Use of the Sun's radiothermal radiation as an external source for research of multi-frequency microwave radiometric system antenna parameters with background noise compensation

I N Rostokin¹*, E V Fedoseeva¹, E A Rostokina¹ and G G Shchukin²

¹Vladimir State University named after A.G. and N.G. Stoletovs Murom Institute, 23 Orlovskaya Str., Murom, 602264, RUSSIA

²Military Space Academy named after A.F. Mozhayskogo, 13 Zhdanovskaya Str., St.-Petersburg, 197198., RUSSIA

* Corresponding author’s e-mail: rostockin.ilya@yandex.ru

Abstract. The work belongs to the field of solving problems related to the metrological support of microwave radiometric research of radiothermal radiation of the atmosphere. The article contains a comparative analysis of the most widely used reference sources of noise radiation used both for internal and external calibration of microwave radiometric equipment for atmosphere control. In the given work the research of a method of external calibration of the antenna system of multifrequency microwave radiometric system with compensation of background noise on radiothermal radiation of the Sun is executed, questions of its practical realization are solved and results of an estimation of directional properties of the antenna system of microwave radiometric system on radiothermal radiation of the Sun are received. The results of practical research of the directional properties of the antenna system of a stationary variant of the multi-frequency microwave radiometric system, consisting in measuring the experimental antenna radiation pattern of the multi-frequency two-mode antenna system on the main measuring channel on two linear polarization (vertical and horizontal) and additional measuring channel with a predominant reception of background radiation coming from the side lobes are presented.

1. Introduction
The radiometer calibration procedure is an integral part of every observation. The calibration procedure shall meet two conflicting requirements. On the one hand, the duration of the calibration signal shall be long enough to ensure a reliable assessment of the calibration level, i.e. channel gain. On the other hand, an increase in the calibration duration increases the probability of pulse interference and trend. Calibration of a radiometric system is usually performed using an internal semiconductor noise generator [1].

The procedure of radiometric system calibration is performed to establish an unambiguous correspondence between the measured radio-luminance temperature of the object under investigation and the radiometric receiver output signal. Usually the radiometric system calibration is performed separately for the antenna and for the radiometric receiver [2].
2. Reference noise sources used for calibration of microwave radiometric equipment

The main instrument used to calibrate radiometric receivers, to determine their sensitivity or to measure the system noise figure is the semiconductor noise generator (figure 1a) with known radiation intensity.

To measure the power of noise signals using a radiometer, the complete scheme of the latter includes a standard voltage source, which can be connected instead of the antenna and used to calibrate the radiometer receiver. Noise generators are used as such sources, because their emission spectrum quite fully reflects the spectrum of received radiothermal radiation. Therefore, when using noise generators, the form of frequency response of the radiometric receiver does not affect the measurement results.

Depending on the type of the object under investigation and the type of receiver, different calibration tools and methods of their certification can be used.

As a starting point thermal noise generators that are cooled or heated devices in the form of coordinated loads or cavities with a radiant aperture whose characteristics are close to those of the "black body" are usually used.

![Reference Sources of Noise Radiation](image)

(a) high-temperature gas discharge noise generator  
(b) high temperature semiconductor noise generators  
(c) COLFET - low-temperature semiconductor check source  
(d) low-temperature, nitrogen-cooled noise generator  
(e) low-temperature wide aperture radiators

**Figure 1.** The most common reference sources of noise radiation.

Noise generators control the stability of the radiometer gain and the coefficients included in the algorithms for calculating measured brightness temperatures. Well-matched loads whose temperature is usually equal to the temperature of the radiometer elements are used as noise generators embedded in the radiometer.

The modern analogue of a low-temperature reference source based on liquid nitrogen (figure 1d) is a semiconductor reference source based on COLFET - effect.

COLFET (figure 1c) is a semiconductor analogue of a noise generator based on liquid nitrogen. A cryogenic equipment is not required, because device operated at room temperature. It emits a noise temperature of 33 to 60 K in the range of 20-24 GHz, the supply voltage regulator ensures that the output noise temperature is constant.
Low Temperature Wide Aperture Radiators (LWRs) (figure 1e) produced by "VNIIFTRI" are used as reference and working measures of radio brightness temperatures at primary calibration of microwave radiometers in the frequency range from 3 to 220 GHz and have a radiation coefficient from 0.9985 to 0.99997 and boiling noise temperature of pure liquid nitrogen \( \approx 77.0 \) K depending on the atmospheric pressure, determined by the following ratio:

\[
T_N = 77.36 + 0.011(p-760),
\]

where \( p \) - atmospheric pressure, mmHg.

Structurally (LWRs) are a closed volume, in the nutrient which is placed in the transmitter, made of mono-silicon and cooled with pure liquid nitrogen, the line of produced (LWRs), differs in the diameters of the radiating apertures (100, 210, 300 and 500 mm) and frequencies of certification [3].

All of the above reference sources of noise radiation allow for internal calibration of a microwave radiometric receiver, or microwave radiometric systems that have receiving antennas of small size, not exceeding the size of the emitting apertures of low-temperature wide aperture radiators.

3. Use of the Sun's radiothermal radiation as a reference source

Radiothermal radiation of the Sun is determined by physical processes occurring in its subsoil and mainly in its upper layers, as well as by the structure of these layers, consisting of photosphere, chromosphere, and corona [4].

The radiation of the Sun has two components: the radio-thermal radiation of the calm Sun and the non-thermal sporadic radiation.

