The Parameters of the RT-13 Radio Telescopes of the "Quasar" VLBI Network of the IAA RAS in S/X/Ka Bands

© Yu. Vekshin, V. Chernov, D. Ivanov, M. Kharinov, E. Khvostov, V. Mardyshkin, A. Mikhailov

Institute of Applied Astronomy of the Russian Academy of Sciences, Saint Petersburg, Russia

Measurement results of the parameters of the RT-13 radio telescopes of the "Quasar" VLBI network in *S/X/Ka* bands are presented in this paper. The receiver noise temperature and calibration signals are measured by special wide-aperture noise load. Load is installed at the receiver feed and cooled by liquid nitrogen. The calculated and measured system noise temperatures are compared. Focusing and directional pattern measurements are performed by point cosmic radio sources, differing for *S/X/Ka* bands. SEFD and antenna efficiency are measured by reference cosmic radio source CAS A. The dependences of the system noise temperature, SEFD, antenna efficiency from the antenna elevation angle are obtained.

Keywords: VLBI, 13 m radio telescope, tri-band receiver, noise temperature, SEFD.

1 Noise temperature measurements

The tri-band receiving system of the RT-13 radio telescope operates in *S*-band (2.2–2.6 GHz), *X*-band (7.0–9.5 GHz) and *Ka*-band (28–34 GHz) at circular polarizations [1]. Since the receiving system input is the tri-band feed, cooled in cryostat, for the noise temperature measurements special noise load — wide-aperture low-temperature noise generator (WLNG) has been developed by FSUE "VNIIFTRI" [2]. The WLNG is mounted on the receiver input (Fig. 1) and the noise temperature is measured by Y-factor method. Receiver output signals are registered at "warm" WLNG, than the WLNG is cooled by liquid nitrogen during 8 hours, than the "cold" load levels are registered. Radiometric control unit is used for output signals registration. The spectrum

Fig. 1. The RT-13 noise temperature measurements by using wide-aperture low-temperature noise generator

analyzer is also used in *S*-band as a spectral-selecting registration system due to the presence of RF interferences (mainly communication networks 3G and Wi-Fi). Physical temperatures of WLNG radiators are controlled by 9 precision temperature sensors. The system noise temperature is measured by calibration signals, injected trough directional coupler before low-noise amplifiers. The value of calibration signals is also measured in K degrees using WLNG.

The results of the receiver $T_{\rm rec}$ and the system $T_{\rm sys}$ noise temperatures measurements of the radio telescope RT-13 at the “Badary” station in both polarization *S*/*X*/*Ka*-band channels are presented at Table 1. The measured values of $T_{\rm rec}$ at radio telescope coincides with laboratory $T_{\rm rec}$ measurements [1]. The $T_{\rm sys}$ and $T_{\rm ant}$ values are given for the zenith position of the antenna. The antenna noise temperature $T_{\rm ant}$ is calculated by developed program as the integral over the sphere of the product of the normalized antenna directional pattern and brightness temperatures of sky and ground. The surface weather model, used by JPL and NASAs DSN for antenna calibrations [3], is applied taking into account absorption by water vapor and molecular oxygen. The model is suitable for calculations in fair weather, as the liquid water content in the atmosphere is not taken into account. The input data used for the calculation in the program are temperature, humidity, pressure and observatory altitude. As can be seen from Table 1 the calculated values of $T_{\rm sys}$ ($T_{\rm sys}$=$T_{\rm rec}$+$T_{\rm ant}$) are close to the measured $T_{\rm sys}$ values. So, the calculated value of $T_{\rm ant}$ may be used in fair weather as the value of “cold” load for the receiver noise temperature evaluation, while absorber can be used as “warm” load. This alternative measurement technique is fast, because it does not require long cooling of load.

Table 1

The RT-13 noise temperature measurement results at "Badary" station

Channel	*T*rec (meas), K	*T*ant (calc), K	*T*sys (calc), K	*T*sys (meas), K
S RCP	20	17	37	37
S LCP	23	17	40	42
X RCP	17	9	26	27
X LCP	19	9	28	29
Ka RCP	47	15	62	64
Ka LCP	52	15	67	68

2 SEFD and directional pattern measurements

Focusing, antenna adjustment and directional pattern measurements (beam-width and sidelobes level) are performed by point cosmic radio sources, differing for each band: by CAS A in *S*-band, by Cygnus A in *X*-band, by Venus and Jupiter in *Ka*-band. System equivalent flux density (SEFD) is measured by reference cosmic radio source CAS A by (1).

$$\mathrm{SEFD} = \frac{1}{g}\frac{\alpha_{\mathrm{sys}} F_{\mathrm{s}}}{\alpha_{\mathrm{s}} - \alpha_{\mathrm{sys}}}, \tag{1}$$

where F_{s} is source flux density, α_{sys} — output signal level, corresponding to the system noise temperature out of the source, α_{s} — output signal level, when aiming to the source, g= $g_1{\cdot}g_2$ — correction factors.

