RF Modeling and Measurements of a Reflectarray for Synthetic Aperture Radar for Earth Observations

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***Abstract*—Design and simulation results of a polarisation-selective reflectarray in Ka band are presented. The reflectarray is part of a dual-offset antenna system for a high-resolution and wide-swath Synthetic Aperture Radar (SAR) instrument that operates in both a high-resolution mode with a directive beam in one polarisation, and a low-resolution mode with a broader beam in the orthogonal polarisation. Fed by orthogonal modes, a sectoral horn illuminates the reflectarray antenna with different beam widths for the two operational SAR modes. Radiation patterns of the feed and reflectarray antenna system are presented.**

***Index Terms*—Reflectarrays, satellite applications, optimisation**

I. Introduction

Single-platform Ka-band interferometric Synthetic Aperture Radar (SAR) instruments are potentially attractive solutions for environmental and security purposes [1], [2]. This has become apparent with the emergence of Along Track Interferometry (ATI) and Ground Moving Target Indication (GMTI) Earth observation missions which require high-resolution and highly sensitive SAR instruments operating on wide swaths.

While in traditional SAR applications, high resolution and a wide swath are difficult to obtain simultaneously, modern digital beam forming (DBF) techniques like Multiple Azimuth Phase Centres SAR (MAPS) and Scan on Receive (SCORE) are promising techniques for achieving both objectives. For MAPS, several azimuthally aligned apertures are needed resulting in a long antenna structure. To enable these instruments to be stowed in available launch vehicles such long antenna structures must necessarily be foldable. Together with additional requirements of high antenna aperture efficiency and low losses, the reflectarray technology [3] is a promising candidate for SAR applications [4]. High aperture efficiencies can be realised on flat substrate structures, which require only a small volume in folded state. In addition, printed circuits on lightweight substrates can be employed [5], reducing weight and costs.

The inherent ability of polarisation selectivity allows for designs with different beam widths for two orthogonal linear polarisations [6], enabling implementation of two different SAR operational modes with different resolutions and swath widths.

As part of the on-going ESA funded activity MASKARA: Multiple Apertures for high resolution SAR based on Ka-band Reflectarray (ESA contract No. 4000126144/18/NL/AF) [7], two design proposals of such reflectarrays applicable for Ka-band antenna systems for high resolution and wide swath SAR instruments were presented in [8]. In that work both single-layer and multiple-layer reflectarray configurations were presented with results based on simulations of both the feed and the reflectarray. While both designs showed promising results, the single-layer design was selected for further development. In continuation of that work, we present, here, a sectoral horn feed design with associated measured radiation patterns to be used as feed in the reflectarray antenna. RF measurements of the entire reflectarray antenna configuration are planned, but not completed at the paper submission deadline.

In the paper, the reflectarray performance is shown based on measurements of the feed in combination with simulations of the sub reflector and reflectarray panels. Presentation of the reflectarray measurements is planned for the conference.

II. Reflectarray Antenna Design

The dual-offset antenna system in its entirety can be seen in Fig. 1 and consists of nine reflectarray panels, each with the size of about $1.5\,\mathrm{m}\times 0.55\,\mathrm{m}$.

The dual-offset setup employed in this system is advantageous compared to a single-offset setup in a number of ways. It affords reduced losses associated to the shorter length of the waveguides from the panels to the feed which is situated in or near the reflectarray panel plane. Additionally, with this antenna architecture, the reflectarray radiates in the specular direction with respect to the incident field which helps avoiding undesired beam squint effects at off-centre frequencies. Further, the use of a sub reflector reduces the amount of necessary hardware such as waveguides, rotary joints, and support masts which is particularly important in terms of the accommodation into the launch vehicle and the associated folding/unfolding of the instrument. Lastly, the optics of the dual-offset configuration is more compact which has a direct impact on the stability of the feed and thus the need of additional reinforcements/supports.

