The Main Principles of a 70-m Radio Telescope Reflecting System Design

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***Abstract*—Design work intended to create a 70-m axisymmetrical reflector antenna with modified reflector profiles started in 1969 in the USSR [1], [2]. It took four years to complete experimental investigations, development of design documentation, technical and financial examination in order to validate the financial risk when realising such a large project. The financing was opened in 1973 and the cooperative efforts of numerous industrial and building/erecting enterprises was crowned with successful commission of RT-70 radiotelescope in 1978 in Yevpatoriya [3]. Since 1982 the pedestal room of the antenna is equipped by six feeds, and the operation mode switching is implemented by means of special asymmetrical dual-reflector communication system. Photograph of such antenna is shown in Fig. 1. In course of design work the intensive progress of geometry-optical method for synthesis of a dual-reflector system with specified characteristics was stimulated. The synthesis problems remain actual up to now [4]. The synthesis theory used under RT-70 designing differs from well-known approaches by the strictness of a task statement and a solution generality. In process of RT-70 designing the complex problems arose due to diffraction phenomen on the twin-reflector commutator the reflector size in which in decimetric wave range does not exceed 4–5 λ. In order to solve these problems the special diffraction shields had to be applied here. In the centimeter wave range the problems connected with diffraction are getting unessential. All these questions are omitted in this article. Another problem the designers encountered was the problem of phase compensation of the reflector system gravitational deformation. The reflector shape is not the second order surface in this system. This problem was solved successfully and results of the radioastronomical investigations of the phase compensation system performance efficiency are given in the paper.**

I. Synthesis

A. Double-Reflector Optical Systems

LET US consider the following problem: assume that a certain continuous unambiguous relationship

$$u_2 = u_2(u_1, v_1), \quad v_2 = v_2(u_1, v_1) \tag{1}$$

has been predetermined between the points that belong to arbitrarily preset wave fronts $\boldsymbol{\rho}_1(u_1, v_1)$, $\boldsymbol{\rho}_2(u_2, v_2)$ and it is required to synthesize a two-mirror system which performs the said conversion of the wave fronts. Fig. 2 shows the path of an arbitrary ray that connects the appropriate points at the wave fronts. The following designations are

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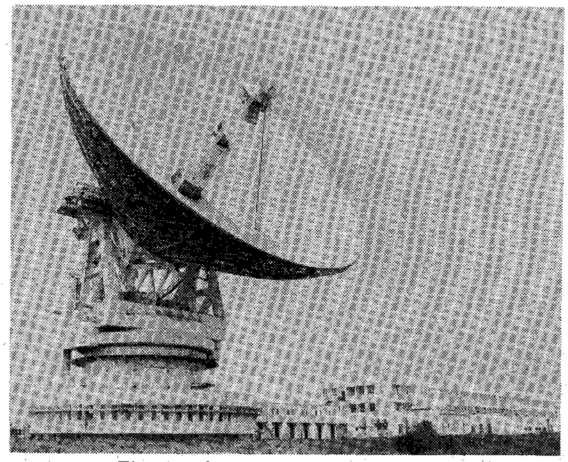

Fig. 1. 70-m Radiotelescope RT-70.

used here:

- $\boldsymbol{\rho}_i$ is a radius-vector of the point at an ith wave front; $i = 1, 2$;
- $\boldsymbol{F}_i$ is a radius-vector of the point on an ith reflecting surface of the lens;
- $\boldsymbol{e}_i$, $\boldsymbol{s}$ individual guiding vectors of rays.

The length of the optical path, m is a function of four vector arguments, it is composed of rectilineal segments and is constant for all rays

$$m(\boldsymbol{\rho}_1, \boldsymbol{F}_1, \boldsymbol{F}_2, \boldsymbol{\rho}_2) = |\boldsymbol{F}_1 - \boldsymbol{\rho}_1| + |\boldsymbol{F}_2 - \boldsymbol{F}_1| + |\boldsymbol{\rho}_2 - \boldsymbol{F}_2| = \text{const.} \tag{2}$$

The ray trajectory is composed of directed rectilineal segments:

$$\boldsymbol{\rho}_1 - \boldsymbol{\rho}_2 + \boldsymbol{e}_1|\boldsymbol{F}_1 - \boldsymbol{\rho}_1| + \boldsymbol{s}|\boldsymbol{F}_2 - \boldsymbol{F}_1| + \boldsymbol{e}_2|\boldsymbol{\rho}_2 - \boldsymbol{F}_2| = 0 \tag{3}$$

