Radiometeorological research at the Murom Institute

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Abstract. The history and current state of research on the atmosphere remote sensing at the Murom Institute of Vladimir State University (MI VlSU) from the creation of the first radiometric receivers in the early 70s to the modern "Radiophysical Research of Natural Environments" laboratory are considered.

1 History of the radio-meteorological field origin at MI VlSU

Research related to the creation of radio-meteorological systems and complexes started at the beginning of the 70's by V.V. Falin, a young assistant of VZMI Murom branch.

At this stage, the development of microwave radiometric equipment was carried out for Vysokogorny Geophysical Institute (VGI, Nalchik), the Institute of Oceanology (IO, Moscow), and the Central Aerological Observatory (CAO, Dolgoprudny). The task of creating own microwave radio-meteorological complex was also solved [1].

On the basis of the SON-4 gunnery station, a transportable version of the complex with a 2.5 m antenna was made. The field tests of the produced equipment, carried out in different areas of the country, confirmed the performance of the complex, and in 1976, using the antenna column from SON-4, a four-channel radiometric receiver was installed on the roof of the Radio Engineering Faculty of the Institute, as the basis of the complex.

In the research, carried out under the guidance and with the direct participation of V.V. Falin (later Doctor of technical sciences, professor, the head of the department) there also participated such scientists as S.P. Gineotis, R.V. Pervushin, V.V. Kostrov, V.A. Nikolaev, V.V. Bulkin et al.

2 Microwave radiometric receiving complex

The four-channel version of the receiver with $\lambda 1 = 0.8$ cm, $\lambda 2 = 1.35$ cm, $\lambda 3 = 1.6$ cm, $\lambda 4 = 3.2$ cm wavelengths was chosen to construct the complex [2].

The antenna system was installed on the roof of the technical floor of the Institute building (figure 1). All microwave elements of modulation radiometers were combined into

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one cylindrical block, placed in front of the antenna on three straps so that the combination of receiving horns and the antenna focus point was the maximum. Shading of the mirror opening did not exceed 1.5%. At the same time for the wavelengths of 1.35 and 1.6 cm a two-wave radiometer, working for one irradiator (input horn) was used. Its distinctive feature was the modulation unit, which was an active-passive ferrite system consisting of a three-arm switch and two Y-circulators included between the output arms of the switch and the inputs of the two receivers.

The radiometer sensitivity control was calibrated by the built-in noise generators (NGS), connected through a directional coupler.

The low-frequency part was structurally made in the form of a modular design cabinet. A separate structural module was used for each of the channels. Connection with the UHF unit was carried out by coaxial cables.

To control the cloudiness height we used an airborne radar station (RLS) ROZ-1, which transceiver unit was mounted on the "counterweight" antenna column (figure 1). Such a location of the unit provided a better balance of the antenna system.

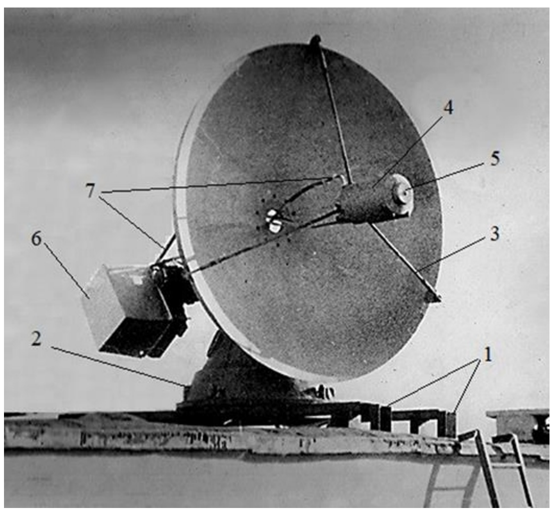

Fig. 1. Antenna system of the complex: 1 - Bearing frame; 2 - Antenna column; 3 - Mounting straps; 4 - Microwave part of the radiometer; 5 - Vent hole cover; 6 - Radar transceiver; 7 - Radar waveguide.

Parameters, characterizing the radio telescope antenna system and sensitivity of radiometers are presented in table 1.

Table 1. Radio telescope parameters.

Parameter	λ1=0,8 cm	λ2=1,35 cm	λ3=1,6 cm	λ4=3,2 cm
Measured DN width, minutes	26.4	37.57	38.2	75
Estimated DN width, minutes	25.5	36	39	78
Measured deviation, minutes	0	57	57	-85.7
Estimated deviation, minutes	0	34	34	-58
Measured level of lateral radiation,	10	12.7	11.5	8

dB				
Estimated level of lateral radiation, dB	20	9	15	13
Sensitivity for radio brightness temperatures, K	0.5-1^0K			

The radar was switched on in active mode only "in the zenith" position and with the radiometers switched off. The orthogonal location of the receiving horns of radiometers and radar transmitter also increased the decoupling level. Cloud height control was carried out by the PPI.

