusion, as stated above, will be seen on launch. However, the results obtained so far show future possibilities for this combination of material and manufacture, for the response has been highly satisfactory.

References

1. Encinas Plaza, J.M., Vilán Vilán, J.A., Aguado Agelet, F., Barandiarán Mancheño, J., López Estévez, M., Martínez Fernández, C., Sarmiento Ares, F. "Xatcobeo: Small Mechanisms for CubeSat Satellites – Antenna and Solar Array Deployment" *Proceedings of the 40th Aerospace Mechanisms Symposium,* (2010), 415-430.