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Design and deploying study of a new petal-type deployable solid surface antenna

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ABSTRACT

Deployable solid surface reflector is still one of the most important ways to fulfill the ultra-high-accuracy and ultra-large-aperture reflector antennas. However the drawback of integrate stiffness is still a main problem for solid surface reflectors in the former research. To figure out this problem, a New Petal-type Deployable Solid Surface Antenna (NPDSSA) is developed in this study. A kind of drag springs are applied as linkages with adjacent petals to improve the integrate rigidity. The structural design is introduced and the geometric parameters are analyzed to find their effects on the rotation and package capacities. The software simulations and laboratory model tests are conducted to verify the deploying process of NPDSSA. Two models are employed to study the property of linkage butts and drag springs. It is indicated that model NPDSSA with the application of linkage butts and drag springs has better integrality and stability during the deploying. Finally it is concluded that NPDSSA is feasible for space applications.

1. Introduction

Deployable reflector antennas on satellites have been researched for decades. The solid surface (or rigid reflector) antenna, as one kind of deployable antenna styles, was ignored by researchers compared with the mesh antenna [1] and the inflatable antenna [2]. The reasons are generally that the other two styles relatively have higher functions and lower costs based on current manufacturing level. However, the solid surface antenna has its own advantages such as high surface accuracy, permanent working capacity, higher frequencies, better mechanic properties and so on [3]. Especially, the recent rocket fairing can provide large space for payloads such as Chinese Long March Series Launch Vehicles [4,5], which makes launching possible for large-aperture deployable solid reflectors. Hence there are much better prospects and potentials for development and applications of deployable solid surface antennas.

Looking back into former research, early concepts have been stated as the stiff-panels supported by truss structure to form the reflector [6,7]. These kinds of concepts can achieve a high precision indeed but the supporting structure and reflector assembling leads to a complex mechanism. Another basic concept is to divide the reflector into multiple same sector petals hinged to the central disk part or hub by different kinds of joints with correspondent mechanisms. The Sunflower solid surface antenna has been proposed for the QUASAT Very Long Baseline Interferometry (VLBI) mission and it is designed as that the six folding rigid petals covered by aluminum honeycomb sandwich are hinged to a cantilevered ring attached to the center section [8,9]. TRW Extended Sunflower [6] has one more folding layer along radial direction compared with TRW Sunflower so as to have a small packing volume. The Dornier/ESA FIRST antenna [10] has been designed as the sector petals linked to the central hub hinged by revolute joints to nest in front of the hub when folding up. The Dornier/ESA MEA reflector [11] has been developed on the basis of FIRST antenna to employ the spherical joints to give petals the freedoms of rotation and twist. The Solid Surface Deployable Antenna (SSDA) [12] has been invented on the combination and improvement of aforementioned concepts, which petals are designed as the special forms inspired by the membrane wrapping fold pattern to level up the adaptability of folding size and shape. The Space Radio Telescope (SRT) in the RadioAstron project [13,14] has been made as a solid central mirror surrounded by 27 solid petals to achieve the high precision for four frequency ranges. Referring to the FIRST antenna and RadioAstron antenna, a new mechanism scheme of Large Petal-type Space Mirror (LPSM) [15,16] has been developed to increase surface accuracy and rigidity by the self-setting locks.

The solid surface reflectors not only fit the large diameter aperture

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Table 1
Comparison of different deployable solid surface antenna concepts.

Concept	ζ = d/D	l/D	No. of panels	Surface accuracy/D
TRW Sunflower	0.44	0.37	19	0.13 mm/10 m
TRW Extended Sunflower	0.29	0.43	55	not known
Dornier/ESA FIRST	0.36	0.51	25	8 μm/8 m
Dornier/ESA MEA	0.36	0.51	25	0.2 mm/4.7 m
SSDA	0.37	0.54	31	not known/ 1.48 m
RadioAstron SRT	0.30	0.42	28	0.5 mm/10 m
LPSM	not known	not known	not known	not known
NPDSSA	0.32	0.37	25	not test/1.2 m

antennas, but also show the benefits in micro-satellite applications. Recently, the payloads [17,18] on micro-satellites have been drawing researchers' attention because of their lightweight and low-cost. The high surface accuracy and rigidity shows the better feasibility of solid surface reflectors for the micro-satellite antenna. In contrast, mesh or inflatable reflectors have complex mechanism and cannot provide a desirable precision.

However, one of the most important problems for aforementioned solid surface reflectors is the drawback of integrate stiffness. For the FIRST and SRT antenna style, each petal is a kind of isolate cantilever and almost has no linkage with adjacent petals. It is difficult to maintain the surface and leads to local destabilization during vibrations. For the SSDA, even though it has the connecting bars, the multiple wings make the surface accuracy influenced easily. Therefore, besides the package efficiency, the integrate stiffness or frequencies and surface maintaining capacity should be also taken into consideration.

