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A VERY LARGE DEPLOYABLE SPACE ANTENNA STRUCTURE BASED ON PANTOGRAPH TENSIONED MEMBRANES

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Summary. This paper provides investigation results on the membrane technology development of a high accuracy (low deformation and high eigenfrequency) membrane antenna structure and its demonstrator for space application.

1 INTRODUCTION

For future earth observation missions from space such as ice-sounding and biomass monitoring space borne radar systems that operate in P-band (432-438 MHz) are needed [1]. In order to provide the required antenna performance in this relatively low radio frequency band, very large antenna apertures are needed. In this study, antenna structure solutions from 65m² up to 100m² surfaces are investigated based on a foldable membrane technology. This solution consists out of three membranes that are installed in 30mm distance to each other and that are tensioned by a deployable pantograph back structure.

In the first part of the paper it is shown that the antenna can be built out of a very light-weight membrane structure up to 100m² radiating surface. This solution fits the in orbit eigenfrequency and accuracy requirements as well as fits the stiffness and packaging requirements for the small European Vega launcher.

In the second part of the paper, the technology development for the tensioned membrane structure is addressed. Therefore, the results of the technology and accuracy study on the manufacturing and assembly process of the needed thin and flexible membrane laminate (glass fabrics, flexible adhesives, Kapton, copper) are presented in the paper. This includes studies on the manufacturing process of the membranes, the flexible assembly of membrane stripes, the boundary fixation structure and technology, the mechanical and thermo-elastic material property investigations, the transverse electrical connections between the membrane planes, and folding and deployment tests.

Furthermore, a 1.5m by 2.5m demonstrator is discussed. It represents one sub-array of the antenna, which is about 1% of the total antenna surface. Here, the shape optimization results for the tensioned membranes are addressed. Finally, the surface accuracy of the demonstrator is measured by the photogrammetry method and compared to the results of a finite element model.

2 CONCEPT OF THE MEMBRANE DIRECT RADIATING ARRAY ANTENNA

The developed antenna is operating at P-band (432-438 MHz) in low earth orbit (638 km altitude, 97.94 deg inclination) for biomass and ice sounding missions. Its mission details and radio frequency (RF) performance is given in [1]. Electrically, the antenna is a direct radiating array (DRA). This array consists of many radiating elements that are arranged in plane as an array of e.g. 36 elements in azimuth direction and 6 elements in elevation direction. The azimuth direction is split into 9 functional “electrical panels” for better foldability of the structure and optimal electrical feeding of the antenna (figure 1, see also figure 2).

