On deployable reflector antennas for a C-Band companion satellite for Sentinel 1

ON DEPLOYABLE REFLECTOR ANTENNAS FOR A C-BAND COMPANION SATELLITE FOR SENTINEL 1

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ABSTRACT

The Copernicus program exploits synthetic aperture radar (SAR) data from the Sentinel 1 mission [1]. One (or more) companion satellite(s) receiving SAR data in bi-static modus, could enhance the information output for the Sentinel 1 mission. In this paper initial feasibility aspects are addressed for deployable and fixed reflector antennas for such satellites. A VEGA launcher might be used for such a receive-only mission. It constrains payload-sizes in a launch configuration. Receive-only feed-arrays are needed, with digital beam-forming (DBF) and further signal processing techniques.

1. INTRODUCTION

A companion satellite, receiving SAR data in a bi-static modus is being investigated by ESA for the SAOCOM mission. It operates in L-band (www.esa.int).
Here we elaborate initial feasibility of C-band solutions:
* A deployable reflector antenna suitable for focal array feeding for a companion satellite for such mission,
* A solid reflector with focal plane array, smaller in size with a need for additional signal processing.

A Vega type launcher [2] is an assumption. A deployable reflector is desirable. It offers suitable effective receiving area for the antenna given the fairing size limitation. A solid reflector would be too small to follow a Sentinel 1 signal. Some additional signal processing can assist, but not fully. A deployable reflector concept is discussed in Chapter 2 and a shorter solid reflector concept is discussed in Chapter 3. Additional signal processing can improve somewhat and is outlined. Discussions are in outline, qualitative format.

It is important to recall, that for a SAR antenna certain considerations are important, namely (a) to provide enough effective receiving area for a suitable realistic signal budget and (b) to provide enough SAR-data for realistic unambiguous responses and (c) to be able to unambiguously handle the echoes in range.
Antagonistic sampling requirements for both azimuth (along track) and elevation (across track) have to be respected for SAR. A receive antenna with a length larger than 10 m would be preferred to comply with azimuthal ambiguity constraints for SAR. Focal plane arraying is known to be able to extend reception angular coverage for wider coverage in range, but with constraints. It can in part handle a limited azimuthal scanning (for TOPS-mode) but with a fast fixed switching scheme using overlapping beams in azimuth together with also switching receive beams in elevation, indeed at a cost of complexity. However, if beams can be formed digitally, one could construct simultaneous beams in processing, which could be optimised.
The scan domain needed is larger for range (elevation) than for azimuth. Elevation ambiguity constraints have an impact in the case of a small reflector. The use of simultaneous beams is of interest, if needed realised with orthogonal excitation sets. Multiple beam on receive is the direction of interest and digital beam-forming the related direction for implementation. Well-timed switching on receive during the inter-pulse period in the elevation plane and multiple receive beams can assist to reach a wider elevation coverage ("switch-on-receive", not to be confused with "scan-on-receive"). One should not address ca ±12° elevation scan volume (DBF, multiple beam, receive-only modus). Operational research investigations should lead to consolidation.

An application of a large toroidal antenna was explored [3, 4] and in previous radiometer studies. A parabolic curve rotated about an axis realises a longer dimension in the plane perpendicular to the (offset) parabola for that radiometer.
For our situation here for SAR we need a long reflector configuration with an elliptical contour with a parabolic shape in the long direction (along track for SAR). A desired shape in the elevation plane can be installed with the concept proposed in Chapter 2. It can be parabolic, but it could be spherical or shaped in that direction of the shorter dimension. Recall that the antenna system operates in a receive modus. A focal plane array with dual polarised feeds is assumed, each polarisation of a feed connected to suitable receiving circuitry, providing signals, to be digitised. Progress in integrated circuitry concerning technology and reduction of necessary power demands pave the way for digital beam-forming as the way to go. Suitable excitations are imposed to provide multiple Rx-beams, but orthogonality conditions may

have to be investigated in conjunction with ambiguity constraints. It is important, that the amplitude and phase characteristic are known for each beam and polarisation. A slightly denser sampling of the focal field can be adopted not necessarily using the usual ‘Potter’, ‘Scrimp’ or other feed elements of some λ diameter, but allowing for smaller waveguide feeds with about 1λ in size, dual-polarised, in a mutual coupling environment, each coupled to its own Rx-circuitry. A Geyer feed is a candidate because of its intrinsic polarisation properties (scalar feed). Oversampling allows for some averaging and reduction of discretisation errors.

