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**ANALYSIS OF RADIOTECHNICAL SIGNALS BY THE FOURIER  
SERIES AND WAVELET FUNCTIONS**

The theoretical bases of the Fourier and wavelet transforms are considered, the main advantages and disadvantages of the Fourier series and wavelet functions are mentioned using the program MATLAB R2013a, the analysis of one-dimensional signals in the command mode are realized, the results of investigations of the wavelet and Fourier spectrograms are presented.

**Keywords:** fast transform, basic function, local features, wavelet coefficients, decomposition.

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**INVESTIGATING THE IMPACT OF MECHANICAL DEFORMATIONS  
ON THE FIELD DISTRIBUTION IN THE ANTENNA APPERTURE FOR  
THE ROT-54/2.6 RADIO TELESCOPE**

A telescope is never perfect because of mechanical, gravitational, temperature and wind-induced deformations of its structure, because of production imperfections and because of accidental small misalignments of constrictive elements. The resulting degrading effect on the beam pattern is negligible if the corresponding deformation of the reflector and the misalignment of the constructive elements (main reflector, sub reflector, receiver) is small compared to the wavelength of observation, i.e smaller than  $\lambda/16$ . The degradation becomes noticeable and disturbing if the corresponding deformation is larger than  $\lambda/10$  [1].

In our work we examined the influence of mechanical deformations on the field distribution in the antenna aperture for the ROT-54/2.6 Radio Optical Telescope.

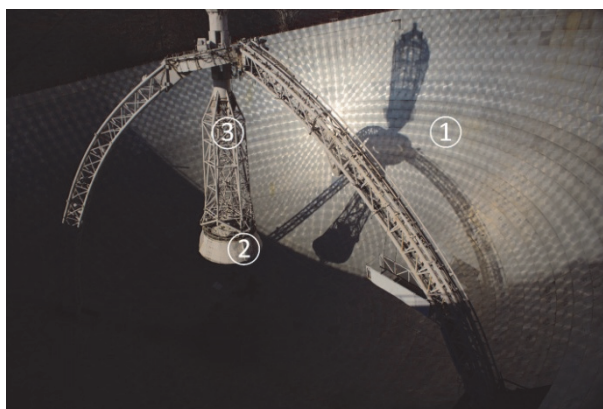
**Keywords:** antenna, deformations, radio telescope.

**Introduction.** Antennae used for Radio Telescopes usually have large dimensions and are generally composed by a set of surface panels with supported structure (also known as a backup structure) [2]. So far, the Arecibo Observatory Radio Telescope located on the island Puerto Rico has the largest in the world spherical multi-reflector antenna. The main collecting dish is 305 m in diameter constructed inside the depression and the backup structure of it is the network of steel cables strung across the underlying karst sinkhole [3]. The only Radio Optical Telescope in the world ROT-54/2.6 located in Armenia on mountain Aragats has the

second largest double-reflector spherical antenna. ROT-54/2.6 was designed and constructed in Radiophysical Measurements Institute (Yerevan, Armenia) managed by the famous Armenian scientist Paris Herouni in 1987 [4]. The main collecting dish is 54 m in diameter and constructed inside the rock depression. It has a spherical shape and its surface consists of 3716 solid panels, specially melted and processed with high accuracy. The application areas of both these large double-reflector spherical antennae are Radio Astronomy and Deep Space Communication.

In 2016, the five-hundred-meter Aperture Spherical Telescope (FAST) in Pingtang county in southwest China Guizhou province was completed, making the FAST telescope the largest in the world nowadays. Measuring 500 meters in diameter, the Radio Telescope is nestled in a natural basin. Generally speaking, the working surface of the antenna FAST is not spherical but a parabolic mirror, generating from special panels [3]. In such highly- directional Antenna Systems of the presented Radio Telescopes, most optimal characteristics can be achieved only when field distributions in the antenna's aperture in terms of amplitudes and phases are close to uniform. These large dimensional antennas can have significant deformations of their backup structure which directly affects the field distribution in the aperture of the antenna which in turn affects the beam pattern and intensity. The associated wave-front deformation of imperfections may be of a systematic or a random nature or both. Systematic wave-front deformations usually produce a deformation of the main beam and the profile close to the main beam and a decrease in the main beam intensity; random wave-front deformations usually produce an intensity decrease of the main beam and a much extended and more or less intense Gaussian type error beam. In general situations, the deformation consists of spatially small-scale random deformations which usually do not change the structure of the beam pattern and the focus and pointing, and large-scale deformations, which may do so [5].

