Lesson learned on the development of a self-deployable VHF antenna for NanoSatellites

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ABSTRACT

Kinéis program aims to build a nanosatellites constellation, which will embark the next generation of AIS (Automated Identification System) payload developed by Thales Alenia Space that include the AIS Antenna product.
This paper presents the product, summarizes its development plan and emphasizes on the findings and lessons learned of a development driven in a "new-space" environment, meaning wide open to creativity and innovations (compared to usual space standards) together with a tight schedule and limited development costs. This requires to deviate sometimes from standard path in Space developments, exposing on the other hand to risks and requiring reconfigurations with agility .

1. CONTEXT

Created in 2018, Kinéis is a satellite operator and global IoT connectivity provider that will launch a 25 nanosatellites constellation in 2023, taking on the challenges of New Space: a tight schedule, scaled-up performances and serial production.

Beyond renewing Argos, Kinéis also made the decision to onboard next generation AIS (Automated Identification System) payloads providing significantly enhanced performances, especially the detection rate in high density areas. This was possible thanks to a long experience in AIS data processing and high level technical partners as Thales Alenia Space and CNES.

The AIS Antenna product (Figure 1) being simultaneously an innovative Antenna and a release/deployment mechanism in a new space context, a compact multi-functional team was set up by Thales Alenia Space to tackle this challenge.

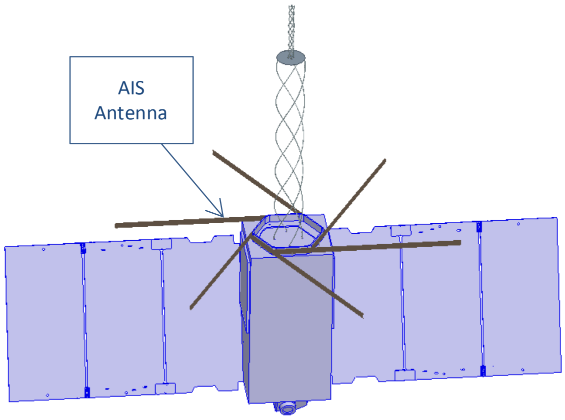

Figure 1. KINEIS Satellite

2. AIS ANTENNA TECHNICAL DESCRIPTION

2.1. Technical Description

This antenna is a small object composed by

- An hexagonal structure called 'mandrel'
- A set of 6 "monopoles" composed by
  - Metallic ribbons ensuring deployment & RF function
  - A coaxial cable transmitting the RF signals from the metallic ribbons to the P/L
- A set of Hold / Release devices based on fuse wire technology and maintaining the Antenna in a stowed configuration until release in orbit.

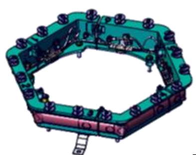

Figure 2. AIS Antenna in its stowed configuration

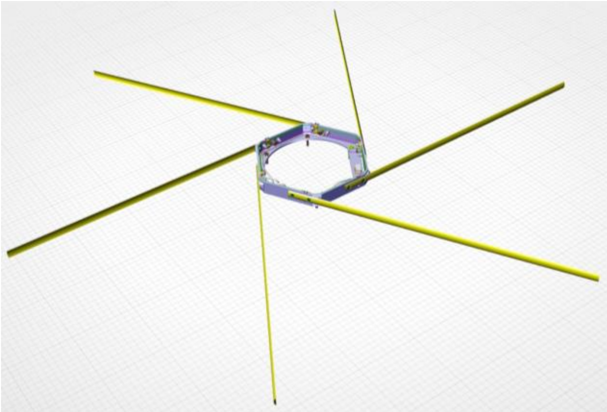

Figure 3. AIS Antenna in its deployed configuration

2.2 AIS Mission and Antenna Functions

Through a Tooled Engineering Approach , and through the assessment of the operational scenarii, Thales Alenia Space identified the main functions and performances of the Antenna and the release / deployment mechanism, which consist in :

- Hold in stowed position on ground and during launch the AIS antenna
- Release and deploy the AIS Antenna once in orbit, triggered by an electrical pulse from the P/F
- Enable the reception of AIS signals from ships with a dedicated RF performance including return losses and gain pattern
- Transfer the signals to the Payload units for processing

These performances have to be guaranteed within some challenging technical constraints:

- Low total mass & Volume (accommodation).
- Not require any active thermal control to heat or thermally monitor the components
- Release and deploy with a very low energy

This set of requirements were digested to converge on a self-deployable Antenna, with non explosive release devices, and drove the materials selections to provide the RF performance, the spring effects, the electrical characteristics, the lightness and finally the robustness to LEO environments without any need of active thermal control.