Chapter 2 discusses structural aspects of a deployable reflector concept. Such concept could also handle a reflector for a push-broom radiometer [3, 4].
Chapter 3 discusses a shorter reflector antenna, almost directly taken from the study of CoReH2O-mission [5] with minor changes: it has been increased a bit slightly “over the maximum” allowed by a Vega fairing [2, 5].
Initial estimation indicates a preferred aperture area of at least 10m² to comply with a SAR budget for bi-static SAR in C-band. The deployable reflector (chapter 2) can handle such figure easily. A solid reflector (chapter 3) has a maximum size near to 5.2 by ~2.0 m², which is below that limit. Some recovery is obtained by switching through the coverage with pencil-beam type patterns. Accommodation under the fairing is a critical aspect (unless one follows a fairing re-design like for SAR-Lupe). Note also, that front-end losses are lower in an Rx-only scenario due to an absence of circulators and some RF circuitry. DBF is applied taking the digitised signals at the level after the LNA. The optimisation might take into account a product of a Tx beam and an Rx beam as suggested decades ago. Further investigations are recommended.

2. LARGE DEPLOYABLE REFLECTOR

The reflector antenna concept for SAR has a long dimension, which follows a parabolic shape and the shorter dimension which can be parabolic or shaped if so needed. The concept could provide an effective receiving area of more than 20 or 30 m². Such large reflector sizing is of interest not only for receive-only missions, like considered here, but also for active SAR missions with demands on gain and antenna effective area for a total SAR end-to-end budget with lower transmit power. A larger size comes with a large focal length, which can be a constraint. A dual reflector shaped scenario could be a possibility but with other aspects (an a-stigmatic sub-reflector, as for example used on Tele-X, could be considered but leads to accommodation complexity and scan limitations). A stowed antenna should comply with launcher volume requirements (VEGA volume under fairing [2]). Redistribution of requirements is still a task for system level studies, but the use of a satellite bus like CoReH2O [5] is anyway an interesting one.

2.1 Large Elliptically Contoured Reflector

A backing structure is used to support a cable truss network on which a warp-knitted mesh provides a precise reflector surface. A pantograph with depth in the out-of-(aperture) plane has suitable inclined joints. A set of supporting profiles in perpendicular (elevation) direction is carried at two outer joints of the pantograph in each cell. As example: 8 profiles in Figure.1.
The curvature of the pantograph approximates in the deployed state a parabolic curve (could be different in shape as well as for instance for a push-broom scenario [3, 4]). Profiles in the direction of the shorter reflector dimension provide a desired shape for the elliptic aperture. V-folding elements are joined to enhance the pantograph stiffness. Suitable inclined joints provide the desired pantograph curvature (here parabolic). A peripheral cable assists to stabilise the form stability further in the deployed scenario. Figure 1 illustrates the concept with more details in Figure 2.

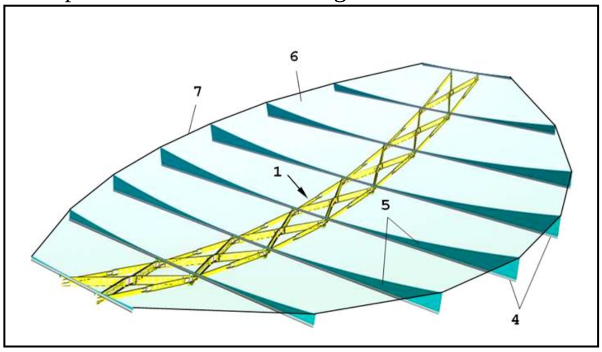

Figure 1. Reflector Concept

1 – Transformable pantograph; 4 – T-shaped stiff profiles; 5 – Shape-generating ribs; 6 – Reflecting mesh; 7 – Peripheral cable.

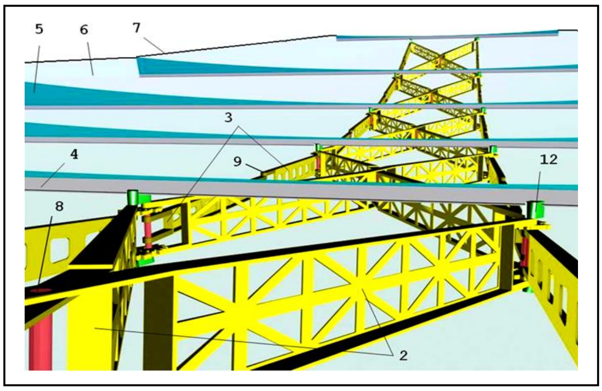

Figure 2. Expanded view from computer model

2 – Levers of the pantograph; 3 – v- folding bars; 4 – T-shaped stiff profiles; 5 - Shape-generating ribs; 6 – Reflecting mesh; 7 – Peripheral cable; 8 – Central hinge of the levers; 9 – Central hinge of the V-folding bars; 12 - Brackets for attachment adjacent sections and profiles.

