ISSN 0010-9525, Cosmic Research, 2014, Vol. 52, No. 5, pp. 403–409. © Pleiades Publishing, Ltd., 2014.
Original Russian Text © M.S. Turygin, 2014, published in Kosmicheskie Issledovaniya, 2014, Vol. 52, No. 5, pp. 440–446.

Antenna Feed Unit for the RadioAstron Project

M. S. Turygin

Special Design Bureau, Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Fryazino, Moscow oblast, Russia

e-mail: tur@sdbireras.ru

Received December 16, 2013

Abstract—The design and parameters of the antenna feed unit in the ranges of 6, 18, and 92 cm are described. The unit was designed and manufactured for the RadioAstron space telescope with a diameter of 10 m. The parameters and test results are presented.

DOI: 10.1134/S0010952514050104

An antenna-feed unit (AFU) is intended for operation in the composition of the space radio telescope and single-dish antenna of the RadioAstron *Spektr-R* spacecraft. AFU receives noise signals with the continuum spectrum, reflected and focused by a paraboloidal reflector, and separates them with respect to two circular polarizations.

The design had to meet the following requirements: the absence of unscreened insulators, high mechanical strength and vibrational stability, compactness, 120–350 K range of working temperatures, 155–200 K regular working temperature, simultaneous reception of two orthogonal circular polarizations, combined reception in several frequency bands, and the coincidence of beam-pattern (BP) maximums in all frequency bands.

Unscreened insulators should be absent because high-sensitivity low-noise amplifiers (LNAs) in four wavelength ranges should be at the AFU output. The 1.35-cm range in the composition of AFU is not considered in this paper. Corona discharge, originating in insulators in outer space, is a powerful source of noise and can damage LNA.

Mechanical strength and compactness requirements are related to the space equipment specificity. LNA and the feed are located on a radiationally cooled platform at a temperature of 155–200 K. The requirements imposed on the technical parameters are presented in Table 1.

It is most difficult to provide for the mechanical strength without unscreened insulators. As a rule, these constructions are as a rule of a waveguide type; however, their size and mass would be unacceptable for space equipment, since working frequencies are relatively low.

Since AFUs should operate at a regular temperature of 155 K, additional restrictions are imposed on the construction and design procedure. Since it is obviously impossible to tune a feed at such a tempera-

Table 1

Working frequency bands:	
92 cm	324 ± 8 MHz
18 cm	1664 ± 60 MHz
6 cm	4832 ± 60 MHz
BP width (–10 dB)	120°
Level of the first and second minor lobes	–18 dB
Field polarization	Elliptic (simultaneous reception for two orthogonal polarizations)
Ellipticity	≥0.9
Efficiency	98%
BP axial symmetry	<0.1 dB
VSWR value at LNA input	<1.2
Decoupling between polarization channels of one frequency band	23 dB
Decoupling between frequency bands	15 dB

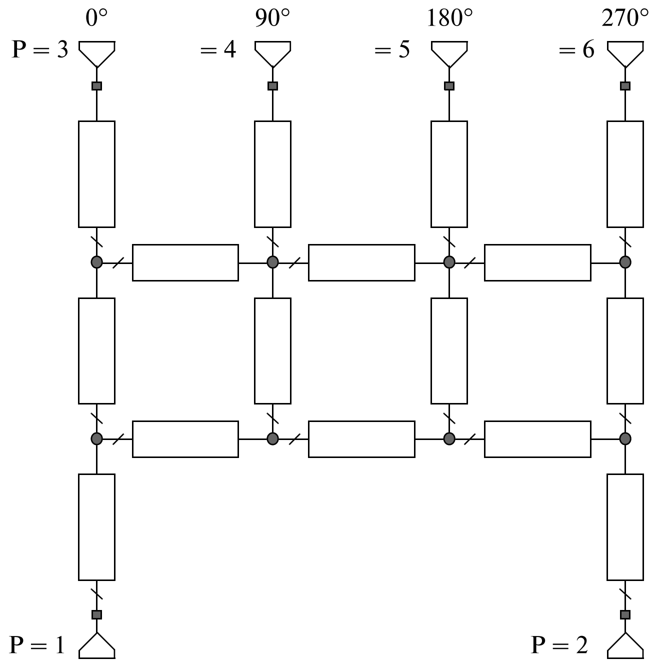

Fig. 1. Scheme of a circular polarization divider.

