A STEPPED-APERTURE ANTENNA CONCEPT FOR LOW FREQUENCY SAR MISSIONS

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INTRODUCTION

In principle, a spaceborne low frequency SAR can allow the measurement of forest biomass, the depth of Antarctic ice, the hydro-geological properties of arid and semi-arid regions, as well as the detection of buried geologic structures such as faults, fractures, synclines and anticlines. However, the long wavelength, which makes the observation of such physical properties potentially possible, and the observation requirements of the radar system, can drive the surface area of the antenna to around 100m^2. The accommodation, deployment and operation of such a large radar system present numerous design constraints and challenges. The stepped-aperture antenna concept presented in this paper attempts to address these challenges.

CONSTRAINTS AND CHALLENGES

Low frequency SAR missions, such as the Earth Explorer Core Mission candidate BIOMASS [1], can have demanding observation and system technical requirements. For example, providing contiguous and complete coverage of the tropical forest regions within 25 days drives the imaged swath width to more than 100km. The situation is exacerbated by the full polarimetry mode, which requires the pulse repetition frequency (PRF) of the radar transmitter to be doubled, placing stringent constraints on the echo window duration. As a result of these constraints, an antenna length of at least 18m is required in the flight direction to allow successful operation in the preferred Stripmap mode. For operation beyond a specified minimum incidence angle, the height of the antenna must be sufficient to permit adequate beam shaping in the elevation plane for the suppression of range ambiguities, which increases the required antenna area towards 100m^2. The provision of this large antenna is a powerful design driver for the space segment and the overall cost because it directly impacts the spacecraft accommodation, the mass budget and the size envelope of the launch vehicle.

Generally, the financial constraints of a mission favour the use of a relatively small launch vehicle, e.g. Vega, rather than a larger and more expensive one, e.g. Soyuz 2-1a. However, the accommodation of such a large SAR antenna within the relatively small Vega fairing presents a considerable challenge. The successful deployment of such a large antenna and the orbit control requirements of the spacecraft also present challenges for the mission.

Other challenges in the design and operation of a P-band SAR payload stem from the ITU Recommendation ITU-R SA.1260-1, which limits the power flux density at the surface of the Earth. In order to protect stations operating in the existing services, SAR transmissions from spaceborne platforms in the Earth Exploration-Satellite Service (EESS) operating in the frequency range 420-470 MHz are subject to technical and operational constraints. The technical constraints for P-band EESS instruments are given in Table 1. The power flux density restriction, especially that corresponding to regions within the first side lobes of the radiation pattern of the SAR antenna, are particularly problematic in the design of the SAR antenna and in the achievement of the required radiometric performance.

Further constraints arise from risk and financial considerations that encourage the use of existing space-qualified technologies. In response to these constraints and challenges, a special form of direct radiating array (DRA) has been conceived, namely a stepped-aperture array SAR antenna, which potentially offers performance benefits, as well as economic, mechanical and electrical advantages.

Table 1 Technical constraints for EESS (active) instruments in the range 420-470 MHz (RECOMMENDATION ITU-R SA.1260-1)

Parameter	Value
Peak power flux density on Earth's surface from antenna main lobe	-140 dBW/(m^2 · Hz))
Maximum mean power flux density on Earth's surface from antenna main lobe	-150 dBW/(m^2 · Hz))
Maximum mean power flux density on Earth's surface from 1st antenna side lobe	-170 dBW/(m^2 · Hz))

ACCOMMODATION IN THE VEGA LAUNCH VEHICLE

In the higher frequency radar bands, the DRA is generally smaller and can therefore be accommodated in the cylindrical section of the launch vehicle's fairing. Such accommodation is favoured because the DRA is typically of a rectangular form. In the approach presented here, the stepped-aperture array antenna is accommodated by means of a folded panel assembly that extends into the conical section of the Vega fairing, thus gaining a useful extension to the antenna length. The width of the folded panel assembly is maximized through the use of a Snapdragon platform [2]. Fig. 1 shows the front and side views of the spacecraft, which is accommodated inside the fairing of the Vega launch vehicle. A truss structure supports the tip of the folded panels, providing additional stiffness, and thus reduces the dynamic response during the launch. Removable hold-down mechanisms between the truss and the panels are foreseen for this purpose. The thickness of the folded stack is a function of the panel thickness and panel spacing. For this preliminary work, a panel thickness of 40mm is assumed, which, allowing for spacing between the folded panels, results in a stack thickness of 535mm. The mechanical design of the folded panel assembly can benefit from the heritage of solar panel technology.