The necessity to develop a system for radio waves attenuation measurement in precipitation was the reason of continuation of the work aimed at creating the equipment and taking measurements of condensed water phase total radiation. In order to obtain real wave attenuation data a trace system was constructed.

A scheme using a double trace of the signal was chosen. Such a solution corresponded to the use of active-passive type system, built on the principle of near-field radiolocation systems with frequency modulation, which provided the use of one generator – a reflective klystrone, modulated by frequency with deviation less than 5 MHz as a source of emitted and heterodyne signal.

The complexity of the received signal analysis with an exact coincidence of the antenna pattern center with the corner reflector axis was to identify the modulation component and, as a result, the difference frequency signal, which determined the nature of signal changes when passing through the trace with precipitation.

The measuring trace was formed between two buildings. Rotary devices with antennas and microwave part were placed under the roof of the technical floor of the main building of the institute, which protected the antenna mirror surface from direct rain. Working wavelengths were 0.8 cm and 1.6 cm. The reflector was of an angle type, the length of the trace was 170 m [3, 4].

The measurement of the change in signal attenuation at the level of not less than 0.05 dB was ensured.

3 Passive-active radar station

The next stage in the development of radio-meteorological systems at the Murom Institute is connected with the Main Geophysical Observatory (MGO, Leningrad). During this period, the main attention was paid to the creation of a passive-active radar location station (PARLS).

The disadvantages of passive and active weather radiolocation are well known. In the first case, the main disadvantage is the impossibility of determining the spatial dimensions of various clouds or other formations (for example - precipitation zone), their range. In the second case, a significant problem is the lack of unambiguous links between the radar reflectivity and water content of clouds and precipitation, which is mainly due to the strong dependence of the radar reflectivity on the spectrum of sizes and velocities of droplets falling (dependence on d6).

In the 70s, G.G. Shchukin formulated the principles of constructing passive-active radio-meteorological systems. According to this method, the average water content of the cloud along the sounding direction was determined by the ratio of the cloud water content along the sighting direction, determined using a passive channel (radiometer) and the length of the probed cloud (rain) zone, determined using an active channel (radar).

The passive channel was the main channel for obtaining information about the state of the meteorological object, while the active channel was used to determine the distance to the detected object and its geometric dimensions. In this connection, the principles of passive-active sounding were initially based on the techniques used in passive monitoring.

The applied use PARLS is the detection of an aircraft possible icing areas.

As a basis for the PARLS construction, an aircraft weather navigation station "GROZA" was used. From a structural point of view, the "GROZA" station was almost ideal for the PARLS creation, because it consisted of two transceiver units - the main and reserve, which are located on one frame and are connected to the antenna-feeder system through a waveguide switch [7]. Thus, one of the blocks was used as an active channel (AC), and in the case of the other one the receiver of the passive channel (PC) was made, which solved the issue of minimizing the dimensions.

Instead of the waveguide switch, a geometrically matched Y-circulator was installed, by means of which two problems were solved: connection of the AC or PC to the antenna and electromagnetic decoupling of channels. The passive channel was a modulation radiometer of superheterodyne type with a transducer on Schottky barrier diodes. The IFA was made on two amplifiers with a bandwidth of 700 MHz and a total gain of 50 dB with a noise factor of 4.5 dB. This allowed obtaining a fluctuation threshold of radiometer sensitivity of 0.3 K at a time constant τ=1 s.

Synchronization of the channels was carried out using the first half-period for the active channel, and the second half-period for the reception of radio-thermal radiation (passive channel) [7].

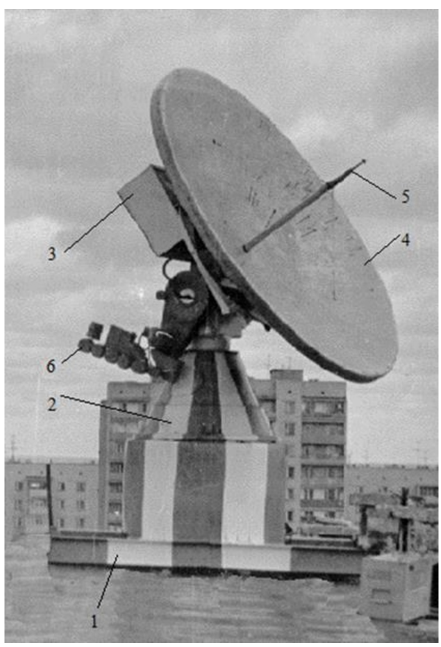

Fig. 2. PARLS antenna system: 1 - supporting frame; 2 - antenna column; 3 - location of AC and PC; 4 - parabolic reflector; 5 - an irradiator; 6 - counterweight.