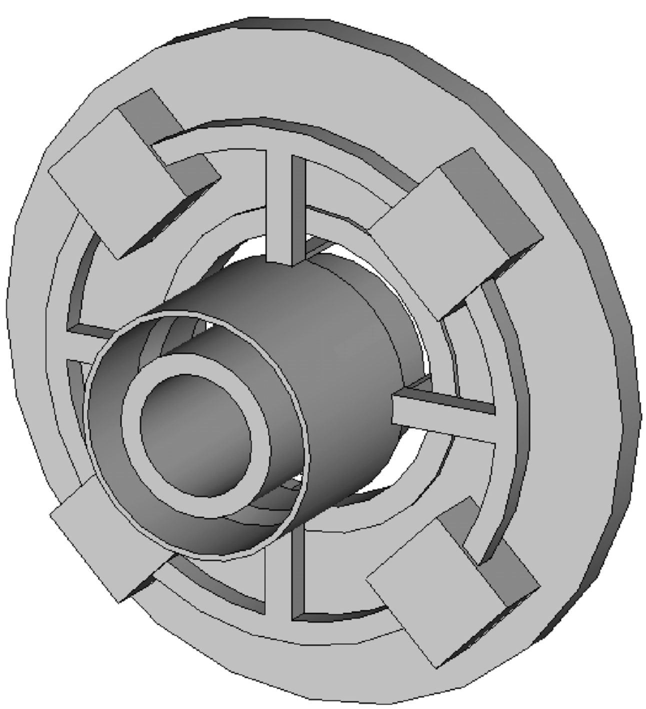

Fig. 2. Receiving unit of a 6-cm feed without the upper screen.

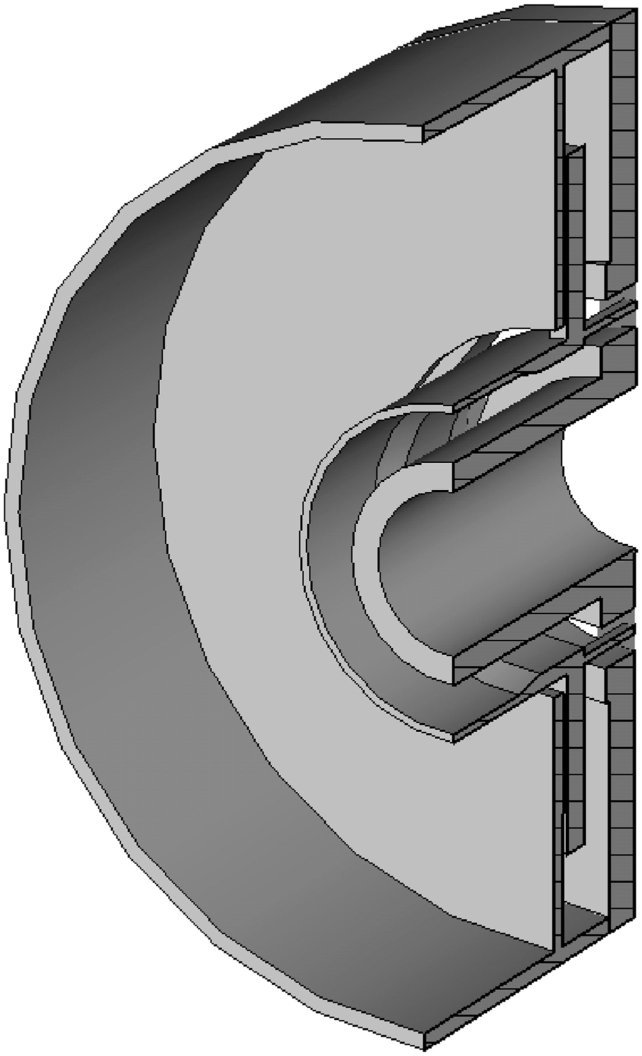

Fig. 3. Section of the receiving unit of a 6-cm feed.

ture, the construction should have a stable temperature of parameters and no tuning elements, or the parameter drift should be exactly predictable.