The main restriction when constructing an antenna system is the phase distortion tolerance in the antenna aperture which should be less than  $\pi/2$  [6]. The ROT-54/2.6 antenna design can be conditionally divided into the following parts: large fixed spherical reflector - 1 (see Fig. 1), the small reflector - 2 which is moving with the help of construction - 3 around the center of the sphere.



*Fig. 1. The overall view of the ROT-54/2,6 antenna construction*

The reflecting surface of the large reflector is the hemisphere with the 54m diameter. Surface panels are cast from aluminum alloy and have a spherical profile. Panels have a small gap between each other to ensure that thermal deformation of one panel will not influence the neighbouring panels. The average size and weight of panels are accordingly 1100x1100mm and 55kg. The overall quantity of the panels is 3716. On the opposite side of the panels, stiffening ribs exist to ensure the stiffness of the panels. The small reflector has a complex profile. In the focus of the small reflector, the feed and supporting structure for the receiver is mounted. The reflecting surface of the small reflector is composed of titanium panels. The small reflector has the following dimensions: the depth is 2643mm and the aperture diameter is 5688mm. In this paper the dependence of the ROT-54/2.6 antenna's parameters in the aperture of the large reflector from the error of constructive elements is examined.

**The theoretical research of errors' joint influence on the phase distortion.**

In highly directional antenna systems, the optimal characteristics can be achieved if the field distribution on the antenna's aperture, in terms of amplitude and phase, are close to uniform. However, in the real case, field distribution is different from uniform for several reasons.

One of the main factors causing the nonuniform distribution of the field in aperture is the surface error of reflectors and other constructive elements of the antenna system. When the antenna dimension significantly exceeds the wavelength, in the antenna theory, the methods of geometrical optics become widely used. In this case, the reflecting mirrors should provide the uniform distribution of the field in the antenna aperture, i.e. the distance for each beam passing from feed to the aperture

after being reflected by two mirrors should be equal. Regardless of the reflectors' profile and quantity, the following equation can be written:

$$\sum x_i = \sum c_i = 0 \quad (1)$$

where  $c_i$  is the distance of the central beam in the mirror system,  $x_i$  - the same for the current beam. The parameters  $c_i, x_i$  are the functions of the antenna's constructive parameters, thus Eq. 1 can be considered as an expression for uniform phase distribution in the aperture. For real antenna, the geometrical dimensions would differ from calculated values. Correspondingly parameters  $c_i, x_i$  would also differ from the calculated ones.

The difference of the beams can be expressed as follows:

$$dS = dS_\theta - dS_o \quad (2)$$

where

$$\left. \begin{aligned} dS_\theta &= \sum dx_i \\ dS_o &= dc_i \end{aligned} \right\} \quad (3)$$

The electrical length is:

$$dS = \frac{d\varphi}{d\pi} \lambda \quad (4)$$

where  $\lambda$  is the wave length and  $d\varphi$  - the phase distortion. The limits for phase tolerance on the antenna's aperture in the antenna theory is  $\pm \frac{\pi}{4}$ , thus the limiting deviations would be  $\pm \frac{\lambda}{4}$ .

In Fig. 2, the main spherical reflector - 1, the corrective small reflector - 2 is shown, the point of system's focus "F", the current point "M" of the phase front line in the aperture, the created beam with a length of "a", "b" and "r". All parameters are shown taking, into consideration the misalignments. Also, there are the following notations:

$x_0Oy_0$  - the fixed coordinate system. The coordinate system center matches with the center of the large hemisphere;

$\nu Ou$  - the movable coordinate system;

$xO_2y$  - the fixed coordinate system, regarding the small corrective reflector;  
 $x,y,u,v$  - the coordinates of the current point of the small corrective reflector,  
in the corresponding system coordinates;

$x_0,y_0$  - the small corrective reflector center " $O_1$ ", the moving coordinates in  
the system coordinates  $x_0Oy_0$ ;

$e$  - a point in the axis of the small corrective reflector;

$f$  - the distance of focus from point " $O_1$ ";

