A microwave radiometer for detection of forest fire under conditions of insufficient visibility

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Abstract. The article demonstrates a super high frequency (SHF) radiometer that can be used for detecting seats of forest fires. The analysis of current approaches and methods for forest fire monitoring is briefly discussed. Comparing to common use of optical or infrared radiation detectors, measuring instruments working at micro wave range are more efficient in conditions of insufficient visibility (dense smoke, thick tree crowns, meteorological environment). The paper shows the structure and technical characteristics of the designed radiometer. The results of laboratory and field testing are also presented.

1. Introduction
Forest fires are one of the most terrible and dangerous disasters widely spread in Russia. In total fires destroy annually from 2 to 12 million hectares of forest areas, major part of which is in Siberia. According to the most optimistic evaluation only in 2018 year the material fire damage amounted more than 10 billion roubles [1]. However the estimates of the Greenpeace department in Russia indicate that this number may be two hundred times greater, so the real damage reached several trillions roubles.

At present fire-prevention and extinguishing measures face a serious problem. The point is that it is impossible to localize precisely the seat of fire in conditions of insufficient visibility. This situation occurs when the fire area is covered with dense smoke and fire airplanes can hardly hit the target. In case of the beginning stage of forest fire the flame may be hidden under thick trees crown and efficiency of extinguishing depends on how soon it will be detected. Also insufficient visibility conditions are related to underground peat fires.

This paper reviews approaches of forest fire monitoring and presents an information-measuring system for fire seat detecting in conditions of insufficient visibility.

2. Approaches and methods
Currently widely used approaches to solve this problem are satellite and aircraft systems for forest fire monitoring. They are based on intensity measurements of optical emission, intermediate infrared radiation (3–5 µm), and thermal infrared radiation (7–13 µm). The most popular forest fire monitoring systems are scanning radiometer AVHRR placed on NOAA satellites and spectrum-radiometer MODIS being used in Terra and Aqua satellites [2]. At the same time Russian scientific centers use data from the Russian module of remote sounding “Nature”.

The “Nature” module is a space platform functioning as part of the international space station (ISS).
It is used for experimental research in order to develop methods of remote sounding via multispectral watch facilities. The results of measurements are needed for solving global and regional issues in climatology, oceanography, and ecology [3].

Nevertheless, in spite of wide capabilities of modern radar equipment its widespread and constant use is difficult when where is dense puffs of smoke. The observations form satellites or aircrafts in infrared range become inefficient because particles of heated dust and hot ashes also radiate infrared rays which cause “blurring” of signals to be analyzed.

Detecting of seats of fire in intricate meteorological and insufficient visibility conditions can be realized via radio technical equipment working in microwave 0.8–1.5 cm range [4]. Super high frequency radiowaves (SHF, 3–30 GHz) compararing to optical emission are weakly reflected and much less attenuated in the atmosphere, gases and aerosols, and have a better penetrability through different barriers. Since the radiometer is not sensible to fog, smoke, foliage of trees and is independent of the time of day, it has a number of advantages [5]. The microwave radometer is preferable for precise localization of seat of fire in difficult of access and dangerous for direct human work areas, in conditions of insufficient visibility when it is not possible to use traditional means of visual detection.

Currently, there are no such commonly used SHF systems for detecting of seats of forest fire. Similar research is being carried out by scientists from the Fraunhofer Institute for High Frequency Physics and Radar Techniques (Wachtberg, Germany) [6] and by INSYSTEM company (Moscow, Russia). The studies [7, 8] discuss operating frequencies for fire detection at about 31.4 GHz and 22-24 GHz. Also the Ku frequency range at 13 GHz should be taken into account [5, 9]. The research [10] suggests using multi-frequency sounding approach.

3. Microwave radiometer structure and characteristics

The designed equipment works on the principle of radio locator and its block-diagram is shown in the Figure 1. The radiometer include a SHF parabolic antenna, an amplifier, a microwave detector, an antenna rotation device, and an information measuring system.

![Figure 1. Microwave radiometer structural scheme.](image)

The antenna system (Figure 2.a) consists of broadband conicoid feed AO6.27 and a mirror antenna narrowing wide directional pattern of the conicoid feed. The mirror (reflector) diameter is 0.3 m, directional pattern of the antenna system variate from 1.7 to 3.8 degrees depending on selected working frequency.

![Figure 2. Construction of the radiometer antenna system: a – front view with a parabolic reflector; b – broadband conicoid feed AO6.27.](image)

The irradiator is made on the basis of a biorthogonal H-shaped waveguide and a square pyramidal...
horn with knife plates of exponential form, which are a continuation of the projections of the H-shaped waveguide. Also as it can be seen from the Figure 2.b the irradiator has two independent coaxial inputs with SHF K-type connectors (sockets) for simultaneous receiving or transmitting 18–40 GHz signals with linear polarization. Gain over the working frequency range is 30–37 dB.

