New concept of ground based-space radio interferometer and modern technologies application for deployment simulation of precise petal space reflector

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Abstract

Radio interferometers make it possible to achieve high resolution of astronomical observations due to the large base of the measuring instrument. The ground-space radio telescope RadioAstron holds the record for angular resolution among radio interferometers, its maximum base was about 340 000. km. The project turned out to be very successful. The new concept is based on the experience of the RadioAstron project and proposes the use of several orbiting radio telescopes that work together in the cm and mm spectral regions. This will further increase the base of the radio interferometer and expand the viewing angle at each current moment of time. Modern technical means make it possible to launch into orbit several identical mirrors operating in the short-wavelength region of the spectrum with an effective area no worse than the effective area of the RadioAstron antenna at a wavelength of 1.35 cm. Thus, the project can be quite budgetary. Now 3D modeling and 3D printing technologies make it possible to speed up and simplify the development of physical models. The manufacture of complex parts used to take days of work. Now we can use 3D printing to make different parts in a matter of hours. In the physical model of a new petal mirror project, we used FDM and LCD printing technologies. The paper discusses examples of manufacturing petal mirror physical model components, limitations and features of these technologies.

Keywords: *ground-space radio interferometer, petal mirror, 3D printing*

1. Introduction

A new concept of ground based-space radio interferometer is proposed and discussed. The concept is based on the idea of using several small telescopes in the space arm of the radio interferometer. The problem of creating a precise space reflector for radio astronomy is considered. Previously, we proposed a new design of an accurate solid petal reflector (Bujakas (2021)). Here, the technologies used in the deployment simulation of the proposed mirror are described.

2. New concept of ground based-space radio interferometer

Advanced projects of ground based -space radio interferometers involve the creation in orbit large precise deployable reflectors. The creation of such mirrors is a complicated and expensive scientific and technical problem. It seems reasonable to consider an alternative way to create a new generation instrument. Instead of one large mirror, put into orbit a set of small precision telescopes and form a ground-space radio interferometric network based on them. The proposal is based on the results of the work of the Radioastron project telescope (Kardashev & et al. (2013)), which demonstrated the possibility of obtaining a record angular resolution using a mirror with a very low AE. This concept is illustrated in 1, 2.

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Figure 1. Antenna array of the New Mexico Observatory.

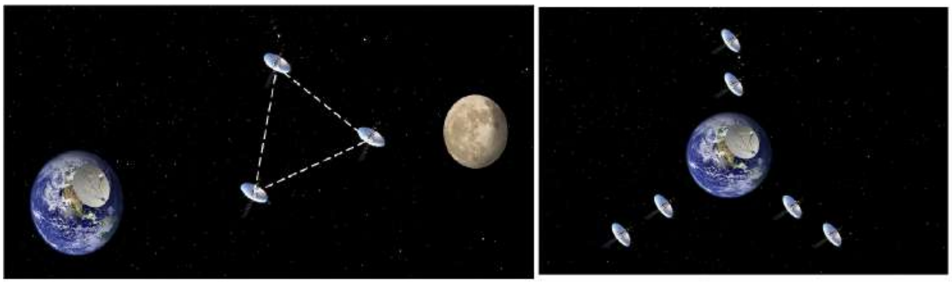

Figure 2. Variants of the ground-to-space antenna array using precise small antennas in space arm of the interferometer.

3. Modern technologies application for deployment simulation of precise petal space reflector

3.1. New petal type reflector

To create the next generation of large space telescopes operating in the short-wavelength area of the spectrum, it is necessary to deploy large high-precision mirrors in orbit. Early we proposed (Bujakas (2021)) a new deployable reflector designed to operate in the cm and mm ranges. A physical model of one of the design options is shown in 3.