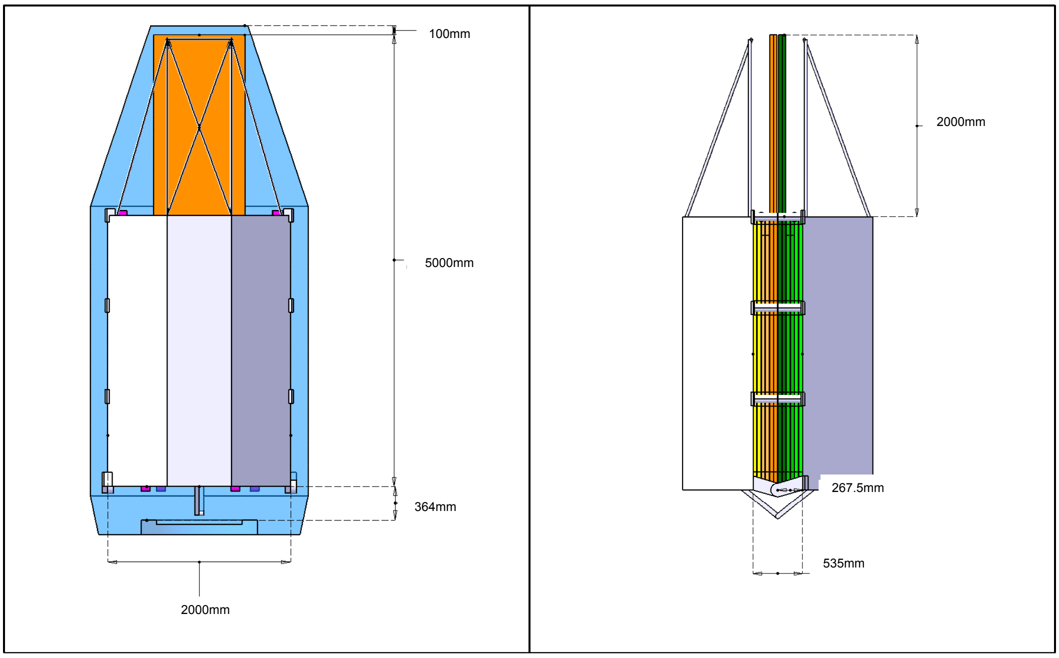

Fig. 1 Front and side views of the spacecraft accommodated within the fairing of the Vega launch vehicle.

DEPLOYMENT SEQUENCE

A simplified deployment sequence is shown in Fig. 2. The stowed configuration (1) is exposed after its separation from the launch vehicle and fairing. Following the firing of the hold down release mechanisms, a motorized deployment actuator unfolds the Snapdragon platform together with the antenna assembly about the principal axis (2), resulting in the locked platform configuration (3). A further motorized deployment of the antenna assembly is made by means of four synchronized actuated hinges (4) until the fully extended state of the antenna is reached (5). Finally, a stored energy deployment of the side panels of the antenna is made, resulting in the fully deployed configuration (6).

The proposed folded panel assembly expands the accommodation efficiency of the Snapdragon platform. Whereas the original Snapdragon platform was proposed to give a two-fold increase in the stowed-to-deployed projected antenna surface area, here the proposed folded panel assembly offers a ten-fold increase. The deployed stepped-aperture antenna dimensions are 22 m x 4 m and its physical area is 74 m^2.

