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A STUDY OF CHARACTERISTICS OF THE RATAN-600 RADIO TELESCOPE EQUIPPED WITH ANTI-NOISE SCREENS

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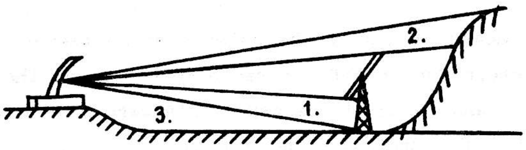
ABSTRACT. *Results are presented of calculations and measurements of the noise temperature and effective area of the RATAN-600 main mirror with the elements enlarged up to 11.2 m in vertical size. The measurements show that the antenna efficiency increases by a factor of 1.5-2 at wavelengths larger than λ13 cm even without accurate adjustment of the elements.*

The telescope sensitivity can be improved by means of reducing the antenna (T_a) and radiometer (T_r) noise temperatures and increasing effective aperture (S_{eff}) of the main reflector. Since now the RATAN-600 is equipped with the very low-noise radiometers (Berlin et al., 1982), then in order to realize its sensitivity the antenna noise temperature must be reduced. It is actual to investigate the different components of T_a and to find a dominating one.

At shorter wavelengths ($\lambda<3.9$ cm) noise radiation of the Earth's surface introduces the dominant contribution from the stray fields of the main and secondary reflectors (Stotskij, 1972; Braude and Esepkina, 1978). The stray field of the feed-cabine with the secondary reflector can not be essentially reduced, whereas the one of the main reflector can be reduced by means of screening of the most noisy regions.

Such regions are the panel basements (region 1 in Fig. 1), hills behind the main reflector (region 2), and also the "gaps" between the panels (Korol'kov et al., 1978; Majorova, 1989). As theoretical and experimental investigations of the antenna noise temperature and its separate components (Korol'kov et al., 1978; Majorova, 1989) have shown, the contribution of radiation from the ground of the telescope (region 3) to the total antenna noise temperature is small. From measurements at λ 3.9 cm the noise temperature of region 3 is about 1 K (Korol'kov et al., 1978), at λ 31 cm it does not exceed 10 K (Majorova, 1989). This is by one order less than the noise temperature of regions 1 and 2.

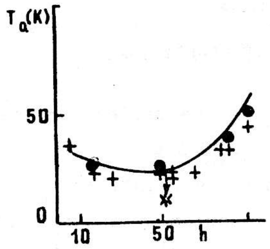
Fig. 1. *A scheme of the focusing system of the radio telescope.*
1 - the main reflector basement,
2 - the hills behind the main reflector,
3 - the main reflector area.



Thus, to reduce the total antenna noise temperature, it is necessary first to screen the regions of panel basements and background hills. This can be done either by increasing the vertical dimensions of the panels or with the help of netlike screens. In the first case, as calculations (Majorova, 1985) at long wavelengths have shown, the effective area of the radio telescope increases as well.

Netlike screens were used to reduce the antenna temperature in the program "Cold" in 1979 too (Parijskij and Korol'kov, 1986). They were suspended below the panels at an angle of about 20° to vertical. Screening of the panel basements, application of special reduced vertical irradiation of the main reflector, and covering of the "gaps" with metal bands made it possible to reduce the antenna noise temperature in this program to 11.5 K at λ 7.6 cm at mean position angles (h=51°) (Fig.2).

Fig. 2. *The noise temperature of the Northern sector at 7.6 cm · - b=7.4 m, + - b=11.2 m - theoretical dependence $T_a(h)$. The asterisk is the noise temperature of the antenna in the experiment "Cold" (λ=7.6 cm).*



This paper presents the results of experimental and theoretical investigation of the antenna temperature and effective area of the radio telescope after the vertical sizes of the main reflector panels have been enlarged up to 11.2 m (initial size was 7.4 m).