Thermal nature of radio emission is due to the fact that the magnetic fields in the chromosphere and the corona of the calm Sun are small, and the kinetic temperature of ionized gas is quite high, ie there is a hot plasma in the weak magnetic field, the most effective mechanism of radiation, which is the inhibitory radiation [5].

The expression for the determination of the radio-brightness temperature of the tranquil Sun, using the microwave radiometric method, can be recorded as follows:

\[
T_\bigodot = \frac{\varepsilon_M T_{CMB} (Y-2)\delta^2/\delta_{HPBW}}{\varepsilon_M (1-2)\delta^2/\delta_{HPBW}},
\]

where \( T_\bigodot \) - angular size of the Sun, equal to 0.5 degrees; \( \varepsilon_M \) - the efficiency of the main petal of directional diagram antenna,

\[
\varepsilon_M = \frac{\delta_{HPBW}}{16 \ln^2} D_{MAX},
\]

where \( \delta_{HPBW} \) - width of the directional diagram by half power level, in radians; if the width of the directional diagram is set in degrees, then

\[
\varepsilon_M = \frac{\pi^2}{518400 \ln^2} \delta_{HPBW}^2 D_{MAX},
\]

\( D_{MAX} \) - antenna gain at maximum,

\[
D_{MAX} = N \frac{16 \ln^2}{\delta_{HPBW}}
\]

\( N \) - normalized multiplier, \( N = \varepsilon_M \),

\( T_{CMB} \) - temperature of the cosmic microwave background,

\( T_{CMB} \approx 2,725 \) K

\( Y \) - factor, determines the ratio of the level of maximum noise signal output of the receiver when the antenna orientation on the Sun to the signal level when the main petal is oriented to the “cold sky”,

\[
Y = \frac{T_{HOT}+T_{SYS}}{T_{COLD}+T_{SYS}},
\]

where \( T_{HOT} \) - temperature of the noise signal in the aperture of the antenna when it is oriented to the Sun,
where \( L_{ATM} \) - atmospheric attenuation; \( T_{ATM} \) – atmospheric noise temperature; \( T_{COLD} \) - the temperature of the noise signal in the antenna aperture when it is oriented to the "cold sky",

\[
T_{COLD} = \frac{\varepsilon_M}{L_{ATM}} T_{CMB} + \varepsilon_M \left( 1 - \frac{1}{L_{ATM}} \right) T_{ATM},
\]

\( T_{SYS} \) - intrinsic noise temperature of the receiving system,

\[
T_{SYS} = T_{RCV} + T_{SPIL}.
\]

where \( T_{RCV} \) - microwave radiometer noise temperature, \( T_{SPIL} \) – background noise temperature of the antenna, coming from the side and rear petals directional diagram.

4. Experimental Studies of Radio Thermal Radiation of the Sun

This section presents the results of practical studies of the directional properties of the antenna system of multi-frequency microwave radiometric system, which consists in measuring the experimental diagrams of directional multi-frequency two-mode antenna system on the main measuring channel on two linear polarization (vertical and horizontal) and additional measuring channel with a predominant reception of background radiation coming from the side lobes [6, 7].

Studies of directional properties were carried out in the far zone of the antenna system in an open polygon, as an external source was used radio-thermal radiation from the Sun.

Figures 2-4 show experimental diagrams of directionality of the mirror antenna of a multi-frequency microwave radiometric system measured by the radiothermal radiation of the Sun [8].

Figure 2. Channel 7.5 cm, dated 23.03.2017: 1 - wave \( H_{11} \) (horizontal polarization channel), 2 - wave \( E_{01} \) (compensation channel), 3 - wave \( H_{11} \) (vertical polarization channel).

Figure 3. Channel 3.2 cm, dated 23.03.2017: 1 - wave \( H_{11} \) (horizontal polarization channel), 2 - wave \( E_{01} \) (compensation channel), 3 - wave \( H_{11} \) (vertical polarization channel).

Figure 4. Channel 1.35 cm, dated 23.03.2017: 1 - \( H_{11} \) wave (horizontal polarization channel).
With this method of measurement, directional diagram of the antenna remains stationary relative to the surface of the Earth, thus excluding possible changes in the level of background radiation of the atmosphere and the underlying surface formed by the rear and side petals of directional diagram of the studied antenna, and changes in the level of received radiation of the Sun is due to the rotation of the Earth around the Sun [9].

Table 1 shows the main parameters of the direct-focus mirror antenna of the multi-frequency microwave radiometric system.

Table 1. Basic patterns of directionality of the microwave radiometric system antenna.

| Parameters                  | Values       |
|-----------------------------|--------------|
| 1. Aperture diameter, mm.   | 2400         |
| 2. F/D ratio                | 0.375        |
| 3. Wavelength, cm.          | 7.5          |
| 4. HPBW                     | 2.13         |
| 5. Directivity, dB.         | 39           |
| 6. Sidelobe level, dBC      | ≤35          |
| 7. Polarization.            | H/V          |

Conclusion
In the case of the use of directional high gain mirror antennas with large emitting apertures with sizes from 1000 to 5000 mm, there is a problem of external calibration of microwave radiometric equipment together with the antenna system [10].

The use of aperture radiators located at the far end of the antenna pattern has significant guidance difficulties and requires large antenna ranges.

In this case the most expedient method of calibration of microwave radiometric measuring equipment together with the antenna system can be the use of natural standards of spectral density of energy brightness. Astronomical sources (relict cosmic radiation, the radiation of stars and planets or their satellites) or the radiation of a cloudless atmosphere are traditionally used as such.

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