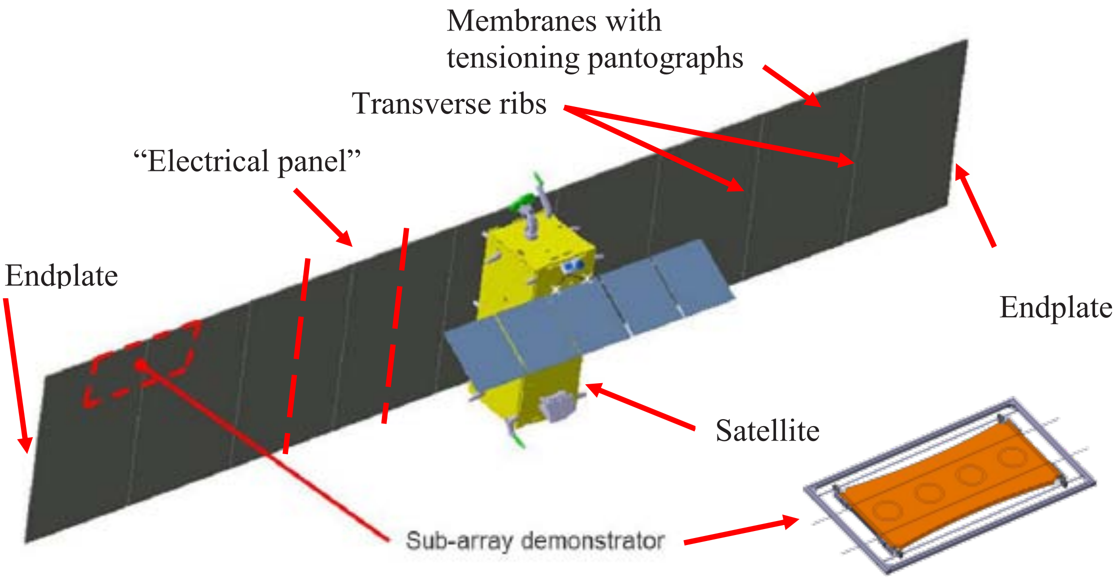

Figure 1: Schematic representation of the concept of the membrane DRA antenna

From structural and mechanical point of view, the antenna is built out of 3 tensioned membranes that are separated by 30mm distance and a tensioning back-structure.

Each membrane has to provide RF properties that are realized by the use of photo-etched copper-clad Kapton polyimide films. For robustness in orbit, the membranes are stiffened by a thin and lightweight glass fabric that is bonded to the membranes by a flexible acrylic adhesive.

The membranes are tensioned by a CFRP back-structure that uses the pantograph principle for deployment in-orbit. Therefore, two identical pantographs are deployed simultaneously starting from the symmetry-axis at the center of the satellite. This system is driven by electrical motors, which transfer a pulling force by deployment-cables to the pantograph levers. This system is shown in figure 2 in a deployed view and in figure 3 - stowed in the

European Vega launcher). Investigations in stiffness and packaging has shown that length of the antenna could be increased up to nearly 30m accommodating 13 electrical functional panels

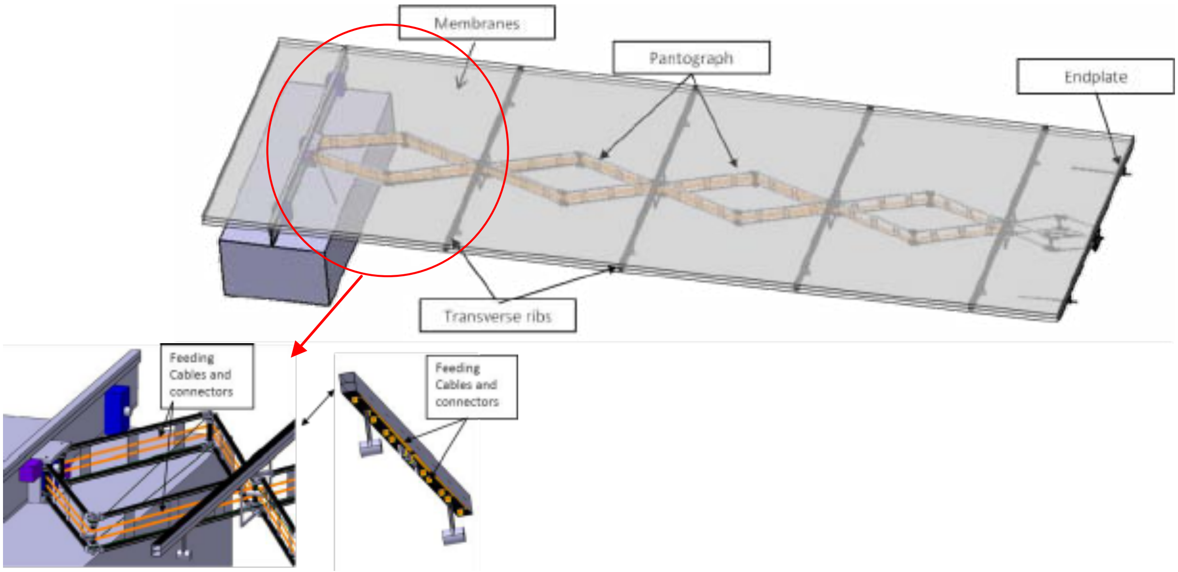

Figure 2: Mechanical design of the DRA antenna; deployed view (one wing shown)

