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Dual Ka-Band Multiple Beam Reflector Antenna for Western European Coverage

Salvador Mercader-Pellicer¹, Francesco Rigobello¹, George Goussetis¹, Louis Dufour¹, Daniele Bresciani², Hervé Legay², Nelson J. G. Fonseca³

¹ Institute of Sensors and Signals and Systems, Heriot-Watt University, Edinburgh, U.K., {s.mercader_pellicer, fr17, g.goussetis, ld61}@hw.ac.uk

² Thales Alenia Space, Toulouse, France, {daniele.bresciani, herve.legay}@thalesalieniaspace.com

³ European Space Agency, Antenna and Sub-Millimetre Wave Section, 2200 AG Noordwijk, The Netherlands, nelson.fonseca@esa.int

Abstract—This paper presents a dual-band multiple beam reflector antenna for a Western European coverage. The dual configuration comprises a wire grid sub-reflector and a polarising main reflector that converts the linearly polarised incidence into circular polarisation with orthogonality between bands. The good performance of the wire grid and the polarising main reflector ensure far-field axial ratio values at the -3 dB region below 1 dB on average without any previous optimisation.

Index Terms—reflector antennas, multiple beam antennas, linear-to-circular polarisers, periodic surfaces.

I. INTRODUCTION

Multiple beam reflector antennas have traditionally been one of the preferred solutions to provide multiple spot-beam coverages from geostationary communication satellites due to their capability to satisfy the high demands on data-rate, system capacity, antenna gain and cross-polarisation levels [1]. In their more common single-feed-per-beam (SFB) configuration, four main reflectors are used to provide a transmit/receive four-colour frequency and polarisation reuse scheme [2]. This high number of reflectors is needed to provide the required level of overlap between adjacent beams, typically at 3 to 5 dB below peak gain, while maintaining high aperture efficiency [2]. Multiple-feed-per-beam (MFB) configurations can be used in order to reduce the number of reflectors, at the expense of a more complex feed array, enabling some aperture sharing between adjacent beams through a complex beam forming network (BFN), generally resulting in some RF performance degradation which are a consequence of the reuse in frequency [3,4].

In order to reduce the number of reflectors while using SFB configurations, polarisation-selective sub-reflector could be used to combine adjacent beams operating in orthogonal polarisation on the same main reflector [5]. In this way, a four-colour scheme could be accomplished with two main reflectors [6,7]. The challenge lies on the design of the polarisation-selective surface [5]. As the current trend in satellite communications (satcom) is to operate in circular polarisation (CP), the surface must be reflective for one handed circular polarisation and transparent for the

orthogonal polarisation [6]. The design of such structures has turned out to be very challenging, leading to manufacturing and mechanical complexities [8,9]. In addition, orthogonal polarisations are generally implemented between transmit and receive signals, further adding to the complexity of the polarisation-selective screen design.

More recently, it has been proposed the use of dual-band linearly polarised (LP) feeds and wire grids to provide the polarisation discrimination, leaving the LP-to-CP conversion to the main reflector [6,7]. The main challenge lies now in the design of a polarising surface that converts an incident LP wave into orthogonal CPs for the transmit and receive bands. Considering the large size of the main reflector and the multiple incidences from the different feeds, the unit-cell that provides such polarisation conversion should present very good angular stability. A unit-cell design with such performance has been published for Ku-band [10]. However, the feasibility of the complete multiple beam reflector antenna has not been demonstrated for a realistic coverage.

This paper presents preliminary results of such Ka-band multiple beam dual reflector antenna, for a typical Western European coverage. The configuration comprises a wire grid sub-reflector fed by two sets of orthogonal LP feeds and a polarising main reflector to convert the incident LP field into CP with orthogonality between bands. The good performance of the wire grid and the polarising surface ensure average axial ratio (AR) levels below 1 dB within the -3 dB region for all the beams, without any optimisation.