It is most difficult to provide isolation of polarization channels. A rather compact and broadband divider of circular polarizations could be designed based on lumped elements (the so-called "quadrifilars"); however, these devices have high losses (about 2 dB), which is unacceptable for low-noise receivers.

The feed in each of the considered ranges can be conditionally divided into two parts: a receiving unit and a divider of circular polarizations. Since BP maximums should coincide, the coaxial location of receiving units is the most suitable variant. The quarter-wavelength section of a circular coaxial waveguide was selected as a receiving unit in the 6- and 18-cm ranges, since this section provides practically necessary BP and is consistent with space in a rather broad frequency band.

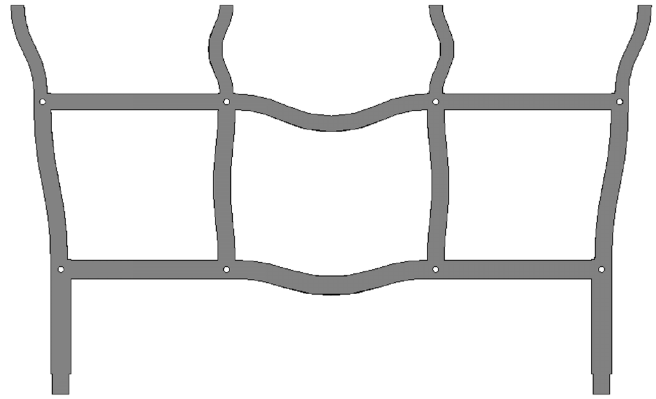

Fig. 4. Circular polarization divider in the 6-cm range; thickness 0.5 mm; scan.

The branch bridge, the scheme of which is presented in Fig. 1, is used as a polarization divider. All elements on the scheme are quarter-wavelength transmission lines of corresponding impedances. The transmission coefficient phases at ports 3–6 are given relative to port 1 and are contra lateral with respect to port 2. The transmission coefficient power is 1/4 between port 1 and ports 3–6; the same power is typical of port 2 (owing to symmetry). We have corresponding circular polarizations (left- and right-hand) at ports 1 and 2 when such a divider is connected to a ring-type radiator (including a coaxial waveguide).

The main problem in designing a receiving unit consists in the creation of a coaxial waveguide rigid fastening without using insulators, which would not affect emission parameters. Four metal insulators, which are shorted quarter-wavelength screened stubs, are used as such fastening. During optimization, these stubs were transformed into the construction shown in Fig. 2.

Metal insulator fastening points are simultaneously the points where a polarization divider is connected. An internal opening is the 1.35-cm feed input. The 6-cm feed receiving unit is completely shown in Fig. 3.

It is necessary to screen metal insulators in order to neutralize their effect on feed BP. An outer cylinder is used to decrease minor lobes and is simultaneously the inner part of the 18-cm feed. The 18-cm feed-receiving unit is designed similarly. The receiving unit in the 92-cm range is a normal ring radiator, since it can be rather rigid without metal insulators due to the long wavelength.

A circular polarization divider (Fig. 1) is based on symmetric airstrip lines. For 6- and 18-cm feeds, the distance between screens was selected so that strips would be wide and thick enough to maintain the necessary rigidity, parametric stability, and low loss. In a real polarization divider, the wavelengths in Fig. 1 generally differ from the 1/4 wavelength due to the compensation of inhomogeneities. The following 6-cm