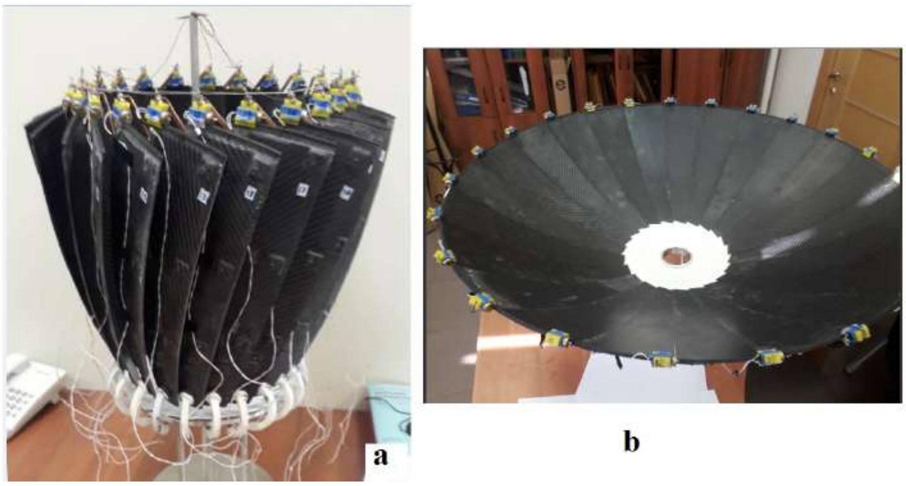

Figure 3. Physical model of a new petal reflector. a- a mirror in the folded state, b - an open mirror.

The new technical solution is based on the classic petal mirror of the Dornier Corporation (Dornier (1987)), the stages of opening of which are shown in 4. The classic design includes a central mirror and a set of petals. Each petal is connected to the base of the central mirror by a cylindrical hinge.

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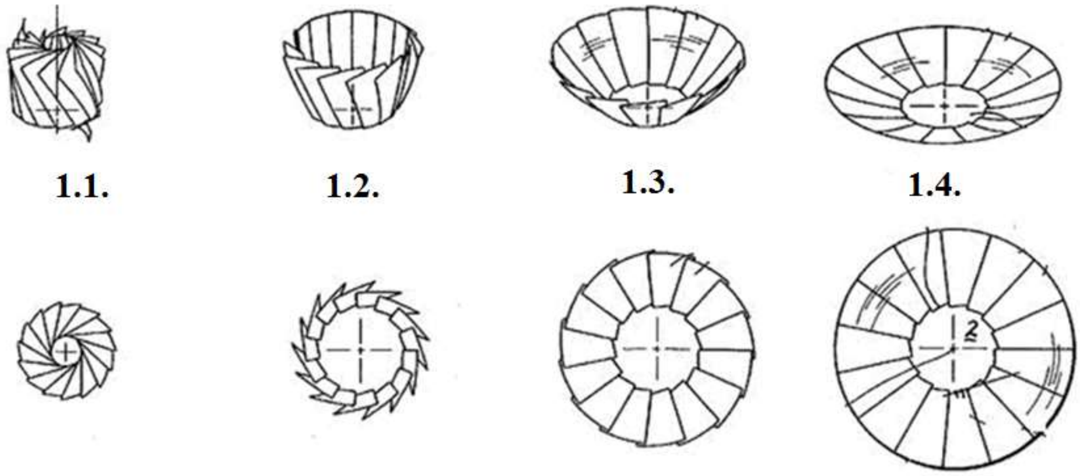

Figure 4. Deployment stages of Dornier corporation reflector.