II. REFLECTOR ANTENNA GEOMETRY AND TARGET COVERAGE

A. Antenna geometry

The reflector antenna geometry, shown in Fig. 1 and based on [6,7,10], comprises a wire grid sub-reflector and a uniform polarising main parabolic reflector to convert the incident LP field into CP. The diameter of the main reflector, the focal distance, the offset height and the offset

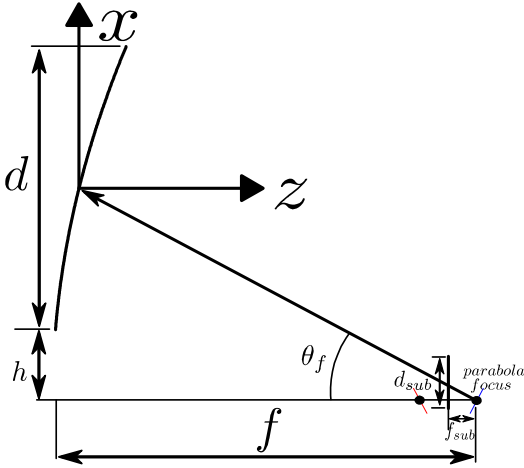


Figure 1. Reflector antenna configuration with parameters $d=2$ m, $f=3$ m, $h=0.5$ m, $\theta_f=28.07^\circ$, $d_{sub}=0.367$ m and $f_{sub}=0.2$ m.

angle are taken from [11], and are respectively $d=2$ m, $f=3$ m, $h=0.5$ m, $\theta_f=28.07^\circ$. The length of the sub-reflector and distance between parabola focus and sub-reflector are respectively $d_{sub}=0.367$ m and $f_{sub}=0.2$ m. The transmit and receive bands are respectively 17.7-20.2 GHz and 27.5-30 GHz.

At each side of the wire grid two set of feeds in single-feed-per-beam configuration are placed, as shown by the blue and red oblique lines at each side of the wire grid in Fig. 1. The wire rods are oriented vertically. The feeds along the blue line centred at the parabola focus are horizontally polarised, while the ones placed along the red line are vertically polarised. Therefore, the fields from the first set of feeds will pass through the wire grid, while the fields from the other set will be reflected by it.

In order to demonstrate the feasibility of this configuration alone, the feeds are supposed ideal Gaussian beams. The edge tapers of the feeds in the x -axis are approximated following the real tapers values from [12], which presents a dual-band circular horn antenna working at 18.3-20.2 GHz and 28.3-30 GHz.

B. Target coverage

A complete four-colour scheme using single-feed-per-beam configurations is commonly achieved by using four single reflectors. In the proposed configuration, the wire grid allows one main reflector to produce two colours, one at each side. Therefore, two dual configurations as the one presented in Fig. 1 are needed to provide the four-colour scheme. It should be noted that even though these two dual configurations would be mounted in two different parts of the satellite pointing at the same region of the Earth, in this paper they are going to share the same physical space for simplification purposes.

The four colours are produced by a frequency and polarisation reuse scheme. The use of the wire grid implies that two colours sharing a main reflector would have the same frequency and orthogonal polarisation. As an example, for the desired coverage in CP, it can be supposed that the fields from blue and red feeds are left-handed CP (LHCP)

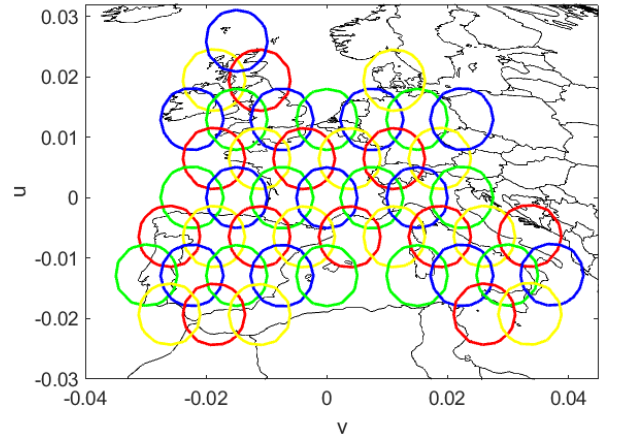


Figure 2. Target coverage where the lines represent the contours at -3dB from the maximum directivities at 17.7 GHz.