The panels were enlarged by attachment of additional aluminium sheets (flaps) 3 mm thick (the same as the panels) to the upper and lower edges of the panels. The mean-square error of the flaps after the adjustment was 1 mm. Their planes were almost level with those of the panels. The sizes of the flaps were somewhat different for different sectors of the radiotelescope due to difference in spaces between the ground and the lower edges of the panels.

TECHNIQUES FOR MEASURING THE ANTENNA NOISE TEMPERATURE

The measurements of the antenna noise temperature were performed at the Northern and Eastern sectors of the radio telescope at the wavelengths $\lambda\lambda$ 1.0, 2.7, 6.2, 7.6, 8.2, 13, and 31 cm. The measurements were made with the help of the cooled coordinated loads of round cross-section at the inputs of the radiometers instead of primary feeds. For calibration the temperature difference of the loads in the warm state and at the liquid nitrogen temperature, $T_0 - T_n$, was used. The SHF loads of the centimeter range were made as a cross of absorbing plates in the round waveguide. Liquid nitrogen was filled directly in the waveguide, which provided a small thermal time lag and guaranteed the absence of temperature gradients. Voltage standing wave ratio (VSWR) of the loads was no larger than 1.15-1.2 in the filled-up state in the frequency band of each radiometer.

To determine antenna temperatures the radiometers were operated in the one-beam mode of reception (Esepkina et al., 1973) with modulation of transmission coefficient most convenient for such measurements. When switching the warm load we registered the signal level equal to the sum of equivalent noise temperatures of the radiometer and load, $T_r + T_0$, at the cold load it was $T_r + T_n$, and with installation of the primary feed the radiometer noises were added by the antenna noises $T_r + T_a$. T_0 was measured with a thermometer inside the warm load, and T_n was recalculated at each wave with the allowance for minor losses ($\varkappa$=0.05-0.1 dB) in the connected thermoisolated section by the formula:

$$T_n = T_n^0 (I - \Gamma^2)(I - \varkappa) + T_0,$$

where Γ is the reflection coefficient. At $T_n^0 = 76.55$ K (690 mm of mercury), $\varkappa = 10^{-2}$, $\Gamma^2 = 5 \cdot 10^{-3}$, $T_n = 78.5$ K.

From these relations T_r and T_n were defined.

The measurement accuracy at different waves was from 3 to 5 %.

RESULTS

Figs.2 and 3 present the measurement results of the antenna temperature of the RATAN-600 radio telescope with the vertical sizes of the panels 11.2 m at $\lambda\lambda$ 2.7, 7.6, 8.2, 13, and 31 cm. Open circles correspond to the antenna noise temperature measured at the Eastern sector, crosses are for the Northern sector measurements. The same figures show the noise temperature measurement results obtained with the panel size 7.4 m at the northern sector of the telescope (Ipatov et al., 1978; Korol'kov et al., 1982) (filled circles). Experimental values of the antenna noise temperature obtained with the panel size 11.2 m at 1 and 6.2 cm are listed in Table 1.

Table 1. Measurement results of the noise temperature of the RATAN-600 Northern sector