Each petal is connected to the base of the central mirror by a cylindrical hinge. It is proved (Westphal (1990)) that there are such directions of the axes of cylindrical hinges, in which the synchronous rotation of the petals transfers the petal reflector from the folded position to the open state without engagement. Later, a modified version of the classical design was used in the RadioAstron project to create a 10-meter antenna for a space radio telescope (Kardashev & et al. (2013)). Possessing a number of advantages (compact folding, simple synchronous deployment, etc.), a classic mirror has one significant drawback. Small errors at the final stage of deployment and small errors in the installation of the axes of the cylindrical hinges connecting the petals with the central mirror lead to a significant deviation of the shape of the surface of the opened mirror along the outer edge of the petals. The latter leads to a significant loss in the quality of the open antenna. Due to an error in the deployment system, the antenna efficiency factor (AE) of the RadioAstron radio telescope in orbit (Westphal (1990)) turned out to be low (AE=0.1).

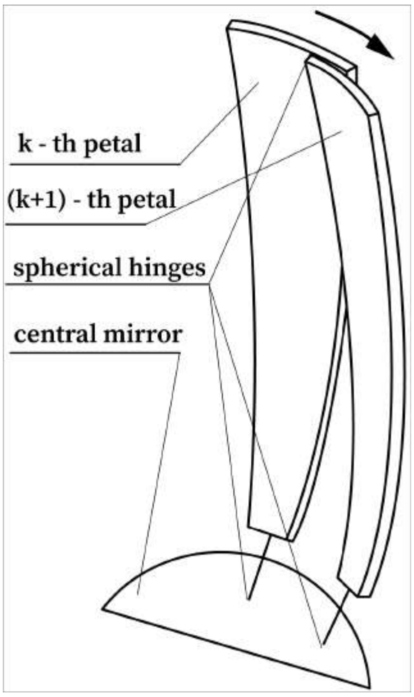

Figure 5. The kinematics of new deployment system. The left vertex of the (k + 1)-th petal is connected with the edge of the k-th petal and moves during the deployment along the edge by the actuator.

To eliminate the named shortcoming, the mirror opening scheme has been changed in the new design: the left vertex of each petal is aligned with the upper edge of the adjacent petal, the deployment is carried out by synchronous movement of the vertices along the edges (5, 6 c).

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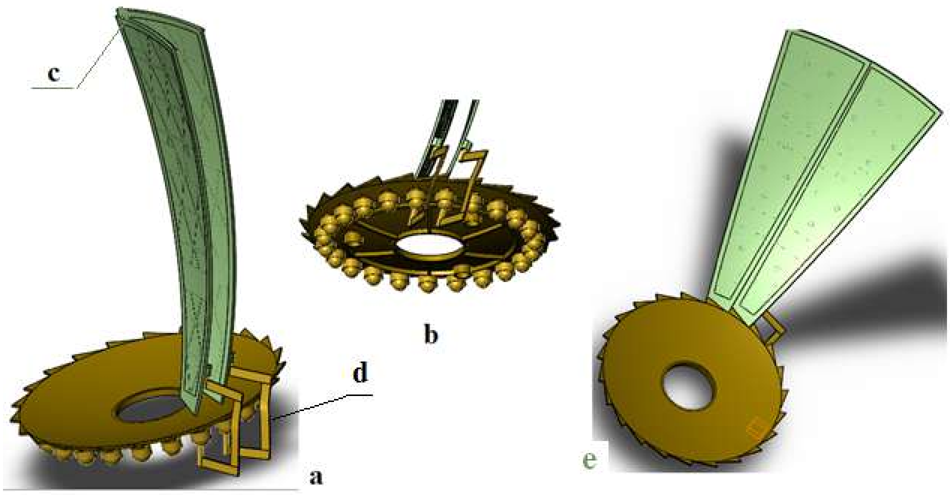

Figure 6. New design of the petal reflector. Central mirror, petals, brackets and spherical hinges. a. Petals in transport position. b. Spherical hinges on the back side of the central mirror. c. A spherical hinge connecting the vertex of one petal to the edge of an adjacent petal. d. The bracket connecting the petal with the central mirror, the bracket is rigidly connected to the petal. e. Petals in opened position.