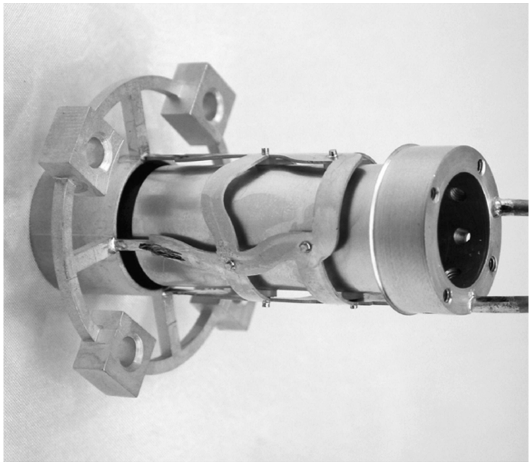

Fig. 5. Polarization divider in the 6-cm range; the outer screen is removed.

Fig. 6. Assembled AFU.

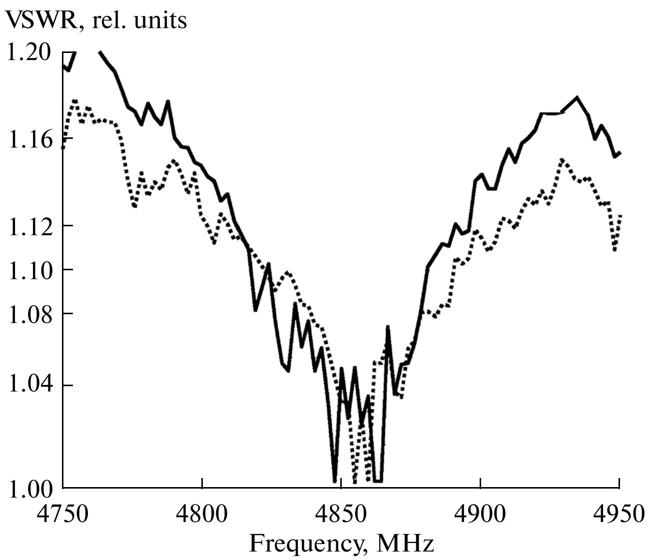

Fig. 7. 4832-MHz feed VSWR in the 6-cm range.

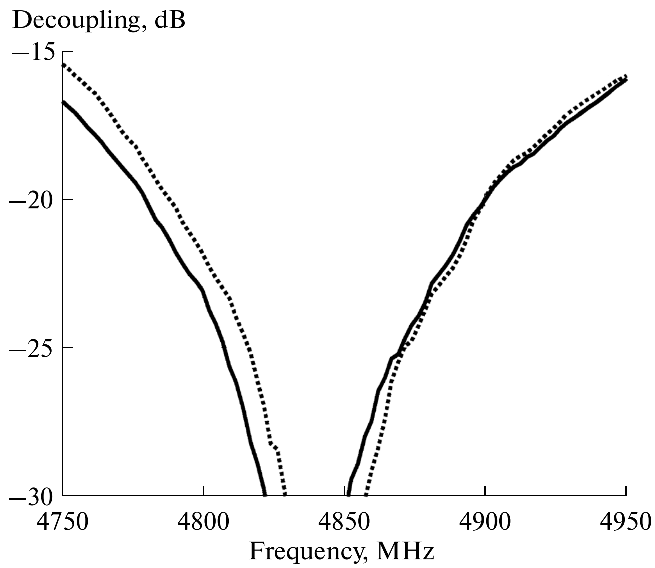

Fig. 8. Decoupling of a 4832 MHz feed in the 6-cm range.

polarization divider shape was obtained during the optimization of the bandwidth and voltage standing-wave ratio (VSWR) (Fig. 4). Strip structures are placed between two cylindrical shields (Fig. 5) and are fastened at nodes using small dielectric loadings. Since loadings are rather far from outer space, as well as screened on almost all sides and small, the probability of corona discharge origination on these loadings is vanishing.

For the 92-cm polarization divider, a similar construction cannot be implemented due to space restrictions; therefore, for this range, a polarization divider was designed as a three-layer screened plane.

The construction of the assembled AFU is shown in Fig. 6.