The upper shorter and lower longer length of the curved pantograph follow from a fact that the pantograph levers and V-folded bars have a thickness (depth). It leads to differences in the synchronised joints for the upper and lower level. For a circular arc all upper joints would be identical from cell to cell. The same applies for all joints on the bottom in the pantograph-levers. For a parabolic arc there is a difference. Synchronisation during deployment is provided by tooth-gear elements at the lever joints. The profiles for the shorter reflector dimension can be straight in the stowed package, but curved thanks to a dedicated hinge point attachment and a peripheral cord. Final reflector accuracy is provided by a suitable cable truss suspension carried by the supporting deployed structure. A foldable warp-knitted mesh acts as reflector surface. The concept can be used for more reflector scenarios. Detailed requirements are not available today for precise sizing of the reflector. The requirements for the deployed situation, the desirable shaping and the focal length are important for an accommodation on a small platform.

It is noted, that the effective elliptical receiving area moves in orbit with its longer dimension along track. At first glance that area is equal (close to) a projection of the reflector periphery on a plane perpendicular to the axis of the parent parabola along which the focal length is given. It is obvious, that the angle, due to other system aspects can be a design parameter related with a driving for compactness before and after deployment under a VEGA fairing constraint. One has to be careful in case of a dual reflector scenario, that conditions like Mitzugutch have limited angular range and cannot be maintained for all beams in elevation. The reflector configuration will be presented with more illustrations during the workshop.

3. SOLID REFLECTOR ANTENNA

In this chapter we elaborate on a reflector antenna with a length of about 1/2 to 1/3 of the actual Sentinel 1 antenna length (which is 12m, [1]). A solid reflector is assumed, a fixed-mesh reflector could be used as well. A focal plane array is considered with a number of elements out of which suitable sub-groups of feeds are managed to realise desired Rx-beams for the elevation plane (range) and azimuth plane (along track). Antenna Rx-beams are formed digitally (DBF).

With the CoReH2O configuration as starting point, the solid reflector could be enlarged only a little bit. Detailed analyses have to refine it to remain or be compliant with Vega fairing. The CoReH2O platform had to provide power infra structure for a radar type mission thus with a transmitter. Here we are only concerned with a receive scenario. No precise requirements are available for a bi-static Rx-only antenna flying in conjunction with Sentinel 1. An assumption is justified, that it should take less power from such a platform [5] to handle a receive-only mission, even with a large feed-array and DBF.

A solid deployable reflector considered for COREH2O mission had a size of about 4.3 by 1.8 meter [5]. We consider to adapt the reflector parameters to satisfy point (a), leading to small increase. The effective area can hardly be realised with a fixed reflector antenna. Azimuthal ambiguity constraints are an issue for a short antenna, considering the Sentinel 1 radar signal (PRF and 12 meter antenna). If we could triple the PRF frequency, we would be able to form a continuous Rx synthetic aperture, but it would violate range conditions, additional processing is needed, a limited compromise can be a complex pre-summing on-board.

A synchronised reception is assumed with Sentinel 1 satellite, using a dedicated radio link for such purpose. Three pencil-type beams are formed to cover a sub-swath in range (about 80 km assumed) to permit an increase in directivity. Within the pulse repetition period, the beams of the smaller satellite (pencil-shaped) cover, say, three range intervals commensurate with about, say, some 80 km swath of Sentinel-1. Coverages are slightly overlapping, thus leading to ambiguity in range. It remains to be investigated if an orthogonalisation process (Gram-Schmid for instance) applied to excitations can provide independence in responses (reminder: amp and phase). One cannot fill the complete synthetic aperture with three strip-maps for further processing synchronous with a Sentinel-1 strip-map, but one achieves a bit better link budget thanks to the higher directivity of the pencil beams. The scheme could be considered for a factor 2, 3 and 4 in reflector sizing, assisted in decoupling in overlapping beams by orthogonal sets of excitations.

