Radiophysical Methods of Fast Diagnostics of Main Mirror Condition and Panels Surface of RATAN-600 Radio Telescope

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***Abstract*— We describe two methods of fast condition diagnostics of the reflecting surface of the RATAN-600 radio telescope. The first one is based on a radio holography, and the second one relies on measurements of the random scattered background in the observations of the extended radio sources. Both methods were used in the antenna measurements, which proved the reflecting surface of the of the radio telescope main mirror to be in acceptable condition even after 20 years since the last resurfacing.**

***Keywords*— radio holography; radio telescope; antenna measurements; RATAN-600**

I. Introduction

Various methods were suggested in 1980s for the radio holographic testing and adjustment of the main mirror of RATAN-600 radio telescope using the autocollimation or self-focusing on the distant ground-based source modes. All of them required custom-made phase-stable two-channel equipment in order to form and record the radio hologram; processing the latter, one could reconstruct the field in the telescope aperture, and calculate and correct the errors in the main mirror reflecting panels' positions.

The most attractive method of radio holography would be that using the antenna itself and a coherent MW transmitter to form a hologram, and a standard radio astronomical receiver to record it. In this presentation we provide the description of such a methodically and technically simple method, and first results of its application to the fast check of the condition of the main mirror as a whole, as well as a single panel's surface quality, in the “South sector + Flat reflector” (S+F) antenna system.

Along with said radio holography method, we employed the radio astronomical technique for the estimation of reflecting panels' surface quality. In the late 1980s and early 1990s a method was suggested and tested successfully for a surface quality assessment of individual panels in the North sector of RATAN-600 during the Sun observations at 3.2 mm, based on random scattered radiation measurements [2, 3, 5]. We give the results of the application of this method in the observations at the wavelength of 10 cm to the actual condition assessment of the panels of the S+F after 20 years since the resurfacing and stabilization of the main mirror reflecting surface [4]

II. A Method for the Radio Holography Signal Recording

In the method proposed, in order to record the 2D radio hologram of a single main mirror panel the reference wave is produced by the reference panel moving in the radial direction, and the interferogram (hologram) $H(a,u_i)$ is recorded using the standard radio astronomical receiver while the panel being measured is turning around its azimuthal axle. The procedure is repeated at several elevation settings u_i. A similar method for the recording of the radio holographic signal formed by the main mirror using the moving carriage with a primary feed mounted on it has been described earlier [4].

Fig. 1 shows the system layout for the recording of the radio holographic signal from a part of the main mirror (*a*) and a single panel (*b*).

The result of the interference of waves produced by the aperture under test $V(a, u_i)$ and the moving reference panel $A_0(a)$ upon passing the receiver with a quadratic detector placed in the vicinity of focus of the antenna system is

$$\begin{aligned} H(a,u_i) &= |V(a,u_i)+A_0(a)|^2 = |V(a,u_i)|^2 + |A_0(a)|^2 \\ &+ V(a,u_i)A_0^*(a) + V^*(a,u_i)A_0(a). \end{aligned} \quad (1)$$

Taking into account a linear phase shift in the field caused by the movement of the reference panel, be its slope *c* deg/mm, one may write

$$A_0(a) = A_0 e^{ica}.$$

As the signals from the reference panel and the measured one are similar in magnitude, the Fourier transform of the part of (1) which is varying slowly in *a*, i.e. the part of the spectrum concentrated near zero spatial frequency, is not too powerful with respect to the whole spectrum, and the holographic record does not require any preliminary processing. Consider the part of the $H(a, u_i)$ that is varying fast in a that is, essentially, the information-bearing part of the hologram. Its Fourier transform will be

$$F\left[\tilde{H}(a,u_i)\right]=F\left[\left|A_0V(a,u_i)\right|\cos ca\right]$$
$$=\sqrt{\frac{\pi}{2}}F\left[\left|A_0V(a,u_i)\right|\right]\left(\delta(\xi-c)+\delta(\xi+c)\right),$$

where ξ is a Fourier space coordinate conjugated with a.

In the case of a holography of the main mirror $|V(a,u_i)|^2$ part of (1) causes low-frequency part of spatial spectrum to be much more powerful than its high-frequency part, which contains the information payload. It may be cancelled if one record the power distribution in the focal plane (actually, $|V(a,u_i)|^2$ itself in the ideal case) and subtract it from $H(a,u_i)$ before performing the Fourier transform.