Since the feed-receiving unit and polarization dividers dock in the plane of single-mode transmission lines, it is reasonable to model these units independently and to calculate the common parameters (VSWR and decoupling between polarization channels) by joining corresponding S matrices. The receiving unit was modeled using the CST Microwave Studio program and the method of finite integration in the

Table 2

Working frequency bands:	
92 cm	324 ± 8 MHz
18 cm	1664 ± 60 MHz
6 cm	4832 ± 60 MHz
BP width (–10 dB)	120°
Level of the first and second minor lobes	≤18 dB
Ellipticity	≥0.9
AFU efficiency in frequency bands, MHz:	
324 ± 8	≥0.78
1664 ± 60	≥0.8
4832 ± 60	≥0.8
from 18000 to 26000	≥0.8
BP axial symmetry	<1 dB
VSWR at AFU output at frequencies, MHz:	
324 ± 8	≤1.6
1664 ± 60	≤1.3
4832 ± 60	≤1.3
from 18000 to 26000 inclusive	≤1.4
Decoupling between polarization channels of one frequency band in a low-voltage switching system, MHz:	
324 ± 8	≥14 dB
1664 ± 60	≥22 dB
4832 ± 60	≥22 dB
from 18000 to 26000	≥22 dB
Decoupling between frequency channels	≥22 dB

time domain. The same program was used to calculate BP. The receiving unit was optimized with respect to the emission efficiency and BP width. The current surface density was one of the intermediate calculation stages. The feeds in the 6- and 18-cm ranges were modeled above an infinite perfectly conducting plane. The 92-cm feed was modeled in completely open space and the effect of a container with equipment was taken into account.

The polarization divider was modeled and optimized using the AWR Microwave Office program and the method of joining matrices of symmetric strip lines and inhomogeneities. The method of finite integration in the time domain in the CST Microwave Studio program was used to model inhomogeneities and clamping elements. The polarization divider was optimized with respect to VSWR and decoupling between polarization channels.

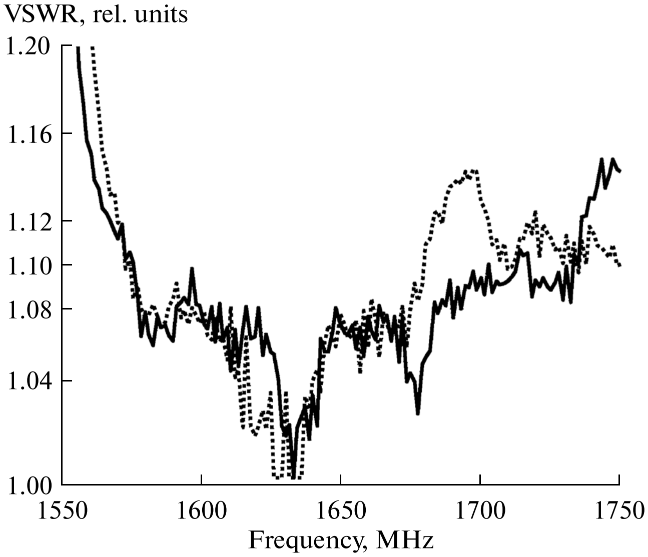

Fig. 9. 1664-MHz feed VSWR in the 18-cm range.

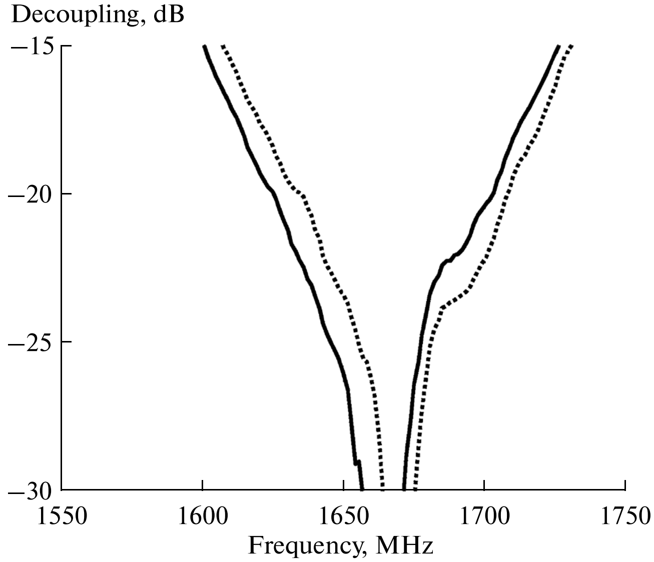

Fig. 10. Decoupling of a 1664 MHz feed in the 18-cm range.