and right-handed CP (RHCP) respectively at frequency f_1^{TX} for the transmit band, and RHCP and LHCP respectively at f_1^{RX} for the receive band. Then the fields from green and yellow feeds are LHCP and RHCP respectively at frequency f_2^{TX} for the transmit band, and RHCP and LHCP respectively at frequency f_2^{RX} for the receive band. One way to achieve this is to break each band in two sub-bands, so that f_1^{TX} and f_2^{TX} would be between 17.7-18.95 GHz and 18.95-20.2 GHz respectively for the transmit band. And f_1^{RX} and f_2^{RX} would be between 27.5-28.75 GHz and 28.75-30 GHz respectively for the receive band.

Fig. 2 shows the target coverage produced by four single reflectors as the one in Fig. 1 fed by 47 LP feeds, so that the effects of the polariser and the wire grid are avoided, as well as the squint due to CP. The patterns have been obtained by an in-house Physical Optics (PO) tool [13]. The contours show the -3 dB value from each beam peak at the minimum frequency, 17.7 GHz. The beam widths are 0.57° , distributed over a hexagonal lattice of 0.43° . The far-field directivities of the offset reflector fed by the ideal Gaussian beam at the parabola focus are 50.30 dB and 53.09 dB at 17.7 GHz and 30 GHz respectively. These directivities take into account several efficiencies, such as radiation, spillover or aperture taper. Therefore, they are very close to the final gain obtained by the antenna. The feeds outside the parabola focus will produce smaller directivities. The worst directivities are 50.09 dB and 52.81 dB at 17.7 GHz and 30 GHz.

III. SIMULATION OF THE COMPLETE DUAL CONFIGURATION AND RESULTS

A. Simulation of the dual configuration

A polarising surface that convert the incident LP field into CP with orthogonality between bands is placed on top of the parabolic reflectors. This polarising surface comprises a uniform array of unit-cells based on the design presented in [10] but scaled up to the frequency bands of interest. The angularly-stable performance of this unit-cell can be seen in Fig. 3, obtained by CST [14]. The blue solid line corresponds

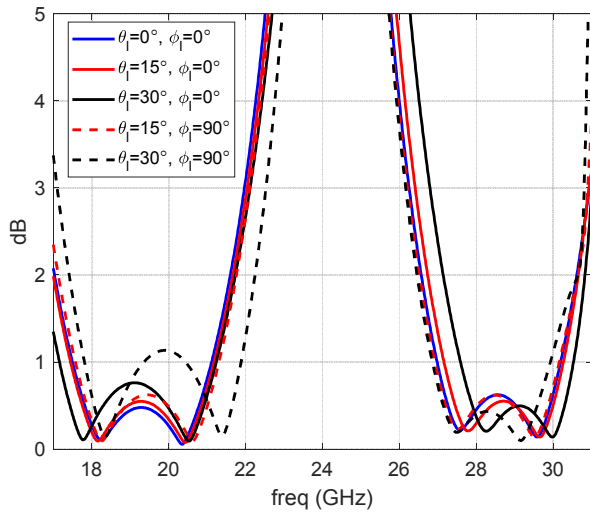


Fig. 3. Axial Ratio (dB) of the selected unit-cell for the polarising reflector simulated in CST for different angles of incidence.

to normal incidence (optimised incidence), red and black lines correspond to oblique incidences of $\theta_i=15^\circ$ and $\theta_i=30^\circ$ respectively, and solid and dashed lines correspond to xz ($\phi_i=0^\circ$) and yz ($\phi_i=90^\circ$) planes respectively.