Of course, "GROZA" too clearly lost on the basic parameters to such weather radars as MRL-2 or MRL-5. However, as calculations have shown, in the case of the antenna diameter of 3000 mm a meteorological potential of MNRLS "GROZA" (274 dB) becomes comparable to the potential of MRL-2 (283 dB).

The most difficult was the question of electromagnetic compatibility of units, which is due to the influence of a powerful probe pulse transmitter on the receiver PC and the effect of heterodyne PC on the receiver AC.

The elements of the decoupling unit (Y-circulator, arrester and modulator) at the frequency of the transmitter provided a transient attenuation of about 80 dB. Additionally, a shift of the central frequency of the PC UF bandwidth and blanking of the heterodyne at the probing pulse emission was carried out. Besides, an additional soft permalloy shield for the PC was used, which provided another 30...35 dB. As a result, a decoupling level of about 160 dB was provided [8].

For the stationary complex the second aerial column from SON-4 was installed on the roof of the Institute and in addition between the frame and the column a "pedestal" was fitted which provided the installation of an aerial 3 m in diameter. The frame with AC and PC was installed on the same support structure as the antenna mirror. This solution provided a reduction in the length of the waveguide to the transmitter and allowed to avoid the use of rotating joints.

The antenna system PARLS is shown in figure 2.

The PARLS tests were carried out as part of the ground complex [7] at the MGO "Turgosh" using the MRL-2 station. The characteristics of the system are presented in table 2. The second version of the system was installed onboard the MGO IL-18 laboratory aircraft [9].

Table 2. Parls parameters.

Parameters	**Values**
Active channel	
Impulse power, kW.	9…14
Probing pulse duration, μs.	3.5
Working wavelength, cm.	3.2
Minimum sensitivity, dB/mW.	-103
Detection range, km. - in passive-active mode. - in active mode. Potential with 3000 mm antenna diameter, dB.	175 350 270
Passive channel	
Sensitivity, °K. Integration time constant, s. Noise factor, dB.	0.3 1 ≤4.5
Decoupling from the active channel, dB.	160±7

4 State of research work in the 90's

In the 1990s the activity of work on the radio-meteorological systems design decreased sharply. The work continued, but it was largely theoretical. During this period, new schemes of radiometric receivers and PARLS, methods of measurement and compensation of interference, calibration, design solutions of individual units, etc. were developed.

Many theoretical works were summarized in the monograph by V.V. Falin "Radiometric microwave systems" [10], in the dissertations defended at that time. Unfortunately, during this period, the radiometric complex and PARLS ceased to operate.

Among the practically realized ideas is the creation of radiothermolocation system with background noise compensation [11] on the basis of a two-mode two-channel antenna.

5 Works on the radio-meteorological research development in the 21st century

A new stage in the development of radio-meteorology at MI VlSU began in the XXI century. The work continued under the direction of E.V. Fedoseeva. By the end of the 10s the basis for a new radio-meteorological complex design was created in general.

The design and development of the new complex was carried out on the basis of the two-mode two-channel antennae of the radio-thermal system with background noise compensation [12], which had been developed earlier.

The complex, which began with the use of one single-wave radiometer (λ = 3.2 cm) to the present time has been developed up to three-channel system: $\lambda 1$ = 1.35 cm, $\lambda 2$ = 3.2 cm, $\lambda 3$ = 7.5 cm. At the same time, each of the radiometers has its own three-channel internal structure, including the main meters on the horizontal (HOR) and vertical (VERT) polarizations, and an additional (AMC) measuring channel.

Realization of such a three-band system with internal additional separation into three channels when working on a common antenna mirror defines conditions for background noise influence compensation on measurement results with a possibility of polarization contrasts estimation [13].

The structural diagram of the multi-frequency microwave radiometric system is presented in figure 3.