The reflectarray antenna must operate between $35.5 - 36.0\,\mathrm{GHz}$ in two modes, a high-resolution mode for one linear polarisation, and a low-resolution mode in the orthogonal polarisation. For each resolution mode, different gain and pattern

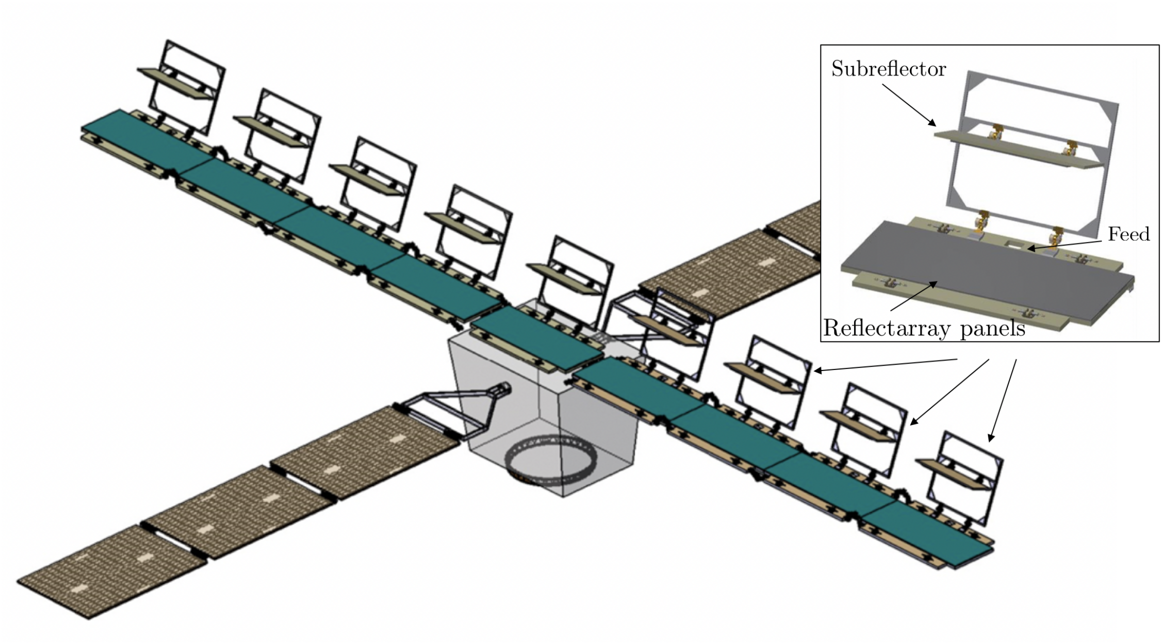

Fig. 1. Spacecraft scheme with nine dual-offset reflectarray panels.

TABLE I
PATTERN REQUIREMENTS

Frequency band	
$35.5 - 36.0\,\mathrm{GHz}$	
High-resolution mode	
Polarisation	x-pol.
Antenna gain	$>$46.7 dBi
HPBW azimuth	0.33°
HPBW elevation	1.2°
Low-resolution mode	
Polarisation	y-pol.
Antenna gain	$>$45.2 dBi
HPBW azimuth	0.33°
HPBW elevation	2.4°
Side-lobe level (SLL) requirements (gain mask)	
θ [°]	Gain [dBi]
1.5	41.5
1.8	38.5
2.5	32.0
5.0	25.0
10.0	20.0
Cross-polar requirements	
XPI	25 dB

specifications apply. The pattern requirements are summarised in Table I.

A. Feed design

The rectangular shape of the reflectarray panels necessitates an elliptical feed pattern and an idealised version of such a feed pattern was used in [8]. Since then a real feed horn has been designed to provide the required elliptical pattern; the design is the sectoral horn shown in Fig. 2 and 3. The feed has an aperture of 55 mm×14 mm and a flare length of 200 mm and can be fed by two orthogonal polarisations through WR-28 rectangular waveguide ports to accommodate the need for two different operational modes of the SAR instrument. In Fig. 2, the horn is shown in the vertical polarisation mode (V-Pol) which is associated to the low-resolution operational mode. The feed was designed and optimised using the software tool ESTEAM, which is a product in the TICRA Tools software framework [9] and from which the picture in Fig. 2 is taken.