The more interference fringes contains the hologram, the better is the spatial resolution in the reconstructed wavefront, thus mirror surface figure, so a monochromatic signal source is preferable for the radio holography. Its required short-time

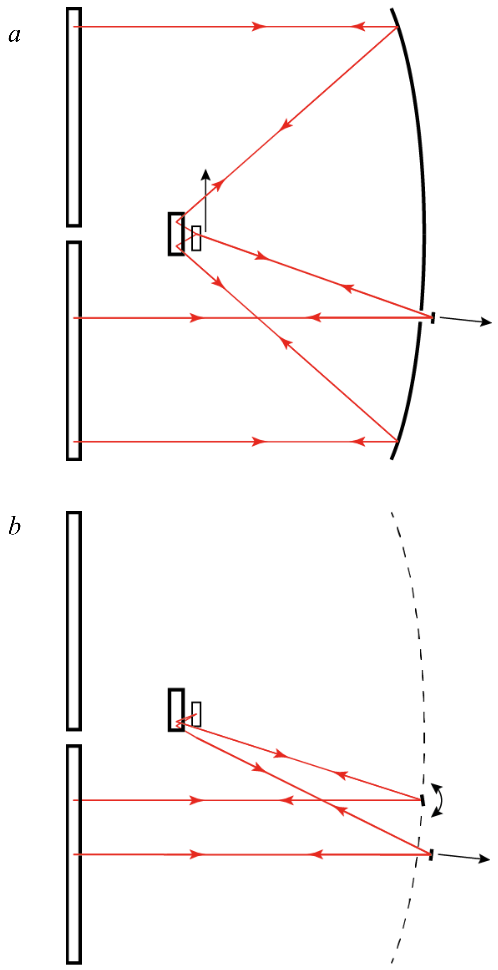

Fig. 1. System layout for the radio holography measurements of the main mirror (a) and a single panel surface (b) in the S+F antenna system

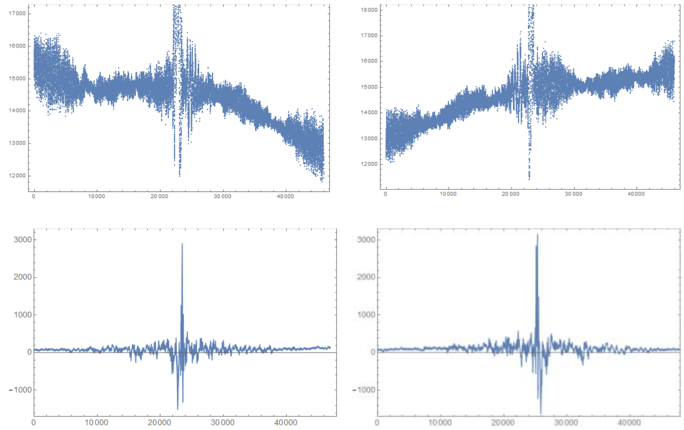

Fig. 2. Holograms of a single panel (top) and a part of the main mirror (bottom) recorded with the panel under test or cariage moving in forward and backward directions

stability is determined by the ratio between the minimum surface error to be measured and the path difference between the reference signal and the measured one, which estimates to 10^{-4}-10^{-5} in the case of radial movement of the reference panel within the range of 1 m. Such characteristics may be obtained, for example, in a voltage-controlled oscillator (VCO) or in a phase-locked loop (PLLO) followed by a frequency multiplier.

The VCO has been developed, based on the IC AD with a phase noise of –103 dBc at 100 kHz frequency offset, temperature instability of 850 kHz/K, and frequency instability 78 kHz/mV of control voltage. Harmonics level is less than –30 dB. Fig. 2 demonstrates a high enough stability of the generator during the recording of the hologram of a single panel (a) and a part of the main mirror (b). Nevertheless, the test results suggest the use of PLL, because of the excessive anomalous noise of the VCO itself.

In the main mirror testing, the spatial resolution achievable with the radio holographic method is not worse than one panel width [4]. In the single panel surface testing, in order to obtain the spatial resolution of $\Delta x = \Delta y = 10$ cm, i.e. 20×50 points over the panel surface, the panel should rotate over the azimuthal and elevation axles in the range of

$$\Delta A=\frac{\lambda}{\Delta x\cos\psi}=\frac{0.1}{\cos\psi}\,\text{rad},$$

where ψ is the angle between the antenna axis and the direction from the focus to the element being measured [4]:

$$\psi=\text{arctg}\frac{\sin\varphi}{\cos\varphi-1+\dfrac{\rho_1(0)}{R_{\max}}},$$

φ is the angle between the antenna axis and the direction from the telescope center to the element being measured; R_{max} is the maximum distance from the telescope center to panels of the main mirror (288500 mm), $\rho_1(0)$ is the distance from the focus to the panel in the center of the aperture (132000 mm).

For the panels on the edge of the sector the horizontal spatial resolution is about 2 times worse than for the panels in the center.