In this paper, a New Petal-type Deployable Solid Surface Antenna (NPDSSA) has been developed on the reference to LPSM. The comparison in Table 1 between NPDSSA and former antenna concepts is complemented based on Ref. [9]. The remainder of this paper is organized as follows. The structure design of NPDSSA is introduced in Sec. 2 and the parameter analyses for NPDSSA are deduced in Sec. 3. The deploying dynamics is studied by software simulations and model tests in Sec. 4. Several remarks are concluded in the final section.

2. Structure design

The concept of NPDSSA refers to LPSM as multiple petals hinged to central hub by joints. And the innovation here also combined with the concept of SSDA is the design of drag springs as linkages with adjacent petals to improve the integrate rigidity.

It consists of feed system, central hub, petals, supporting bars, linkage butts, single-direction pins and drag springs as shown in Fig. 1.

The parabolic surface is divided into the central hub and multiple petals as shown in Fig. 1. Here two colors, sky blue and sea blue, are utilized to make a distinction easily for the adjacent two petals. It is convenient for structure and mechanism statement that the feed system fixed on the central hub is not expressed in this figure.

On the back of antenna, two ends of each supporting bar are linked to the central hub and petal hinged by two kinds of single-direction pins respectively. There are two linkage butts fixed on two ends of petal outer side. The adjacent butts separately on two petals are linked with two ends of the drag spring. In the totally deployed state, the panels are located in the parabolic surface and the drag springs are tensed in the shortest state so that all the parts become a integrate reflector structure.

About the deploying mechanism scheme, this new way is using two single-direction pins to achieve the petal rotation around two orthogonal directions. The folded structure shown in Fig. 2 can also make all the petals revolute in front of the central hub.

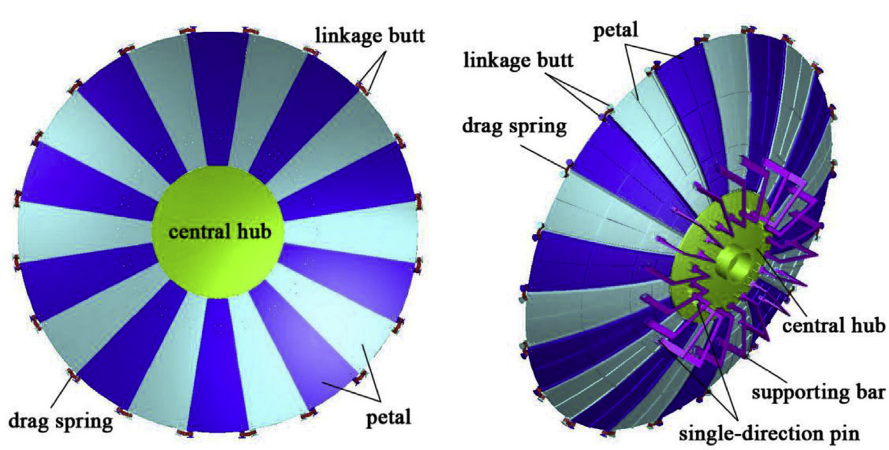
Specifically, each petal is hinged to the upper end of supporting bar by the pin 1 in Fig. 3. The rotation axis of single-direction pin 1 is parallel to the symmetry axis of sector petal. Then the lower end of each supporting bar is hinged to the central hub by the pin 2. The rotation axis of single-direction pin 2 is along the tangential direction of the circle where pin 2 locates. Thus each petal is turning around pin 1 and rotating down around pin 2 for reflector deploying.

Drag spring is another important part for mechanism scheme. As an example, the petal A has the linkage butt AL on the left end while the petal B has the linkage butt BR on the right end in Fig. 3. For any adjacent two petals, the butt AL and butt BR are linked by the drag spring. The drag spring is tensed with elastic potential energy when the structure is folded. As soon as the folded structure is unlocked to deploy, the drag spring quickly shortens to drag the butt AL and BR together. Finally in totally deployed state, the drag spring still has the tension stress to keep two petals stable.

Not only the torsion springs in single-direction pins can provide the driving moment, but also the drag springs can drive the structure to deploying. In the view of the mechanism scheme, the two orthogonal single-direction pins and drag springs make the design simple and effective.

3. Parameter analyses

The geometric parameters of the NPDSSA are analyzed to get the optimal set for the best package efficiency.



(a) front in vertical view (b) back in axonometric view

Fig. 1. Structure design of NPDSSA in deployed state.