Study variants of hard CFRP reflector for intersatellite
communication

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Abstract. The paper deals with the justification of space antennas reflector layout for advanced
telecommunication satellites. The selection of design decisions is based on numerical
simulations of heat transfer and mechanics processes characteristic of the geostationary orbit
conditions. The advantages of parabolic shell of small thickness reflector scheme reinforced
with star-shaped ribs on the convex side are demonstrated.

1. Introduction
Parabolic reflectors of mirror space antennas are widely used in space communication systems. Small
linear density and high dimensional stability are the most important operating characteristics.
Increasing the operation frequency of antenna increases the accuracy requirements of the reflector.
Shape tolerances of the reflector must not exceed the \( \Delta = \frac{\Lambda}{16} \) value, but tighter tolerances \( \Delta = \frac{\Lambda}{50} \)
can be used, where \( \Lambda \) is the antenna operating wavelength [1].

Carbon fibre reinforced plastics are commonly used as a material for reflectors due to the high
specific strength, low coefficient of thermal expansion (CLTE) and a relatively high thermal
conductivity.

2. The current state of research in the field of space mirror antennas reflector
Since the beginning of the 1990s, three-layer membrane layouts consisting of carrier layers,
honeycomb core and elements of the framework have been common. An example of such design is
the ETS-VI satellite, developed by Toshiba, Japan [2]. The folding reflector segments are sandwich
panels with a honeycomb core of aluminum and carrier layers made of carbon fiber reinforced plastic
(CFRP) [3]. Similar reflectors have been created by HPS GmbH, Germany (figure. 1) [4]. This type
of reflector has high stiffness parameters but rather poor weight characteristics, in the order
of 2.5 kg/m².

An alternative to the three-layer membrane layout is a dual gridded reflector made of carbon plastic
(figure 2) [5]; however, this design also leads to increased structural weight. The diameter of the HPS
GmbH reflector is 1.2 m, the reception frequency of the antenna is 27.5-30.0 GHz, and the
transmission frequency is 17.5-20.5 GHz. The linear density is 3.09 kg/m². The reflector linear
density can be reduced using smooth thin-walled shells with different kinds of reinforcement.
structures (rib layout). The ultralight carbon fibre reflector designed by ESA for the Artes 3 and Artes 4 missions is an example of such a type structure. The diameter of the Ka-band antenna reflector is 2.6 m [6].

Another design variant is that of a smooth shell with ribs, as in the Artemis satellite. The reinforcement element was integral with the shell of the reflector (figure 3), with a diameter of 2.85 m, and Ka- and S-band of the antenna [7]. The Eutelsat 115 West B satellite mirror space antennas reflectors are rotational shells with a 3D reinforcement structure on the backside. A feature of the reinforcement construction is that it is a hoop-like structure. The antenna operates in Ku-band and the diameter of the reflecting surface is about 2 m [8].

Space System Loral, USA, designed the Intelsat 30 satellite where Ku-band antennas where 2 meter diameter reflectors are installed [9-11]. A truss connected to the shell is employed as a reinforcement. ISS Reshetnev, Russia, jointly with Thales Alenia Space, Italy-France, developed a Russian communication satellite, Yamal-402, with a rigid ultralight space antennas reflector. A 3D truss rigidly fixed to the reflector serves as a reinforcement for the 1.75-meter Ku-band reflector (figure 4) [12, 13]. For this type of reflector, the linear density characteristic is in the order of 2 kg/m², but to ensure the rigidity of the construction it is necessary to justify the selected layout of ribs. There is currently no theoretical justification for this selection.

3. Reflector structural design selection
The structural design of the reflector means the totality of its basic parameters determining the shape and size of the reflector, manufacturing principles and the materials used. Analysis of domestic and foreign experience has shown that creation of ultralight reflector based on thin ribbed shell of CFRP is the most advanced solution. Using this layout reduces the linear density compared to conventional three-layer constructions substantially, by several times.

A quasi-isotropic multilayer structure ensures the lowest value of reflector shell CLTE. It also provides the highest value and uniform thermal conduction coefficient. In this research, a layup of
[0°/+30°/-30°/+60°/-60°/+90°] Aspro A-50 fabric was used (layer thickness – 0.1 mm). The reflector linear density was 1.15 kg/m². The data were used for the design of the reflector are listed in table 1.