The wire grid comprises vertical cylindrical rods periodically repeated in the horizontal axis. The horizontal periodicity is $p_{WG}=3.2$ mm, while the rods' diameter is $d_{WG}=1$ mm. Therefore, since the wire grid length is $d_{sub}=0.367$ m, 110 vertical rods can be fitted. Taking into account the high number of vertical rods and the size of the wire grid (22.12λ at 17.7 GHz), its analysis can be carried out by a Floquet modal expansion of the fields under local periodicity assumptions, as in the case of the polarising surface. The unit-cell of the wire grid comprises an infinite long cylindrical metallic rod in the x -axis with periodicity p_{wg} in the y -axis and diameter d_{wg} . Both unit-cells are modelled for the different angles of incidence in CST [14].

Once the databases of both periodic structures are produced, the local reflected fields can be obtained. Then PO can be used to obtain the fields radiated from the wire grid onto the main surface and the far-field from the main surface.

B. Results

Common ESA mission requirements include gains > 47 dB, carrier to interference ratio (C/I) > 15 dB and axial ratio (AR) < 1 dB for all the beams, with a design goal of AR < 0.5 dB. The gain for all the beams will be dictated by the reflector geometry and the different efficiencies. As mentioned in Section II.B, the directivities obtained by the selected offset reflector are above this value. However, the wire grid and the polarising surface will cause a small directivity deterioration. On the other side, the AR requirements are fulfilled at unit-cell level, as it can be seen in Fig. 3. However, the far-field of the dual configuration is expected to deteriorate mainly due to the offset geometry and the large range of angles of incidence over the uniform polarising surface from the numerous feeds.

Colours blue and red differentiate in polarisation, and for this example are computed at the middle frequencies of the first sub-band of the transmit and receive bands, i.e., 18.325 GHz and 28.125 GHz respectively. Colours green and yellow are then computed at the middle frequencies of the second sub-band of the transmit and receive bands, i.e., 19.575 GHz and 29.375 GHz respectively.

The directivity of the complete configuration takes into account the depolarisation properties and losses of the wire grid and polarising surface. The best and worst directivities (D) for colours blue/red at 18.325 GHz and green/yellow at

	Blue	Red	Green	Yellow
Best D (dB)	50.40	50.39	50.99	50.98
Worst D (dB)	49.81	50.08	50.77	50.53
Worst AR (dB)	0.58	0.93	1.06	1.32

Table 1: Best and worst directivities (D) and worst axial ratio (AR) in dB for colours blue/red and green/yellow at 18.325 GHz and 19.575 GHz respectively.

