AGREED **APPROVED BY**

Director of the SAO RAS, **Chairman of the Russian Telescope Time Allocation Committee,**

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Circular Letter of the Russian Telescope Time Allocation Committee

The following radiometric complexes are being announced for use at the radio telescope RATAN-600 of the Federal State Budgetary Institution of Science of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) since the beginning of 2019:

1. Radiometers of the continuum of the range 1.0-21.7 GHz (1.0, 2.3, 4.8, 8.2, 11.2 and 21.7 GHz) with bandwidths of ~10-12% relative to the central frequency with the secondary mirror № 1
2. The ERIDAN three-frequency complex at 4.8, 11.2 and 21.7 GHz with bandwidths of ~10-12% relative to the central frequency with the secondary mirror № 2.
3. Multibeam radiometric complex in the 4.7 GHz frequency range for the fast radio bursters (FRB) searching with the secondary mirror № 5.
4. Solar spectral-polarization complex at the frequencies of 0.75-18 GHz with a high dynamic range with the secondary mirror № 3.
5. Solar spectral-polarization complex of high resolution at the frequencies of 3-18 GHz with the secondary mirror № 3.

You will find below a brief description of radiometric complexes and the corresponding observational methods implemented at the RATAN-600, as of early 2017. Detailed information can be found in the library of the SAO RAS or at the home page of the observatory, http://www.sao.ru in the user manual section.

1. Radiometers of the continuum of the range 1.0-21.7 GHz (1.0, 2.3, 4.8, 8.2, 11.2 and 21.7 GHz) with bandwidths of ~10-12% relative to the central frequency with the secondary mirror № 1. **Method: the measurement of radiation intensity in the radio continuum in the frequency range of 1.0-21.7 GHz on the receiving and measuring complex of the continuum with the secondary mirror № 1.**

2. The ERIDAN three-frequency complex at 4.8, 11.2 and 21.7 GHz with bandwidths of ~10-12% relative to the central frequency with the secondary mirror № 2. **Method: the measurement of radiation intensity in the radio continuum at the three-frequency (4.8, 11.2, 21.7 GHz) receiving and measuring complex with the secondary mirror № 2.**

3. Multibeam radiometric complex in the 4.7 GHz frequency range for the fast radio bursters (FRB) searching (secondary mirror № 5). **Method: Measurement of the spectral flux density of radio sources in the frequency range 4.4-5.0 GHz with a high temporal resolution on the multibeam spectral complex of the secondary mirror №5.**

Responsible for the methods 1-2: N.A. Nizhelsky (nizh@sao.ru), P.G. Tsybulev (peter@sao.ru).

Technical features. The current level of the detecting equipment of the RATAN-600 radio telescope is provided by the ultra-low-noise, uncooled amplifiers with high electron mobility transistors (HEMT) and digital signal processors in the data acquisition system.

For the intensity measurements in the radio continuum, three radiometric complexes are used (Table 1a, b and c):
1) At the frequencies of 1.28, 2.3, 4.8, 8.2, 11.2 and 21.7 GHz, located at the secondary mirror № 1 (Table 1a).
2) The ERIDAN three-frequency complex at 4.8, 11.2 and 21.7 GHz, located at the secondary mirror № 2 (Table 1b).
3) At the frequencies of 4.7 GHz, located at the secondary mirror № 5 (Table 1c). A quadratic detector is installed at the output of each "narrow" channel. The data are recorded in the "Total power radiometer" (TPR) mode, so the radiometric complex consists of 16 independent radiometers. Dividing the 600 MHz band into 4 sub-bands allows you to measure the dispersion of radio waves in an interstellar medium. The presence of such dispersion is a sign of a distant radio source (and not local interference). Signals are recorded using a standard data acquisition system with a frequency of 16384 counts per second for each of the 16 channels. Four radiometers on the Western sector of the RATAN-600 antenna allow you to observe 4 adjacent parts of the sky simultaneously, thereby expanding the view field 4 times.

All the continuum radiometers of the RATAN-600 are the direct receivers of the microwave signals in the given frequency bandwidth square-law detection for obtaining the output signal. The operating mode of all the receivers is "total power radiometer". The data is collected using a regular universal registration system based on the new hardware-software subsystem ER-DAS (Embedded Radiometric Data Acquisition System) [1].