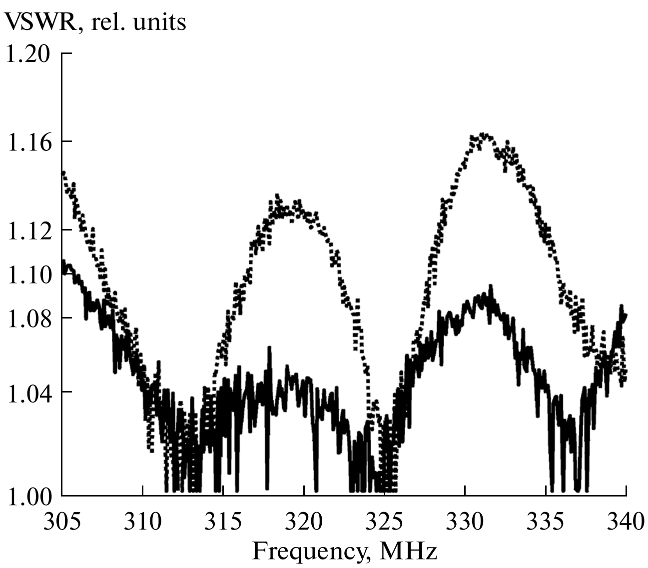

Fig. 11. 324-MHz feed VSWR in the 92-cm range.

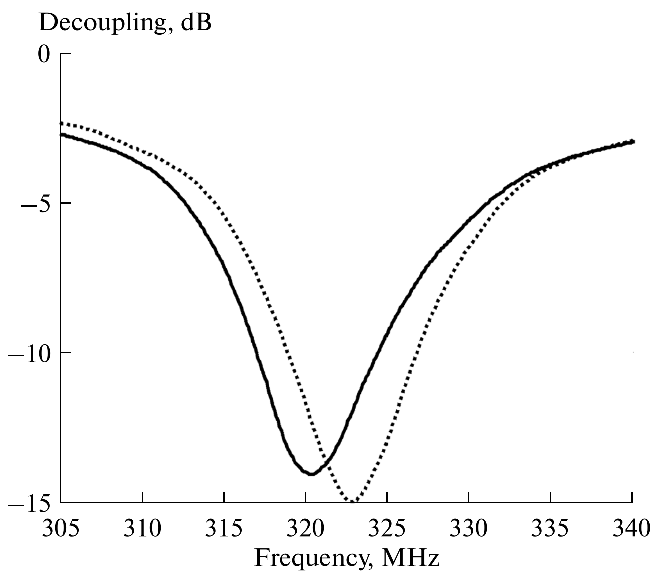

Fig. 12. Decoupling of a 324-MHz feed in the 92-cm range.

Table 2 illustrates the measurements of the AFU parameters.

Figures 7–12 present measured VSWR and decoupling between AFU polarization channels for the 6-, 18-, and 92-cm ranges at temperatures of 293 K (a solid curve) and 158 K (a dotted curve).

Figures 13–15 show the calculated and normalized AFU BPs for the ranges of 6, 18, and 92 cm, respectively. BPs are presented for the axial sections, and the BP maximum is considered to be at 0 dB.

Thus, the AFU technological sample was designed based on the performed calculations. The sample underwent mechanical, thermal, and radiotechnical tests. The second designed AFU sample was installed on the flight model of the space radio telescope.