The AIS Antenna performances are summarized below:

- has a deployed diameter around 1 meter while the stowed diameter fits within 260mm
- the fully equipped mass is <500g
- the total current needed to release the Antenna is <1Amp under 15V during a few seconds
- no additional power is required for deployment completion and self- locking
- the temperature is managed to cope with the qualified limits of its components by mastering the thermo-optical coefficients (emissivity / absorptivity) of the components exposed to deep space and a classical MLI is accommodated over the connectors
- the Antenna is totally demisable at end of life (French Law constraint for satellite operations)
- is robust to radiations, Atox, temperatures etc… thanks to a proper selection of materials

2.3. AIS Antenna design drivers & innovations

Being a fully new product, co-engineering sessions were planned in order to clearly share all constraint and needs, sometimes between Thales Alenia Space – P/L team and Thales Alenia Space Antenna team, sometimes between Thales Alenia Space and Kineis Customer.

The first driver was the self motorisation together with the achievement of the RF performance of the whole chain from monopole to the payload units .

- the selected material for the monopoles must offer a good spring effect to release the antenna and provide the RF performance.
- The selection of the coax cable was mostly driven by the overall AIS performance and synergy with other units which require better performance than for the AIS antenna
- The Innovation is mostly around the way to connect the monopole to the coax cable and guarantee its integrity against the S/C environments. The technologies to connect the main coaxial conductor to the monopole and to connect the shield of the cables to the AIS Antenna grounding path were the topics of techno processes with early validation tests.

The second driver was the Hold/Release device : power need, accommodation and EMC compatibility:

- Due to the low power available Thales Alenia Space innovated by developing a conductive polymer able to fuse with a current <100mA and voltage <10V (much lower than traditional fuse wires),
- Subsequently the crimping technology to connect this polymer wire to the classical HR harness was developed & qualified,
- The way to tension properly the HR device during the installation on the Antenna to maintain the monopoles was also developed.

In the end, the team innovated by developing very small, light and low cost components , combining a brand new technology for HR device with classical and space qualified solutions for the rest of the harness.

The third driver was the overall cost development, recurring cost objective, and the time-to-market.

- In this perspective, robust low cost materials with enhanced heritage in Thales Alenia Space were preferably selected like the PEEK for the mandrel. Self-thermal control was preferred, meaning also robustness and low cost.
- the innovation consisted in the testing methodology (see section 4.2) and the Development Plan with a lot testing approach rather that a usual testing philosophy (see section 3), and with pragmatic tests before CDR to replace long and / or questionable analysis.

3. MECHANISM DEVELOPMENT AND TEST PLAN

The AIS Antenna development plan is oriented on the following approach agreed with the Customer :

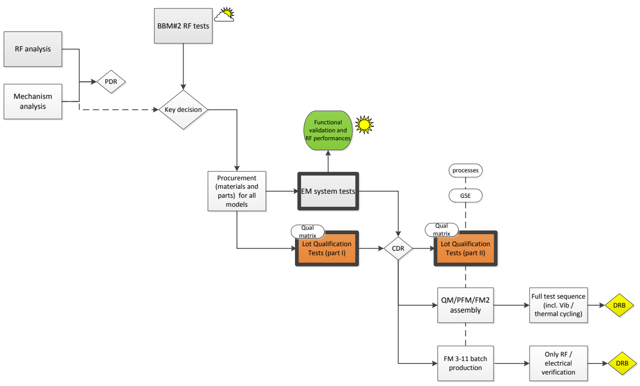

Figure 4 : AIS Antenna development logic

In this sequence two fundamental aspects were:

RF Validation by Engineering Model (EM): the functional validation is made on a RF representative EM and supports in particular the Critical Design Review (CDR) which concludes the item design phase. However the planning does not allow any iteration loop in between EM and PFM/FM manufacturing. A risk analysis led to identify an early Bread-Board Model (BBM #2) to validate the preliminary RF performances.