The manufactured feed is shown in Fig. 3 when situated in the measurement chamber. In the vicinity of the horn aperture three optical sensors are visible. These are included for measurement purposes only and will not be present in the actual feed to be used with the reflectarray antenna system. To ensure that the presence of these sensors do not contribute to a wrong conclusion of the final feed performance, detailed simulations of the actually manufactured feed, including the optical sensors have been undertaken based on CAD file data of the manufactured feed. When comparing with a model without the optical sensors it was concluded that the presence of these did not to any noteworthy extent impact the radiation patterns from the feed.

The measured reflection coefficient is shown in Fig. 4 for the two polarisation modes and it is apparent that it remains well below -20 dB in the entire band. Representative plots of the horizontally- and vertically-polarised radiation patterns are shown in Fig. 5 for the central frequency of 35.75 GHz. Both simulation and measurement results are shown. The horn has a main beam directivity around 20.0 dBi and 20.4 dBi for the vertical and horizontal polarisations, respectively, as detailed

TABLE II
MEASURED FEED PATTERN CHARACTERISTICS

Frequency	Directivity	On-axis XPD
Horizontal polarisation		
35.50 GHz	19.9 dBi	35 dB
35.75 GHz	20.1 dBi	35 dB
36.00 GHz	20.1 dBi	34 dB
Vertical polarisation		
35.50 GHz	20.3 dBi	37 dB
35.75 GHz	20.5 dBi	34 dB
36.00 GHz	20.4 dBi	33 dB

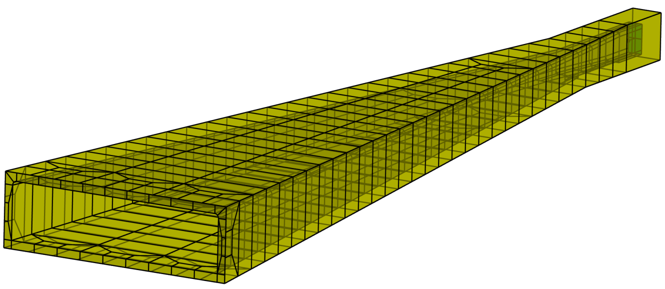

Fig. 2. Simulation model of the sectoral horn feed. The shown model is associated to the vertical polarisation mode. A corresponding model with orthogonal port orientation was used for the opposite polarisation.

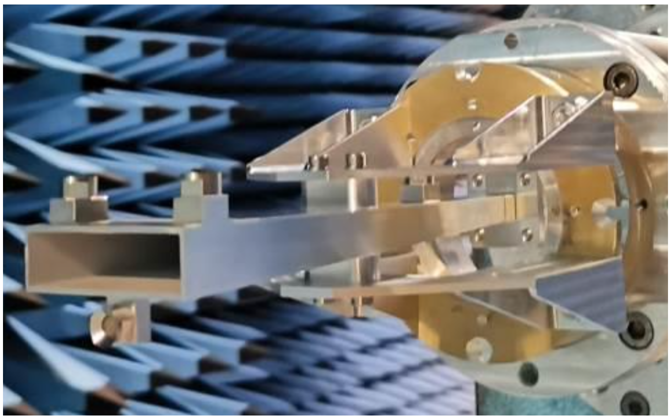

Fig. 3. The sectoral horn feed situated in a measurement setup.

in Table II. Furthermore, an on-axis XPD better then 30 dB is obtained throughout the frequency band in both polarisation modes.

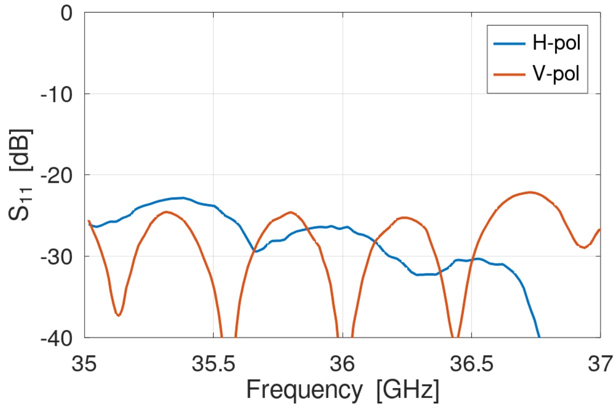

Fig. 4. Measured reflection coefficient of the sectoral feed horn for the H and V polarisations.