The equations (2), (3) are symmetrical relative to permutation of indexes: 1–2. The vectors $\boldsymbol{e}_i \boldsymbol{s}$ are determined by expressions:

$$\begin{aligned} \boldsymbol{e}_1 &= \text{grad}_{F1}|\boldsymbol{F}_1 - \boldsymbol{\rho}_1| = -\text{grad}_{\rho 1}|\boldsymbol{F}_1 - \boldsymbol{\rho}_1| \\ &= \dot{\boldsymbol{\rho}}_{u1} \times \dot{\boldsymbol{\rho}}_{v1}/|\dot{\boldsymbol{\rho}}_{u1} \times \dot{\boldsymbol{\rho}}_{v1}| \\ \boldsymbol{s} &= \text{grad}_{F2}|\boldsymbol{F}_2 - \boldsymbol{F}_1| = -\text{grad}_{F1}|\boldsymbol{F}_2 - \boldsymbol{F}_1| \\ \boldsymbol{e}_2 &= \text{grad}_{\rho 2}|\boldsymbol{\rho}_2 - \boldsymbol{F}_2| = -\text{grad}_{F2}|\boldsymbol{\rho}_2 - \boldsymbol{F}_2| \\ &= \dot{\boldsymbol{\rho}}_{u2} \times \dot{\boldsymbol{\rho}}_{v2}/|\dot{\boldsymbol{\rho}}_2 \times \dot{\boldsymbol{\rho}}_{v2}| \end{aligned} \tag{4}$$

where: $\dot{\boldsymbol{\rho}}_x = \partial \boldsymbol{\rho}/\partial x$, subscript at the operator grad indicates a point, the coordinates of which are used to calculate a gradient.

In the homogeneous isotropic media the $\boldsymbol{e}_i$, $\boldsymbol{s}$ vectors must meet the condition rot$\boldsymbol{e}_i = 0$, rot$\boldsymbol{s} = 0$. To fulfill the first condition the rays $\boldsymbol{e}_i$ are to be determined as normal to the corresponding wave fronts $\boldsymbol{\rho}_i$. Applying the operator rot to (3) and considering, that rotb$\boldsymbol{a}$ = brot$\boldsymbol{a}$ + gradb × a where b, $\boldsymbol{a}$—are scalar and vector fields, and concurrently taking into account (4), we obtain:

$$\text{rot}\boldsymbol{s} = \text{rot}(\boldsymbol{\rho}_1 - \boldsymbol{\rho}_2)/|\boldsymbol{F}_2 - \boldsymbol{F}_1| = 0 \tag{5}$$

provided that $|\boldsymbol{F}_2 - \boldsymbol{F}_1| \neq 0$ (the reflecting surfaces are not self-intersecting), because the rotor smooth surface $\boldsymbol{\rho}_1 - \boldsymbol{\rho}_2$ is always equal to zero [5].

Let us now find the expicit expression for s and introduce designation $|\boldsymbol{F}_2 - \boldsymbol{F}_1| = \mathrm{B}$, $|\boldsymbol{F}_1 - \boldsymbol{\rho}_1| = \mathrm{r}_1$, $|\boldsymbol{\rho}_2 - \boldsymbol{F}_2| = r_2$, $\boldsymbol{\omega} = \boldsymbol{h} + \boldsymbol{e}_1 r_1 + \boldsymbol{e}_2 (m - r_1)$, where $\boldsymbol{h} = \boldsymbol{\rho}_1 - \boldsymbol{\rho}_2$. By dropping the value $|\boldsymbol{\rho}_2 - \boldsymbol{F}_2|$ from (3) by means of (2), we get $\boldsymbol{\omega} = (\boldsymbol{e}_2 - \boldsymbol{s})B$. By multiplaying the last equation scalarly by an arbitrary vector $\boldsymbol{x}$, we get:

$$B = \boldsymbol{\omega} \cdot \boldsymbol{x}/((\boldsymbol{e}_2 - \boldsymbol{s}) \cdot \boldsymbol{x}) \tag{6}$$

Due to the fact that the medium where the ray is propagating, is isotropic, the value of B should not depend on the choice of $\boldsymbol{x}$, that is dB = grad$_x$ $Bd\boldsymbol{x} = 0$ at arbitrary $\boldsymbol{x}$, $d\boldsymbol{x}$ from whence follows $[\boldsymbol{\omega}(\boldsymbol{e}_2 - \boldsymbol{s})] = 0$. When solving this equation for $\boldsymbol{s}$, we get:

$$\boldsymbol{s} = \boldsymbol{e}_2 - 2\boldsymbol{\omega}(\boldsymbol{\omega}\boldsymbol{e}_2)/\boldsymbol{\omega}^2 = \boldsymbol{s}(r_1, u_1, v_1, u_2, v_2). \tag{7}$$

From the Fermat's principle it follows that:

$$dm = (\boldsymbol{e}_2 - \boldsymbol{s})\, d\boldsymbol{F}_1 - (\boldsymbol{e}_2 - \boldsymbol{s})\, d\boldsymbol{F}_2 + \boldsymbol{e}_1\, d\boldsymbol{\rho}_1 - \boldsymbol{e}_2\, d\boldsymbol{\rho}_2 = 0 \tag{8}$$

at arbitrary values of differentials $d\boldsymbol{F}_1$, $d\boldsymbol{F}_2$, $d\boldsymbol{\rho}_1$, $d\boldsymbol{\rho}_2$. It is possible, if

$$(\boldsymbol{e}_i - \boldsymbol{s})\, d\boldsymbol{F}_i = 0 \tag{9}$$

$$\boldsymbol{e}_i\, d\boldsymbol{\rho}_i = 0 \tag{10}$$

where $\boldsymbol{s}$ is defermined accordingly to (7).