Then, a confirmation of RF performances was secured on the EM, validated in Thales Alenia Space CATR (Figure 5). Finally, a deeper and more complex validation was made in CNES CATR facilities (Figure 6) with the complete antenna configuration

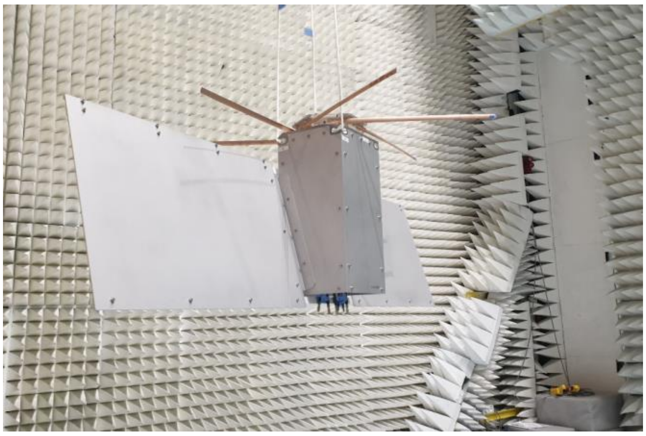

Figure 5. AIS Antenna testing in Thales Alenia Space *CATR*

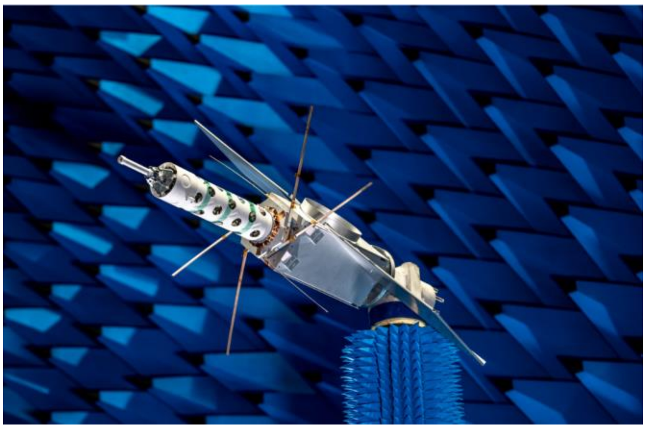

Figure 6. AIS Antenna testing in CNES CATR ©CNES, DE PRADA Thierry, 2021

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Qualification through LAT test campaign + 3 models :

The overall philosophy is to use a **Lot Testing approach** like the Lot Acceptance Tests performed on destructive items in standard space business for example pyrotechnic devices. The idea is to control from end to end the manufacturing process **-**from the procured raw material batches, through manufacturing steps and until the final assembbly-, and to test only a limited part of the items, considering the others have the same performance.

The "LAT 1" test campaign takes place before CDR with the objective to validate the elementary performances of the components, and provide the necessary justifications for the design validation (CDR). The new processes developed specifically for the AIS Antenna design are qualified through LAT1-Pxx tests. The elementary performances of the components are verified through 8 dedicated LAT1-Fxx to address each major function.

The “LAT2” tet campaign (based on QM, the PFM and FM2) takes place after the CDR when the design and performances (LAT1 + RF performances) are validated. With the same philosphy as explained above, this campaign serve as to demonstrate the performance but also the repeatability and stability of the processes and performances. The other FM will be fully similar to the tested models; thanks to the batch procurement and the batch manufacturing philosophy, minimizing the variability between models and the need to extensively test all models. Nevertheless, all FM models will be electrically controlled and verified wrt to the most important performance which is the RF performance but this simplification allows to cut significantly the manufacturing cost to meet Newspace objectives.

4. FINDINGS AND LESSONS LEARNED

4.1. New Space development in a skilled background

The NewSpace business and development is driven by time-to-market and budget constraints, and leads to test early the concepts and built progressively the solution together with its specification. It is therefore of crucial importance to be able to rely on a strong expertised team to anticipate and consider the usual disciplines applicable to the space applications, eg: RF performances, radiations , Atox, EMC environments, materials compatibilities in deep space, thermal behaviour in vaccum and in low earth orbits, state of the art for space applications including cleanliness, etc…

Thales Alenia Space approach was to reinforce these two aspects of the development. On one hand, the development is based on enhanced test campaign (see section 3) and supported by a set of experts in several fields of the affected performances. On the other hand, Thales Alenia Space expertise helped the project to build and complete the specification of the AIS Antenna through a tooled engineering approach (developed in section 4.2). These two collaborative paths have in particular outlined some difficulties and key performances of the AIS Antenna performance not necessarily anticipated at the beginning of the project

4.2. Tooled Engineering Approach

The Tooled Engineering Approach is based on Thales ARCADIA/Capella methodology, implemented in a ORCHESTRA set of engineering tools.