Table 1a. Parameters of broadband receivers of the RATAN-600 (secondary mirror №1, six-frequency complex).

f_0 (GHz)	Δf_0 (GHz)	ΔF (mJy/beam)	BW sec	AR arcsec
21.7	2.5	50	1.0	11
11.2	1.4	15	1.4	15.5
8.2	1.0	10	2.0	22
4.7	0.6	5	3.2	35
2.25	0.08	40	7.2	80
1.28	0.06	200	10	110

Table 1b. Parameters of broadband receivers of the RATAN-600 (secondary mirror №2, three-frequency complex «Eridan»).

f_0 (GHz)	Δf_0 (GHz)	ΔF (mJy/beam)	BW sec	AR arcsec
21.7	2.5	95	1.5	16.5
11.2	1.0	30	2.1	23
4.7	0.6	10	4.8	53
2.25*	0.08	80	11	121

* - tested;
f_0 – central frequency (GHz);
Δf_0 - bandwidth (GHz);
ΔF - sensitivity by the spectral density of the flow per unit of the resolution element (mJ/beam);
BW is the width of the diagram for average heights (δ ~ 42 °);
AR - angular resolution for medium altitudes.
BW – width of the beam pattern for medium altitudes (δ~42°);

Table 1c. Technical characteristics of the RATAN-600 receiving complex №5 (for each radiometers).

B (GHz)	Δf (MHz)	ΔF (mJy/beam)	$HPBW_x$ (sec)	AR (arcsec)
4.40-4.55	150	10	3.2	35

4.55-4.70	150	10	3.2	35
4.70-4.85	150	10	3.2	35
4.85-5.00	150	10	3.2	35

B – received radiometer band;
ΔF - flux density sensitivity, calculated for the maximum integration time when observing a discrete radio source (~ 4 s).
f_0 – central frequency (GHz);
Δf_0 - bandwidth (GHz);
B – received radiometer band;
ΔF - sensitivity by the spectral density of the flow per unit of the resolution element (mJ/beam);
BW is the width of the diagram for average heights (δ ~ 42 °);
AR - angular resolution for medium altitudes.
BW – width of the beam pattern for medium altitudes (δ~42°);

Instrumental parameters. The angular resolution of the radio telescope depends on the height of the antenna installation. Its value by declination is three to four times worse than in the right ascension, due to the knife-shaped beam pattern. The detection limit of the radio telescope is about 8 mJy (accumulation time 3 sec) at 4.8 GHz at medium angles under good weather conditions.

The radio telescope RATAN-600 is a radio telescope with an antenna of a variable profile [2-7]. RATAN-600 is a reflector type radio telescope with an antenna of a variable profile [2-7], that is, both the aperture and focal length of its antennas change depending on the elevation of the object. The elevation of the antenna varies from 3.5° to 97°. The focal length varies from 155 m to -40 m (from the center of the circle). At the same time, the aberration zone in the focus of the secondary mirror changes significantly: the greater the focal length, the less the focal image of the source is distorted. Such features of the RATAN-600 antenna geometry allow measuring the flux densities of the source in the same antenna position in the frequency range from 1.0 to 21.7 GHz for 1-2 minutes. Independent observations can be carried out on two antenna sectors in three configurations: the Northern sector, the Southern sector, the Southern sector with a Flat reflector. The following declination ranges are available:

(i) Northern sector: -42°<DEC<+50° (it is necessary to use the "fixed" focus mode at low declination).
(ii) Southern sector:
in the upper culmination: +72°<DEC<+90°,
in the lower culmination: +49°<DEC<+90°.
(iii) Southern sector with a Flat reflector: -42 ° <DEC <+71 °. Objects with DEC>71° can only be observed in the mode from item (ii).

Observations with the Northern sector are carried out with the radiometric complex of the secondary mirror №1. Observations with the Southern sector and the Southern sector with a Flat reflector are performed on radiometric complexes of secondary mirrors №2 and №3 (see the methods 4-5).