The forms of the refracting surfaces $\boldsymbol{F}_i$ must satisfy (9). Equation (10) state, that the rays and their wave fronts are to be orthogonal. Equation (7) is performed in accordance with the definitions. The condition of integrability of (9) has the form $(\boldsymbol{e}_i - \boldsymbol{s})$ rot $(\boldsymbol{e}_i - \boldsymbol{s}) = 0$ and is fulfilled, because rot$\boldsymbol{e}_i = 0$ in conformity with the definition and rot$\boldsymbol{s} = 0$ is governed by (5). The fact, that (9) is integrable is of great importance for the considered synthesis problem.

The radius-vector of a point on the first surface is determined by the expression $\boldsymbol{F}_1 = \boldsymbol{\rho}_1(u_1, v_1) + \boldsymbol{e}_1(u_1, v_1) r_1$ therefore it is advisable to select the values of u_1, v_1, r_1 as variables. Then, $d\boldsymbol{F}_1 = \boldsymbol{H}_u\, du_1 + \boldsymbol{H}_v\, dv_1 + \boldsymbol{e}_1\, dr_1$, where: $\boldsymbol{H}_u = \dot{\boldsymbol{\rho}}_{1u} + \dot{\boldsymbol{e}}_{1u} r_1$; $\boldsymbol{H}_v = \dot{\boldsymbol{\rho}}_{1v} + \dot{\boldsymbol{e}}_{1v} r_1$; and (9), provided that $i = 1$, will take the form:

$$\boldsymbol{s} \cdot \boldsymbol{H}_u\, du_1 + \boldsymbol{s} \cdot \boldsymbol{H}_v\, dv_1 - [1 - \boldsymbol{s} \cdot \boldsymbol{e}_1]\, dr_1 = 0 \tag{11}$$

If we seek the solution in the form $r_1 = r_1(u_1, v_1)$, then (11) is equivalent to the system of differential equations in the form of partial derivatives of the first order:

$$\dot{r}_{1u} = \boldsymbol{H}_u \cdot \boldsymbol{s}/(1 - \boldsymbol{s}\boldsymbol{e}_1) \tag{12}$$

$$\dot{r}_{1v} = \boldsymbol{H}_v \cdot \boldsymbol{s}/(1 - \boldsymbol{s}\boldsymbol{e}_1) \tag{13}$$

The equations may be solved by the way of consecutive integrating of usual differential equation. There are no any mathematical complications here.

In order to find the second surface it is possible to solve the differential equation by $i = 2$ or to find r_2 from the (2). Really, substitution of (7) into (6) gives:

$$B = \boldsymbol{\omega}^2/2\boldsymbol{\omega} \cdot \boldsymbol{e}_2 \tag{14}$$

$$r_2 = m - r_1 - B \tag{15}$$

where r_1—is the result of solution of differential equations for $i = 1$.

This condition may be used for the purpose to control the accuracy of numerical integration of differential equations when comparing their solutions with conformable algebraical solution like (15).

It should be emphasized, that the considered synthesis method for dual-reflector systems of a common type may be simply applied for the dual-surface lens made from the isotropic material. For them it is valid:

$$\dot{r}_{1u} = n\boldsymbol{H}_u \boldsymbol{s}/(1 - n\boldsymbol{s} \cdot \boldsymbol{e}_1)$$

$$\dot{r}_{1v} = n\boldsymbol{H}_v \boldsymbol{s}/(1 - n\boldsymbol{s} \cdot \boldsymbol{e}_1)$$

when n-lens material refraction index

$$\boldsymbol{s} = \boldsymbol{e}_2 n - \boldsymbol{\omega}(n\boldsymbol{\omega} \cdot \boldsymbol{e}_2 \sqrt{\boldsymbol{\omega}^2 - n^2(\boldsymbol{\omega} \times \boldsymbol{e}_2)^2})/\boldsymbol{\omega}^2.$$