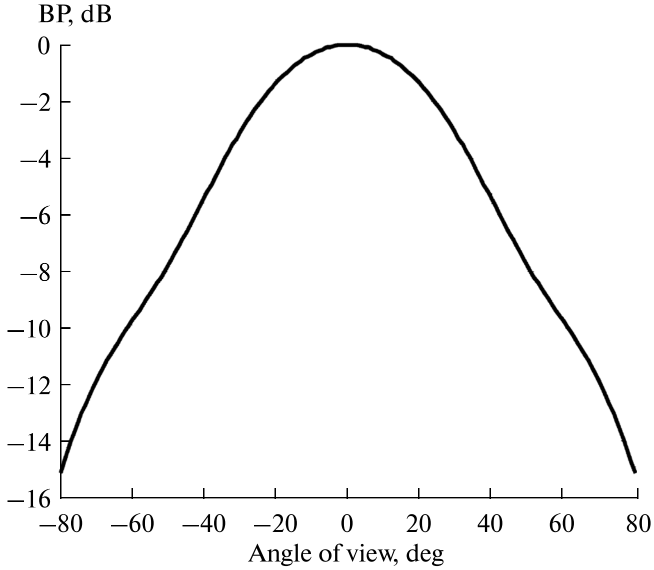

Fig. 13. 6-cm feed BP.

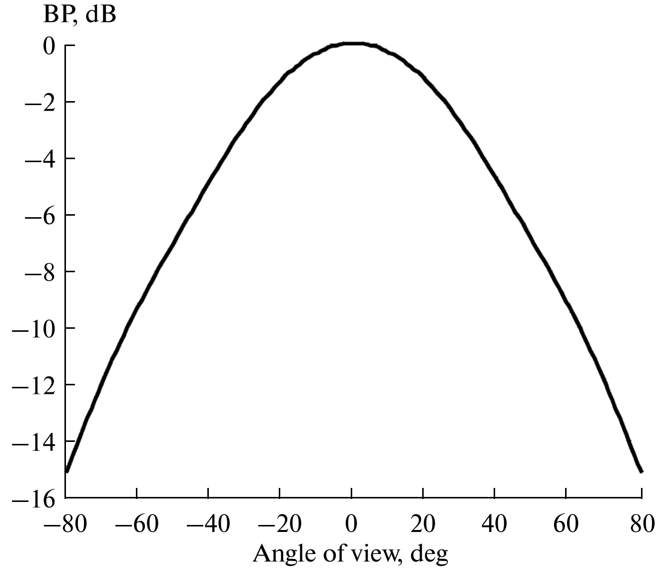

Fig. 14. 18-cm feed BP.

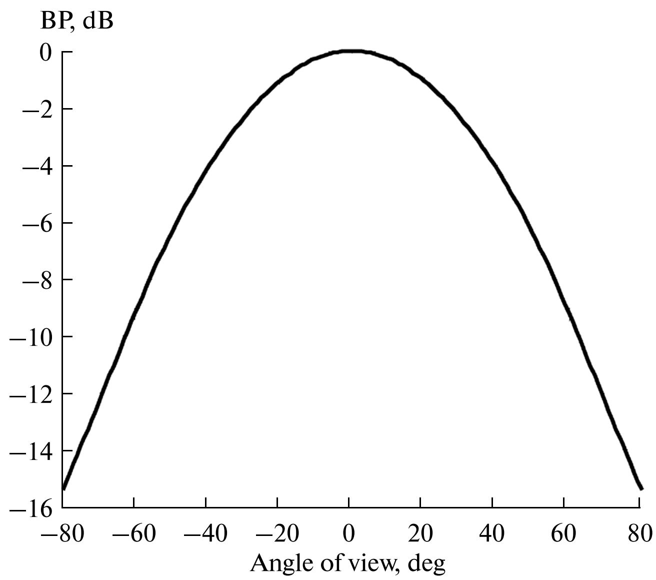

Fig. 15. 92-cm feed BP.

ACKNOWLEDGMENTS

The RadioAstron project was supported by the Astrospace Center, Lebedev Physical Institute, Russian Academy of Sciences, and by the Lavochkin Association in the scope of the contract between the Russian Space Agency and many Russian and foreign scientific and technical organizations.

Translated by Yu. Safronov