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Continuum radiometers of the RATAN-600 radio telescope

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ABSTRACT

The paper presents the main directions in developing continuum radiometer complexes of the RATAN-600 radio telescope and demonstrates their current state.

Key words: radio receivers, detectors, radio astronomy

1 Introduction

The RATAN-600 radio telescope currently operates as three independent radio telescopes, using three sectors of the main reflector: northern, western, and southern (or southern sector with a periscope). Radiometers for continuum observations are located on four receiving complexes of secondary mirrors No. 1, 2, 3, and 4 of the radio telescope. One of the tasks solved within the framework of this work is to equip the receiving complexes with the maximum number of radiometers, which allows constructing instantaneous spectra of cosmic radio sources in a wide frequency band (5 octaves, 1–32.5 GHz).

One of the directions in developing the RATAN-600 continuum radiometer complexes is the construction of modular radiometers. Here, the word "modular" means a type of design in which the radiometer has the smallest possible size to date and is made as a small microwave module with the maximum degree of integration (one module – one radiometer). Work in this direction began in the late 90s under the leadership of Yu.N. Parijskij and A.B. Berlin. As a result, a focal array of 16 radiometers was developed: the MARS-3 radiometric system, described in Berlin et al. (2012). A further advancement in the "modular" direction was the development of a modular C-band radiometer (4.4–5 GHz), presented in Tsybulev et al. (2018). A developer is the NPF Mikran (Micran Research and Production Company), Tomsk. Further, in collaboration with the NPF Mikran, an array of centimeter modular radiometers of the 21–23.5 GHz, 13.4–15.4 GHz, and 7.7–8.7 GHz bands was developed (Nizhelskii et al., 2018; Tsybulev et al., 2022).

The five listed radiometric modules with their basic parameters are shown in Fig. 1. All continuum radiometers are constructed according to the general scheme of a direct amplification receiver. The operating frequency band with a width of 5–20 % is formed by a bandpass filter. A low-noise amplifier with an extremely low (as far as a modern element

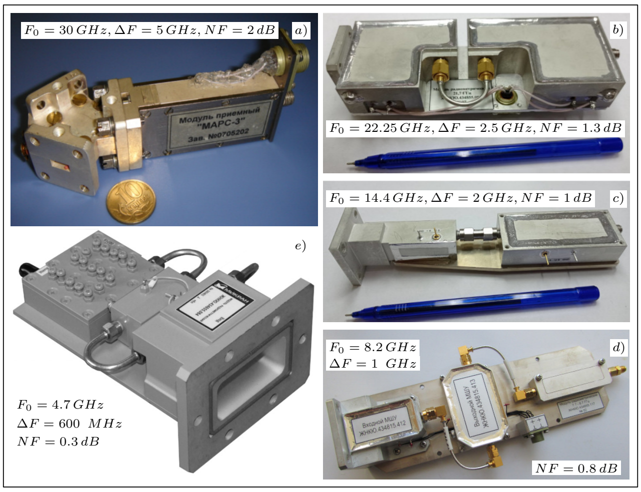

Fig. 1. RATAN-600 modular radiometers.

base can allow) level of intrinsic noise without cooling (at room temperatures) is installed at the input of the radiometer. A quadratic detector based on a low-barrier Schottky diode, or a tunnel diode, is installed at the output. The radiometer total gain is 10^6–10^7.

2 Current configuration of continuum receiving complexes

As new radiometric modules were designed, manufactured, and delivered to RATAN-600, they were installed on all four operating receiving complexes of the radio telescope. As a result, new modular radiometers were being installed on the radio telescope over several years; the present-day configuration of the receiving complexes is shown in Table 1.

Table 1. RATAN-600 continuum radiometers (the last four lines refer to a four-band radiometer; four such four-band radiometers are installed in receiving cabin No. 5).

Central frequency, GHz	Bandwidth, MHz	Flux density sensitivity, mJy	HPBWx, arcsec
Secondary mirror No. 1			
30	5000	100	9
22.25	2500	50	11
14.4	2000	25	13
11.2	1000	15	15.5
8.2	1000	10	22
4.7	600	5	45
2.25	80	40	80
1.25	60	200	110
Secondary mirror No. 2			
30	5000	200	11
22.25	2500	95	16.5
14.4	2000	50	18
11.2	1000	30	23
8.2	1000	20	30
4.7	600	10	53
Secondary mirror No. 3			
30	5000	200	11
8.2	1000	20	30
4.7	600	10	53
Secondary mirror No. 5			
14.4	2000	50	11
2.25	80	40	80
4.475	150	10	35
4.625	150	10	35
4.775	150	10	35
4.925	150	10	35

Receiving cabin No. 1 contains eight radiometers in the 1.25–30 GHz range, cabin No. 2 is equipped with six radiometers in the 4.7–30 GHz range, and cabin No. 3 with three radiometers (4.7–30 GHz). Receiving cabin No. 5 contains six radiometers (2.2–14.4 GHz range), but four radiometers of the 4.7 GHz range are four-channel with adjacent bands of 150 MHz each, so the total number of radiometric channels in this receiving complex is 18.