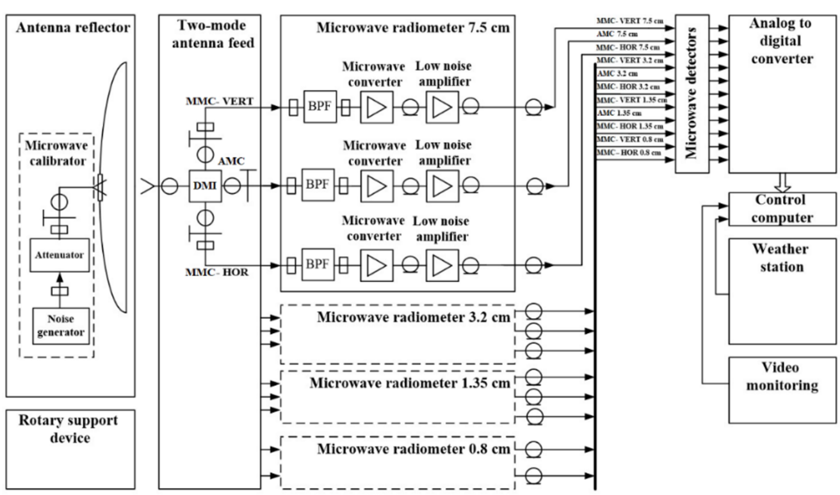

Fig. 3. Block diagram of a multi-frequency microwave radiometric system: DMI- Dual-mode irradiator; BPF - Waveguide Band Pass Filter; MMC-VERT - Signal of the main measuring channel of vertical polarization; MMC-HOR - Signal of the main measuring channel of horizontal polarization.

At the input of the processing unit three input signals are received, which, under the condition of absolute polarization decoupling of channels and isotropy of radio-noise radiation received from the scattering area of the main antenna channel DN, provide

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formation at the output of the signals processing unit, in which there are no components, caused by the radiometer own noise and the reception of background noise through the scattering area of the antenna DN.

Measurement of the polarization characteristics of the hydrometeors radio-thermal radiation forms the basis for remote determination of precipitation intensity, parameters of the rain drops size distribution and rain spatial structure parameters.

The results of mathematical modeling have shown that background radiation compensation received through the main antenna channel can be performed with a high degree of accuracy of the order of hundredths of brightness temperatures for each angular direction, with higher compensation accuracy for the far lateral directions [14, 15, 16, 17].

The development of a system of gathering and processing of the data of multifrequency microwave radiometric system, allowing to carry out radiometric data automatic processing by transition from analogue to the digital form of the solution of background radiation influence compensation problem approached the stage of a ready-made data processing program implementation [18].

To date, the technical implementation of the developed multifrequency microwave radiometric system for the atmosphere remote sensing has been carried out in stationary, stationary field and mobile variants. The position of the multiband microwave radiometric system in the stationary version with a 2.5 m mirror on the roof of the main MI VlGU building is shown in figure 4.

Fig. 4. Antenna system of modern complex: 1 - Straight-focus mirror with a diameter of 2400 mm; 2 - Multichannel two-mode irradiator with removed weather protection; 3 - Multifrequency waveguide microwave calibrator; 4 - Angular actuator; 5 - Azimuthal actuator.

In 2020 a "Radiophysical studies of natural environments" research laboratory was organized at the Murom Institute. The scientific head of the laboratory is Doctor of Physics and Mathematics, Professor G.G. Shchukin. The coordinator of the work is Doctor of Technical Sciences I.N. Rostokin.

The creation of a two-mode irradiator for four wavelengths: 0.8; 1.35; 3.2 and 7.5 cm is carried out now. The main technical characteristics of the four-channel microwave complex for application of antennas with diameter of 1 m (mobile version) and 2.4 m (stationary field) according to the modeling results are given in table 3.

Table 3. Multiband microwave radiometric system parameters.

Parameters	Values			
1Wavelength, λ cm.	7.5	3.2	1.35	0.8
Radiometric sensitivity, ΔT at a constant integration time τ = 1s.	0.03	0.04	0.05	0.07
Bandwidth, Δf MHz	800	1000	800	800
Receiver noise temperature, $T_{N\ rec}$ °K.	13	13	101	438
Receiver gain, G dB.	60	60	53	50
Mobile version (D = 1000 mm, F = 320 mm)				
Antenna pattern width by level-3 dB, 0	5.07	2.16	0.91	0.54
Antenna gain, Kgain dB.	31.54	38.94	46.43	50.98
Stationary version (D = 2400 mm, F = 900 mm)				
Antenna pattern width by level -3 dB, ^{0}	0.21	0.09	0.038	0.023
Antenna gain, K_{gain} dB.	59,15	66.55	74.05	78.59

The work at Murom Institute to create a multi-band microwave radiometric system is being carried out under the leadership of G.G. Shchukin. The greatest contribution to the creation of these systems was made by E.V. Fedoseeva, I.N. Rostokin, and E.A. Rostokina. In general, the process of forming the basis for such a sounding system, which could be included in current weather tracking structures and compiling dangerous phenomena ultra-short-term forecasts with an advance of up to three hours is under way.

6 Conclusion

Over the past years, the Murom Institute can distinguish several stages in the work on systems creation and remote sensing methods development. A large number of articles have been published on the topics of the work, certificates of authorship and patents for inventions have been received, three monographs and several textbooks have been prepared and published. Eight candidate theses and four doctoral dissertations were prepared and successfully defended.

The experience gained by the present time allows us to expect that the tasks set within the "Radiophysical research of natural environments" laboratory will be successfully fulfilled.

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