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Multifunctional radar system for remote control of environment and the Earth's surface

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Abstract. The radar method for remote detection at large distances of radiation pollution in the atmosphere and on the Earth's surface is considered. The design of radar for determine of radioactive formations in the atmosphere and near the Earth surface is developed. In the developed radar for increase the efficiency of detection and identification of the composition of radioactive contaminants, the antennas are divided into transmitting and receiving. This allowed for the detection of radiation contamination microwave signal with a tunable wavelength. The fiber-optic communication system is used to transmit signals from receiving antennas. The results of investigations of radioactive pollution in the atmosphere are presented.

1. Introduction

The development of nuclear energy and enterprises that use technologies using radioactive elements increases the probability of radioactive contamination both in the atmosphere and on the surface of the Earth [1-8]. Unlike most hazardous contaminants, the radioactive emissions into the atmosphere can move on the long distances from the them formation source [8-14]. To control them are used, various devices that are the monitoring of the Earth surface and the atmosphere condition [13-16, 18-26]. These devices have several significant drawbacks during the radioactive emissions control. The main of them relates to the determination of the radioactive contamination over long distances [27-29]. In addition, the low resolution of many methods used in these devices is made the difficulties during the detecting of the small radioactive contaminants. Such contaminants are often formed after the decay of the main source of pollution [27, 29-34]. The high dependence of optical, thermal and other methods from the weather conditions, in some cases does not allow the used them even at small distances (for example, 1000 m).

The radar methods for monitoring air pollution do not have these disadvantages. Poor weather conditions are reduced the radar working distance, because the radiation power can be increased to a certain limit. It should be noted that the radar method of environmental monitoring is a direct measurement of the degree of ionization of a radioactive cloud (pollution level). This is extremely

important, especially during are taking the measurements in the difficult conditions, for example, a radar is placed on a moving object.

To solve new problems, it is necessary to improve the radar characteristics and expand its functionality. Therefore, the modernization process: the various radar units is constantly ongoing, the changing the system for constructing the antenna complex, the developing new systems for transmitting information and algorithms for its processing. One of the options for such modernization, which is aimed at the radar characteristics improving and its functionality expanding, is presented in our work.

2. Radar complex for the detection of radioactive contamination

The completed earlier investigations have shown that during the radioactive ejection into atmosphere in its was formed the plasmoid. The plasmoid is the ionization formation are arising due the ionization of the air [11-16, 29-34]. The reflection of the microwave radiation from a plasmoid allows to determine the presence of radioactive contamination in the air. The conducted investigations by different scientists have shown that the reflection coefficient of microwave radiation R from plasmoid depends on the exposure dose P_{exp} and wavelength λ [27, 29-34].

Therefore, for the expanding the functionality possibility of the radar, we propose the following. Unlike off traditional method of plasmoid investigation by radar is separated the antennas of transmitting and receiving [27, 29-34]. As a radiating antenna we propose to use the parabolic antenna with a wide radiation pattern which rotates in the range of 360 degrees. In addition, in this antenna is easy to realize the tuning of the microwave radiation wavelength in the range of 2 – 12 cm and the change in the radiation power. On a fixed part of the antenna complex in a circle place 8 spiral receiving antennas with a 60-degree field of view. A schematic representation the proposed by us of the antenna complex is shown in Figure 1.
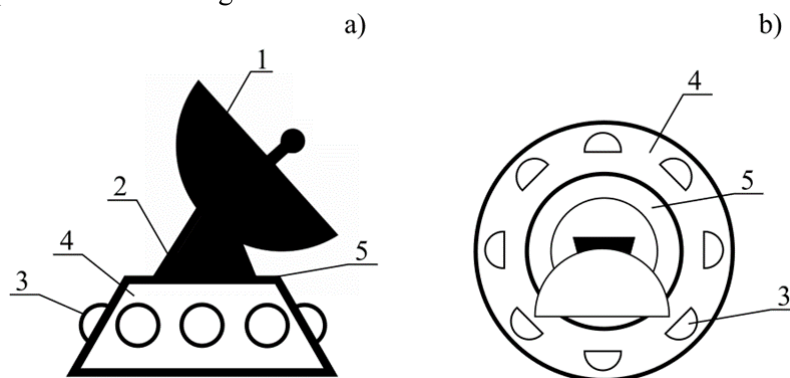

Figure 1. The structure of the antenna complex of the radar station (a – side view,
b – top view): 1 – parabolic antenna with an emitter; 2 – a system for scanning a parabolic antenna in a vertical plane, 3 – a spiral receiving antenna; 4 – fixed base for mounting spiral antennas; 5 – movable base for rotation of the parabolic antenna.

