MASKARA: Multiple Apertures for high resolution SAR based on KA band Reflectarray

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INTRODUCTION

MASKARA, Multiple apertures for high resolution SAR based on Ka band reflectarray, is a project currently being developed within ESA contract No. 4000126144/18/NL/AF.
Airbus Defence and Space SAU Madrid, is the prime contractor for the project and the industrial consortium includes Airbus Defence and Space Ltd Portsmouth and TICRA. Airbus DS Madrid is in charge of the mission, the thermomechanical design and analysis, the manufacturing and testing of a RF Breadboard model (BBM). SAR and mission requirements, as well as thermomechanical support is carried out by Airbus DS Portsmouth. TICRA is leading the reflectarray RF design and analysis.

Based on multiple apertures concept, the purpose of MASKARA is to design a Ka band system operating at 35.75 GHz that will procure Along Track Interferometry (ATI) and Ground Moving Target Indication (GMTI) for a SAR instrument. As alternative for previous studies based on reflectors, MASKARA will consist on nine apertures and must be compatible with Vega-C launch conditions. Each of the nine apertures will have a dimension of ca. 1.5 m x 0.55 m in order to cope with both pattern and mechanical requirements and constrains.

This paper summarise the current status of the project, the selected solutions as well as the next project steps including the BBM concept. Table 1 summarises the main antenna pattern requirements and their summary performances at MASKARA CSR.

Table 1. MASKARA Antenna Pattern requirements summary

Requirement	Specification	MASKARA CSR status
Antenna Ohmic Losses	0.5 dB (TBC)	2.4 dB
High Resolution mode Gain	>46.7 dBi (TBC)	44.6 dBi
HPBW Azimuth	0.33 deg (TBC)	0.33 deg
HPBW Elevation	1.2 deg	1.2 deg
Low resolution mode Gain	>46.7 dBi (TBC)	43.1 dBi
Low res. HPBW Azimuth	0.33 deg (TBC)	0.33 deg
Low res.HPBW Elevation	2.4 deg	2.4 deg

PROJECT STATUS

Project Milestones

MASKARA has kicked-off on January 2019 and is scheduled to be finished in 24 months.

The project has completed SRR (Systems Requirements Review) and CSR (Concept Selection Review) phases. Along these study phases the team has reviewed several architecture concepts in order to maximise the system performances. One of the first trade-offs has been to selected the primary architecture to be developed along the study. On an initial stage two potential configurations have been investigated: Centralised configuration and Distributed configuration.
From CSR on, Distributed configuration is selected to be further developed. Next section summarises the different trade-offs carried-out.

Trade-off Concepts

In order to select the most promising architecture to obtain the better antenna and hence system performances, a detailed trade-off has been performed.

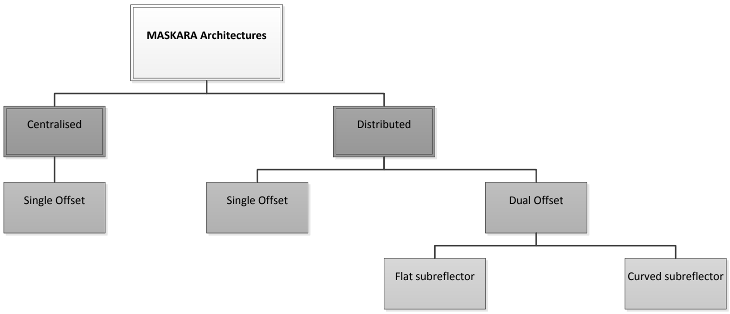

Fig. 1. MASKARA architecture trade-off

Centralised vs Distributed Configurations

Starting from the top of Fig 1, the first trade-off was to select a Centralised or a distributed configuration. Centralised configuration consists of a mast for allocating all the feeds and the respective reflectarray panels, two deployable arms of 4 panels each.