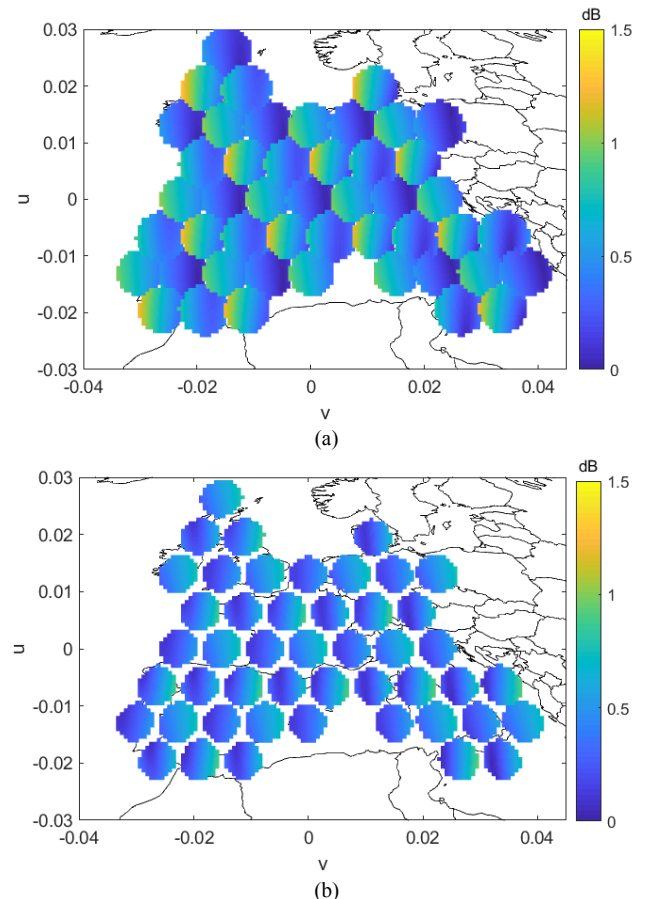


Fig. 4. AR within the -3 dB region for all the beams at the (a) transmit band, where colours blue/red and green/yellow are computed at 18.325 GHz and 19.575 GHz respectively, and at the (b) receive band, where colours blue/red and green/yellow are computed at 28.125 GHz and 29.375 GHz respectively.

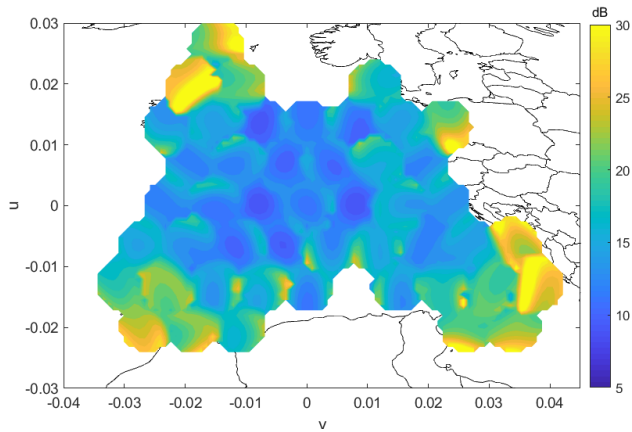


Fig. 5. C/I (dB) at 18.325 GHz for the proposed multiple beam reflector antenna.

19.575 GHz at summarized in Table 1. For comparison purposes, it should be noted that the directivities of the metallic single offset reflector with the feed at the focus are 50.6 dB and 51.27 dB at 18.325 GHz and 19.575 GHz respectively. A similar situation occurs at the receive band. The aforementioned deterioration is observed, but the directivities still fulfilled the specifications.

The far-field AR for all the beams at the -3 dB region, for the transmit and receive bands are shown in Fig. 4. As previously mentioned, each colour is computed at the middle point of each sub-band. The worst AR values within the regions of interest for each colour at the transmit band are summarized in Table 1. As it can be observed both in Fig. 4 and Table 1, the AR specifications ($AR < 1\text{dB}$) are almost fulfilled for most of the beams. The C/I (dB) at a single frequency (18.325 GHz) is shown in Fig. 5. Overall, the C/I in the central region is between 10 and 15 dB, which is very close to the specifications ($C/I > 15\text{ dB}$). It should be noted that these results are obtained with no previous optimisation. As it was shown in [15], the cross-polarisation can be reduced mainly in the horizontal plane (where higher cross-polarisation is expected) for several feeds at the same time with a progressive element rotation. More advanced optimisation techniques commonly used in reflectarray optimisation [16-18] could be used if needed.

IV. CONCLUSION

A Ka-band multiple beam reflector antenna comprising a main offset parabolic polarising reflector and a wire grid has been presented for a Western European coverage. The polarising surface comprises a uniform array of unit-cells that converts a linearly polarised incidence into a circularly polarised wave with orthogonality between bands. The dual configuration is fed by two sets of linearly polarised feeds, one at each side of the wire grid. Therefore, this solution allows to reduce the typical four-reflector configuration using single-feed-per-beam architectures to only two main reflectors. Furthermore, the polarising surface produces the desired circular polarisation for the transmit and receive

bands. This solution achieves overall axial ratios below 1 dB for the coverage area without any previous optimisation.

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