B. Dual-Reflector Systems with Spherical Wave Feed

It is common practice in the antenna engineering to transform the spherical waves into spherical or into plane wave. In this case (ref. to Fig. 2) $\boldsymbol{\rho}_1 = 0$, $\boldsymbol{e}_1 = \boldsymbol{i} \sin \Theta_1 \cos \varphi_1 + \boldsymbol{j} \sin \Theta_1 \sin \varphi_1 + \boldsymbol{k} \cos \Theta_1$ and the (12), (13) will take to form:

$$\dot{r}_{1\varphi} = r_1 \sin \Theta_1 \boldsymbol{\nu}_1 \cdot \boldsymbol{s}/(1 - \boldsymbol{e}_1 \cdot \boldsymbol{s}) \tag{16}$$

$$\dot{r}_{1\Theta} = r_1 \boldsymbol{\tau}_1 \cdot \boldsymbol{s}/(1 - \boldsymbol{e}_1 \cdot \boldsymbol{s}) \tag{17}$$

where $\boldsymbol{\nu}_1 = \dot{\boldsymbol{e}}_{1\varphi}/|\dot{\boldsymbol{e}}_{1\varphi}|$, $\boldsymbol{\tau} = \dot{\boldsymbol{e}}_{1\Theta}$

Let us integrate (16) taking into account the initial condition $r_{10} = r(\Theta_1 = 0, \varphi_1 = 0)$, then (16) will take the form $r_1 = 0$ and the problem will be reduced to the integration of (17) as an usual differential equation, in which φ is the parameter with the previously mentioned initial condition.

The reflector systems used in practice have a symmetry plane. Let us consider the parameters by which such systems can be given. We will avail of the notion of a center beam that lies in the symmetry plane of a reflector system and its direction coincides with the direction of the feed radiation pattern maximum for an incident wave front and with the direction of the beam passing through the centre

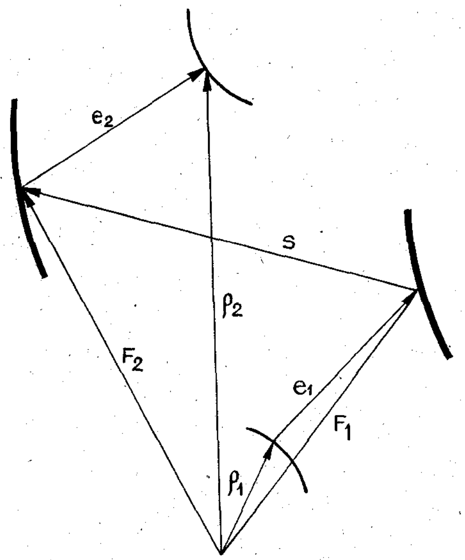

Fig. 2. Ray path in double-reflector system.

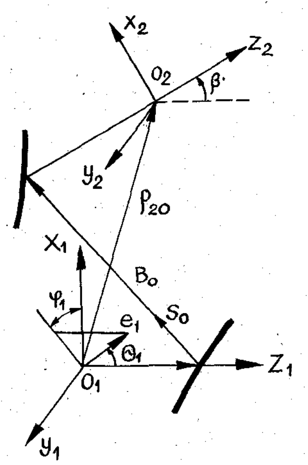

Fig. 3. Center ray path and coordinate systems for double-reflector system design.

of the antenna aperture for a passing wave front. The center beam path and the coordinate systems are shown in Fig. 3. The planes X_1, O_1, Z_1 and X_2, O_2, Z_2 of the coordinate systems lie in the system symmetry plane. The vector $\boldsymbol{\rho}_{20}$ gives the position of the point O_2 of the output coordinate system, the angle β gives an inclination of the output bundle of rays relative to the incident one. The value $|\boldsymbol{r}_{01}|$ is the initial condition for the equation (17), B_0 is an oblique thickness of the reflector system. If $\boldsymbol{k}_1$, $\boldsymbol{k}_2$ are the unit vectors of the O_1Z_1 and O_2Z_2 axes then the optical path length m entering into (17) is determined by

$$m = B_0 \pm \boldsymbol{a} \cdot \boldsymbol{k}_2 \sqrt{B^2 - (\boldsymbol{a} \times \boldsymbol{k})^2} \quad (18)$$

where: $\boldsymbol{a} = \boldsymbol{r}_{01}(\boldsymbol{k}_1 - \boldsymbol{k}_2) - \boldsymbol{\rho}_{20}$. The "+" sign is put before the square root if the angle $\hat{s_{10}, \boldsymbol{k}_1} > \pi/2$ and vice versa.

Of special importance are the reflector systems that have a rotation symmetry and transform a spherical wave front of the feed into a plane wave front at the antenna output. Here, the differential equation (17) is appreciable simplified and takes the form:

$$\frac{dr_1}{d\Theta}\Big/ r_1 = \frac{(m - 2r_1)q \pm x}{m \mp xq} \quad (19)$$

where: $q = tg\Theta/2$, $x = x(\Theta)$ is an appropriate coordinate of the aperture point through which a collimated ray passes. The upper sign corresponds to Cassegrain systems and the lower one, to Gregorian systems.