This arrangement of the receiving antennas 3 allows to maintain the operability of the station along the entire azimuthal angle in the case of the out of service to one of them. In addition, the scanning and the rotating of the emitting antenna does not significantly affect to the characteristics of the receiving antenna. A big problem arises in case the antenna complex placing of the developed by us on a moving object in the presence of other antenna complexes and various kinds of interference, for example, powerful key elements of a ship power station [13, 17, 28]. To exclude the influence of various kinds of interference on the signal transmitted from the plasmoid transmitted from the receiving antenna, especially of low power to the processing devices, it is proposed to use fiber-optic communication lines [35–39]. Optical elements are highly resistant to electromagnetic radiation [35-43]. The structural diagram of the radar to detect radiation pollution is presented in Figure 2. The radar viewing angle is 360 degrees, the scanning angle of the vertical plane is from 10 to 90 degrees.
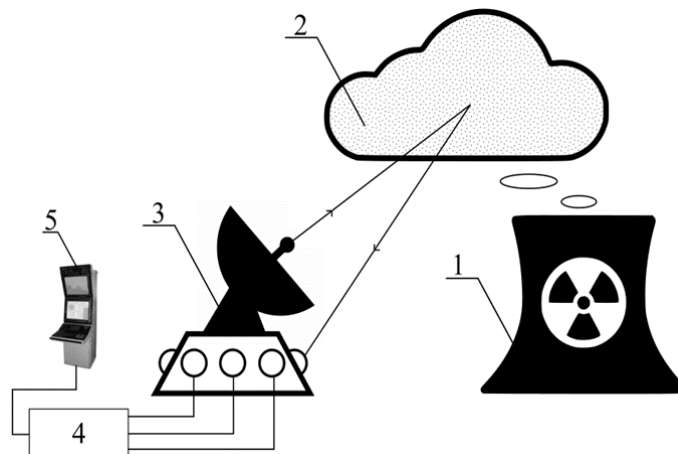
Figure 2. The structural diagram of the radar to detect and study radioactive contamination in the atmosphere:1 – nuclear power plant or other source of radioactive emissions; 2 – a zone of plasmoid formation; 3 – developed antenna complex; 4 – receiving path using fiber optic; 5 – signal processing and indication devices.

An insignificant distance (less than 150 m) for transmitting information allows to develop the following design of the optical receiving path (Figure 3).

The elements which are in the shielded case 10 (Figure 3) are located in the fixed part of the antenna complex 4 (Figure 1). The double screening of the case provides a high degree of attenuation of external interference [28, 39]. The optical receiving elements 6 and other systems are placed in stationary cabins or holds of the ship, which also excludes the influence of a large number of various kinds of interference on them.
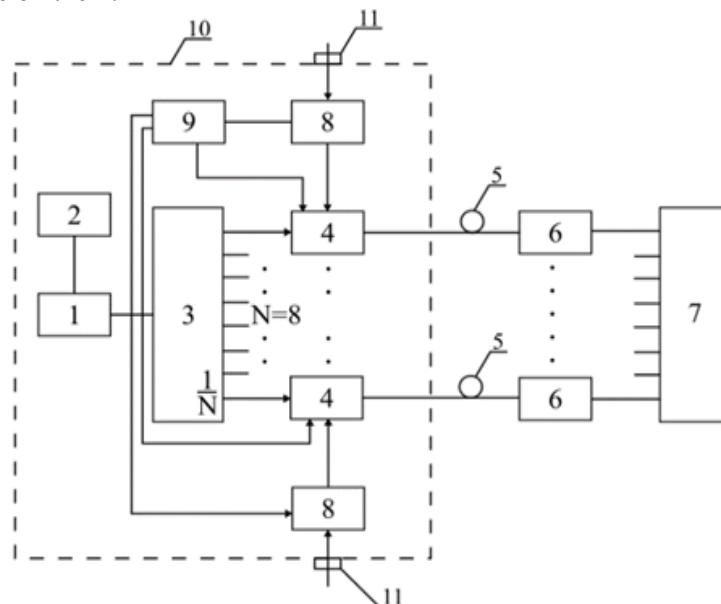

Figure 3. The structural diagram of the receiving path of the radar: 1 – laser; 2 – power driver; 3 – optical divider;4 – optical modulators; 5 – optical fibers; 6 – photodetectors; 7 – a device for processing and displaying data; 8 – low noise amplifiers; 9 – multifunctional power driver; 10 – case; 11 – microwave connectors for signals from receiving antennas.

The main parameter, which is measured to study radiation formations, is the reflection coefficient R. It is determined as follows:

$$R = P_{ref} / P_{rad} \tag{1}$$

where P_{ref} – the amplitude of the reflected wave, P_{rad} – the amplitude of the radiated wave.

If the ionization formation was formed from particles of various radioactive elements (this is extremely rare of the mainly during a testing of the nuclear weapons and serious accidents at nuclear power plants) by scanning of the wavelength λ of microwave radiation, it is possible to establish the type of these particles and them concentration. In other cases, the scanning the value of λ makes it possible to estimate the exposure dose in various parts of the cloud with an error not exceeding 10 %. This result suits the services responsible for environmental monitoring and radiation safety.