The first step of the method is to understand the Customer’s needs. The analysis of the operational scenario of the product use and the functional analysis allow to identify and allocate the Key Value Attributes (KVA) and the global expected performances.

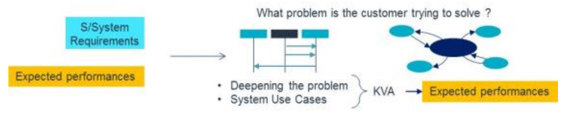

Figure 7. Understand the Customer’s needs

The second step of the methodology is to identify the functions and deploy them on a preliminary architecture, leading to concatenate a consistent set of Technical Requirements (TRD). These requirements are allocated to the lower level components.

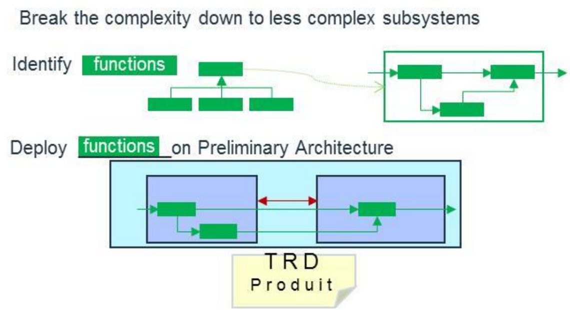

Figure 8. Build the Technical Requirement Document

For the AIS Antenna development , the 2 main operational scenarii “RF testing” (Figure 9-1) and “in-orbit deployment” (Figure 9-2) allowed to discuss and understand the Customer’s needs and constraints. They highlighted some “unsaid” problemantics.

For example, the RF testing scenario allowed to discuss the influence of the external appendages of the satellite (the other UHF Antenna , the solar arrays, the dispenser interface and propulsion, the presence of the star tracker), and in the end converged on the representativity of the S/C simulator for the RF performance measurements during AIT phases.

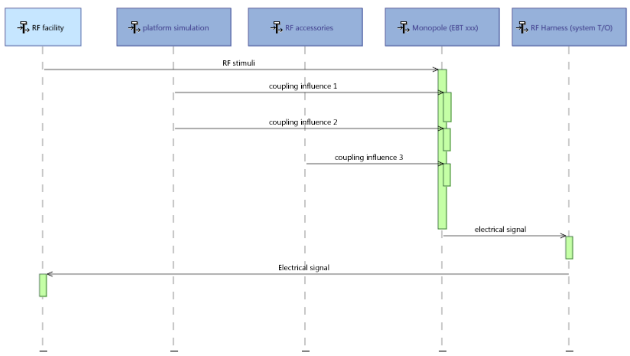

Figure 9-1. RF performance test during AIT activities

Another example is the in-orbit deployment scenario, when the discussion allowed to put to light some “hidden” constraints either linked to the platform itself (like the onboard energy available to release the Antenna) or the preferred operational scenario that consists in waiting for several days in orbit before triggering the release of the Antenna, which in return brings several contraints and drivers for the AIS Antenna design. This methodology allowed to better clarify the requirement, select the appropriate solution (in our case a fuse wire with a very low power need), and adapt the qualification test campaign with the appropriate temperature / time mission profiles.

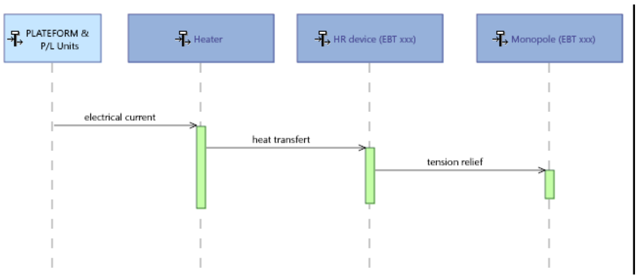

Figure 9-2. in-orbit deployment scenario

The strength of the methodology is the progressive convergence towards a full set of requirement in parallel of testing early the concepts , select the most efficient ones, and optimize the time to market readiness.

With a space standard approach, one would have basically designed the product and all parties found out that the product was missing some key features or functions after the CDR, impacting drastically the development schedule.