Before the recording of the radio hologram of a single panel the carriage is positioned so that the primary feed would be in a point of maximum of the field distribution in the focal plane. This is essential when there is significant spacing between the reference panel and the one being measured. In such manner, one can perform a fast check of 25 successive panels with a single reference one. The registration of the 2D hologram of the panel surface would be performed under the program control. While recording a hologram of a part of the main mirror, the carriage with both the primary feed and the receiver mounted on it is moving in the appropriate direction with a constant speed [4].

III. Results of the Application of the Radio Holography to the Fast Check of the Condition of the Main Mirror and the Panel Surface

The signal coherence time required for the radio holography is determined by the time delay corresponding to the maximum path difference between the reference wave and the measured one, which is about 1 m, hence the signal source frequency stability requirement of ΔF~1 MHz over the time of the hologram recording in the autocollimation mode.

Fig. 3 shows the amplitude (*a*) and phase (*b*) of the reconstructed field in the single panel aperture. There are three recesses in the amplitude distribution, which may be associated with protruding representative pads on the panel

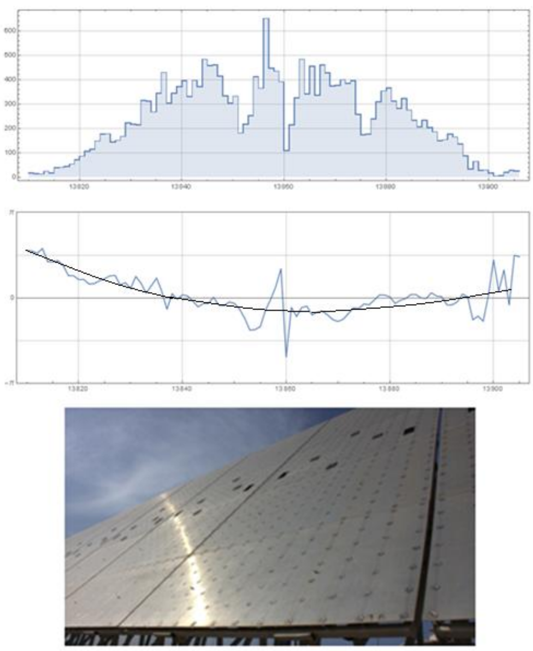

Fig. 3. Reconstructed amplitude (*a*) and phase (*b*) distributions from the hologram of a sigle panel; panels of RATAN-600 (*c*)

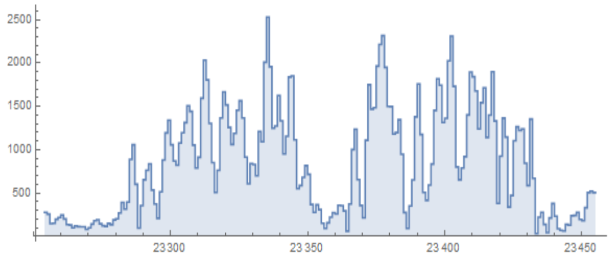

Fig. 4. Reconstructed amplitude in the aperture of the part of the main mirror

surface (*c*). The panel curvature and profile distortions with RMS ~0.1 mm are clearly seen in the reconstructed phase distribution. Random surface errors *per se*, that is a panel surface topography, could only be obtained in the 2D hologram recording and successive field reconstruction.

In fig. 4 an amplitude distribution reconstructed from a hologram of a part (40 panels) of the main mirror is depicted. The projection of the central hole in Flat reflector (cf. fig. 1) is clearly seen, as well as multiple recesses in amplitude caused by failures of backlash cancelling mechanisms of corresponding panels.

If the degree of coherence of a signal is high enough, the accuracy of the method is limited by steadiness of movement of the reference panel and the carriage with a receiver, and also by the condition of the surface atmospheric layer. We estimate its RMS value to be no more than 0.15 mm.

IV. Estimation of the Surface Errors on the Base of the Measurements of the Random Scattered Radiation Background

In fig. 5 a signal from Sun at the wavelength of 3.2 mm is shown, produced with the single panel #675 in the North sector of RATAN-600 radio telescope. Random scattered background is marked with dashed lines, corresponding to the scale of 20 cm related to the surface adjusting screws placement, as well as to the scale of 70 cm related to the panel curvature [3, 5]. Sun observations with individual panels of the North sector after their geodesic adjustment on a rack lead to the estimate for the RMS error of the surface of 0.14 ±0.03 mm [5].