Flux density of CAS A is determined at the measurement time by (2) [4].

$$F_{\mathrm{CASA}} = F_{1980}\left[1 - (0.0097 - 0.003\,\lg(f)\right]^{M-1980}, \tag{2}$$

where f — frequency in GHz, M — measurement year. Values of F_{CASA} at 2016 year are presented at Table 2.

$$F_{1980} = 10^{5.745 - 0.770\,\lg(f_{\mathrm{m}})},$$

where f_{m} — frequency in MHz.

Correction factor g_1 takes into account angular size of the source CAS A (disk diameter $d = 4.3'$) and antenna beamwidth of RT-13 θ_{A}. g_1 is determined by (3) [4]

$$g_1 = \frac{\left(\frac{d}{1{,}2\theta_{\mathrm{A}}}\right)^2}{1 - e^{-\left(\frac{d}{1{,}2\theta_{\mathrm{A}}}\right)^2}}. \tag{3}$$

Correction factor g_2 takes into account source flux density absorption in the atmosphere. Evaluations of g_2 and calculations of g_1 are presented at Table 2. The antenna relative efficiency is determined by (4).

$$\mathrm{RE} = \frac{2k \cdot 10^{26}}{\pi(\frac{D}{2})^2}\frac{T_{\mathrm{sys}}}{\mathrm{SEFD}} = 20.168\frac{T_{\mathrm{sys}}}{\mathrm{SEFD}}, \tag{4}$$

where k — Boltzmann constant, $D = 13.2$ m — antenna diameter.

Table 2

Flux density and correction factors for CAS A

Band	F, Jn	g_1	g_2	$g = g_1 \cdot g_2$
S (2.4 GHz)	1020	1.005	1.005	1.010
X (7.5 GHz)	447	1.065	1.009	1.075
Ka (28.5 GHz)	170	2.356	1.256	2.959

Observation of radio source Taurus A simultaneously in *S*/*X*/*Ka* bands at "Badary" station is presented at Fig. 2. There is a problem with powerful radio sources in *Ka*-band. For focusing and sidelobes measurements in *Ka*-band sources Venus and Jupiter appeared to be suitable. The dependences of the system noise temperature, SEFD, antenna efficiency from the antenna elevation angle are measured by source CAS A and presented for "Badary" station at Fig. 3–4. Measurement results of the parameters of the RT-13 radio telescopes at 60 elevation angle at the "Badary" and "Zelenchukskaya" stations are presented at Table 3.