This equation was assumed as a basis for calculation of dual-reflector radiotelescope system, and (17) as a basis for calculation of the beam waveguide feed of the antenna.

C. Antenna Aperture Phase Distortions

The practical implementation of an antenna is accompanied by perturbations of the reflector system design geometry. It is connected with both the production technology and environmental effect-heat and gravitational fields, wind, etc. For practical purposes, it is convenient to characterize perturbation of a great number of passing rays due to the above factors at the point $\boldsymbol{\rho}_2(u_2, v_2)$ by the value $\delta m = f(u_1, v_1, u_2, v_2, \phi)$ where: ϕ is a perturbation value. Then the value of $\psi = 2\pi\, \delta m/\lambda$ will define a spatial distortion of the passing wave phase. Usually, it suffices to know only that portion of the value δm which is proportional to the perturbation value ϕ. In this case, the presentation required for a linear portion of δm is essentially determined by the expression (8)

$$\delta m = (\boldsymbol{e}_1 - \boldsymbol{s})\, d\boldsymbol{F}_1 + (\boldsymbol{s} - \boldsymbol{e}_2)\, d\boldsymbol{F}_2 + (\boldsymbol{e}_2\, d\boldsymbol{\rho}_2) - (\boldsymbol{e}_1\, d\boldsymbol{\rho}_1) \quad (20)$$

where the differentials $d\boldsymbol{F}_i$, $d\boldsymbol{\rho}_i$ have their origin in the external perturbing factors and in the general case they are not tangent vectors of the appropriate surfaces, i.e. $\delta m \neq 0$. In general case the value of ϕ is a function of:

point coordinate in the reflector aperture;
elevation h of the reflector system;
linear function of gravitational deformations of the reflector system components ω.

The feed and subreflector move as solids while the reflector system is rotating in elevation within the gravity field.

The feed offsets by a value of $\boldsymbol{a} = \boldsymbol{i}a_x + \boldsymbol{k}a_z$, the subreflector offsets by a value of $\boldsymbol{b} = \boldsymbol{i}b_x + \boldsymbol{k}b_z$ and in addition it rotates around its vertex through an angle φ.

What concerns the displacements of reflector as a whole then they may be taken into consideration by means of appropriate corrections to the feed and subreflector offsetting. At the same time, however, a change occurs in the reflector shape, which will be characterized by a deformation vector:

$$\Delta \boldsymbol{f} = \boldsymbol{k}w + \boldsymbol{e}_\gamma u + \boldsymbol{g}_\gamma v \quad (21)$$

where:

$$\boldsymbol{e}_\gamma = \boldsymbol{i}\cos\gamma + \boldsymbol{j}\sin\gamma, \quad \boldsymbol{g}_\gamma = \frac{d\boldsymbol{e}_\gamma}{d\gamma}$$

The components w, u, v are functions of the coordinates x, γ and elevation h, and contain even and odd components denoted by upper index "$\pm$."

The impact of deformations on the radio-technical performance of antenna is characterized by decreasing of the antenna aperture efficiency in the maximum of the antenna radiation pattern and by its angular displacement Θ_m from this maximum.

Depending on the value of P_i deformation the value of $\Delta\chi$ is quadratic form of kind:

$$\Delta\chi \sim \sum^{i,j} A_{i,j} P_i P_j \tag{22}$$

$$\Theta_m \sim \sum^{i} k_i p_i. \tag{23}$$

Since the deformations in function of the elevation are regular functions then by a program-simulated change of the subreflector (as it is determined in (22)) it is possible to minimize the value of $\Delta\chi$.

There is another way to minimize (22) connected with changing of the shape deformation vector Δf reasoned by the construction of the reflector supporting frame. These two principles form the basis of design of the RT-20 reflector system. The value of Θ_m is considered in the telescope pointing program.

II. Reflector System of the RT-70 Radio Telescope

A. Optical System Main Requirements

The geometrical dimensions of a reflector system are shown in Fig. 4. The shapes of reflectors are so modified that homogeneous phase and nearly uniform amplitude distributions are generated in the antenna aperture. As a geometrical approximation, one and the same amplitude/phase distribution can be realized in the construction of Cassegrain and Gregorian antennas. When selecting the Gregorian type for the RT-70, the following conditions were taken into account:

- the theory and experiment have shown that the pattern of the radiating system (subreflector + feed) of the Gregorian antenna has a higher radiation efficiency and abrupt field cut-off outside the optical edge, which reduces the antenna noise temperature.
- the forms of the phase distortions of the Gregorian antenna are monotonically increasing functions, that permits us to expect a more complete compensation of the phase distortions caused by the forces of weight than in the Cassegrain antenna.