In the process of equipping RATAN-600 with new radiometers, the task of unifying the peripheral equipment of radiometers was also solved, namely power supply sources and systems, direct current amplifiers at the outputs of quadratic detectors, systems for switching on calibration signals of radiometers, and power supply systems for calibration noise generators. All the listed components of the radiometer periphery are made according to uniform schemes and on the same element base. We also unified the data logging systems of the continuum radiometric complexes (see Tsybulev, 2011).

3 Decimeter ranges

The current situation in the decimeter ranges is known to radio astronomers: it is becoming increasingly difficult to observe cosmic radio sources due to the deterioration of the interference situation. The sources of interference are ground-based communication facilities, transport, Earth's artificial satellites, radar, etc.

To build the RATAN-600 radio telescope, a "radio-quiet" place was chosen: in the 60s–70s, there were no interference emissions in the 900–3000 MHz range at the location of the radio telescope. At present, the situation has changed dramatically. This was especially reflected on radio continuum observations when sufficiently wide ($\sim$10 %) frequency bands are required. Therefore, radio astronomers have to shift the bands of their radiometers to the remaining relatively quiet sections of the decimeter ranges, narrow the reception bands, and construct analog and digital interference suppression systems.

One of the current modern methods of active interference suppression is the installation of a digital high-speed spectrum analyzer at the output of the radiometer instead of a quadratic detector. The spectrum analyzer must have a sufficient number of spectral channels and enable a real-time removal of radio interference, synthesizing a wide reception band by summing only "clean" spectral channels and "clean" sections of each channel separately. This will allow maintaining sufficiently wide frequency bands of radiometers. This approach is based on the relatively narrow-band nature of radio interference (communication facilities) in the decimeter wavelength range.

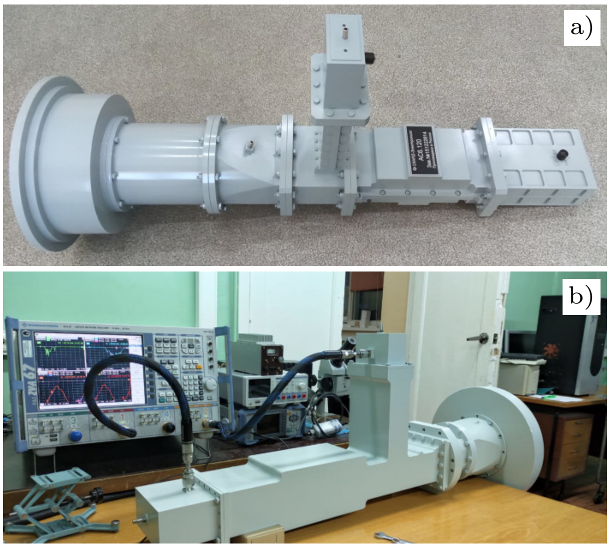

Fig. 2. Dual-frequency antennas of the decimeter ranges 13 and 25 cm: a) designed by AO SKARD-Elektroniks (SKARD-Electronics JSC), Kursk; b) designed by the Special Design Bureau of the Institute of Radio Engineering and Electronics of the Russian Academy of Sciences, Fryazino.

To implement this approach for RATAN-600, two decimeter horn antennas have been designed, each of which has two operating ranges: 1400–1500 MHz and 2200–2300 MHz, see Fig. 2. The phase centers of both ranges are aligned in this antenna. The dual-frequency of the antenna allows saving space on the focal line of the secondary mirror of the radio telescope, as well as reducing the level of off-axis aberrations for these ranges. In addition to forming the operating bands, the antennas suppress interference emissions (GSM 900, GSM 1800, 3G), which eliminates the risk of overloading the radiometer amplifiers. The width of the antenna beam patterns is 110 degrees, which corresponds to the aperture of the operating sector of the RATAN-600 primary mirror.

A further direction of work in the decimeter ranges is designing and manufacturing appropriate digital receiver-spectrum analyzers for the possibility of active interference suppression. Spectrum analyzers will also allow the implementation of a high-speed observation mode for fast radio bursts.

4 Conclusions

All modular radiometers listed in the paper are installed on the receiving complexes of RATAN-600 and included in round-the-clock observations according to approved observational programs. Preparations for installing dual-frequency decimeter horn antennas and manufacturing the corresponding radiometric equipment are in progress. We are currently conducting monitoring and analysis of the interference situation in the decimeter ranges and discussing technical specifications for designing and manufacturing digital receiver-spectrum analyzers.

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