DEPLOYED STIFFNESS

The results of a preliminary modal analysis of rectangular and stepped apertures are shown in Table 2. For each of the apertures, the following simplified model assumptions are made, in order to investigate the mass and geometry advantages of this innovative antenna with respect to a canonical shape: homogeneous panels of length 22m and width 4m, a panel thickness of 40mm, a Young's modulus of $0.0686 \times 10^9 N/m^2$, a Poisson coefficient of 0.3 and an area density of $3 kg/m^2$. The results indicate that a stepped-aperture should be significantly stiffer than a rectangular aperture of similar size and properties. The stepped-aperture concept improves the stiffness because it eliminates mass from the extremities of the rectangular form, pushing the torsional model to higher frequencies. This effect is helpful from the Attitude and Orbit Control System (AOCS) point of view, since manoeuvres can be shaped and smoothed in order to avoid the excitation of the bending modes.

Table 2 Results of modal analysis for rectangular aperture and stepped-aperture arrays

Mode	**Symbol**	**Unit**	**Rectangular array**	**Stepped-aperture array**	**<u>Comments</u>: corresponding modes for the stepped-aperture array**
Symmetrical bending	f_1	[Hz]	0.1773	0.2230	Symmetrical bending
Asymmetrical bending	f_2	[Hz]	0.1778	0.2236	Asymmetrical bending
<u>Torsional</u>	f_3	[Hz]	0.9772	1.1747	2^{nd} symmetrical bending
Asymmetrical torsional	f_4	[Hz]	0.9774	1.1764	2^{nd} asymmetrical bending
2^{nd} symmetrical bending	f_5	[Hz]	1.1106	1.4803	*<u>Torsional</u>*

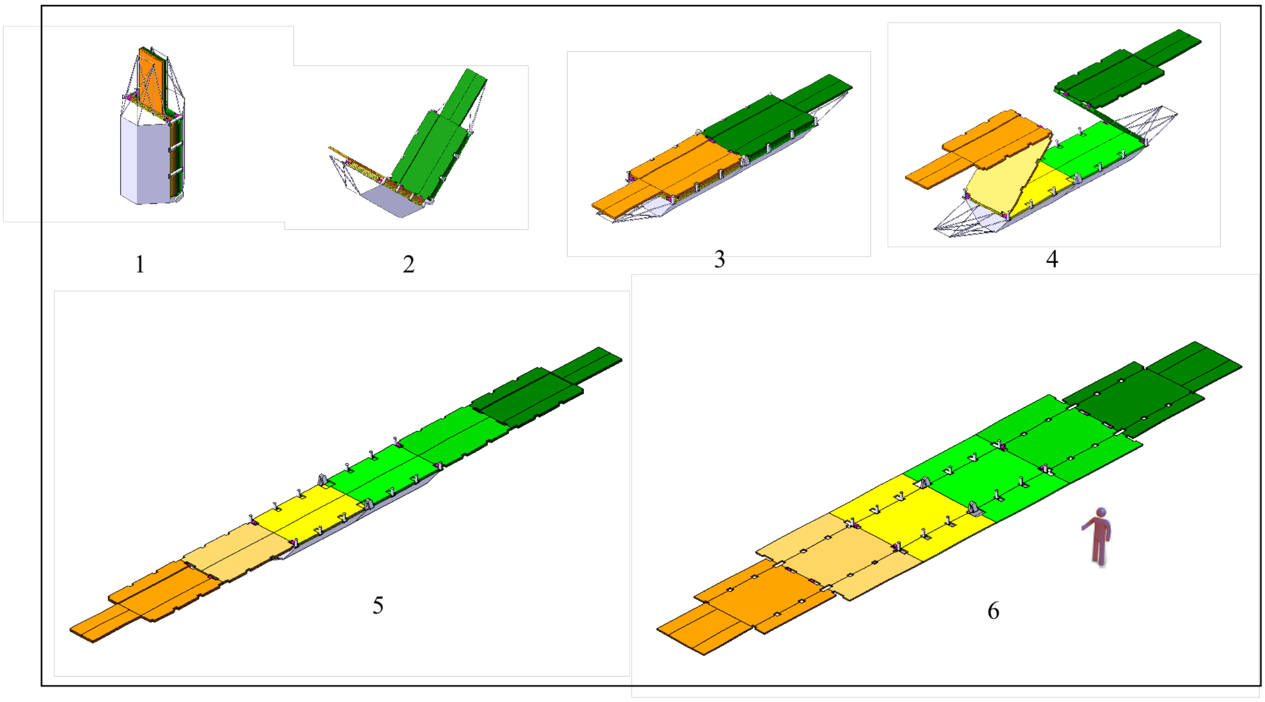

Fig. 2 Simplfied deployment sequence of the stepped-aperture array.

