Reflect-Array Sub-Reflector in X-Ka Band Antenna

C. G. M. van 't Klooster(1), A. Pacheco(2), C. Montesano(2), J.A. Encinar(3) A. Culebras(4)
(1)ESA, Estec, Noordwijk, The Netherlands
(2)EADS CASA Espacio, Madrid, Spain
(3)University Politecnico Madrid - UPM, Spain
(4)Rymsa Arganda del Rey, Spain

Abstract- **An X-Ka band high gain antenna configuration is discussed in which the gain is improved by using a reflect-array on the sub-reflector. The implementation is for a dual reflector antenna with a dual frequency feed. Experiences in Spanish institutions have been combined, like reflect-array developments (UPM), feed design and technology (Rymsa) and design and technological manufacturing processes (EADS CASA Espacio). Control of reflection properties (specific design of reflect-array) assists to obtain good performances for an antenna configuration. It allows making efficient use of the antenna aperture for two different bands for high-gain, whilst controlling separate bands.**

I. INTRODUCTION

Interplanetary satellites use frequency bands allocated for Deep Space (S, X or Ka-band) for the telecommunication functions (telemetry, telecommand and data channels). S-band gets overcrowded and interferences with terrestrial services occur more and more frequently, therefore S-band is gradually abandoned for Deep Space. The available bandwidth is only 50 MHz in X-band, leading to 'overpopulation' with more and more interplanetary satellites in service. S/X-band is used on ESA missions like Mars Express and Venus Express. The S/X band antennas have a dichroic sub-reflector transparent for S-band (with a feed in primary focus) and reflective for the X-band feed (secondary focus). These S/X-band antennas use classical surfaces. Some improvement in efficiency is possible by exploiting the feed and dichroic behavior in combination with reflector shaping, but it has appeared to be small.

The mass of such antenna is important. Utilization of novel available materials for reflectors allows reducing the mass. Tri-axial CFRP (Carbon Fiber Reinforced Plastic) reflector technology has matured. A tri-axial CFRP reflector has been used already for a high gain antenna for a Japanese Mars mission (6.5kg [1]) and on various other telecom missions.

One considers today higher frequency bands with 31.8–32.3 GHz for Space-Earth and 34.2–34.7 GHz for Earth to Space. Higher data rates are possible and more bandwidth is available in Ka-band. More users (space-crafts) could be served. Shorter wavelength will impose more stringent requirements on precision for instance for tri-axial or other CFRP reflector technology. Tri-axial technology could be adapted somewhat. Dedicated low-mass technologies are imperative anyway. RF properties, accuracy and dedicated thermal-optical properties are required over wide temperature ranges and need attention. CFRP has somewhat worse reflectivity properties in Ka-band compared to X-band. Solutions for metallization, like thin film with thin metal coating improves RF reflection properties, well-known to CASA.

A high gain antenna optimized for X-band and accurate enough to support Ka-band would allow an improvement of the link budget of several dB's compared to the earlier S/X band antennas. The ESA 35 m Ground Station antennas are prepared to allow Ka-band reception for the Deep-Space bands as well as for Near-Earth applications.

Slightly different frequency bands are also considered in Ka-band for Near-Earth and L-2 missions (Lagrange point). The James Webb Space telescope will use the 26GHz band. In Japan, a mission for space VLBI (VSOP2) considered 37-38 GHz band for data downlink. Such type of missions calls for Ka-band or potentially X-Ka band antennas sometimes with transmit functionality only for a Ka-band data-downlink.

High data rates may require different modulation techniques to be used which has impact on antenna parameters like phase stability and group-delay parameters, to be considered in the design phase. Specifics for high data-rates depend on the mission. Available power on-board the spacecraft is a limiting factor in Deep-Space missions. The utilization of Ka-band has started and so antenna designs for X/Ka band are needed.

The atmospheric loss is higher in Ka-band (compared to X-band) impacting on the link-budget. The loss varies and is strongly dependent on local tropospheric parameters near to the ground station. It will have impact on data transmissions from space. Ka-band data transmissions could be organized as pre-programmed tasks, exploiting storage and re-transmission considerations or other considerations. Carefully planning of (costly) ground stations is an issue with many SC missions.

The paper outlines a few configurations for X/Ka band antennas with a potential to be efficient, with a combination of frequency bands and within which a control of complex boundary conditions could be employed, differently for the different bands. Methods have been investigated, making use of techniques comparable to reflect-array implementations. Reflect-array properties are managed in such a way, that they provide the appropriate EM boundary conditions such as to improve the radiation performances in our case in particular for the Ka-band functionality. But principles are generic and would allow separate control of the two frequency bands. Critical bread-boarding has been carried out for some of the sub-systems, which can be used or are present in an X/Ka band antenna configuration.