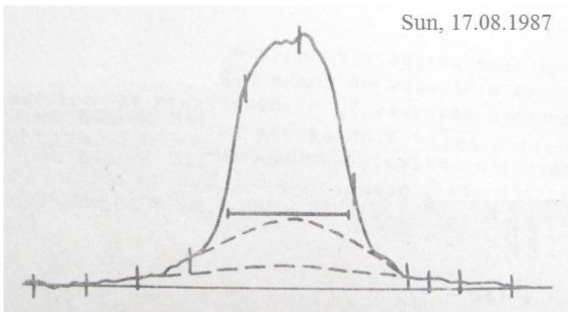

Fig. 5. Sun drift curve at the wavelength of 3.2 mm obtained with the panel #675 of RATAN-600 North sector

a

b

c

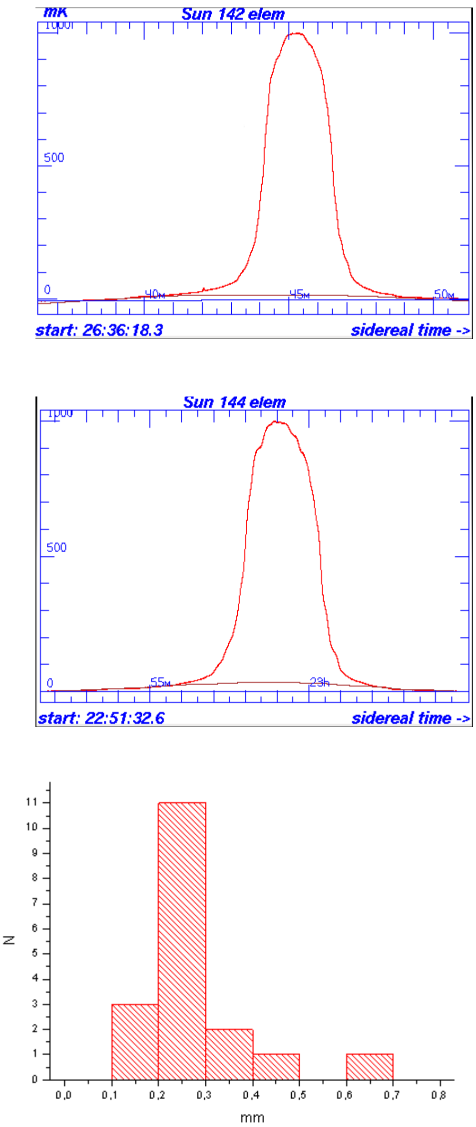

Fig. 6. Sun drift curves for the panels #142 (*a*) and #144 (*b*) of RATAN-600 South sector; the random scattered background related to the adjustment screws placement of scale 20 cm is shown under the curves; histogram of the RMS surface error for 20 measured panels (*c*)

In 2016-2017, 20 years after resurfacing of the main mirror panels [3], random scattering background measurements have been performed in S+F antenna system at the wavelength of 10 mm. Fig. 6 demonstrates the Sun drift curves for panels #142 (*a*) and #144 (*b*) in South sector. The scattered background of 20 cm scale is shown under the curves.

Let us find an estimate for the RMS error of panel surface using the random scattered background measured in the observation of an extended source. If the response of the antenna to an extended source was determined, then one could calculate the RMS surface error σ from the areas of the response S_0 and the random scattered background S_b [3]:

$$\sigma = \frac{\lambda}{4\pi}\sqrt{\ln\left(1+S_b/S_0\right)}.$$

Fig. 6, *c* shows the histogram of the RMS surface error related to the surface adjusting screws placement for 20 panels in South sector. Our assessment implies that almost 90% of panels in South sector have the RMS surface error better than 0.3 mm, while 10% of panels have the RMS surface error of 0.5 mm and worse, hence the readjustment of their surface is necessary. The precision of the error estimate is ~0.1 mm, limited by an accuracy of the scattered background of the relevant scale extraction.

V. Conclusion

The main advantages of two methods described are their efficiency and the simplicity of realization. 2D holography of the main mirror panel takes 2-3 hours, which is the same as high precision laser geodesic method does [6], but unlike the latter, it does not involve manual operations on the antenna, using heavy equipment like elevating work platform, etc. and can be fully automated. The Sun observation with a single panel, as well as a single 1D radio holography measurement of a panel or part of the main mirror, takes only a few minutes and allow for a fast though rather coarse assessment of the main mirror condition, which is inaccessible with any other methods ever used on RATAN-600 antenna. The disadvantage of both methods is rather limited accuracy of 0.1–0.15 mm RMS, although it is quite enough for the purposes of the fast online check of the main mirror and panel surface condition. The measurements performed using the methods described proved the panels' surface to be in acceptable condition after 20 years since the resurfacing and stabilizing of RATAN-600 main mirror surface [3].

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