

# METROLOGICAL SUPPORT OF MICROWAVE RADIOMETERS REMOTE SENSING OF THE EARTH

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Most of tasks on development of methods, technologies and systems of RSE are solved on the basis of manufacturing and use of the equipment of middle and high sensitivity in optical, IF and microwave (MW) ranges. The modern IF and MW radiometric devices (a range of wavelengths is from 4  $\mu\text{m}$  up to (0,75 mm – 0,5 m)), mounted on artificial Earth satellites allow to obtain global observation data of fields of terrain covers own electromagnetic radiation, World ocean and an atmosphere (differ from the optical range where the reflected sunlight is received).

Own thermal electromagnetic radiation of terrain objects in the MW range has behavior of noise radiation which in open space is characterized by brightness temperature (physical quantity – Kelvin), or spectral density of energy brightness (SDEB) – physical quantity's  $\text{Wt}\cdot\text{m}^{-2}\cdot\text{Hz}^{-1}\cdot\text{sr}^{-1}$  and in the closed paths is characterized by noise (or antenna) temperature (physical quantity – Kelvin) or spectral density of noise power (SDNP) – physical quantity  $\text{Wt}\cdot\text{Hz}^{-1}$ .

In the MW radiometry of RSE required parameters of radiating objects and processes of terrain, atmosphere and ocean are obtained from brightness temperatures or SDEB measured on different frequencies, under different angles, with the different frequency and spatial sensitivity, on different polarizations. For reconstruction of environment characteristics one of the impotent condition is a requirement of high accuracy of brightness temperatures measurements. The basic requirements to the modern RSE MW radiometers include the following [1]: spectral range – 3-220 (400) GHz, receiver's sensitivity ( $\tau=1$  sec) – (0,1 $\div$ 0,05) K, polarization – V, H, intermediate, stream effectivity of antenna system (on the main beam level of the directivity pattern) – 0,95 $\div$ 0,98, instability of spectral channel transfer factor (from 1 sec) –  $5\cdot 10^{-4}$ , onboard calibration level – (~2,7; ~270; ~300; ~340) K, onboard calibration error – (0,3 $\div$ 0,5) K, nonlinearity of spectral channel transfer factor –  $5\cdot 10^{-4}$ , cross-polarization factor – -(25 $\div$ 30) dB, transfer factor change during operation time (3-5 years)–  $\leq \pm 3$  dB, radio-brightness temperature measurements error – <1,0 (0,5) K.

Providing of unity and correctness of radiometric measurements is a complex task includes manufacture of the tool; development and certification of standard calibration and measurements means; onground preflight and onboard calibration procedures development and certification; measurement methodics development and certification; MW radiometers preflight examination with finding out of their metrological characteristics in conditions as much as possible approached to the conditions of space flight.

In this sequence tasks of basic measured values (brightness and noise temperatures or SDEB and SDNP) standards development and certification, MW radiometers antennas' parameters standard measurement instrument (MI) development, metrologically certificated measurement methodics development, MW radiometers calibration and examination are now constitutive.

For all that huge importance of brightness temperature measurements (SDEB) there is no the national standard of these units in the MW range in any country. At the same time in optical and IF ranges such standards exist in Russia and other countries.

Absence of the national standards of BT and SDEB in the MW range is conditioned by the following reasons:

1. A lot of developers manufacture their own working standards – heated, cooled or passive wide-aperture radiators. Such radiators calibration is realized by the developers under

individual procedures, there is no comparison between radiators of the different manufacturers and countries.

2. In the MW radiometry quite a lot of applications are solved by use of relative methods of measurements. In relative methods it is often possible to do measurements without an absolute standard.

3. As natural standards are often applied or astronomical sources (background space radiation, radiation of stars and planets or their satellites) either radiation of atmosphere or radiation of homogeneous area of terrain with well enough investigated characteristics of its emission. Metrological characteristics of such natural standards and convenience of their application often do not meet modern requirements.

MW satellite radiometers pretend on uncertainties (errors) of measurements not worse 0,5 K have been already developed. For achievement of such small values and validation of their accuracy complex efforts are necessary – well known and certificated onboard and on-ground calibration means (working standards), metrologically certificated measurement and calibrations procedures, preflight examination means and methods capable besides of fail-safe checks to define metrological characteristics of the whole measuring complex including a MW radiometer, an onboard system of data processing and transmission, onground system of data reception and processing, i.e. all this complex of the equipment has to be examined and certificated as a single mean of measurements. For successful solution of such problems development of the national standard (NS) in the MW range of BT unit and SDEB unit is necessary with errors of reproduction and transfer not worse than  $(0,2 \div 0,5)$  K.