II. ANTENNA CONFIGURATIONS

Different dual-reflector antennas have been investigated, including usual Gregorian, Cassegrain and differently shaped approaches, with a dichroic sub-reflector (inductive or capacitive) or a dual frequency feed to handle two bands from a common aperture within one antenna. Hybrid solutions have been considered also, taking benefit of a combination of other controlling means available. One can coat a reflecting surface (or both reflecting surfaces) with reflect-array like structure to provide control of reflecting properties – or in other words: to provide the appropriate EM boundary conditions. It can be done in a frequency dependent manner or adapted for the two (or more) bands. It allows improving antenna parameters like a higher efficiency. In this way one could for instance use the classical dual reflector geometries or also other reflector geometries (even flat-plate or composed flat-plate like in a limit) and let desirable shaping be provided by the additional effect of a reflect-array for maximum efficiency.

One can also correct discrepancies as caused for instance by the feed. This is what we describe with experiments in support. One can optimise the shaped reflector configuration for X-band and use reflect-array properties for Ka-band optimisation.

The reflect-array could be positioned under constraints on an already shaped sub-reflector. We have the capability to realise desirable EM boundary conditions in a complex manner (full polarisation in principle). Such an approach is an alternative or assists to physically shaping of metal reflectors.

Dual frequency feeds have been developed in the past [2]. A complex three-band feed for the high gain antenna flies now on Cassini spacecraft around Saturn. Optimisation of a dual frequency feed for both X and Ka-band is somewhat complex for the separated spaced transmit and receive frequencies in both X- and Ka-band. The phase centre locations for X- and Ka-band channels can be somewhat different, depending on the design and thus geometrical feed parameters and allowed opening angle for the feed. It requires dedicated and demanding optimisation effort, using good modelling tools.

A dual frequency feed was realised by Rymsa. It was tested and had difference between phase centre for X- and Ka-band. The analysis of the antenna configuration showed the effects which was confirmed by the test results for the latter feed. The X-band result was very good (dual reflector configuration with shaped reflector surfaces). The impact of a displacement of the Ka-band phase centre has been determined and led to a decrease in efficiency.

The team has demonstrated to be able to recover Ka-band performances by inclusion of a Ka-band reflect-array mounted on top of the sub-reflector. The latter reflect-array assisted to introduce the necessary phase response such as to optimise the efficiency for the Ka-band pattern.

Application of a dedicated reflect-array technology allows also to control the two frequency bands separately, with very small influence on X-band, whilst allowing improving the Ka-band performances. In this way the antenna performances can be realised for an X/Ka band antenna with dual-frequency feed.

It is interesting to indicate, that one has other possibilities as well, for instance for shaping or optimisation of shaped surfaces further. One can optimise the dual reflector assembly for X-band and configure a Ka-band sensitive reflect-array on top of the sub-reflector for other purposes, even for some limited beam shaping in Ka-band. It should be even possible to consider a reflect-array on top of the sub-reflector for Ka-band interacting in such a way that it can correct for an off-axis located feed, thus allowing the feeds for X and Ka-band to be placed adjacent in principle. However the needed integer number of phase changes (0º-360º) leads to some discretisation effects with impact on side-lobe performances. For some applications it can reduce the complexity of the dual band feed system in the antenna drastically.

III. REFLECTOR ASSEMBLY

Within the development activity the shaped dual reflector assembly was determined, using well-known optimization techniques. The reflector configuration has a diameter of 1.3 meter, comparable to the antenna assembly as flying on Venus Express. The shaping has been optimized for the X-band frequency. The precise location for the Ka-band frequency, with its shift along the axis was taken as a new configuration, with the main reflector shaping maintained as in X-band. The optimum shape of the sub-reflector geometry for Ka-band has been determined. The effective difference has been expressed in phase difference and this phase difference has been used to derive a reflect-array configuration which produces such phase difference. The result is an improvement of the Ka-band antenna performances.

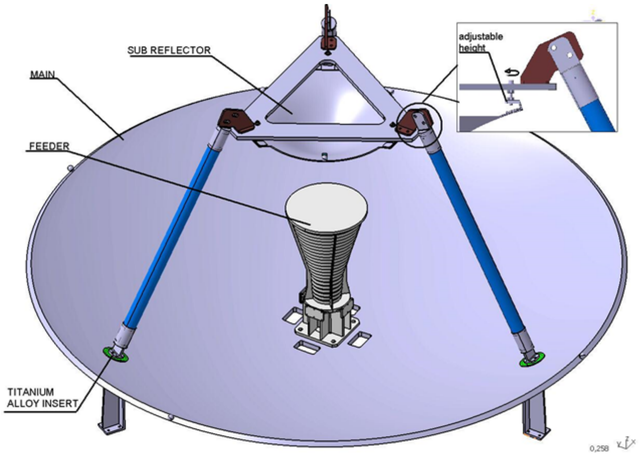

Figure 1. Schematic X/Ka Antenna Configuration (Courtesy CASA)

IV. FEED ASSEMBLY

A dual frequency feed configuration was investigated and bread-boarded by Rymsa. A feeding part with narrow opening angle was considered for Ka-band part, with a slightly wider opening angle for the X-band part.