In addition, to help the selection of the most efficient design in a minimum time while minimizing the risks, three other tools are used:

Causal Influence Diagram:

The idea is to examine the existing TRD with a reverse approach, see how the external parameters or variables can affect the product performances and verify that the variability of these parameters are well accounted in the IVVQ strategy (like illustrated in Figure 10-1). In the opposite case, complete the Development Plan.

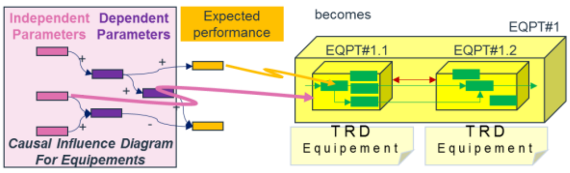

Figure 10-1. Causal Influence Diagram

In the frame of the AIS Antenna design a Causal Influence Diagram has been drawn (see extract in Figure 10-2). As an example, it brought to light that the connection of the monopole to the coaxial cable was a new process while the impact of the quality of this connection on the Antenna RF performance was unknown. A dedicated validation test was added to control and monitor this quality and check the RF performance are met on an early Engineering Model (EM)

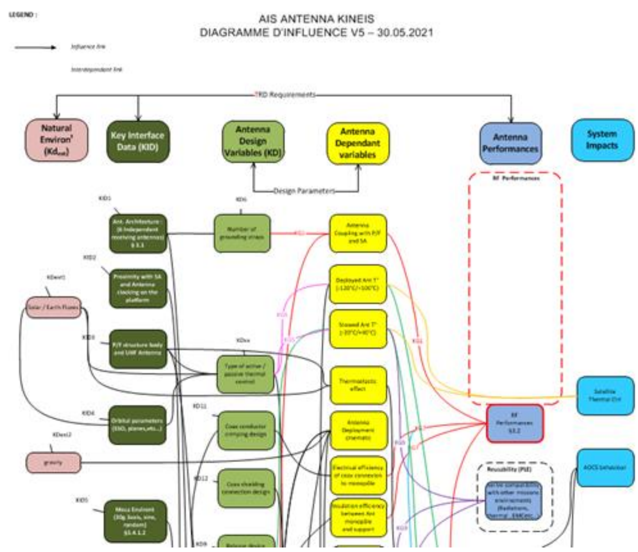

Figure 10-2. Kineis AIS Antenna CID extract

Set Based testing of the baseline and back-up

In front of several potential solutions, sometimes non discriminable because of some unknowns or so-called "knowledge gaps", the recommended way is to proceed with some simple derisking testing early in the development, to select by concrete arguments and test values the baseline design and discard the not suitable alternatives (like illustrated in Figure 11-1)

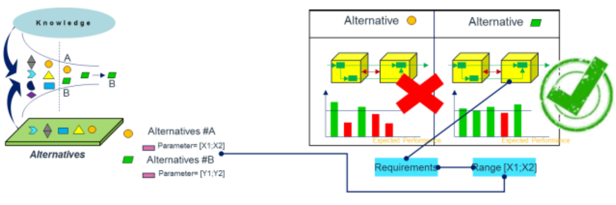

Figure 11-1. Set Based concurrent engineering

In the frame of the AIS Antenna design many derisking tests have been carried out. As an example, (see Figure 11-2), two materials have been tested in CATR to show that both candidates could meet the expected performance.

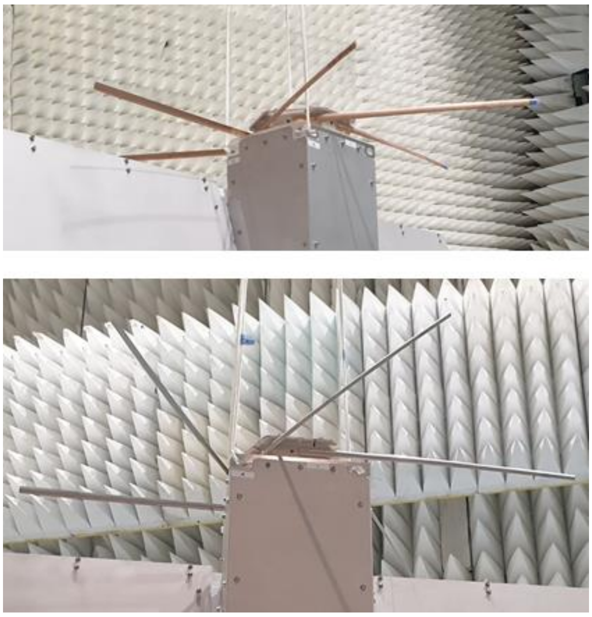

Figure 11-2. AIS Antenna. Testing of concurrent solutions

Key Decision Tree

In the end, after running the previous tools, a natural list of Key Decisions appear to be taken in duly time and in a relevant sequence to manage efficiently the development. They form a Key Decision Tree to lead the efficient development with a minimium rework and in accordance with the other upper level programmatic needs.