	T_a (K)				
λ (cm)\ h	6°	35°	51°	64°	75°
1.0	78	35			38
6.2	32		22	22.5	26.5

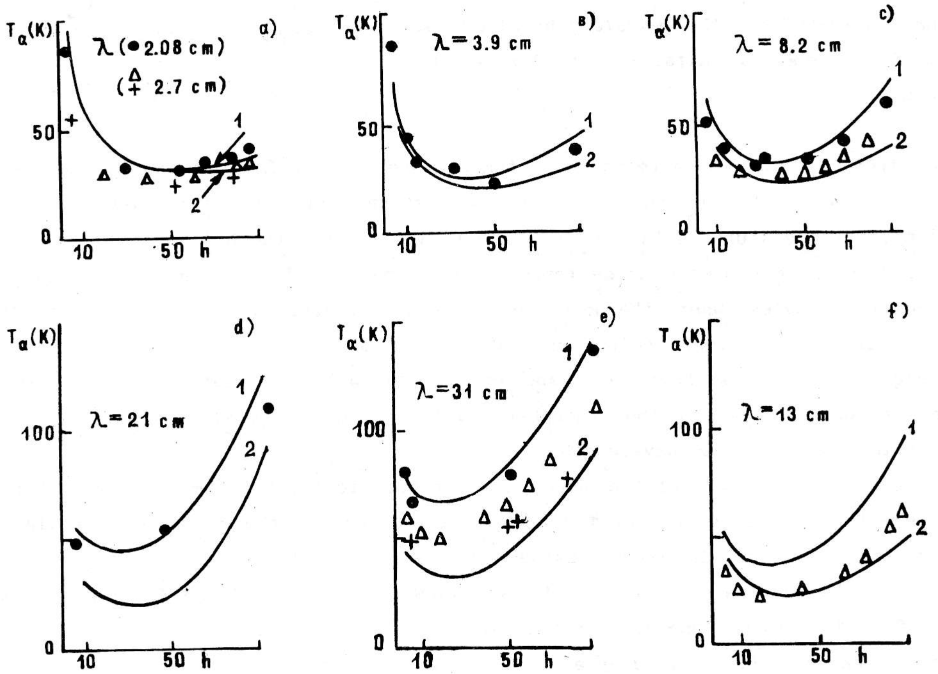


Fig. 3. *The noise temperature at 2.08 cm, 2.7 cm, 3.9 cm, 8.2 cm, 13 cm, 21 cm, 31 cm. (Measurement results:* · *- b=7.4,* + *- b=11.2, Northern sector;* *- b=11.2 m, Eastern sector; Theoretical dependences: 1 - b=7.4 m, 2 - b=11.2 m, Northern sector)*

The solid lines in Figs 2 and 3 show the theoretical dependencis of T_a (h) obtained by Majorova (1989, 1985). The computations were performed for the Northern sector with the panel size 7.4 m at the wavelengths 2.08, 3.9, 7.6, 8.2, 13, 21, 31 cm (curves 1 in Figs.2 and 3). The calculation accuracy was 10-13%. Majorova (1985) has reported preliminary estimations of the telescope efficiency ($G=S_{eff}/(T_a+T_r)$ with the enlarged panel sizes (b=11.1 m).

Using the techniques proposed by Majorova (1989, 1985), we computed the dependences $T_a(h)$ for the Northern sector with the vertical sizes of the panels b=11.2 m (curves 2 in Fig.4). Analyzing the obtained results we can note that, as it has been expected (Braude and Esepkina, 1978); Majorova, 1989), the principal effect due to the enlargement is attained at long wavelengths. So, at λ31 cm the noise temperature has been reduced due to increase of the vertical size of the main reflector by 30-40 K (Northern sector).

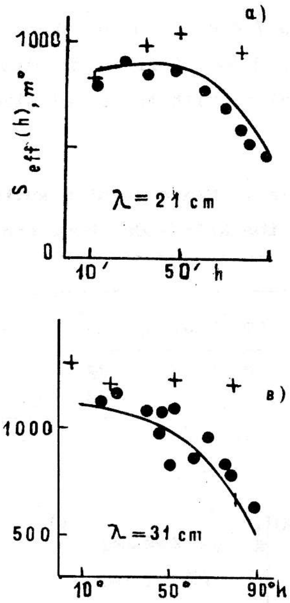


Fig. 4. *The effective area of the Northern sector of the RATAN-600 at the wavelengths 21 cm and 31 cm (measurement results: · - b=7.4 m, + - b= =11.2 m).*

The difference of the antenna noise temperature at the Eastern and Northern sectors is explained by the fact that at the Eastern sector the contribution to the total noise temperature is increased by the radiation from the hills.

At λ 3.9 cm the antenna noise temperature is reduced due to the flaps mainly at high position angles, where the noise temperature decreases by 10-15 K. The considerable difference in antenna noise temperatures at low position angles ($h=5^\circ$) at the wavelength 2.08 cm (without the flaps and 2.7 cm (with the flaps) is explained by different contributions of the atmosphere radiation to the noise temperature of the radio telescopes at these wavelengths.