$x_e$  - the distance of point "e" from the top of the small corrective reflector;

$U_e$  - the distance of point "e" from axis "OV";

$U_f$  - the distance of focus from axis "OV";

$\gamma$  - the angle of rotation of the small corrective reflector over point "e";

Taking into consideration Eq.3, the following equation can be written:

$$dS_0 = dn + db + da \quad (5)$$

In addition, we have:

$$n = \frac{\cos\theta}{\cos(2\theta - \theta_1)} R, \quad a = \sqrt{(V_f - V)^2 + (U_f - U)^2}$$

$$b = \sqrt{(n_1 - V)^2 + (r_1 - U)^2}, \quad U_0 = y_0 \cos\psi - x_0 \sin\psi$$

$$V_0 = y_0 \sin\psi + x_0 \cos\psi, \quad V_e = V_0 + \sqrt{e^2 - (U_e - U_0)^2}$$

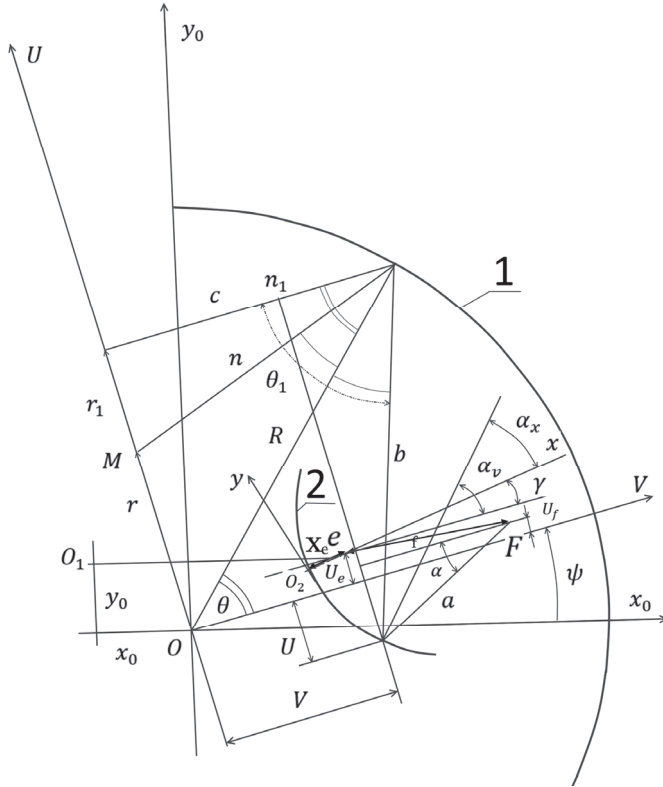


Fig. 2. The design scheme of a double reflector spherical antenna

In Eqs.6, parameter  $\alpha_x$  is the angle between the small corrective reflector's current point's normal and axis  $O_2x$ .

$$\left. \begin{aligned}
 V_f &= V_0 + \sqrt{f^2 - (U_f - U_0)^2}, & V_{02} &= V_e - x_e \cos \gamma \\
 U_{02} &= U_e - x_e \sin \gamma, & V &= V_{02} + x \cos \gamma - y \sin \gamma \\
 U &= U_{02} + y \cos \gamma + x \sin \gamma, & \alpha_v &= \alpha_x + \gamma \\
 \theta_1 &= 2\alpha_x + 2\gamma - \alpha, & \alpha &= \arctan \frac{U_f - U}{V_f - V} s \\
 \theta &= \theta_1 + \arcsin \left( \frac{U}{R} \cos \theta_1 - \frac{V}{R} \sin \theta_1 \right), & n_1 &= R \cos \theta \\
 r_1 &= R \sin \theta
 \end{aligned} \right\} (6)$$