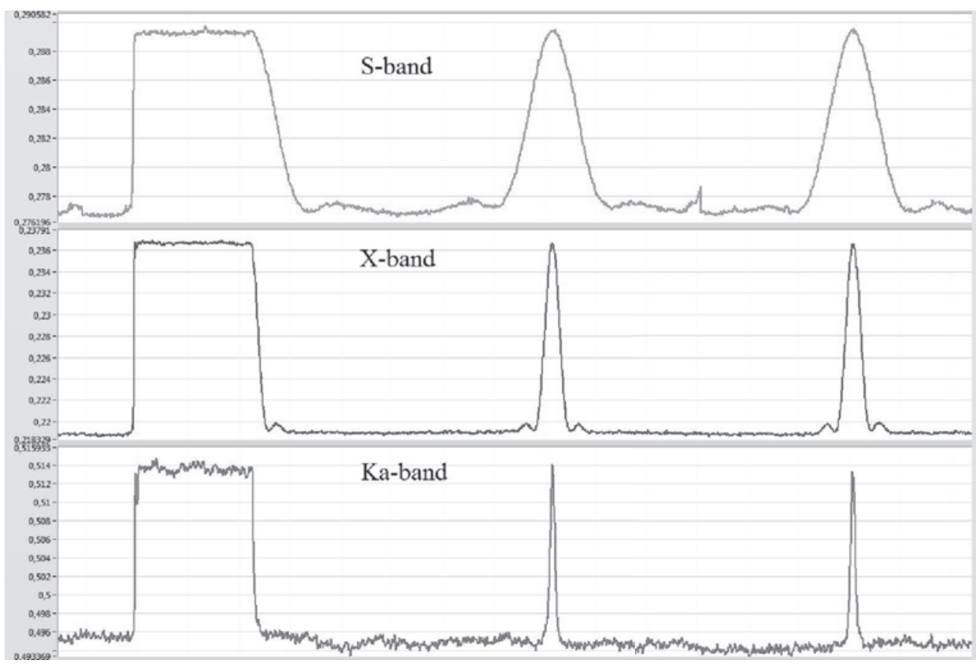

Fig. 2. Source "Taurus A" observations simultaneously in *S*/*X*/*Ka* bands

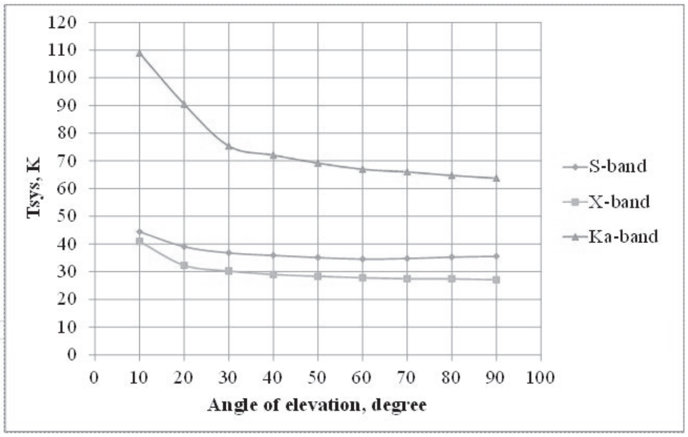

Fig. 3. System noise temperature vs. angle of elevation

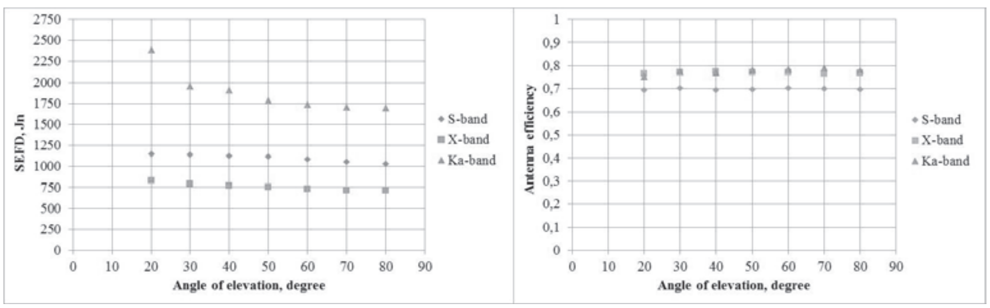

Fig. 4. SEFD vs. angle of elevation (*left*). Antenna efficiency vs. angle of elevation (*right*)

Table 3

Measurement results of the RT-13 parameters at 60 elevation angle at "Badary"/"Zelenchukskaya" stations

Band	Trec, K	Tsys, K	SEFD, Jn	Efficiency	Beamwidth, ′	Sidelobs, dB
S	20/24	37/40	1070/1150	0.70/0.70	34/35	−12/−13
X	17/18	28/30	730/770	0.78/0.8	10/10	−13/−14
Ka	47/48	67/72	1730/1910	0.78/0.76	2.5/2.5	−13/−13

3 Conclusion

Measurement parameters of RT-13 are close enough to expectable ones and they are up to the latest world standards. The two-element interferometer, comprising RT-13 radio telescopes, is in operation since 2016.

References

1. *Chernov V., Evstigneev A., Evstigneeva O. et. al.* The S/X/Ka receiver system for radio telescope RT-13 of the Quasar VLBI Network // Trudy IPA RAN, 2017. — Is. 41. — P. 79–84.
2. *Yurchuk E., Arsaev I., Lapshin A. et. al.* Wide-aperture low temperature noise generator — operating noise temperature measure unit for calibrating the receiving system of the VLBI radio telescope “Quasar-M”// All-Russian astronomical conference (VAK-2013) “Multi-face universe”. 23–27 september 2013, St. Petersburg, Russia: abstracts. — SPb., 2013. — P. 282.
3. *Reid M. S.* Low-noise systems in the deep space network // John Wiley & Sons, Inc, New Jersey, 2008.
4. *Baars J. W. M.* The paraboloidal reflector antenna in radio astronomy and communication. — Springer, New York, 2007.