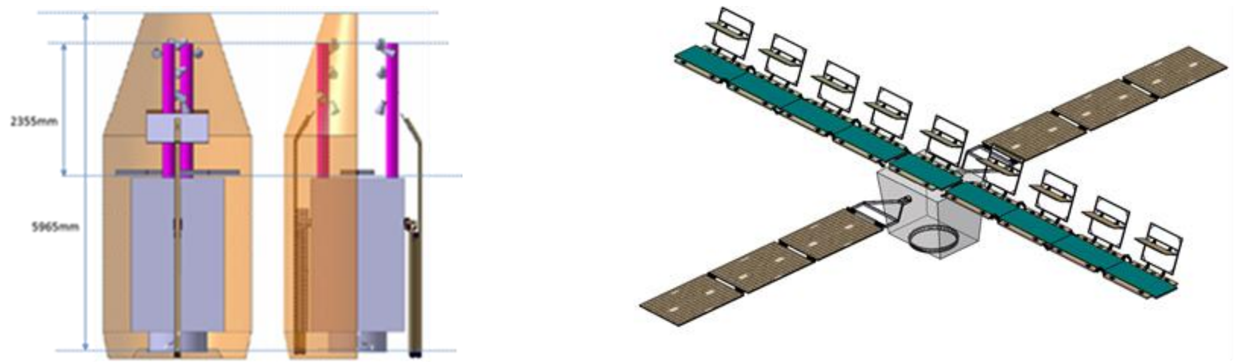

Fig 2. Centralised (left) and distributed (right) configurations

The advantages of centralised configuration with respect to the distributed configuration are related the mechanical aspects, mainly mass and the associated implications:

- Less mass on each deployable arm: there is no necessity of allocation the feed chain.
- High stiffness in stowed and deployed.
- Less demanding requirements for the HDRMs and DEMs in terms of loads and stiffness.
- Not need of having dedicated DEMs for the deployment of the feed / subreflector.

All in all, these benefits of the centralized configuration are not a killing factor for the distributed configuration. On the other hand, there are significant drawbacks from the system point of view that leads to not consider as a first option the centralized configuration.

Feed location:

- From phase displacement point of view, the total error will be function of the feed location and the distance with respect to the illuminated reflectarray panel. In the worst-case situation, the latter would amount to >6m. The error would most likely be due to movement caused by thermal stress As the phase centre location must be stable to within 80 micron (or possibly 320 micron according to the system requirements.), there would be an immediate incompatibility in this respect).

- If the feed horns are mounted on the body of the spacecraft, then the illumination angle the furthest panels is quite shallow and the panels must be tilted substantially in order for the specular ray direction to line up with the beam direction (needed to meet RF performance requirements). This would result in a loss of gain due to the reduced area of the projected aperture.

In case the panels are all deployed so as to be less ‘tilted’, then the feed horns would need to be deployed on a boom in order to reduce the incidence angles by the desired amounts. There would now be two distinct deployment systems, each with its own set of stability issues. Again, maintaining the relative positional accuracy between the horns and reflectarray panels might be expected to dominate the mechanical design.

In summary, the panel stability in deployed configuration as well as the required accuracy for the deployment mechanisms, the need of a dedicated boom-per-feed to compensate the RF degradation performances in terms of pointing and pattern, means that the centralised configuration is not the preferred solution for MASKARA antenna architecture.

Single Offset vs Dual Offset

There are two main aspects to account for in order to establish the most adequate configuration for the application

- RF performances
- Accommodation

Regarding the RF performances, there is a clear impact on the losses by using the single offset configuration, just by the extra length of the waveguides from the panel to the feed. In addition, for the single offset configuration, there is an aspect that, initially, the single offset configuration could present benefits regarding the dual offset configuration: the potential gradients on the reflectarray surface by means of the shadows induced by the subreflector. However, this aspect can be controlled by taking into account the orbital parameters and selecting a configuration that avoids shadows, by placing adequately the subreflector.

From accommodation point of view, the deployment of a subreflector present less elements, only structural elements, without RF elements, than the deployment of a more complex system including waveguides, rotary joints, feed, OMT and support mast. Besides, the optics of the dual-offset configuration is more compact than the one for the single offset configuration which has also a direct impact on the stability of the feed, the need of additional reinforces/supports, impacting on the loads over the main panels

Architecture Conclusion

Considering the aforementioned pros and cons of the traded-off configurations, it is proposed to develop a distributed architecture, based on a dual optics configuration. For the subreflector/mirror, the preferred solution is a rectangular flat mirror which presents better accommodation features than a single-curved one.

MASKARA DESIGN STATUS

The project has completed SRR (Systems Requirements Review) and CSR (Concept Selection Review) phases. Along these study phases the team has reviewed several architecture concepts in order to maximise the system performances, selecting the Distributed architecture with dual optics configuration. After CSR, a dual-offset architecture based on a single layer configuration is selected to be developed for the reflectarray design.

RF Design

In case of the single layer design, the reflectarray elements will be printed on top of a PCB laminate while the bottom will be a continuous copper plane, constituting RF ground. For the two-layer case, a thin laminate layer will separate the two reflectarray element layers. Two PCB laminates were considered as potential candidates:

- Nelco NY9217, dielectric constant: 2.17, dissipation factor: 0.0008
- Rogers RT/duroid® 6002, dielectric constant: 2.94, dissipation factor: 0.0012

Both materials have similar properties and come in thicknesses which are multiples of 5mil (0.127mm). Differences include slightly lower loss in the Nelco laminate, and lower thermal expansion coefficients in the Rogers laminate.