STEPPED-APERTURE ARRAY

Fig. 3 shows the arrangement of the 296 radiating elements that form the stepped-aperture array. An element spacing of 0.5m (0.725λ) is chosen to avoid the folds (indicated by the broken lines) in the antenna panel assembly.

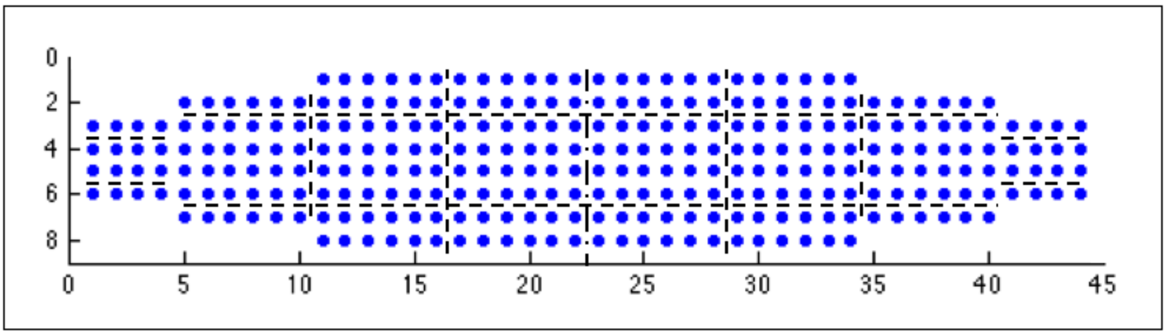

Fig. 3 Stepped-aperture array showing the arrangement of the radiating elements.

RADIATION PATTERNS

Spaceborne SAR antennas are often in the form of a rectangular aperture in which the radiating elements are uniformly illuminated, because this arrangement provides the highest efficiency and it is also relatively easy to implement. However, such an approach results in high sidelobes (-13 dB) in the radiation pattern, as shown in Fig. 4(a), and this would not be compatible with the ITU recommendation on the level of power flux density at the Earth's surface. In the case of the rectangular aperture, it is therefore necessary to apply appropriate weighting to the element excitation in order to reduce the radiation sidelobes to an acceptable level. The application of the aperture weighting increases the complexity of the antenna architecture that is required for driving the radiating elements.

In the case of the stepped-aperture antenna, there is an inherent weighting of the aperture illumination, which reduces the first sidelobes of the radiation pattern to a around -17.5 dB, as illustrated in Fig. 4(b). It is thus closer to meeting the ITU recommendation, even when each of the radiating elements is equally excited. The first sidelobes of the radiation pattern are further reduced to around -20 dB by simply applying two levels of excitation to the radiating elements, as shown in Fig. 4(c). The results shown in Fig. 4 were obtained by means of a modified MATLAB programme [3].