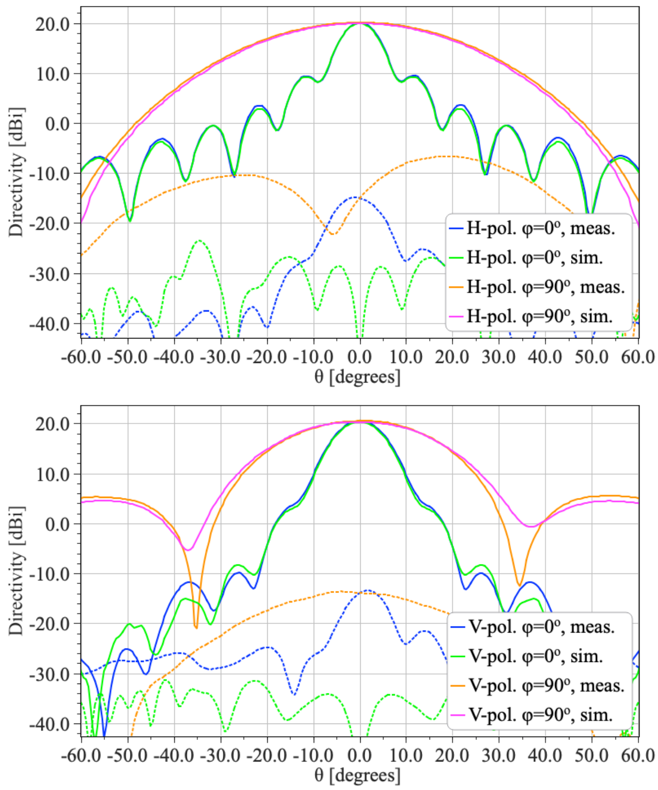

Fig. 5. Measured and simulated patterns of the sectoral feed horn. Top: H-polarisation; Bottom: V-polarisation. The dashed lines represent the cross polarisation.

B. Reflectarray Panel Design

As detailed in [8] the reflectarray is designed using the software tool QUPES, which is a product in the TICRA Tools software framework [9]. Here, a direct optimisation approach is employed in which all reflectarray elements are optimised simultaneously to fulfil the pattern specifications [10] without undue emphasis on intermediate results such as the phase response of individual elements.

In order to fulfil the pattern requirements, a polarisation-selective reflectarray is required, i.e., the response of the reflectarray must depend on the polarisation of the incident field. The reflectarray consists of roughly 82.500 elements situated on a Rogers 6002 substrate with thickness of 0.762 mm. The elements are selected as a Jerusalem Cross with an open quadratic loop [11], as depicted in Fig. 6, each confined in a unit cell of 3.15 mm×3.15 mm. This element provides a near-linear phase curve with low mutual coupling between two orthogonal linear polarisations [8], making it suitable for dual-polarisation applications. Several quantities in Fig. 6 could have been subject to optimisation, however, with the large amount of elements all but the two lengths L_x and L_y are kept

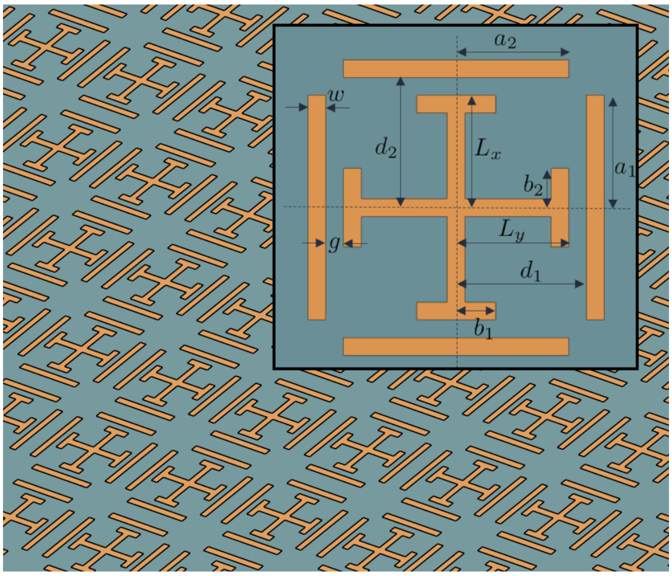

Fig. 6. Close-up view of the reflectarray panel simulation model with insert showing the Jerusalem Cross with open loop element. The quantities L_x and L_y have been optimised and vary for each element. The remaining quantities are fixed.