Both thickness and dielectric constant are vital for the resonance response of the periodic reflectarray elements. This resonance response controls the phase of the reflected waves and it is often depicted in so-called phase curves. The phase curve plots the phase of the reflected wave with respect to the incident one as a function of geometrical parameters of the unit cell. A good phase curve is one that covers at least a full 360 degrees of phase, while being as flat and linear as possible.

Reflectarray designs have been synthesized with both sets of material properties, and they yield very comparable performances. However, the datasheet for the Nelco laminate only provides the dielectric constant at 10GHz while the Rogers datasheet states that the value is stable from 8-40GHz. Therefore, in order to minimize risk, the Rogers 6002 laminate has been chosen as the baseline candidate.

Single Layer configuration.

A single-layer reflectarray is considered with a cross section as shown in Fig.3 .The design is simpler than a multilayer configuration, but the reflectarray element needs to handle the incoming x- and y-polarized fields differently due to the different requirements for the reflected x- and y-polarized beams. A dual polarized element is therefore needed. A simple example of a dual polarized element is the rectangular patch. Adjusting the x- and y-dimensions of the rectangular patch affects the phase of the corresponding x- and y-polarized reflected field. Unfortunately, the rectangular patch has a strong coupling between the polarizations such that e.g. adjusting the size of the patch in the x-direction also affects the phase of the reflected y-polarized field. In addition, rectangular patches are not known for providing the optimal performance due to a phase curve range that is usually limited to <360 degrees. Thus, more advanced element designs have been considered.

The choices for polarization selective single-layer elements are somewhat limited. Potential candidates include rectangular patches, crossed dipoles, Jerusalem crosses, rectangular loops, etc. However, based on a literature survey that was performed, the choice of the single-layer element fell on the element presented in [1] which consists of a Jerusalem cross with open loops.

Multiple Layer configuration.

The term multilayer means in our case more than one separate layer containing reflectarray elements. In our case, two layers with metallic reflectarray elements have been considered, one layer for each orthogonal polarisation. The layer structure is shown in Fig 4, where apart from the two element layers, there are two dielectric layers and a ground layer.

More layers complicate the design, but also increase the degrees of freedom, potentially providing possibility of enhanced performance. In the present project, a two-layer design is of special interest because two linear polarizations must exhibit quite different patterns. This requires that the x- and y-directed response of the reflectarray cells can be controlled independently. A two-layer cell is investigated to see if the performance can be enhanced by separating the x- and y responses into two single polarized elements isolated by a dielectric, instead of one dual-polarized element.

In terms of potential candidates for the element, a significantly wider range of possibilities are available since the element only needs to be single polarized. One potential candidate is the use of parallel dipoles. This type of element has been extensively used by the group of Prof. Encinar at UPM from which many high performance reflectarrays have been designed [2]-[3]. For this reason, our choice fell on the same type of element.

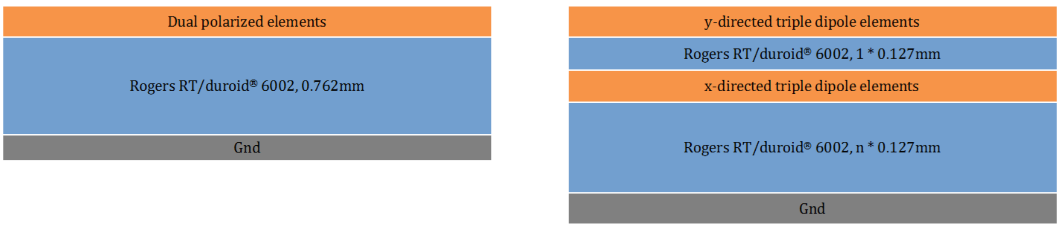

Fig 3: Layer structure of the single (left) and multilayer (right) reflectarray concepts.

Reflectarray design

Based on Single layer configuration, Fig 4 shows the RF model and the pattern performances for the high and low resolution modes at 35.75 GHz. The single-layer reflectarray is designed by first creating a database over the periodic response of the unit cell for a range of L_x values, L_y values, and incidence angles, followed by a direct optimization of the array elements directly on the far-field pattern specifications [4].

The dimensions of the panel (1.5x0.55m) and the size of the unit cell (3.15 mm) result in 475 unit cells along x, and 173 unit cells along y – a total of 82,175 unit cells. Since both L_x and L_y must be optimized for each unit cell, the resulting optimization problem has more than 150,000 unknowns.