For compensation of the reflector phase distortions, use should be made of the program-simulated change of the subreflector position. The subreflector positioning mechanism should ensure the longitudinal travel of the subreflector to compensate for the even phase distortions, but the angular turn around its vertex through an angle of φ and its cross offset by a value b to compensate for the odd phase distortions. The last two motions are related by $b/\varphi = R$, where the value R can be varied.

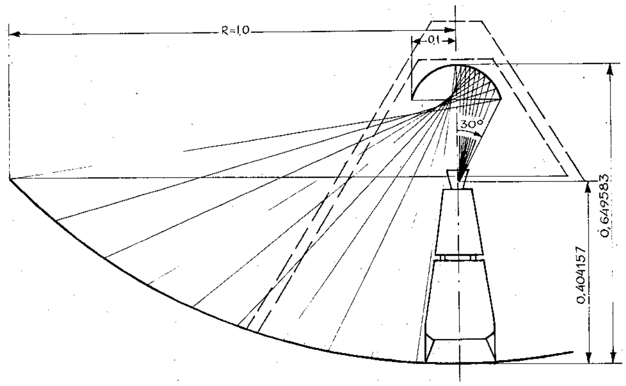

Fig. 4. Basic dimensions of RT-70 Reflector System.

The reflecting surface of a reflector is formed by duralumin facets arranged in the form of 14 circular belts. The facets are secured to the truss by means of pin units, providing access to them from the side of the reflecting surface for their adjustment. Each facet is provided with four bench mark holes reference points for investigating the reflector deformations and adjustment. For the adjustment of the reflector system and for the study of its deformation characteristics the opto-mechanical systems with the measurement results recorded and computer-processed are used. A root-mean-square (rms) error of the measurements of the values w, u, linear values a, b, angular values is 0.5 mm, 0.11 mm and φ − 5 seconds of arc, respectively.

The deformations of the reflector shapes ought to be adequately approximated by the relations $\Delta m^+ = -30.9t^2 + 20.7t^4$, $\Delta m^- = -(22t + 16.8t^3)\cos\gamma$.

The amplitude values of the measured deformations that characterize the feed and the subreflector offsets are $a_x = -13.3$ mm, $a_z = -1$ mm, $b_x = -48.1$ mm, $b_z = -7.2$ mm, $\varphi = -17$ min of arc. The even components change from the $\sin h - 1$ law and the odd components from the $\cos h$ law depending on the elevation.

For different exploratory and flight programs, provision was made for the change of the equipment cabins and feeds. However, the difficulties revealed during the practical execution of these operations made us give up this concept. In 1982 a modernization was carried out with the result that only one equipment cabin with six stationary feeds was left and the modes of operation were switched with the aid of a special nonsymmetric rotating beam waveguide system. This has made it possible, in particular to separate the receiving and transmitting channels of a planetary radar thus enhancing its efficiency and reliability.

B. Reflector System Design

The subreflector geometry was calculated according to (19) subject to the initial condition $r(0) = 0.245432$. The main reflector shape was calculated according to (14), (15). Fig. 5 and Fig. 6 show the aperture amplitude distribution and feed pattern main lobe shape which were put into an energy balance equation to obtain a relation $x =$

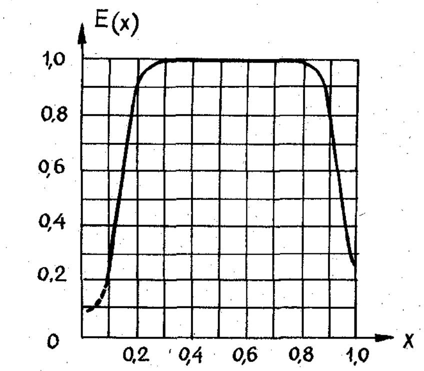

Fig. 5. Amplitude distribution in RT-70 aperture.

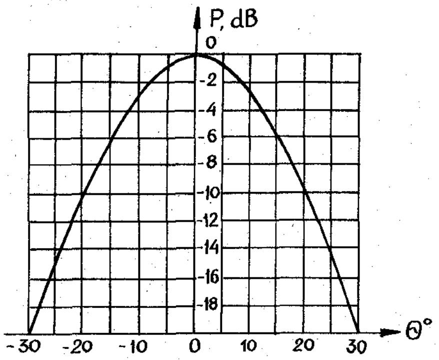

Fig. 6. Feed pattern main lobe.