Parameters “x” and “y” can be calculated from the following equations (6)

$$\left. \begin{aligned} x &= A - l - p \cos 2\theta, & y &= B - p \sin 2\theta \\ A &= 1 - 2(1 - \cos \theta) \cos^2 \theta, & B &= \sin \theta - (1 - \cos \theta) \sin 2\theta \\ p &= \frac{1}{2} \frac{c^2 - (A - f)^2 - B^2}{c - (A - f) \cos 2\theta - B \sin 2\theta}, & c &= 1 - 2l + f \end{aligned} \right\} \quad (7)$$

where  $l$  is the distance between the vertex of the small corrective reflector and the center of the large hemisphere. The total differential at taking into consideration Eqs. 2-3 and Eqs. 5-6 can be expressed as follows:

$$\begin{aligned} dS &= 2\cos\theta dR - 2dR_\zeta + 2\sin^2\theta \cos\psi dx_0 + \\ &+ 2\sin^2\theta \sin\psi dy_0 + 2\sin^2\theta de - (\sin 2\theta - \sin\alpha) dU_e + \\ &+ (\cos 2\theta + \cos\alpha - 2) dx_e - (\cos 2\theta + \cos\alpha) dx + 2dx_\zeta - \\ &- (\sin 2\theta - \sin\alpha) dy - \sin\alpha dU_f - (1 - \cos\alpha) dm + \\ &+ (e \sin 2\theta - \sin\theta + m \sin\alpha) d\eta \end{aligned} \quad (8)$$

where

$$\left. \begin{aligned} m &= f - e \\ d\eta &= R d\gamma \\ \alpha &= \arcsin \left[ \frac{y}{\sqrt{(f - x - l)^2 + y^2}} \right] \end{aligned} \right\} \quad (9)$$

$dR_\zeta$  - is the error of large hemisphere at some point of the surface, when the point is located on the axis of the small corrective reflector.

$dX_y$  - is the error of the small corrective reflector surface on the axis  $O_2x$ .

In Eq.8, phase deviations are calculated from the intersection of the central beam with the antenna’s aperture plane, i.e.  $\theta = x = y = r = 0$ .

Eq. 8 can be used to study the systematic errors. For the current point of  $\theta$ , the equation gives the linear dependency of the phase deviation on the errors of the antenna construction, however the phase deviation on the antenna aperture is non-

linear. The influence of each constructive error can be calculated separately, assuming that other types of constructive errors do not exist.

The phase deviation dependency  $dS$  on the antenna's aperture plane coordinates for each  $dx_n$  error is shown in Fig. 3.

The curves for  $\Delta x$  and  $\Delta x_1 (\Delta y, \Delta y_1)$  show the constructive error influence of  $x(y)$  coordinate on the phase distortion. The curve  $\Delta x(\Delta y)$  takes into consideration the situation when the point of the small reflector has a constant error equal to 1 over  $x(y)$ . Curve  $\Delta x_1(\Delta y_1)$  shows the situation when errors change according to the law:

$$\Delta x = \frac{x}{x_1} \Delta x_1, \quad \Delta y = \Delta x_1 \operatorname{tg} 2\theta \frac{x}{x_1}.$$

Random errors can be expressed, using the RMS summation. If  $\sigma$  is the RMS error of the beam, traveling from the antenna's aperture plane to the focus and  $\sigma_i$  is the RMS error of the corresponding constructive elements, then:

$$\begin{aligned} \sigma^2 = & 4(\cos\theta - 1)\sigma_R^2 + 4\sin^4\theta \cos^2\psi \sigma_{x_0}^2 + 4\sin^4\theta \sin^2\psi \sigma_{y_0}^2 + \\ & + 4\sin^4\theta \sigma_e^2 + (\sin 2\theta - \sin\alpha)^2 \sigma_{U_e}^2 + (\cos 2\theta + \cos\alpha - 2)\sigma_{x_e}^2 + \\ & + (1 - \cos\alpha)^2 \sigma_m^2 + \sin^2\alpha \sigma_{U_f}^2 + (\cos 2\theta + \cos\alpha)^2 \sigma_x^2 + \\ & + 4\sigma_{x_\zeta}^2 + (\sin 2\theta - \sin\alpha)^2 \sigma_y^2 + (e \sin 2\theta - \sin\theta + m \sin\alpha)^2 \sigma_\eta^2 \end{aligned} \quad (10)$$