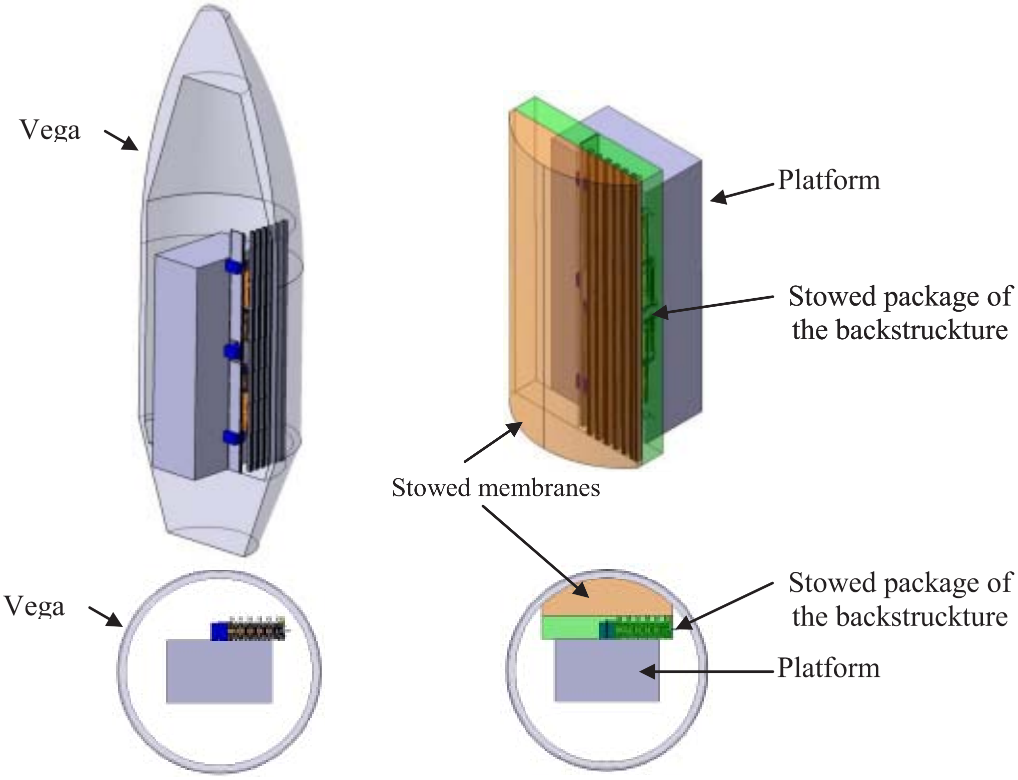

Figure 3: Schematic of the antenna accommodation in the Vega launcher

3 TECHNOLOGY DEVELOPMENT FOR THE TENSIONED MEMBRANE ANTENNA STRUCTURE

AKAFLEX KCL 2-17/50 HT is used as the base material for the membrane antenna surface, which provides the electrical functionality (photo-etched copper clad on a Kapton foil) and the needed mechanical properties. A thin glass-fabric (Interglas 02034) is bonded onto the Akaflex by a thin, flexible acrylic adhesive (DuPont Pyralux LF0100). This lay-up is shown in table 1.

This material is manufactured in an autoclave 2 hours at 190°C and 9,9 bar pressure.

Material	Component	Brand-name	Thickness
Akaflex KCL 2-17/50 HT	PI substrate	DuPont Kapton VN 50	50 µm
	Adhesive	Modified C-stage epoxy resin	15 µm
	Copper layer	RA (rolled and annealed) copper	17 µm
Adhesive		DuPont Pyralux LF0100	25 µm
Glass fabric		Interglas 02034	27 µm

Table 1 : Membrane material plys

For the shown sheet material, detailed mechanical properties were determined. It was observed that it has the same mechanical properties before and after thermal cycling (shown in figure 4). After the thermal cycling of specimens, no micro cracks were found under the microscope.

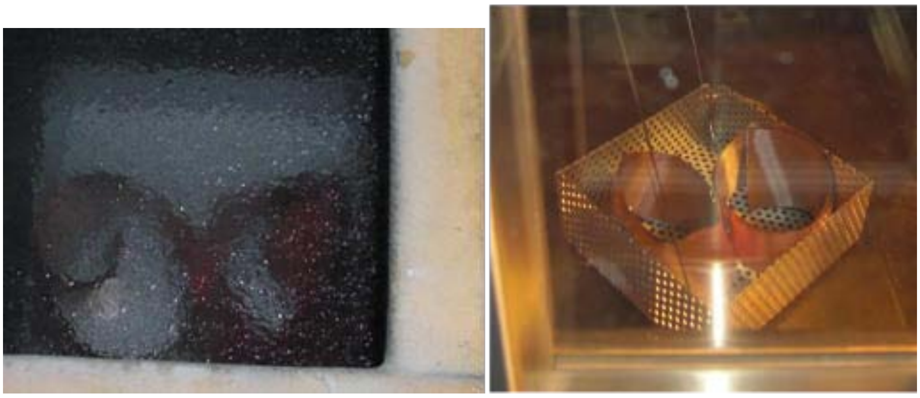

Figure 4: Thermal cycling of the membrane material; specimens in liquid nitrogen (left); at 150°C (right)