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4. Solar spectral-polarization complex at the frequencies of 0.75-18 GHz with a high dynamic range with the secondary mirror № 3. **Method: Measurement of radio emission (intensity and polarization) of discrete radio sources and the Sun in a large dynamic range up to 60 dB at the frequencies from 3 to 18 GHz at the spectral-polarization complex with the secondary mirror №3.**
Responsible for the method is A.A. Storozhenko (asc-work@mail.ru)

The functionality of the complex is related with a significant increase in the dynamic range for the purpose of registering reference sources in the microwave waveband at the levels of both the limiting sensitivity for this instrument and for recording the brightest radio sources on the Sun reaching millions of degrees of the antenna temperature. This is achieved by the introduction of automatic attenuators on the signal amplification lines across all channels of the complex. The complex can be used for a variety of antenna measurements, as well as for powerful signals from geostationary satellites. The complex was installed in 2016 in the RATAN-600 receive cabin № 3, which is working at the southern sector antenna system with a Periscopic reflector for conducting multiple observations of the dynamics of the Sun in azimuths and in tracking modes.
A full power mode of the receivers with registration of right and left circular polarizations on all channels is realized.
All necessary features of the complex during the observations, such as the rapid analysis and full reduction of observations are also realized in the automatic mode. The format of the observational data is consistent with the observational database existing since 1995.

Parameters of the complex:
Frequency range: 3.0 GHz – 18 GHz;

2 levels of frequency resolution: 1st level: 80 channels, bandwidth of 100 MHz,
2nd level: 10 channels, bandwidth of 1500 MHz;
Registration speed: 0.0025 sec/112 channels;
Noise temperature: 300 K;
Dynamic range:> 60 dB;
Inter-channel decoupling:> 20 dB;
Ellipticity: (1-5)%;
The width of the horn diagram in the entire range: +-60 degrees;
The decoupling between the RH and LH polarizations:> 20 dB;
The offset of the phase centers for RH and LH: 0.5 mm.

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5. Solar spectral-polarization complex of high resolution at the frequencies of 3-18 GHz with the secondary mirror №3. **Method: the measurement of radio emission (intensity and polarization) with frequency resolution up to 1% in the frequency range 0.75-18 GHz with secondary mirror № 3.**

Responsible for the method is V.M. Bogod (vbog@sao.ru).

Technical features. Designed complex is aimed for wide wavelength analysis of solar structures with a high-precision of polarization. It was installed in 2005 in the receive cabin of the RATAN-600 secondary mirror № 3 in the southern sector antenna system with a periscope mirror for conducting multiple (up to 60) observations per day for study of the solar structures dynamics. The process of the observations at the complex is fully automated, including express analysis and complete processing of observations. A database of observations has been created and is regularly expanded.
The combination of a RATAN-600 large effective surface with the multi- frequency simultaneous observations (4.5 octaves) at 112 frequency channels and with a frequency resolution of 1% and with high accuracy of circular polarization (0.05-0.1%) is unique and distinguish the RATAN solar data from other instruments in the world. The solar observations are performed repeatedly for 4 hours around midday in the multi-azimuth mode with a single phase center at all frequencies.
Methodical features. The unique methods for measuring coronal magnetic fields in the lower corona of the Sun have been implemented.
Astrophysical features. World priorities are achieved in the measurements of coronal magnetic fields for a number of objects on the Sun. Also the measurements of the height magnetic field structure e above the spots are unique. The results of observations are regularly posted on the websites http://www.spbf.sao.ru/prognoz/ and http://www.sao.ru/hq/sun/. Observations are reduced in the automatic mode. The multi-wavelength database of solar radio astronomical observations with a high one-dimensional resolution has been created and continuously updated.
Instrumental parameters:

Frequency range: 0.75–18 GHz;
Number of channels: 112;
Spectral resolution: 1% with a 100 MHz frequency analysis band;
Registration speed: 0.0025 sec/112 channels;
Noise temperature: 300 K;
Dynamic range:> 100000;
Inter-channel decoupling:> 20 dB;
Speed of RH and LH polarization switching: 400 Hz;
Ellipticity: (1-5)%;
The width of the horn diagram in the entire range: +-60 degrees;
The decoupling between the RH and LH polarizations:> 20 dB;
The offset of the phase centers for RH and LH: 0.5 mm.