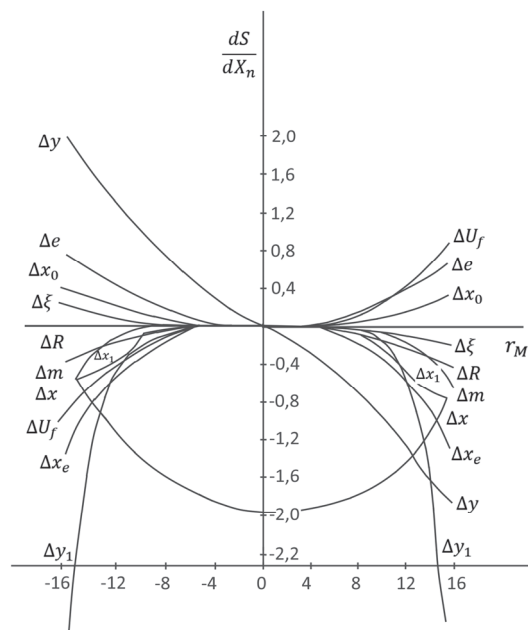


Fig. 3. The curves of the phase deviation on the antenna's aperture plane

**Conclusion.** In this paper it is shown that in the theory of tolerances of large multi-reflector antennae, it is possible to obtain simple working formulae convenient for studying the joint influence of the antenna's inaccuracies on the phase distortion on the aperture plane with the help of differentials. This is the scientific value of the work.

Final working formulae were obtained for estimating both the random and systematic errors of a double reflector spherical antenna with a large mirror diameter of 54,000 mm.

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**ՄԵԽԱՆԻԿԱԿԱՆ ԴԵՖՈՐՄԱՑՈՒՄՆԵՐԻ ԱԶԴԵՑՈՒԹՅԱՆ  
ՀԵՏԱԶՈՏՈՒԹՅՈՒՆԸ ՌՈՂ-54/2.6 ՌԱԴԻՈԴԻՏԱԿԻ ԱՆՏԵՆԱՅԻ  
ԲԱՅՎԱԾՔՈՒՄ ԴԱՇՏԻ ԲԱՇԽՎԱԾՈՒԹՅԱՆ ՎՐԱ**

Ռադիոդիտակների կառուցվածքը ենթարկվում է տարաբնույթ դեֆորմացումների՝ պայմանավորված սեփական կշռով, ջերմային ընդարձակումներով, քամու ազդեցությամբ, ինչպես նաև նախագծման ժամանակ օգտագործվող տարրերի անկատարությամբ: Դեֆորմացումների ազդեցությունը անտենայի բացվածքում փուլա-ամպլիտուդային բաշխվածության անհարթության, հետևաբար՝ նաև ուղղվածության դիագրամի (ՈԻԴ) վրա ընդունելի է, եթե դեֆորմացումների չափը փոքր է անտենայի աշխատանքային ալիքի երկարությունից, այսինքն՝ փոքր է  $\lambda/16$ : Դեֆորմացումների ազդեցությունը անտենայի ՈԻԴ-ի վրա դառնում է զգալի, երբ դեֆորմացումների չափը մեծ է  $\lambda/10$  [1]: Ուսումնասիրվել է մեխանիկական դեֆորմացումների ազդեցությունը ՌՈՂ-54/2.6 ռադիոդիտակի անտենայի բացվածքում դաշտի բաշխվածության վրա:

**Առանցքային բաներ.** անտենա, դեֆորմացումներ, ռադիոդիտակ:

**А.Р. ХАЧАТРЯН, А.С. САРГСЯН**

**ИССЛЕДОВАНИЕ ВЛИЯНИЯ МЕХАНИЧЕСКИХ ДЕФОРМАЦИЙ  
НА РАСПРЕДЕЛЕНИЕ ПОЛЯ В РАСКРЫВЕ АНТЕННЫ  
РАДИОТЕЛЕСКОПА РОТ-54/2.6**

Телескоп никогда не бывает совершенным из-за механических, гравитационных, температурных и ветровых деформаций структуры, несовершенства производства и случайных небольших несоосностей конструктивных элементов. Влияние на диаграмму направленности антенны незначительно, если соответствующая деформация отражателя и несоосность конструктивных элементов (основного отражателя, вспомогательного отражателя, приемника) мала по сравнению с длиной волны наблюдения, то есть меньше  $\lambda / 16$ . Деградация становится ощутимой, если соответствующая деформация больше  $\lambda / 10$  [1]. Рассмотрено влияние механических деформаций на распределение поля в апертуре антенны для радиотелескопа РОТ-54 / 2.6.

**Ключевые слова:** антенна, деформации, радиотелескоп.