The laminated membrane material has a mean areal density of 285 g/m² and a mean thickness after curing of 118 µm. The material shows a bilinear tensile behavior with a Youngs's modulus of 9500 N/mm² in roll direction and 8900 N/mm² in orthogonal direction in the first linear sector (up to 0.5 % of strain). The ultimate strength of the material is at 125 N/mm² for both directions with more than 3% strain at break. The thermo-elastic behavior was determined by using a standard vertical-push-rod dilatometer with rolled membrane specimens (see figure 5). A CTE of 17.6×10^{-6}/K was determined for the roll direction and a CTE of 18.1×10^{-6}/K in the orthogonal direction.

Figure 5: Dilatometer test with rolled specimens for determining of the CTE values

Additionally, new methods for bonding of membrane strips with electrical connections and electrical connections in out-of-plane direction were investigated in this study. These were used for assembling the demonstrator, discussed in the following.

4 TECHNOLOGY AND FUNCTIONALITY DEMONSTRATOR

For studying of the membrane manufacturing technology, verifying the accuracy prediction (complex FEM models) and studying the foldability of the antenna structure, a demonstrator (2,5 x 1,5m) was designed, manufactured and tested. Details of the demonstrator design are shown in figure 6. It uses a frame structure for prestressing of the membranes in both directions (x-axis: screw system; y-axis: cable system). Three flat laminated membranes were assembled, positioned, aligned, electrically connected and mounted onto the support frame shown in the figure. The frame provides folding and deployment possibilities as well. Contour shapes of the membranes have been optimized for reducing the out-of-plane deformations.

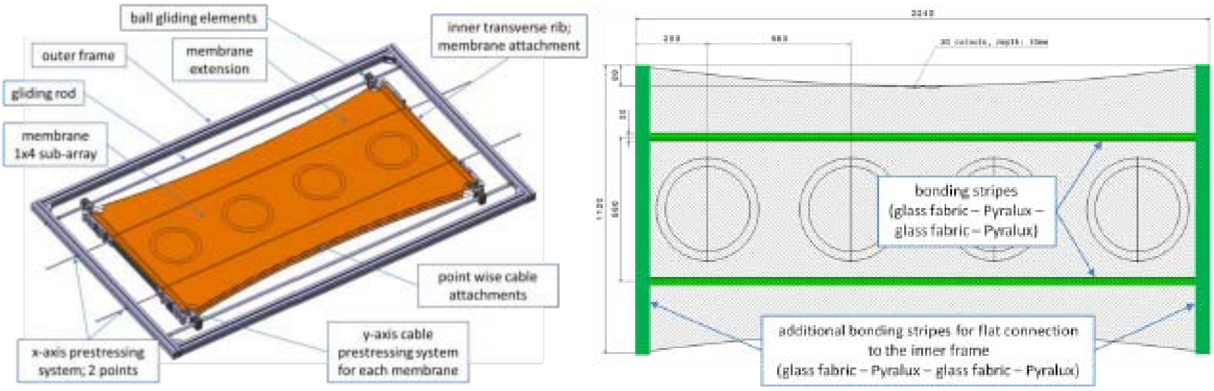

Figure 6: Definition of a technology demonstrator

Figure 7 shows the laminated and assembled bottom (ground plane) membrane of the antenna demonstrator, equipped with membrane pockets for point-wise steel cable attachment (Y-axis prestressing) and equipped with photogrammetry targets (white/gray dots on figures).