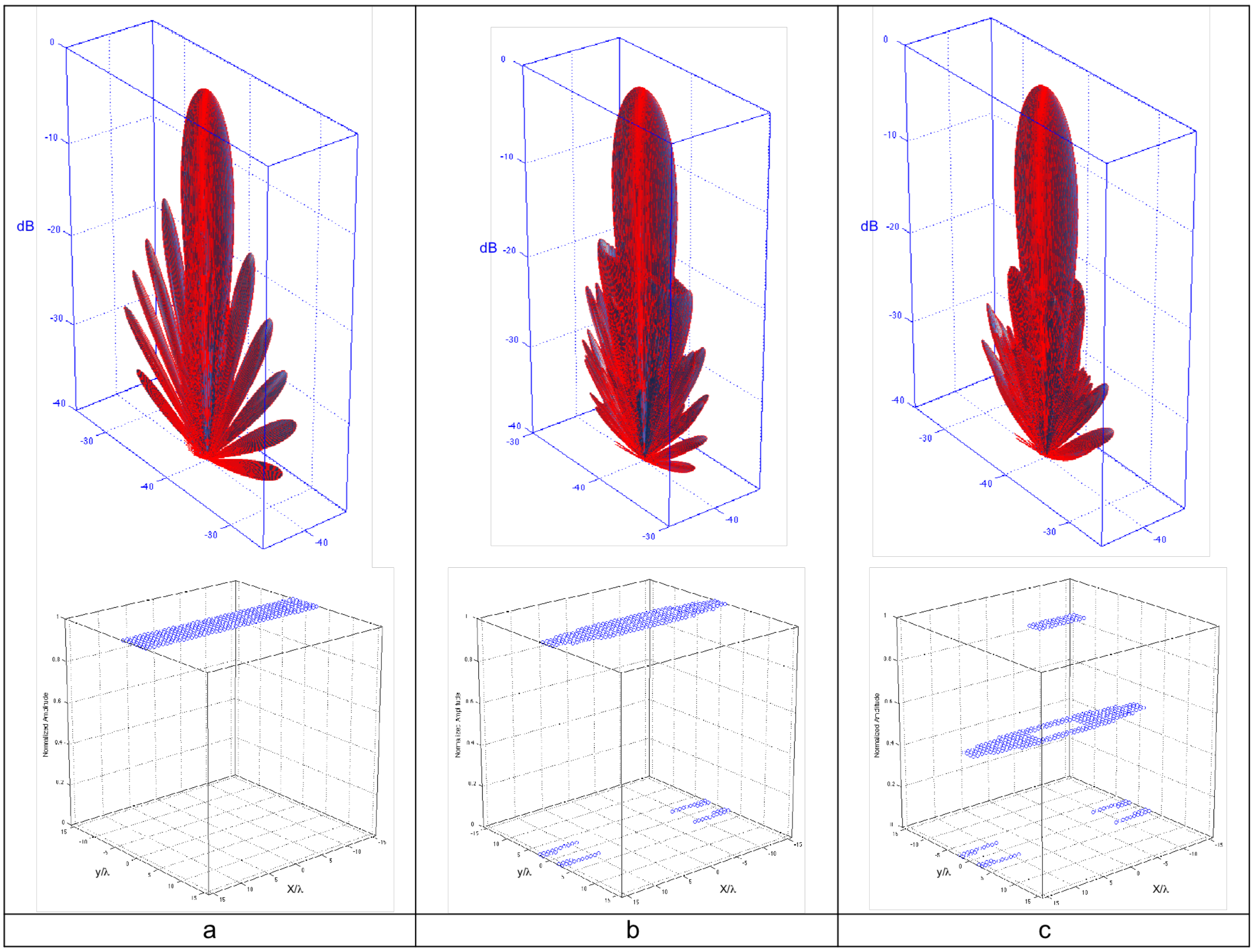

Fig. 4 Element excitations and radiation patterns for (a) a rectangular aperture with equal element excitations, (b) a stepped aperture with equal element excitations and (c) a stepped aperture with two levels of excitation.

CONCLUSION

The stepped-aperture array SAR antenna potentially offers performance benefits, economic, mechanical and electrical advantages. However, mass is a possible issue when such a large structure is accommodated in the Vega launch vehicle.

REFERENCES

[1] P. Bensi et al., "A New Earth Explorer – The Third Cycle of Core Earth Explorers," ESA Bulletin, European Space Agency, No. 131, Aug. 2007, pp. 30-36.

[2] R. Torres, S. Lokas, H. L. Moller, M. Zink, D. M. Simpson, "The TerraSAR-L mission and system", Geoscience. & Rem. Sens. Sym., 2004. IGARSS apos;04. *Proc.2004 IEEE Intnl,* Vol.7, 20-24 Sept. 2004 pp. 4519-4522.

[3] J. C. Bregains, F. Ares, E. Moreno, "Visualizing the 3D Polar Power Patterns and Excitations of Planar Arrays with MATLAB", IEEE Antennas and Propagation Magazine, Vol 46, No.2, April 2004.