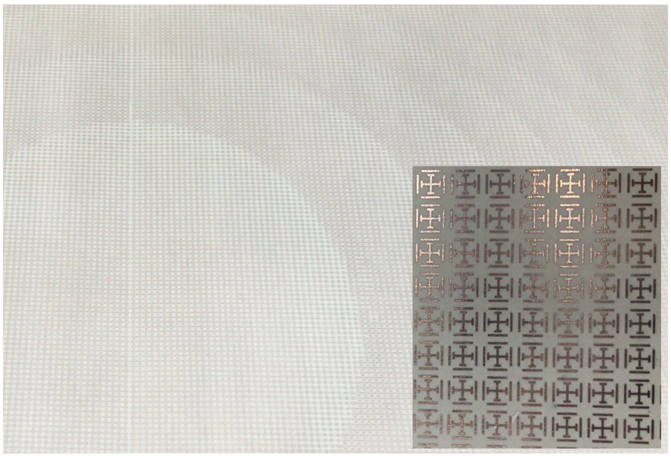

Fig. 7. The manufactured reflectarray panel with an insert showing some elements in detail.

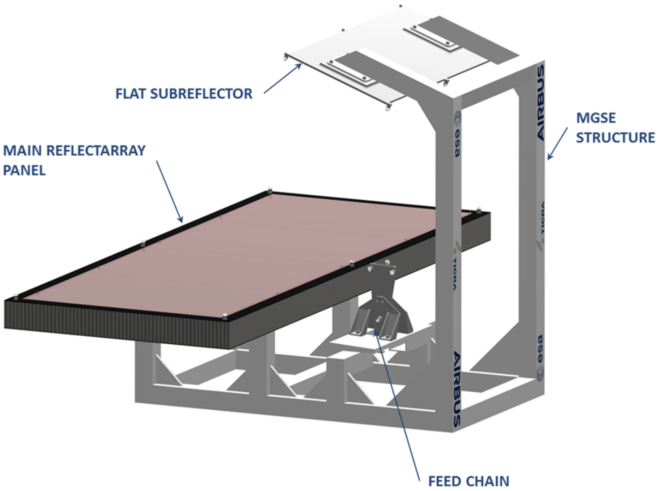

Fig. 8. The measurement setup of the reflectarray with subreflector and feed.

constant which limits the amount of optimisation variables to approximately 165.000. A picture of the manufactured reflectarray panel is shown in Fig. 7 and in Fig. 8 the measured assembly consisting of the reflectarray panel, subreflector and feed is depicted when located in the measurement frame.

III. Reflectarray Performance

The radiation patterns measurements of the assembled reflectarray, including both feed, subreflector and reflectarray panel are still on-going and not ready in time for the paper deadline. It is planned to show the actual measurements of the total reflectarray antenna assembly at the conference. Here, we present results from simulations of the subreflector/reflectarray performance under the illumination of the feed, represented by the actually measured feed patterns.

To this end we employ GRASP, which is a product in the TICRA Tools software framework [9], together with QUPES. Practically, the measured feed patterns are represented as spherical-wave expansions (SWE) which illuminate the sub reflector which subsequently illuminates the reflectarray panel yielding the radiated fields, see insert in Fig. 1 showing a single reflectarray panel. In Fig. 9, the resulting radiation patterns of the reflectarray antenna are shown for the high- and low-resolution schemes in the top and bottom panels, respectively, for the centre frequency of 35.75 GHz. The peak gains and half-power beam widths (HPBW) are listed in Table III for all three frequencies.