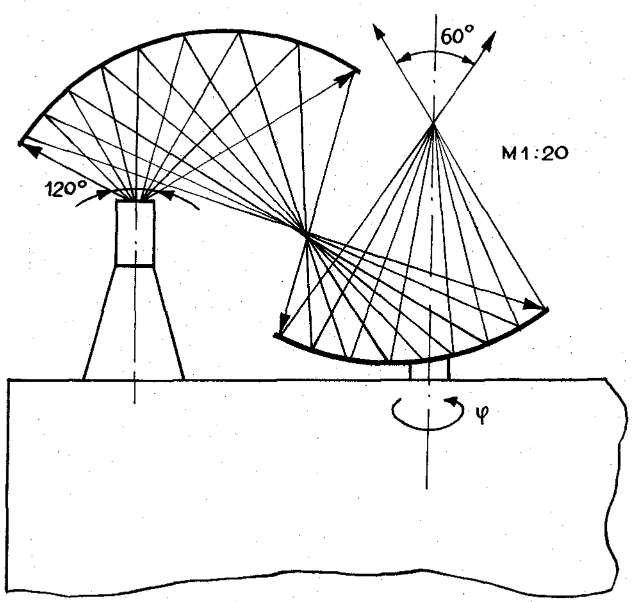

Fig. 7. Rotating beam waveguide system and rays path in it.

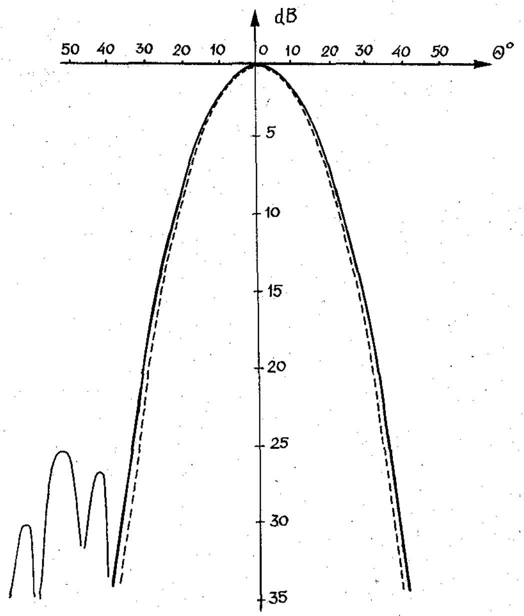

Fig. 8. Beam waveguide system pattern in plane of symmetry.

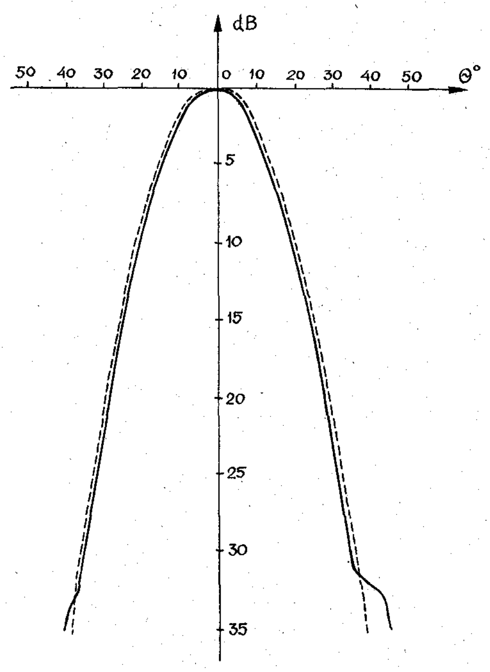

Fig. 9. Beam waveguide system pattern in orthogonal plane.

$x(\Theta)$. The beam waveguide system shown in Fig. 7 is used to correlate the radiation pattern $f_1(\Theta_1, \varphi_1)$ that illuminates the subreflector with the feed pattern $f_2(\Theta_2, \varphi_2)$. The constraint equations used in the beam waveguide design have the form $\Theta_1 = 0.5\Theta_2$, $\varphi_1 = \varphi_2$. The angle of illumination of the beam waveguide reflector was taken to be 120°, that has made it possible the use of small-size two-mode cylinder feeds. The geometry of the beam waveguide reflectors was calculated according to (17), (14), (15), where φ is a parameter. The optical path length was estimated according to (18).

Shown in Figs. 8 and 9 are theoretical (dotted line) and experimental waveguide patterns in the symmetry and orthogonal planes, respectively, which are measured at a frequency of 6000 MHz.

C. Radio-Astronomic Measurement Results

This section will deal with some results obtained during the radio-astronomic measurements and it characterizes the performance of the phase compensation system. The measurement results at $\lambda = 5$ cm are given in Table I.