If used with three beams, it is still a factor 3 less in efficiency, but if the range coverages are sufficiently decoupled, one can work with narrow beams in parallel, one should be able to continue azimuthal SAR processing (with ambiguity, for which extremely limited beam shaping is possible with DBF in azimuth (7 rows of feeds would permit +- 1 beam in azimuth and an intermediate beam, which is not enough to capture about the azimuth scanning of Sentinel-1 antenna for the TOPS mode), if sub-groups of, say, 4 and overlapping is used in the sub-array. Power orthogonality can be used at excitation level for range, for which it might be desirable due to beam overlap for adjacent beams. How much: it has to be studied: It requires further analysis to derive the best pattern requirements for the beams for the three-times (or 2 or 4) narrower swaths to handle a single (sub) swath of Sentinel-1 (assumed as said to be some 80 km). Satellite reception synchronisation could be based on a two way link, comparable to the one used in Space-VLBI (Quasat, Radio-Astron, etc.) or based on comparable approaches installed for Terra-SAR-X...

Feed-arrays have been encountered already in several telecommunication missions, designed with conjugate field matching. Recently it has been considered for a microwave instrument with a radiometer application. A toroidal reflector and a focal plane array allowed to realise a number of simultaneous overlapping pencil beams in despite of the deformation due to the toroidal reflector. A set of highly efficient pencil-type beams has been considered, with low side-lobes suitable for radiometry [4]. Side-lobe requirements for SAR are less stringent, nevertheless a sub-division in range with three more narrow shaped beams deserves care. Excitation orthogonality has already been investigated in previous ESA studies (contract TRP-6552/1985) for SAR antennas some 30 years ago together with a consideration of a product of separate Tx- and Rx- patterns.

4. ANTENNA SCENARIO

Compared to CoReH2O scenario, we increased slightly the reflector size to 5.2 by 2.2 meter. The VEGA fairing [2, p 81] allows for a slightly longer reflector length, but the diameter near to 2.20 m is obvious critical.

An initial estimate has been made with Grasp program. The value of 2.2m leaves no clearance and must obviously be refined, but can be adapted. Positive fractions of a dB are found by considering a super-elliptic rim. A simple 3 by 7 array cluster of feeds has been employed in this very initial analysis, allowing allocation to different elevation beams in (overlapped) groups of two feeds. It can be considered a sub-set of an expected larger focal array of some 7 (azimuth) by 15 (elevation) elements in a hexagonal grid with one of the three symmetry lines along elevation. The number of feeds can be even larger (if smaller feeds are used, it can be almost doubled – even with respect for the power hungry RF- and digital circuitry and DBF). The actual sizing and precise overlapping scenarios needs to be investigated. Here the peak gain of a beam formed using a two feed element group out of the total array is 45.9 dBi (maximum) in elevation at 5.3 GHz. Main-plane patterns are shown in Fig.4 for a slightly scanned beam, a contour plot is given in Fig.5. The first black contour line is at 41 dBi.

The elementary optimisations have not yet been carried out to provide the best prediction (edge illumination aspects, side-lobe levels required, etc. it is a first descriptive approach for feasibility indications.

