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A Reflector Radio Telescope with a Resolving Power of 15 Seconds of Arc

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According to the terminology introduced in (1), all existing types of radio telescopes may, by analogy with optical telescopes, be divided into radio reflectors, in which tautochronism is ensured by the geometry of the reflector, and radio refractors, in which it is achieved with the aid of transmission lines. The advantage of reflector systems is their broad frequency range and wide bandwidth, and the absence of an additional source of phase fluctuations and losses in transmission lines.

In 1954 (see (2, 3)) a new type of reflector radio telescope was proposed—the variable-profile antenna (VPA). In comparison with parabolic reflector radio telescopes, the VPA has the following advantages: a) the possibility of obtaining large collecting areas and resolving power; b) the presence of a large excess resolution (4), which leads to greater sensitivity for the same receiving area at all wavelengths longer than 5 cm (5)*; c) high accuracy in determining coordinates (8). At the same time, the universality of parabolic mirrors is retained, which is necessary under conditions of rapidly changing leading ideas in radio astronomy.

The only operating system of the new type is the large Pulkovo radio telescope, which at a wavelength of 3 cm has a horizontal resolving power of about one minute of arc (3), exceeding the resolution of all parabolic radio telescopes currently in existence. On the basis of a refined geometrical theory of the VPA (9), it was established that the operating wavelength of the large Pulkovo radio telescope could be sharply shortened by replacing its flat reflecting elements (panels) with cylindrical ones having a radius of curvature of about 120 m. This replacement was carried out during 1964–1966. Taking advantage of the segmented nature of the antenna, this was accomplished practically without interrupting regular radio-astronomical observations.

Below are given the results of an investigation of the radio telescope in the 8-millimeter range. The root-mean-square error of the surface of each panel was $\sigma = 0.13$ mm (over the mean horizontal section of the element). However, to achieve the required accuracy of the surface of the main reflector of the VPA,

Fig. 1. Directional pattern of the large Pulkovo radio telescope at a wavelength of 9 mm, obtained from a ground-based source.

Figure 1: Fig. 1. Directional pattern of the large Pulkovo radio telescope at a wavelength of 9 mm, obtained from a ground-based source.

not only high accuracy in manufacturing the individual panels is required, but to no lesser degree the assurance of their precise positioning, which requires adjustment of the antenna. A combination of adjustment methods was applied, including geodetic methods, radio range-finding, and also adjustment by signals from a ground-based generator and from cosmic sources.

When operating on the horizon, adjustment of the antenna by the signal of a ground-based generator made it possible to eliminate practically completely all errors except errors in the surfaces of the individual elements ($\sigma = 0.13$ mm); however,

* The Kraus (6) and Nançay (7) systems, which appeared later, do not possess excess resolution.

with increasing height, owing to imperfections of the mechanisms moving the shields, the error increases and reaches, at an elevation angle $\theta \approx 35^\circ$, the value $\sigma = 0.96$ mm.

The feed used in the investigations of the radio telescope and in astronomical observations made it possible to use only the central part of the reflecting surface, with a vertical dimension of 2 m and a horizontal dimension of 112 m.

The form of the directional pattern and the effective area of the antenna were investigated both with the aid of a ground-based source and from records of Venus, the Moon, and the Sun at wavelengths of $8 \div 9$ mm.

Fig. 1. Directional pattern of the large Pulkovo radio telescope at a wavelength of 9 mm, obtained from a ground-based source.

When operating with a ground-based generator, the antenna surface was given the form of an elliptic cylinder, with the generator located in one of the foci of the central section and the feed in the other. The coefficient of utilization of the illuminated area of the antenna, when measured with the ground-based generator, proved to be $\eta = 0.47$, and in observations of Venus at an elevation angle $\theta = 35^\circ$, $\eta = 0.28$ (the effective area of the antenna being 105 and 63 m^2, respectively). The width of the horizontal pattern at a wavelength of 8.5 mm at half-power was $15'' \pm 1''$, with a sidelobe level of less than 10 dB and a scattered background below 23 dB.

Fig. 2. Brightness distribution over the disk of Venus at a wavelength of 8.5 mm (average of 8 records).

The form of the directional pattern, obtained with a ground-based source at a wavelength of 9 mm, is shown in Fig. 1.

Fig. 2. Brightness distribution over the disk of Venus at a wavelength of 8.5 mm (average of 8 records).

Figure 2: Fig. 2. Brightness distribution over the disk of Venus at a wavelength of 8.5 mm (average of 8 records).

Table 1

Method	Range of resolutions
Single radio telescopes ([5])	1 radian ÷ 1 arc second
Large interferometers ([11])	Several arc minutes ÷ 0.1 arc second.
Method of sounding through the interplanetary medium ([12])	1 arc second ÷ 0.025 arc second
Interferometers with independent heterodynes ([13])	0.1 arc second ÷ 0.001 arc second and higher

It is interesting to note that, when operating at a wavelength of 9 mm in the near-surface layer of the atmosphere, with baselines of about 200 m and an aperture of about 100 m, no influence of signal-phase fluctuations of atmospheric origin was detected. The antenna pattern shown in Fig. 1 remained stable, together with all the sidelobes, over the course of a day or more. Thus, the presence of atmospheric turbulence in a horizontal periscopic system, dis–

located directly at the Earth' s surface, did not lead to any noticeable decrease in resolution.

In September 1967, observations of Venus, the Moon, and the Sun with a resolution of 15″ were carried out with the large Pulkovo radio telescope. The brightness distribution over the disk of Venus at a wavelength of 8.5 mm, obtained by averaging 8 records, is shown in Fig. 2.

Further improvement of the adjustment methods will apparently make it possible to realize, at high elevation angles as well, the accuracy of antenna setting achieved at the horizon.

Thus, already at present the new type of reflector radio telescopes (APR) has a resolving power 6–7 times greater than that of the best paraboloids ([10]). Theoretical estimates show that in systems of the APR type the limiting resolving power may be close to one arc second ([5]). A further increase in resolving power is impossible because of the turbulence of the Earth' s atmosphere and the curvature of the Earth.

Table 1 explains the place of the various methods of obtaining radio images in modern radio astronomy.

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Note: Figure translations are in progress. See original paper for figures.