As a conclusion we learned that even if the time demand to set-up these tools and formalize these rationales are clearly not negligible and are a human investment, the benefit in the end is obvious even for a low cost product : it allowed to clarify the needs early in the project and avoided to discover impacting requirements much later, with much greater impacts than the invested time.

In this context, the next paragraphs presents two examples of the concurrent derisking testing approach handled during this development.

4.3. Thermal control in LEO environments with low cost objectives

For nanosatellites, the available resources for thermal control are very limited, in opposition with standard geostationnary satellites. In this context active thermal control, heater line, or thermistance lines to monitor any potentially sensitive component are not favored by designer especially for external antenna. The passive thermal protections are also very limited due to the kinematic of the deployment. Indeed, all the lateral faces shall be kept free of any protection (with margins) to avoid any interference with the surrounding pieces of equipments or structure for deployment.

On the other hand the LEO (Low Earth Orbit) environments are as stringent as other orbits and temperatures can vary within very wide ranges if nothing is put in place to limit the heat fluxes absorbed or rejected in deep space.

The most efficient way according to Thales Alenia Space experience is to control the temperatures by acting on (or at least knowing accurately) the thermo-optical properties of the material surfaces exposed to deep space : α absorptivity and ε emissivity are the key characteristics. The mandrel material has been characterized and the performance is acceptable as is. The metallic monopoles, without any surface treatment could climb to unacceptable temperatures for themselves and for the coaxial cables connected to them (heat conduction along the monopole). Among the possible solutions: covering layer, surface modification by mechanical or chemical attack, the Thales Alenia Space expert team suggested the sand blasting as a compromise regarding the thermo-optical enhancement and the technological readiness level. Thales Alenia Space thus selected early a balanced process considering TRL, performance and costs.

On Figure 12, the efficiency is improved (when the ratio α/ε is the minimum) when increasing the number of sand blasting passes. To conclude, the sand-blasting investigation tests showed us that:

- An asymptotic plateau is obtained at a certain level meaning the controlled and optimized value is reached
- But the sand blasting process mustn't be too much aggressive not to modify the monopole geometry.

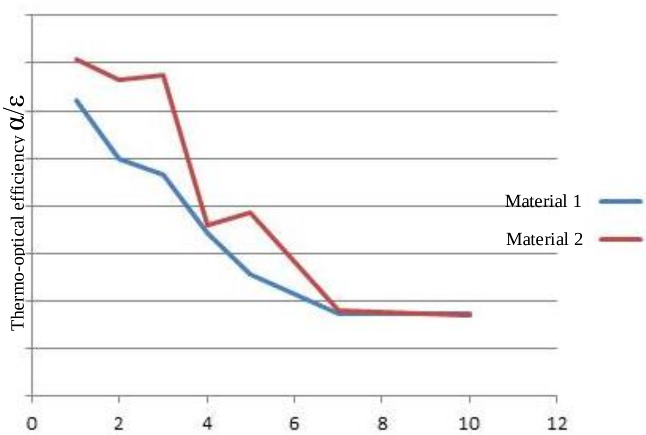

Figure 12. an example of thermo-optical efficiency optimization in the absence of active thermal control

4.4. Cold welding risks

The cold-welding phenomenon is the possibility under deep vacuum (<10^{E}-7mbar) to develop surface adhesion without any external heat source. This phenomenon is particularly true for metal to metal contact and, occur at any temperature, and is dependent on the vacuum level, the contact pressure and the affinity of the materials to cold-weld.

According to the ECSS guidelines most common solution is to use dissimilar metals (which is not our case in the AIS Antenna baseline design). ESA handbooks and NASA experiments also talk about very important contact pressures to reach significant adhesion forces, typically 50% of the yield limit of the material, which is not at all the case for the AIS Antenna. Indeed the contact pressure between monopoles is driven by the spring effort contained by the release device, typically 1 Newton.