3. The results of experimental investigation and discussion

To conduct a study of the level of radioactive pollution of the atmosphere, it is necessary to solve the problem of estimating the reflection coefficient R of an electromagnetic wave from a plasmoid as a function of the radiation wavelength λ of the radar station. Figure 4 shows, for example, the dependence of the reflection coefficient R of microwave radiation for the plasmoid (formed from ^{16}N isotope ions) from the wavelength λ.
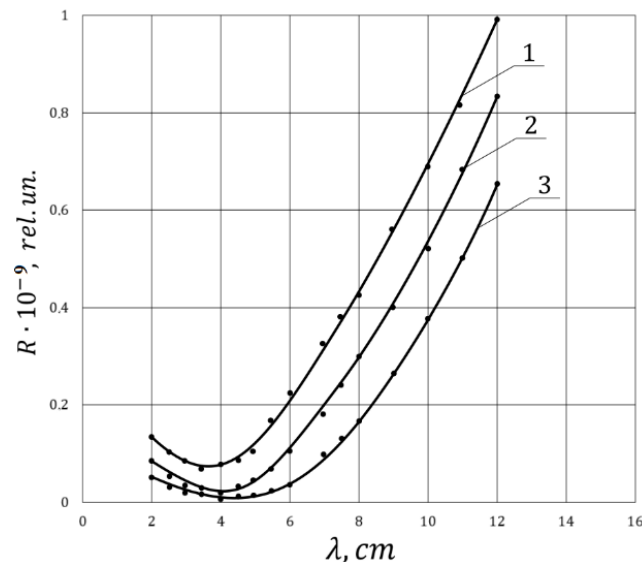

Figure 4. The dependence of the reflection coefficient R from wavelength λ. Graphs 1, 2, and 3 correspond to the values of ^{16}N isotope ions concentration N_i in cm^{-3}: 10^{10}; 10^9; 10^8.

The power of the signal reflected from the plasmoid and the radiation power of the station, which is set during the study, are used to calculate the reflection coefficient. The reflected signal power is measured at different wavelengths, resulting in a curve. Laboratory measurements are made at different ion concentrations.

An analysis of the obtained dependences showed that the concentration of N_i ions has a significant effect on the position of the minimum point (the value of λ, from which a continuous increase in the reflection coefficient of microwave radiation by a plasmoid begins). In addition, it was found that for each type of ion this value of λ is different. Therefore, to conduct more detailed studies of these dependences in the vicinity of the minimum, it is necessary to develop a parabolic antenna with a tuning step of a wavelength of 0.1 cm or less. This will significantly expand the possibilities of studying the physical properties of plasmoid using radar.

The using in the received path of the FOCL for transmitting receiving signals, we improved the radar resolution in the study of a large number of small-sized radioactive contaminants (a large cloud scattered into small formations). The results of using the receiving path with FOCL for the detection of radioactive contamination at a distance L from the radar are presented in Figure 5. Radioactive contamination from a source located at a distance of more than 70500 m from the radar rises into the atmosphere to a height of H. In the area of the source of pollution, wind flows act that tilt the

discharge plume and scatter plasmoid. This is fixed on the obtained images (Figure 5). The main exposure to radioactive release is reflected and reflected microwave signals from objects and buildings, such as nuclear power plants.
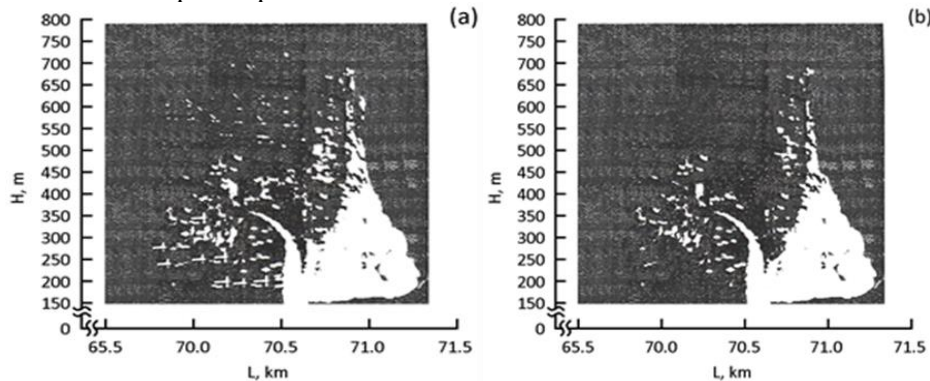

Figure 5. The radar image of radioactive contamination in the atmosphere: a – without using FOCL in the receiving path, b – with using fiber optic in the receiving path.

An analysis of the images shows that the use of FOCL in the receiving path allows a more clear definition of the areas of radioactive contamination, the direction of its distribution and the likely nature of the destruction into smaller parts.

4. Conclusion

The obtained investigation results shown that the radar complex with the optical receiving path of the developed by us has the better characteristics at the compared to previously used. The use of the complex allows to research the plasmoids at the distances of the more than 300 km. These distances are not available for other methods of the environmental condition control.

The using of the FOCL for the microwave signal transmission in the receiving path of a radar allows successfully to make the investigations in case is placing a station at the objects with increased electromagnetic activity (for example, sea ship). In addition, the developed radar can be used for the determination of the various moving and stationary targets in air and sea space, as well as on the Earth surface.

5. Acknowledgment

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