TABLE I

	Compensation of Even Components of Deformation Only		Compensation of Both Even and Odd Components of Deformation	
h°	Effective Area sq. m	Beam Axis Offset, Minutes of Arc	Effective Area sq. m	Beam Axis Offset, Minutes of Arc
10	2330	6.5	2750	−9.5
20	2360	6.2	2770	−9.0
30	2440	5.7	2790	−8.3
40	2540	5.1	2810	−7.4
50	2630	4.2	2820	−6.2
60	2720	3.3	2840	−4.8
70	2790	2.2	2840	−3.3
80	2840	1.2	2850	−1.6
90	—	—	—	—

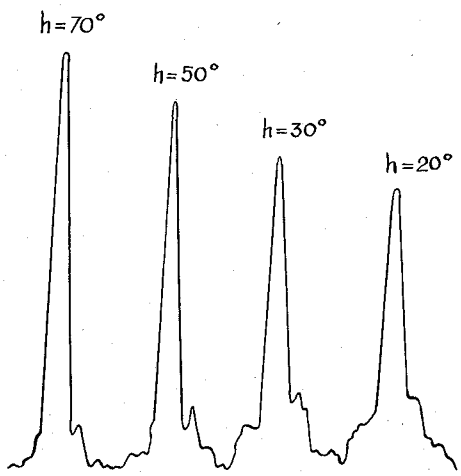

Fig. 10. RT-70 pattern with compensation for even phase distortions only.

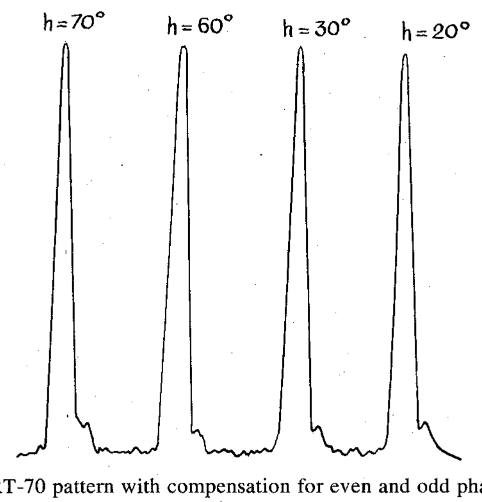

Fig. 11. RT-70 pattern with compensation for even and odd phase distortions.

The positive sign of offset of the beam axis corresponds to its turn towards the zenith. Shown in Fig. 10. are the experimental patterns measured in a vertical plane at $\lambda = 3.25$ cm against the DR-21 radio source with the phase compensation of the even components of deformation only. The distortions of the coma type are clearly seen.

TABLE II

Wavelength, cm	6	5	3.55	1.35	0.82
Coefficient a	0.015	0.03	0.035	0.07	0.2

The same patterns with the compensation of the even and odd components of deformation are given in Fig. 11. The coma type distortions that do not vary with elevation are due to errors of the initial adjustment of the reflector system or of the subreflector lateral shift drive.

In the mode of phase compensation the value of S_{eff} was determined versus the elevation by experiment. This relationship is of the form: $S_{\text{eff}}(h) = S_{\text{eff}}(90°)\ (1 - a \cos^2 h)$ where the values of coefficient a are given in Table II.

Conclusion

In the design of the reflector system for RT-70 radiotelescope the designers came across two basic problems:

- synthesis of a dual-reflector systems with predetermined features;
- compensation of the gravitational deformations of a reflector system with the modified shape of the reflecting surface.

These problems were successfully solved and the results obtained can be applied when designing the reflector antennas of various purposes.

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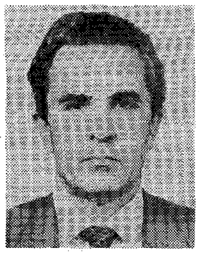
Starting from the time of the first earth satellite launch in 1957, he dealt with the development of radio supporting systems for spacecraft flights and the data transmitting from them. He currently is Chief Research Director of the Deep Space Communication Center equipped by antennas RT-70, and gives a lecture course in the Moscow Aviation Institute.

Dr. Grishmanovsky was conferred a candidate's degree in 1963 and in 1988 a doctor's degree in engineering. He is Lenin and State prize winner.



Alexander N. Kozlov was born in 1937 in Moscow. After graduation from the Moscow Aviation Institute with specialization in radioengineering in 1960, he has been working in the field of antenna feeder microwave facilities for the space communication links.

From 1973 to 1985 he was a leading designer and manager of the building and erection of the RT-70 antenna for the Deep Space Communication Centers in Yevpatoriya and Ussuriisk. He has a candidate's degree in technical sciences and is a State prize winner for the RT-70 creation.

Vladimir B. Tarasov was born in 1936 in Stavropol. He graduated from the Moscow Aviation Institute with specialization in radioengineering in 1960, and was one of the pioneers in the creation of first antennas for the deep space communication ADU-1000 in Yevpatoriya in 1960–61. He received the candidate's degree of technical sciences in 1975.

Mr. Tarasov has implemented a set of theoretical calculations on the reflector system RT-70, and is the leading specialist in designing the geometry of reflector and lens focusing systems for the ground-based and onboard microwave antennas.