Due to the enlargement of the panel sizes we practically attained a certain threshold level, where the noises of the antenna are caused by the atmospheric radiation and the radiation of the spaces between the panels alone. A contribution of the latter from the estimates made by Majorova (1989) and Parijskij and Korol'kov (1986) may be from 4 to 10 K, depending on the wavelength and polarization.

As can be seen from the diagrams in Fig.3, the reduction of the antenna noise temperature at 8.2, 13, 21, 31 cm due to increase in the vertical sizes of the panels to 11.2 m is rather large (20-40%). However, the tendency of T_a to rise with increasing position angle at $h>50^\circ$ at these wavelengths suggests that not all potentialities of reduction of the antenna noise temperature have been exhausted. Further decrease in antenna noise temperature and therefore increase in brightness temperature sensitivity of the radio telescope can be achieved by complete screening of the panel basements and gaps with the help of nets (Aliakberov et al., 1985), and also by enlargement of the feed size (Majorova, 1985).

Parallel to the investigation of the noise temperature, measurements of the effective area of the radio telescope were made. The measurements were performed using the standard methods (Stotskij, 1972) by observations of reference cosmic sources at the Northern sector of the telescope. The measurement results of S_{eff} at 21 cm and 31 cm are presented in Fig. 4. The filled circles correspond to the values of the effective area before fixing the flaps on the panels (b=7.4 m), the crosses mark the effective area of the radio telescope after attachment of the flaps (b=11.2 m). Table 2 shows the values of $V=S_{eff}(11.2)/S_{eff}(7.4)$ which characterize the gain in effective area resulting from attachment of the flaps (V_{calc} are the calculated values, V_{exp} - the experimental ones).

Table 2. Calculated and experimental values of the Northern sector efficiency

h	λ8 cm		λ13 cm		λ21 cm		λ31 cm	
	V_{calc}	V_{exp}	V_{calc}	V_{exp}	V_{calc}	V_{exp}	V_{calc}	V_{exp}
10°	1.0	1.0	1.0	1.0	1.2	1.0	1.4	1.2
50°	1.1	1.0	1.2	1.0	1.5	1.2	2.1	1.3
90°	1.4	1.0	1.6	1.0	2.0	2.0	2.2	2.2

Measurements have shown that at short wavelengths ($\lambda<8$ cm) the effective area does not vary with the increase of vertical sizes of the panels. This agrees with the results of calculations in (Majorova, 1985) and also suggests that the accuracy of the flap surfaces does not influence the effective area at these wavelengths.

With increasing wavelength and position angle of the source observed the gain resulting from enlargement of the panel sizes grows. At the wavelengths 21 cm and 31 cm and h=90° the effective area of the radio telescope with the flaps increases two times and more, which is confirmed by measurement results.

Some discrepancies between the calculated V_{calc} and experimental V_{exp} values at the wavelengths 8 cm and 13 cm can be explained by the large rms error of the flap areas. (The effective area was measured prior to their adjustment).

CONCLUSION

Note the principal advantages attained due to enlargement of the panel sizes with the flaps.

First, the essential decrease of the noise temperature and increase of the effective area of the radio telescope at long wavelengths, and therefore the increase of its efficiency $G=S_{eff}/(T_a+T_r)$. So, at position angles close to 90° the efficiency of the radio telescope grows by a factor of 2.5-3 at 21 cm, 31 cm due to the flaps. This is especially important for operation in the mode of full circular aperture ("Zenith" mode).

Second, the use of the flaps allowed, at the wavelengths shorter than 6 cm, to approach the so-called "level of three-degree background", when the noise temperature of the antenna is defined by the sky noises only.

Third, enlargement of the vertical sizes of the main reflector leads to essential widening of the working wavelength range of the radio telescope. As it has been shown in (Majorova, 1988) it becomes possible to use the RATAN-600 at decimeter wavelengths, up to $\lambda = 1$ m, which will extend essentially the scope of new astrophysical problems for the radio telescope.

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