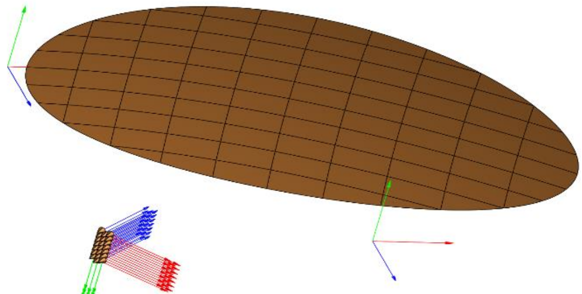

Figure 3. Reflector Concept, 5.2m by 2.2m

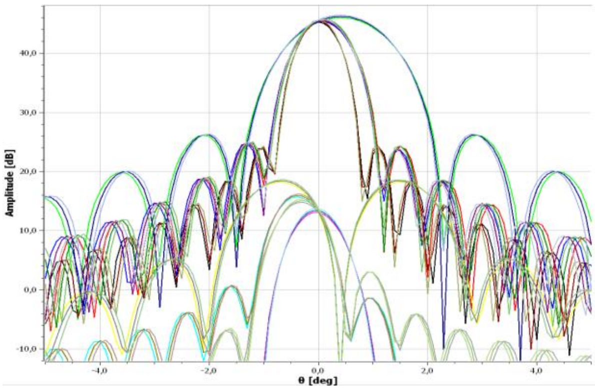

Figure 4. Main-plane patterns,
Two feeds, slightly scanned beam

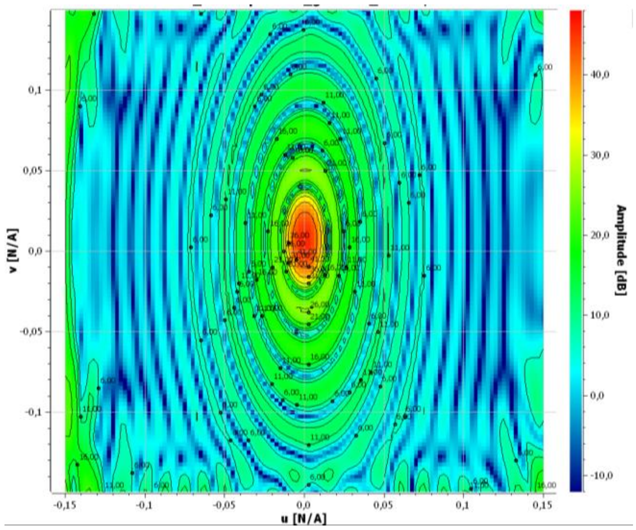

Figure 5. Contourplot u-v space, slightly scanned beam

With the feed-array in the direction of a shorter reflector size ("green" Fig.3), one can provide (overlapped) sub-groups for range beam-forming. Overlapped sub-groups in the other direction ("red" Fig.3) provide overlapped beams in the azimuth direction. Clearly the upper limit in number needs to be derived. It needs detailed investigations, if following a TOPS mode is imperative, as the azimuthal Rx beam handling is a combination of beam overlap and DBF on receive. Here one azimuthal beam covers an equivalent of several azimuthally scanned azimuth beams of Sentinel-1, to be investigated in better detail for the bi-static scenario. It depends also on the distance between Sentinel 1 and this platform and the nr of pulses to be used (nice operational research to be undertaken still in view of the bi-static scenario to be optimised). Assuming a synthetic aperture length for a non-scanned Sentinel-1 azimuth beam of some 5 km, the distance of the Rx additional satellite should be not more than to have sufficiently long co-coverage in a bi-static scenario. Azimuthal scanning by DBF in azimuth (discrete nr of different azimuth beams though) can provide increased synthetic aperture with a difference in incidence angle (another way of looking at bi-static scenario). Also a higher resolution could be endeavoured. Clearly bi-static schemes should be investigated in more detail.

Initial estimations have been made with a simple cluster of 2 Potter feeds out of the larger array of similar feeds (by far not optimised). Only a set of 7 by 3 feed elements was considered, with an estimate for an on-axis beam, a first beam (overlap) and a scanned beam, using 2 elements out of an assumed array of 7 elements, just to indicate principles. Distortion of outer beams can be reduced by reflector shaping, at a cost of some directivity. With a focal array approach one could optimise further and take beam deformation out by conjugate matching procedures near the focal plane (as in [4] and as started long ago in telecommunication applications).

5. CONCLUDING REMARKS

Two reflector antenna concepts have been discussed for initial feasibility for a companion satellite flying in formation with Sentinel-1. Assumptions have been made. A detailed system study is needed, which should include operational research aspects for bi-static.

A concept-feasibility with a potential for large effective area has been discussed in Chapter 2 for a deployable reflector. A feed-array is anticipated to be used, which needs detailed study, in conjunction with over-all system aspects.

A shorter reflector has been considered in Chapter 3. It achieves an effective receiving area near to as required for a power budget. Additional signal processing is needed, which can be investigated with a digital beam-forming assumed to be available. The outlook for bi-static SAR is interesting, for new responses to be derived in Earth Remote Sensing. Clearly more study is needed, which benefits to explore and accordingly to flow down appropriate requirements for the antenna configuration.

6. REFERENCES

1.https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1

2. http://www.arianespace.com/wp-content/uploads/2015/09/Vega-Users-Manual_Issue-04_April-2014.pdf

3. C.G.M. van ‘t Klooster, E. Medzmariashvili, S. Tserodze, L. Datashvili, N. Tsignadze, “Large Deployable Reflector Configurations for Space-based Applications in Telecom, Science and Remote Sensing”, Proc. 1st Int Sci Conf. Tbilisi 2009.

4. C. Cappellin, K. Pontoppidan, P.H. Nielsen, N.Skou, S. S. Søbjærg, A.Ihle, M.Ivashina, O.Iupikov, K. v. ‘t Klooster, “Design of a Push-Broom Multi-Beam Radiometer for Future Ocean Observations”, EUCAP Conference Lisbon, Portugal 2015.

5. http://esamultimedia.esa.int/docs/EarthObservation/SP1324-2_CoReH2Or.pdf.