To the same conclusions NIST's experts came where in the last some years intensive preparation work on development of national standards of BT unit in MW and terrahertz ranges are conducted [2, 3].

In the last 10-15 years in FSUE "VNIIFTRI" works on development of standard wide-aperture radiators – working measures of brightness temperatures in a range of frequencies from 6 GHz up to 220 GHz have been going on. YBT 95-A-2000 (highest accuracy installation (HAI)) for reproduction and transfer of the BT and SDEB unit size in the MW range of the spectrum from 18 GHz up to 118 GHz and a calibrating procedure for means of brightness temperatures measurements (МИ 2605-2000) [4] were authorized in 2000. Low-temperature wide-aperture radiators LTWAR 100 (the aperture's 100 mm) cooled by liquid nitrogen as the standard measure are used in the HAI. Confidential borders of the LTWAR 100 certification error (at confidential probability  $P=0,95$ ) over BT are equal  $(0,5 \div 1,5)$  K. The error of BT unit size transfer to the working standards of 1-st category –  $(0,5 \div 2,5)$  K.

Excluding the LTWAR 100 some types of low-temperature wide-aperture radiators have been developed differ by apertures ( $\varnothing 100\text{mm}$ ,  $\varnothing 200\text{mm}$ ,  $\varnothing 300\text{mm}$ ,  $\varnothing 500\text{mm}$ ) and frequencies of certification, and also wide-aperture radiators for MW radiometer onboard calibration (a range of frequencies from 140 GHz up to 220 GHz) of Chinese weather satellite FY-3 (prospective launch – May, 2008). The general part of works were carried out under custom projects for the space institutes of Chinese People's Republic develop MW satellite radiometers for natural resource and meteorological purpose.

Functioning at the present time in FSUE "VNIIFTRI" the national primary standard (NPS) of SDNP unit and noise temperature ( $\Gamma_{\text{ЭТ}} 21-91$ ) in coaxial and waveguide pathes was certificated in a range of frequencies from 2 MHz up to 178 GHz. As primary standard measures of noise temperature unit are used cooled by liquid nitrogen low-temperature generators of noise (LTGNs). In a range of frequencies from 2 MHz up to 12 GHz (coaxial LTGNs) not excluded systematic error (NESE) of reproduction's  $\theta=0,3$  K, and standard deviation's (SD)  $S=0,1$  K at  $\dot{O}_{\text{OE}}^{\dot{Y}} = (78,8-84,6)$  K (depending on a frequency) and in a range of frequencies from 5,6 GHz up to 178 GHz (waveguide LTGN)  $\theta = (0,2 \div 0,9)$  K,  $S = (0,1 \div 0,6)$  K at  $\dot{O}_{\text{OB}}^{\dot{Y}} =$

(78,4÷122) K. Confident borders ( $P=0,95$ ) of functioning LTGNs calibration error in a range of frequencies from 12 GHz up to 178 GHz changes from 0,5 K up to (2-4) K. Waveguide standard LTGNs of NIST (USA) were certificated in a range of frequencies from 18 GHz up to 325 GHz with errors  $\sim (0,3\div 2,1)$  K at  $\dot{O}_{OB}^y \approx 76$  K. Therefore there is an instrument and methodical basis of the remote sensing MW radiometers metrological support in FSUE "VNIIFTRI".

Providing of measurements unity in the country means first of all traceability of all brightness temperatures measurement means to the national standard of brightness temperature and SDEB unit in the microwave range of the spectrum.

Required characteristics of the MW radiometers in lots of ways surpass parameters of existing standards base (on error value, a range of the frequencies, required antennas' apertures, etc.), therefore for the metrological support of the MW satellite radiometers designed for errors of brightness temperatures measurements  $\leq 0,5\div 2,0$  K in a range of frequencies from 5,0 up to 220 GHz it is necessary to implement the following works:

1. On the basis of YBT 95-A-2000 to develop the NPS of brightness temperature unit and spectral density of energy brightness unit in a range of frequencies from 17 GHz up to 178,3 GHz, in the future from 5 GHz up to 220 GHz (400 GHz).

2. On the basis of YBT 96-A-2000 to develop the NPS of unit of effective area and gain factor of the directed antennas with apertures up to 0,8 m in the MW range of the spectrum from 17 up to 178,3 GHz, in the future from 3 GHz up to 220 GHz.

Proposed standards will provide execution of onground and onboard calibrations of the most part of MW radiometers of RSE in the physical units reproduced by the national standards, their examinations for the purposes of the type certification, certification of measurement methodics and calibrations. The means of metrological support have developed will allow to obtain valid data of remote measurements with guaranteed, metrologically valid accuracy, i.e. will allow to have qualitative, competitive in relation to the foreign data, completed information product.

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