3.2. Computer simulation

To test the proposed technical solution, a computer model of a new transformable structure was built and its research was carried out. Computer simulation was carried out in the SolidWorks package (Bujakas & Glotov (2022)). Virtual models of structural elements (petals and a central mirror) and an assembly of deployable mirror were built. The assembly includes a system of joints that guarantee statistical determinability (stress free) and geometric invariability of the structure at each moment of deployment (7, 8).

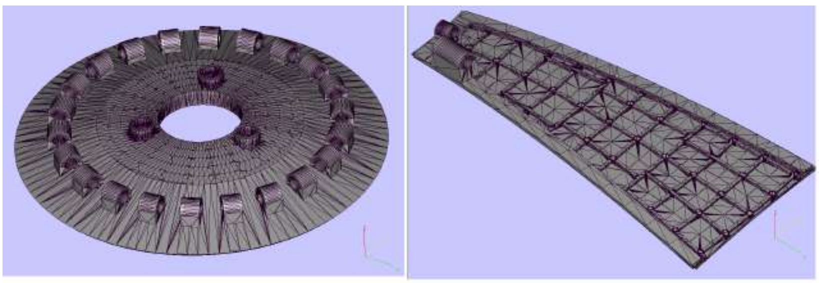

Figure 7. Virtual models of the central mirror and the petal.

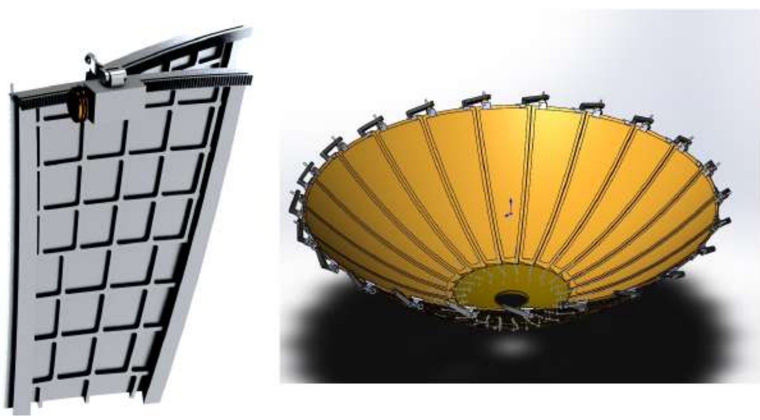

Figure 8. Virtual models of the deployment unit and assembly of petal reflector.

Computer simulation confirmed the feasibility of the proposed deployment kinematics.

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3.3. Physical simulation

The physical model of a transformable petal reflector is a complex structure consisting of a variety of elements and includes: a central mirror, petals, actuators, spherical hinges, gearboxes, rods of complex shap. The manufacture of structural elements required the involvement of various technologies. **Central mirror** is made of ABC plastic on CNC (9). The working surface of the mirror repeats the shape of the reference parabolic, on the reverse side, to facilitate the design and maintain rigidity, CNC milling made stiffeners.