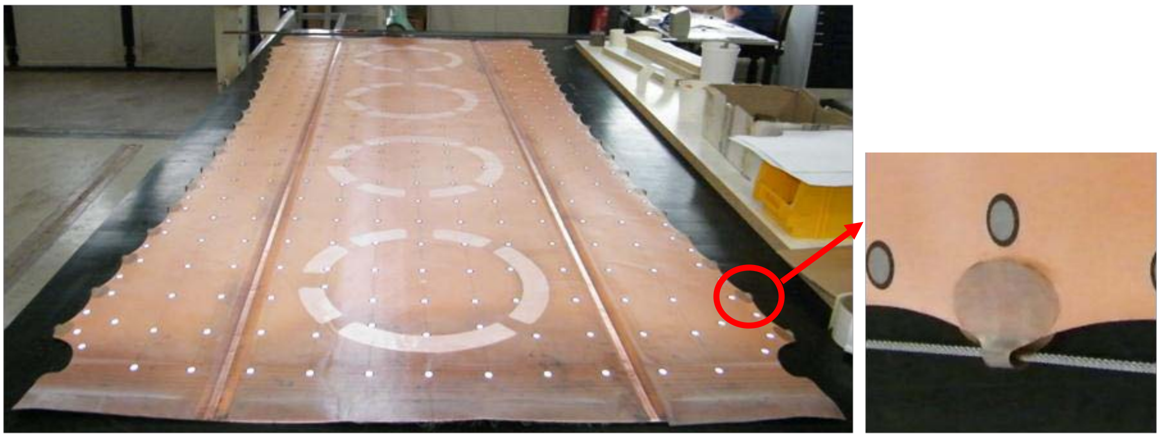

Figure 7: membrane laminate assembly, right: tensioning cable attachment

Figure 8 shows deployment and foldability of the membranes for stowing them in a dense package during the launch of the VEGA launcher.