As mentioned, the results in [8] were obtained using an idealised elliptical feed pattern, and gains in excess of 47 dBi and 45.5 dBi, for the high- and low-resolution modes, respectively, were reported thus complying with the requirements of Table I. The high-resolution setup requires a gain larger than 46.7 dBi and using the sectoral horn presented here the resulting gain just reaches this value without any notable margin. For the low-resolution case the gain slightly exceeds the requirements. The differences between the radiation patterns using the sectoral horn feed and the idealised feed model in [8] result in a gain reduction of 0.6 dB in both polarisation modes which is believed to be caused by the less ideal illumination of the subreflector and increased spill-over. Lastly we note that the half-power beam width for the high-resolution case are not in compliance with the requirements in the azimuthal plane.

TABLE III
Reflectarray Pattern Characteristics

Frequency [GHz]	35.50	35.75	36.0	Requirements
Gain, HR [dBi]	46.7	46.7	46.7	46.7
HPBW, az., HR	0.46°	0.46°	0.47°	0.33°
HPBW, el., HR	1.2°	1.2°	1.2°	1.2°
Gain, LR [dBi]	45.3	45.5	45.4	45.2
HPBW, az., LR	0.34°	0.34°	0.33°	0.33°
HPBW, el., LR	2.1°	2.4°	2.3°	2.4°

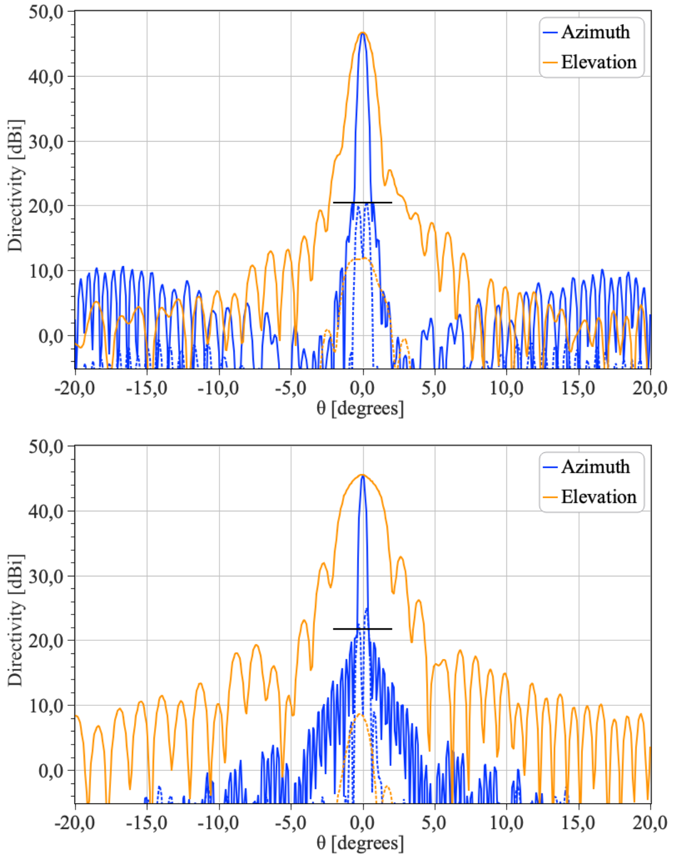

Fig. 9. Simulated radiation patterns based on measured patterns of the sectoral feed horn. Top: High-resolution mode; Bottom: Low-resolution mode. The black bars signify cross-polar limits due to the XPI requirements in Table I.

IV. Conclusions

We have presented a feed design of a sectoral horn to be used in a Ka-band reflectarray antenna system for a high-resolution and wide-swath SAR instrument which is to operate in both low- and high-resolution modes using two orthogonal linear polarisations. The horn exhibits a reflection coefficient below -25 dB in the frequency band of interest. RF simulation results of the designed reflectarray antenna together with measured feed patterns have been presented. For the conference, these will be compared to measurement results of the full antenna system. The total antenna system provides a gain of about 46.7dBi for the high-resolution mode and 45.3 dBi for the low-resolution mode within the frequency band.

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