High-frequency low-noise amplifiers AC180260-074 and AC260400-021 are used for SHF signals amplification in 18–26 GHz and 26–40 GHz respectively with gain ~30 dB. The amplifiers (see Figure 3.a) are made in a leakproof metal case with SMA input and output connectors. Power supply of 5 V is given through an isolated PC4 socket. The amplifiers were tested via certified measuring equipment. Figure 3.b shows amplitude frequency response that have been measured with the scalar analyzer of chains P2M-40. As it can be seen the amplifiers correspond to essential technical requirements.

The high-frequency detector D5B-50-05-13 is designed to detect continuous or modulated microwave signals in a wide frequency range. The detector has a slight unevenness of amplitude frequency characteristic and standing wave ratio in wide bandwidth from 0.01 to 50 GHz. An equivalent scheme of the detector is shown in the figure 4.

The detector response time (rise / fall) is 7 ns. During rise time the output detector voltage changes from 10 % to 90 % while switching on power level minus 10 dBm (0.1 mW). Own capacitance of the detector is \( C_p = 30 \) pF, its typical value of voltage sensitivity is 500 mV/mW.

The information measuring system should realize data acquisition, digital filtering and the detector signal processing. The other functions are antenna rotation device control, determination of antenna orientation (careen, pitch, lateral movement), seats of fire examining. For this purpose the authors used multifunctional platform National Instruments CompactRIO with installed NI-9234 module. CompactRIO has an integrated real-time controller and chassis with installed FPGA which provides with high speed of signal processing and computing flexibility. The radiometer software [11] is designed
in graphical language of programming – LabVIEW.

4. **Radiometer checkout**
The first step was to test the whole system in a laboratory (see the figure 5). The measurements confirmed operability of the radiometer. The authors have found strong response to short (~125 µs) electromagnetic SHF impulses generated with a gas lighter piezoelectric element. The next test involved measurements of emission from real fire flame, a photograph from this experiment is shown in figure 6.

![Figure 5. Laboratory testing of the microwave radiometer.](image1)

**Figure 5.** Laboratory testing of the microwave radiometer.

![Figure 6. Field testing of the designed instrument with open flame.](image2)

**Figure 6.** Field testing of the designed instrument with open flame.

During the experiment with open flame the authors did not observe increasing of SHF emission from fire as it has been for a piezoelectric element. It seems that emission intensity from small fire is too weak to be detected and the radio brightness temperature is quite low.

5. **Conclusion**
A microwave radiometer for detecting seats of fire was designed. The reception path was checked and measured with the use of certified equipment. Laboratory checkout showed operability of the radiometer. During field testing it was established that small fire did not radiate SHF radio waves that the instrument was able to detect. It the future it is planned to make measurements for a large forest fire.

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**References**
[1] Forest Fires in Russia, available at: https://tass.ru/ekonomika/5951954
[2] Katkovsky L V and Vorobyov S Yu 2010 *Doklady BSUIR* 6(52) 5-12
[3] Malinnikov V A, Stetsenko A F, Altynov A E and Popov S M 2009 *Monitoring of the Natural Environment by Aerospace Equipment* (Moscow: Moscow State University of Geodesy and Cartography Press) p 142
[4] Nikolaev A G and Pertsov S V 1970 *Thermal Radiolocation* (Moscow: Voenizdat Press) p 132
[5] Bianchi G 2014 Radiometer Aids: Fire Detection *Microwaves & RF* 66-71
[6] Radiometer finds sources of fire, available at: https://phys.org/news/2011-01-radiometer-sources.html

[7] Alimenti F, Roselli L and Bonafoni S 2016 Microwave radiometers for fire detection in trains: theory and feasibility study Sensors 16 906

[8] Wahl N, Heinen S, Essen H, Kruell W, Tobera R and Willms I 2010 An integrated approach for early forest fire detection and verification using optical smoke, gas and microwave sensors WIT Transactions on Ecology and the Environment 137 103

[9] Alimenti F, Zito D, Boni A, Borgarino M, Fonte A, Carboni A, Leone S, Pifferi M, Roselli L, Neri B and Menozzi R 2008 15th IEEE Int. Conf. on Electronics, Circuits and Systems (Malta: St. Julien's) pp 1265-1268

[10] Sister V G, Ivannikova E M, Gudkov A G, Leushin V Yu, Sidorov I A, Plyushchev V A and Soldatenko V P 2016 Detection of Forest and Peat-Bog Fire Centers by Means of Microwave Radiometer Sounding Chemical and Petroleum Engineering [in Russian – Khimicheskoe i neftegazovoe mashinostroenie] 52 123-125

[11] Gubin N A, Grigorev K A, Chensky A G and Zolotarev N S, RU Certificate of State Registration of Computer Programs No. 2019610570 (14 January 2019)