The influence of the X-band coupling locations appeared to be very critical to allow good Ka-band performances for both transmit and receive band, requiring good geometrical control. It can be improved in future work. A displacement of the phase centre was measured and was carefully assessed. Fig.1 shows the feed configuration, which for X-band was fed in phase quadrature and for Ka-band by means of a septum polariser. The X-band quadrature network is not shown.

Figure 2. Dual frequency Feed, X/Ka band (Courtesy Rymsa)

Several optimisations and precise complex measurements have been carried out.

V. Reflect-Array Assembly on a Sub-Reflector

A very wide experience is available at the Universidad Politecnica de Madrid (UPM). A capability for determination of reflect-array parameters for various tasks was demonstrated in [3] where a pencil beam and a contoured beam was designed for different coverage directions. Such type of expertise has been used to derive needed reflect-array parameters for our Ka-band configuration, to be mounted now on the curved sub-reflector. The elements for the reflect-array have a size of about 4 to 5 millimeter, it becomes clear, that manufacturing requirements are very stringent. UPM has derived the reflect-array design for the curved surface that corrects the complex co-polar feed pattern.

EADS CASA Espacio's has proprietary capabilities to design, handle and install thin metallised layer. The mentioned reflect array, was realized with a two-layer design, exploiting laser-assist in the alignment of the layers.

Fig. 3 shows a realized sub-reflector with a Ka-band reflect-array on top.

Figure 3. Sub-reflector with Ka-band reflect-array on top (Courtesy CASA)

The precise testing configuration involved near-field testing of the sub-reflector with a Ka-band feed at the appropriate distance. The structure to support the feed was analysed with Grasp in order to derive the effect caused on the radiation performances.

The results from the measurements have been imported in Grasp, using spherical wave expansion. In this way the antenna patterns have been derived, using the measured performances (feed with sub-reflector patterns) as input.

A sub-set of results is presented in table 1 below. One column shows the results when the measured results (sub-reflector + feed) are used in the Grasp model. The other column is based on a Grasp model with the feed data injected.

Band	Freq. (GHz)	Measured GRASP Model (dB)	GRASP Model (dB)
X-Band	7.10	38.51	38.46
	7.25	38.50	38.50
	8.35	40.05	39.95
	8.50	39.99	39.94
Ka-Band	31.80	51.12	51.02
	32.30	51.15	51.10
	34.20	51.45	51.50
	34.70	51.52	51.57

Table 1. Comparison of directivity values based on Grasp analyses.

As an example the X-band and Ka-band patterns are shown for the case with the measured performances of the feed with sub-reflector (Fig.4).

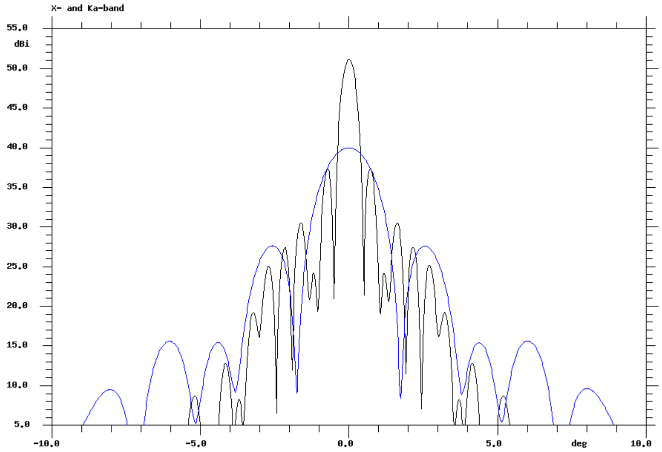

Figure 4. Dual frequency Feed, X/Ka band pattern, using measured data for feed combine with sub-reflector in analysis (Courtesy CASA).

The resulting directivity for X-and Ka-band is respectively 40 dBi and 51.1 dBi (for 8.35 and 32.3 GHz respectively), using the main- and sub-reflector geometry as derived for optimum performances in X-band.

VI. Concluding Remarks

The utilization of a reflect-array on top of a sub-reflector has been discussed. A feed pattern with a dislocated Ka-band phase-center has been corrected by means of the latter reflect-array. A sub-reflector with a Ka-band reflect-array has been realized and measurements of the combined feed and sub-reflector (with reflect-array) have been carried out.

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