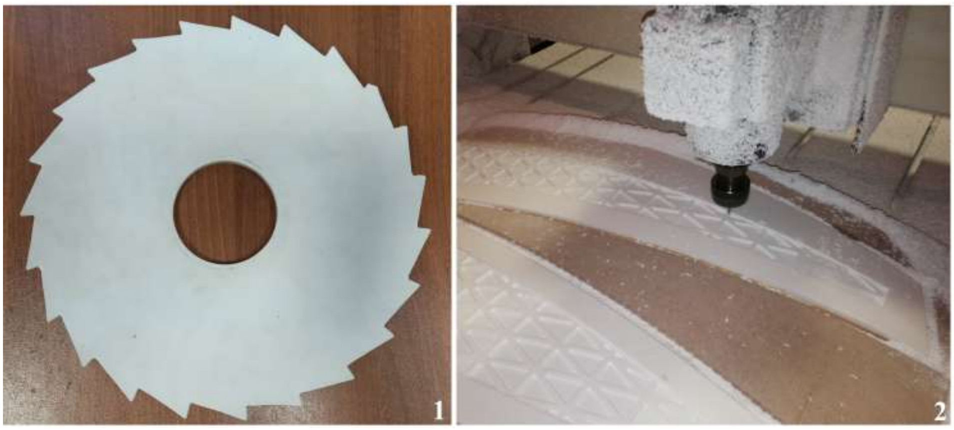

Figure 9. 1 - Central mirror of the composite parabolic reflector, 2 - Manufacturing of stiffeners of the parabolic element of the composite mirror on CNC.

Petals. The following technologies were successively tested for petals fabrication.

Figure 10. Various technologies for petals of a parabolic reflector fabrication.

Carbon fiber technology (10.1, 10.2), CNC milling technology (10.3), 3D printing technology (10.4), mold casting (10.5). The final selection was made using carbon fiber petals that met the specifications for stiffness, strength and weight.

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Spherical hinges. The design includes a significant number of spherical hinges that connect adjacent petals and each petal with a central mirror.

Figure 11. Spherical hinge.

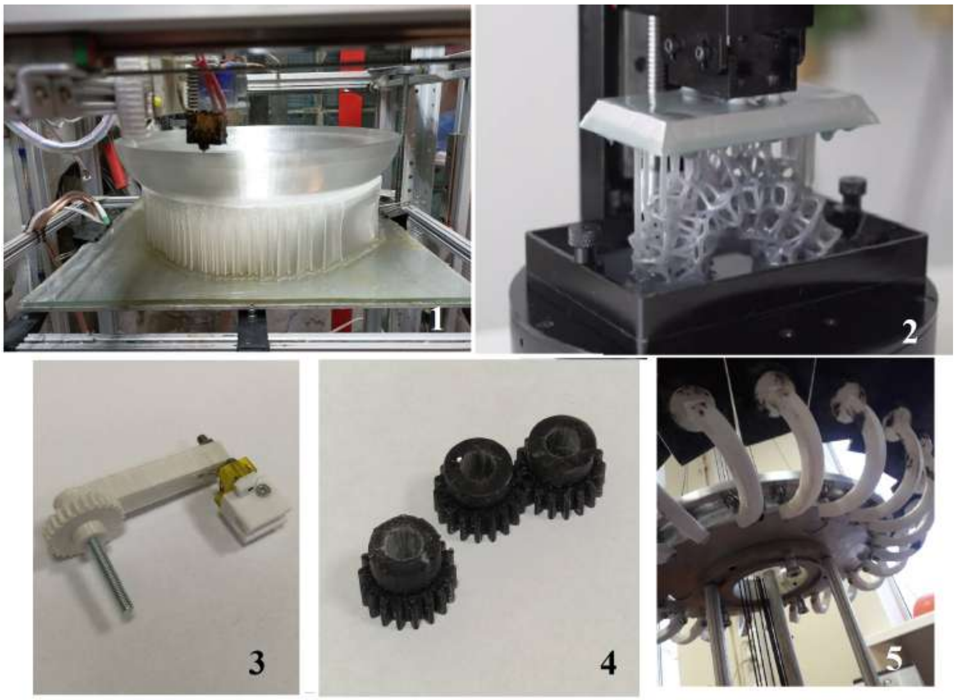

Figure 12. 3D printing technologies in physical simulation of petal reflector deployment.

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Assembly of physical model on a parabolic template.

Figure 13. Assembly of a petal mirror on a parabolic template. 1 - petals, 2 - curvilinear rod connecting the petal with the base of the central mirror 3 - the base of the central mirror.

4. Conclusion

Ground-space radio interferometers with several telescopes in the space arm will significantly expand the possibilities of observational astronomy.

Modern technologies, in particular 3D printing technologies, can significantly speed up the development of physical models, perform complex details with simple means.

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