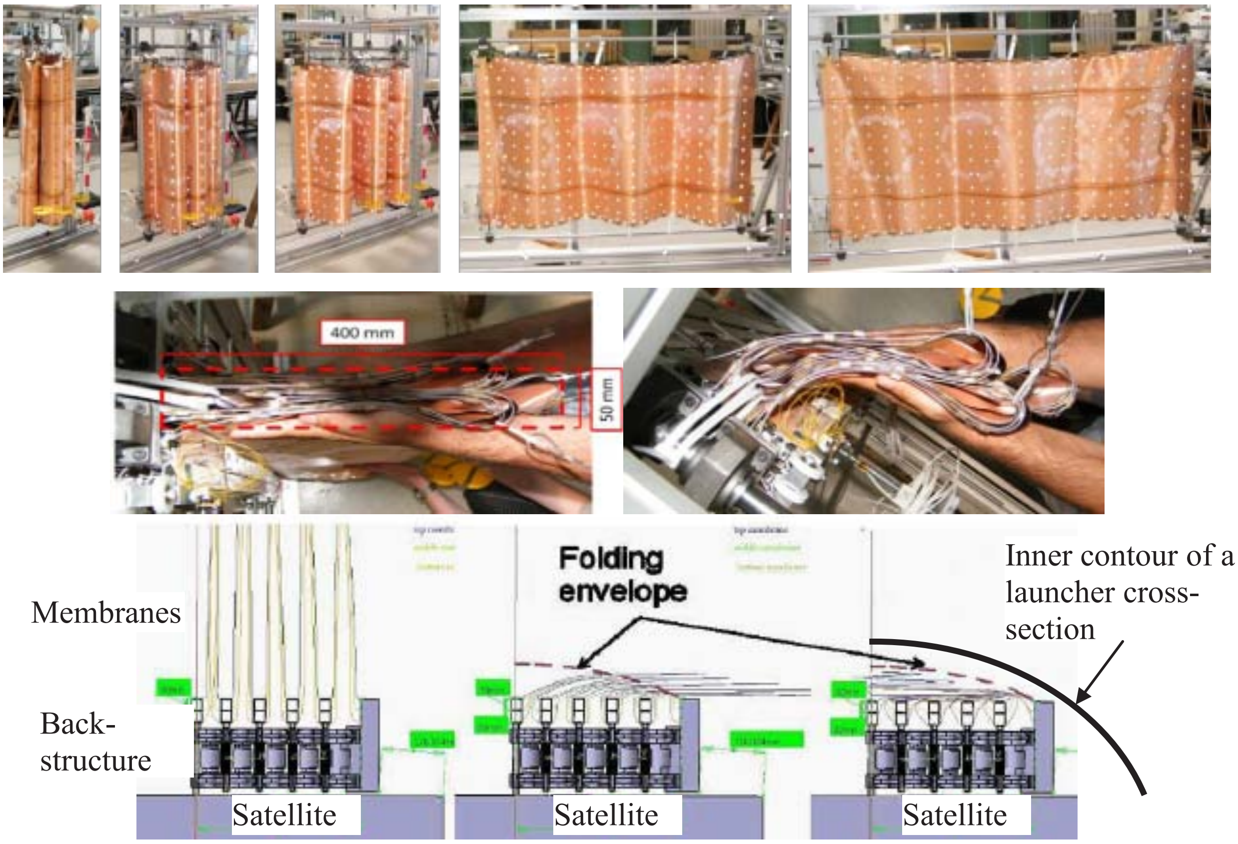

Figure 8: folding and deployment (figures are not in the same scale)

Both FE-modeling and photogrammetric measurements show a high flatness accuracy of the membrane surfaces. Figure 8 shows a good qualitative comparability of the deformation patterns although the gravity effects causing out-of plane deformations could not be compensated completely. The measured surface deformations were still well below the required flatness accuracy that is a maximum of ±1mm deviation. A root mean square (RMS) of the measured deformations is calculated as 0.45mm, while predicted deviations fall in the range of 0.3mm RMS.

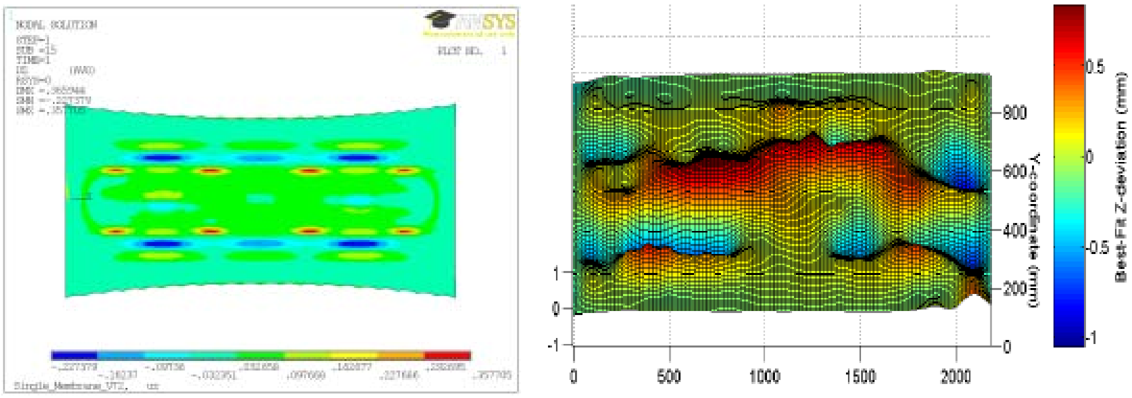

Figure 9: comparison between FE-modeling and photogrammetry measurements

4 CONCLUSIONS

A new tensioned membrane DRA antenna concept is presented in this paper. It is characterized with the high stiffness, low mass and high flatness accuracy and can be folded into the European Vega launcher with up to 30 m length of the effective surface (platform still to be defined).

The DRA concept technology and feasibility was demonstrated via manufactured single sub-array supported by the rectangular frame. It includes:

– Three electrical laminated membranes, transverse ribs, and electrical wire-walls which connect electrically the front (with round slots) and the rear (ground plane) membranes and pass through the middle (feeding and radiating) membrane without an electrical contact. Auxiliary support structure includes outer support frame, tensioning bars and deployment guides.

- Good surface flatness quality of 0.45 mm RMS was demonstrated under the gravity conditions (better figure is predicted for 0g conditions).
- It is shown that the membranes could be prestressed in both in-plane directions fitting the stiffness and flatness accuracy requirements.
- Folding of the membrane DRA is confirmed to be feasible into VEGA
- Deployment of the demonstrator was performed, no visual damage of membranes and electrical wall-wires was observed

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