The rib layout is selected based on comparative analysis of temperature and stress-strain state of the reflector with various reinforcement patterns. Four candidate reinforcement patterns were selected after considering Russian and foreign experience (figure 5):

a) A 30 mm height five-pointed star pattern. The rim of the reflector is supported by a circular rib 30 mm high.

b) A constant rib height isogrid pattern where the isogrid triangle finning is positioned at the back surface of the reflector. The step and height of ribs is 125 mm and 20 mm respectively. The rim of the reflector is supported by a circular rib 20 mm high.

c) A variable rib height pattern similar in type to the previous variant, but with non-constant rib height from 30 mm (at the edge) to 3 mm (in the centre). The rim of the reflector is supported by a circular rib 30 mm high.

d) A 30 mm height six-pointed star pattern. The rim of the reflector is supported by a circular rib 30 mm high.

![Figure 3. Artemis satellite.](image1)

![Figure 4. Yamal-402 satellite antenna reflector.](image2)

**Table 1.** Data used for the design of the reflector.

| Reflector dimension      | Value, mm |
|-------------------------|-----------|
| Diameter (aperture)     | 1200      |
| Focal length            | 500       |
| Construction depth      | 180       |
4. Reflectors temperature and stress-strain state simulation

The flight of the spacecraft with a reflector on a geostationary orbit at the March equinox was considered. The rotation axis of the parabolic reflector shell would be directed toward the Earth and its transverse axis would coincide with the spacecraft velocity vector. In determining the structure thermal deformation it was assumed that the reflector was rigidly fixed via the adapter to its outer edge.

Incident solar and reflected radiation fluxes and the Earth thermal radiation were defined for the temperature state simulation, using the finite element analysis Siemens Femap 11.1 package [14]. The
reflector temperature field simulation results, also calculated using the finite element analysis (FEA) Siemens Femap 11.1 package, showed that the highest temperature difference and the thermal deformation in the reflector structure arise at the moment of its turning around the axis relative to the sun, which corresponds to 25200 seconds flight (figure 6, 7). Reflector finite element models include more than 5600 2D elements.

5. Results analysis
The thermal deformation analysis of the reflector (table 2) showed that, with almost identical values of the mass and linear density, the lowest temperature deformation is given by the five- and six- pointed star-shaped reinforcement pattern.

![Figure 6](image)

**Figure 6.** The temperature distribution on the surface of the reflector at 25200 s moment for different reinforcement patterns: a) five-pointed star, b) isogrid structure, constant rib height; c) isogrid structure, variable rib height; d) six-pointed star
Figure 7. The thermal deformations on the surface of the reflector at the time 25200 s moment for different reinforcement patterns: a) five-pointed star, b) isogrid structure, constant rib height; c) isogrid structure, variable rib height; d) six-pointed star

Table 2. Comparison of weight and temperature values for different reflector reinforcement patterns

| Reinforcement pattern          | Mass, kg | The linear density of the reflector, kg/m² | Maximum temperature deformation, mm |
|-------------------------------|----------|-------------------------------------------|-------------------------------------|
| Five-pointed star             | 1.502    | 1.224                                     | 0.0587                              |
| Isogrid structure, constant rib height | 1.549    | 1.262                                     | 0.0975                              |
| Isogrid structure, variable rib height | 1.479    | 1.205                                     | 0.0955                              |
| Six-pointed star              | 1.513    | 1.235                                     | 0.0922                              |

6. Discussion
Not only linear density and temperature deformations are important for space reflectors. As is shown by the analysis, the isogrid structure with the variable rib height has the lowest value of linear density; however, this layout is rather hard to manufacture. The lower are the ribs in the pattern, the easier it is
in fabrication. First of all, the number of ribs is important in terms of the number of ribs joints. That is what determines the manufacturing precision. There are significantly fewer ribs joints in the five-pointed and six-pointed star patterns. This was the reason for choosing these patterns for the further analysis.

7. Conclusions
Four perspective reinforcement patterns of superlight Q/V-band 1200 mm diameter reflector were examined. Thermal and stress-strain state was obtained. It is demonstrated that the lowest value of deformation (less than 0.06 mm) was obtained for the five-pointed-shaped shell.

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