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Precise two-stage deployment of a petal space antenna

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Abstract. One of the directions in modern radio astronomy is observing in the centimeter and millimeter ranges of the electromagnetic spectrum. The reflectors of radio telescopes operating in these ranges are generally parabolic mirrors. The sensitivity and angular resolution of a radio telescope depend on the mirror surface area. At the same time, due to the short wavelengths, high precision of the reflecting surface is required. This paper discusses a new design for a solid-state petal mirror. To enhance the accuracy of the reflecting surface, a two-stage deployment scheme of the petal antenna is proposed. In the first stage, a preliminary unstressed low-precision deployment of the antenna is performed. In the second stage, a high-precision fixation of the deployed reflector final state takes place. It is proposed to use self-adjusting locks to fix the final state of the deployed antenna. The results of computer and physical modeling of the new mirror design are presented. The method for controlling the deployment repeatability of the transformable reflector model is discussed.

Keywords: instrumentation: high angular resolution; telescopes; waves

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1 Introduction

Various types of transformable structures are being developed and used for creating space antennas. Large solid-state petal antennas have found application in radio astronomy for research in the centimeter and millimeter ranges of the spectrum (Kardashev et al. 2012; Huang et al. 2018; An et al. 2020). The classical design of a petal mirror was proposed by the Dornier Corporation as part of the work on the FIRST (Far Infrared Space Telescope) project.[1] A similar design was later used in the RadioAstron project, which operated in the centimeter range of the spectrum (Alexandrov et al. 2011).

While the classical design offers compact storage and a relatively simple deployment system, it has two significant drawbacks. First, in the operational state, the long petals are cantilevered to the central mirror, resulting in low rigidity of the deployed reflector. Second, in this design, the long petal is connected to the central mirror with a cylindrical hinge. Thus, small errors in the hinge installation lead to large errors on the outer edge of the petal, which significantly reduces the antenna quality (Kovalev et al. 2014). Our task is to eliminate these drawbacks.

2 Design description

The idea behind the new design is to move to a two-stage deployment of the antenna. The design is described in detail in Bujakas & Glotov (2024). In the first stage, a preliminary low-precision unstressed deployment of the antenna occurs, and in the second stage the high-precision fixation of the final state of the deployed reflector is achieved. In the new transformable mirror design, each petal is connected to the base of the central mirror with a spherical hinge, and the actuators are moved to the outer edge of the petals. It has been previously shown (Bujakas 2022) that at each moment of preliminary deployment, the structure remains unstressed and geometrically unchanged (statically determinate).

To deploy the reflector, a deployment system consisting of identical units is used, with the number of units equal to the number of petals. These units are placed on the outer edges of the petals, connecting adjacent petals in pairs. Each unit includes an actuator, a lever used to move one petal relative to another, self-adjusting locks, and a spherical hinge. The deployment is carried out by rotating the lever counterclockwise.[2]

[1] Patent US4899167A, 1986.
[2] https://disk.yandex.ru/d/aKhLi_aC4EnXog

3 Physical model of the new petal antenna

The physical model of the petal antenna implementing the proposed two-stage deployment is shown in Fig. 1. The model consists of 23 petals and corresponds to the design presented in Section refDesignDescription. The petals and the central mirror were fabricated using 3D printing. The diameter of the mirror in the deployed state is 50 cm. During tests, we confirmed that the model deploys automatically, convincing us of the viability of the proposed two-stage antenna deployment scheme.

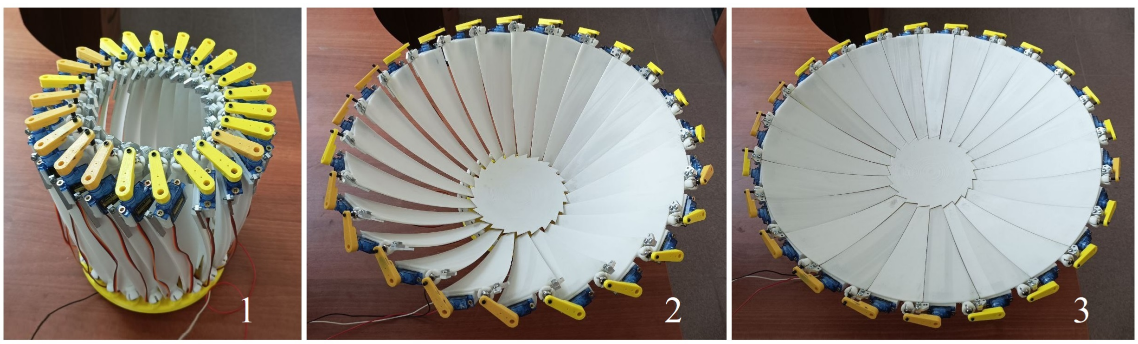

Fig. 1. The stages of deployment of the physical model: 1—mirror in the folded state, 2—partially opened mirror, 3—mirror in the opened state.

4 Deployment repeatability control using 3D scanning

The repeatability control of the model deployment was carried out using a non-contact 3D scanning method. We used a 3D scanner[3] (Fig. 2a, b) with a resolution of 1 mm, projecting a grid onto the reflective surface of the deployed mirror and determining the positions of the grid nodes to form a point cloud (Fig. 2c). The data obtained was processed using the open-source software CloudCompare[4](Fig. 2d).

Two cycles of mirror deployment and fixation were performed. At the end of each cycle, the positions of the petals were measured. The point cloud obtained from the first scan was used as a template. The point cloud from the second scan was compared to this template. Approximately fifty thousand points were automatically selected from the second cloud, and the distance from each point to the template

[3] https://support.3dsystems.com/s/article/Sense-Scanner?language=en_US
[4] https://www.cloudcompare.org/

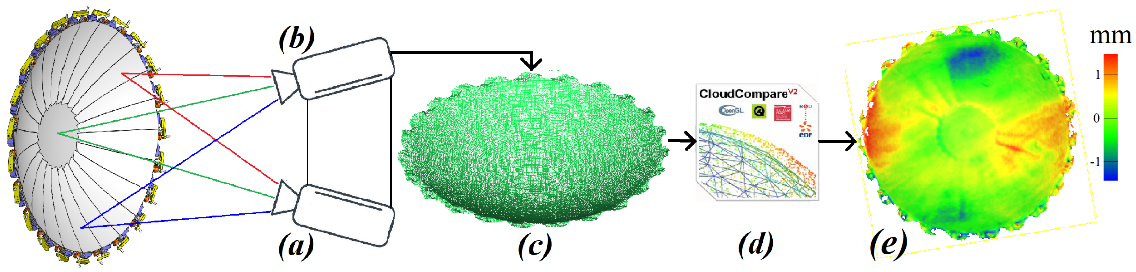

Fig. 2. The process of scanning and analyzing the mirror surface. (a, b)—3D scanner (the projection unit and registration unit, respectively); (c)—point field; (d)—CloudCompare; (e)—a result of the scanned data processing using CloudCompare.

surface was calculated. Each point and its surrounding area were assigned a color based on the distance (Fig. 2e).

The obtained data allows the determination of deformation locations and the calculation of their magnitude. Modern 3D scanners with a resolution of 0.02 mm enable high-precision control of the mirror shape and deployment repeatability.

5 Summary

This work proposes a new two-stage deployment scheme for a precise petal radio astronomy antenna. We constructed computer and physical models, which confirmed the feasibility of the new technical solution. A method for controlling the repeatability of the deployment of the transformable mirror model using 3D scanning was considered. We believe that these results could be useful in the development of new-generation space radio telescope antennas operating in the centimeter and millimeter ranges.

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