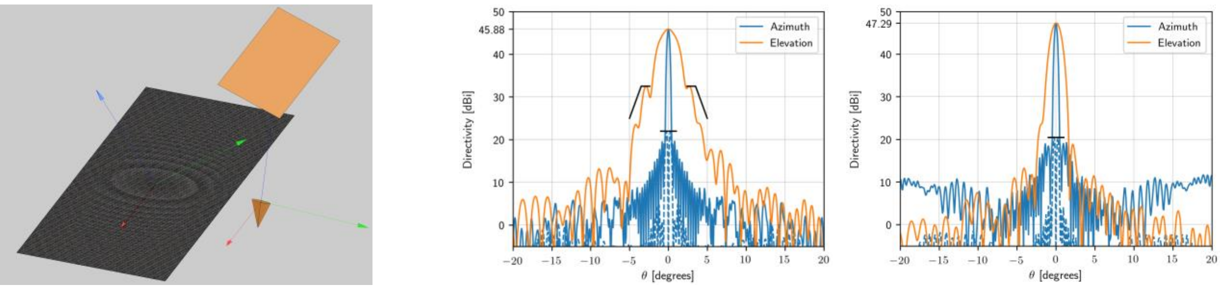

Fig 4 : Reflectarray QUPES [5] model (left). Pattern performances 35.75 GHz, low resolution (center) and high resolution (right)

Thermo-mechanical Design and Analysis.

For the CSR phase a thermomechanical analysis has been performed showing the following conclusions:

- Thermal design and analysis:
  - The thermal design has been done considering minimizing the TED at maximum. Hence, Kapton-Germanium sunshield is considered. However, this element might have some influence at RF and accommodation levels. For future phases it could be proposed to estimate thermal conditions without sunshield in order to assess TED performances.
  - The different mechanisms have not been considered in this preliminary stage and will play a role in the future design.

- Mechanical Design:
  - One MASKARA mechanical design solution has been proposed including the structural elements, the mechanisms and all the RF components. It includes CFRP aluminum honeycomb sandwich, Hold Down and Release Mechanisms and Deployment and Latch mechanism.
  - Current MASKARA mass is estimated in 215 kg, including maturity contingencies for CSR phase.
  - The envelope in stowed configuration has been evaluated showing some volume constrains depending on the thermomechanical configuration selected.

- Mechanical Analysis
  - Two MASKARA FEM have been created for studying the stiffness (stowed and deployed) and the thermal distortions (deployed)
  - The stowed configuration shows a first modal shape at f=47Hz that is below the current requirement of 60 Hz.
  - The deployed configuration (using a bottom support structure) show a first modal shape at f=1.4Hz that is compliant with the current requirement of 1 Hz.

- Thermal distortions analysis:
  - Two thermal worst cases (taking into account sunshield) have been analyzed.
  - Sunshield removed case will produce a mispointing degradation (x2).This trade-off will be further developed for CDR phase.

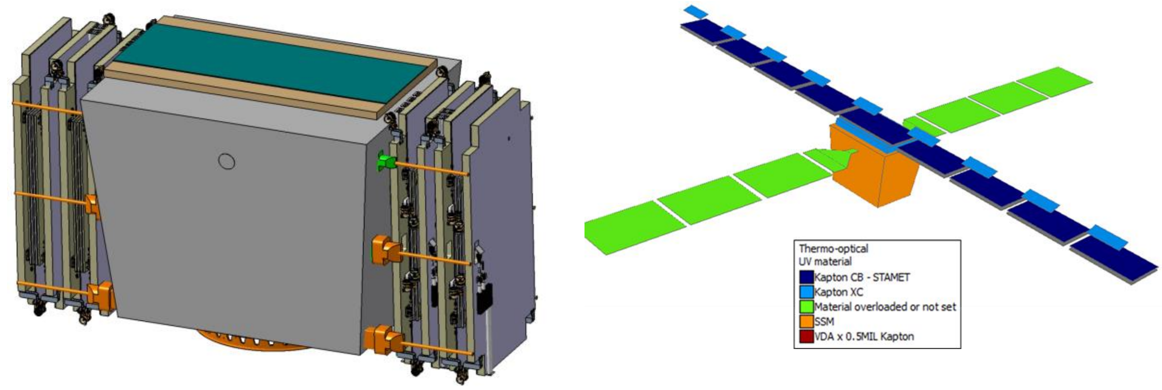

Fig 5: MASKARA stowed configuration (left) and material properties for TED analysis (right)

FURTHER STEPS

The selected concept after CSR is based on a single layer structure, provided that the RF performances are equivalent between multilayer and single layer concepts and there are advantages on manufacturing for the single layer configuration. The project faces CDR (Critical Design Review) milestone with two main objectives:

- Detailed design of RF reflectarray based on current performances.
- Detailed thermomechanical concept.
- Breadboard definition: CDR phase will end-up with definition of the breadboard model to be manufactured and tested

ACKNOWLEDGEMENTS

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