In these conditions cold-welding risk was insignificant at the beginning of the project.

But the latest progress in tribology in deep vacuum conditions lead to reconsider the criticality when micro-vibrations may exist including with dissimilar materials. Considering also the waiting period in orbit before release and the low motorization force generated by the tape springs, the risk was not considered at a sufficiently low level, even for a New Space development and with in-orbit redundancy.

Several solutions were assessed to avoid any metal/metal contact (meaning 0% contact), but they present some important drawbacks.

A first solution (Figure 13-1) consisted in implementing a mesh onto the monopoles. This mesh shall be light, RF transparent, and occulting as few as possible the surface not to affect significantly the thermo-optical and motorization properties. The technology limitations prevented from having a more aerated meshing and was not satisfactory together with presenting an obvious risk for the deployment.

Figure 13-1.cold-welding protection 1

A second solution (Figure 13-2) consisted in implementing some Kapton tapes at the appropriate contact regions between monopoles. The asset of the solution is that Thales Alenia Space already well knows the RF and thermo-optical impacts of the surface by this material. The application process is already qualified as well. However the contact between monopoles (verified with electrical continuity) cannot be 100% avoided without fully covering the monopole which would have dramatically modified the motorization conditions.

Today this solution, although not technically perfect, is selected as baseline as it is clearly mitigating the risk already assessed as low.

The lesson learned is that despite the New Space context, the level of acceptable risk compared to a standard solution is not relaxed. Moreover, annealing completely some risk can induce side effects and other risks not anticipated by the project so compromise was necessary

Figure 13-2.cold-welding protection 2

6. PROJECT STATUS

The AIS Antenna design has now passed a CDR review, and will enter in Q4/2021 in the production phase to deliver the first PFM around the end of 2021.

7. CONCLUSION

The AIS Antenna development is based on two major complementary approaches to optimize the budgets, and to minimize the time-to-market; both of them by minimizing the rework which is proven to be source of tremendous delays and extra-costs.

The first approach is a Tooled Engineering Approach involving experts in many fields of the space designs, maintaining a continuous collaboration with the Customer to understand the needs and clarify the specifications, and using method + tools enabling a fast and agile design Thales Alenia Space has set up these methods which were used for KINEIS project.

The second approach is a deliberate testing approach, with unusual magnitude and pace vs traditional space development. Many derisking tests, mock-up, breadboards have been manufactured and tested before the CDR (illustrated on Figure 14), incrementing progressively the design refinement and avoid facing performance non conformances during the qualification.

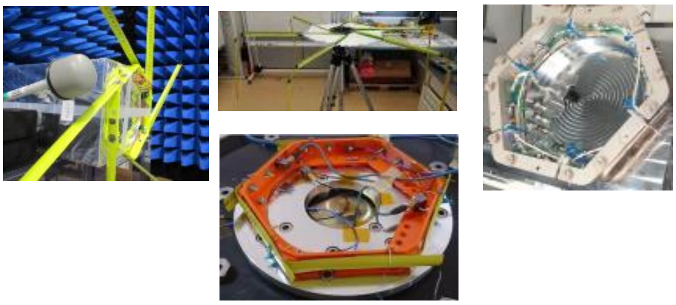

Figure 14.incrémental bread-boarding approach

The lessons learned of this project are that

- The implementation of a time demanding method at the beginning of the project is efficient to avoid rework in particular in a context where the set of applicable requirement may be incomplete and the use of the product clarified in the course of the project. The return on investment is in this context is particularly efficient and help develop quickly
- It is also crucial to be able to rely on a strong multi-skilled team to anticipate and consider the usual disciplines applicable to the space applications to support the method
- Self thermal control and self motorization are key aspects on nanosatellites for which early testing help justifications
- More generally, nanosatellites imply small objects, easier to produce and to test, smaller than usual Antennas or mechanisms. Incremental testing is therfore a cost and time effective startegy to mitigate the risks of rework.
- However the project showed that even if the early major risks were efficiently managed, the risks with only low occurrence likelihood are not more affordable than on standard space application development, and special disciplines like cold-welding, contamination, erosion etc… are not neglected by the Customers in the name of time-to-market and cost performance; this emphasizes even more the above statement to rely on a strong skilled team.