Background method of radar detection of a moving small target object in the task of classifying active radars

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Abstract. The article deals with the classification of radar equipment based on two features: on the location of the receiving and transmitting points in space, as well as by the method of generating an informative signal at the receiving point. The most significant parameters in the development of a moving target detector near the underlying surface have been observed.

1. Introduction
The work is currently under way to develop radar systems to detect moving small aircraft near the underlying surface using the background radar method.

The unconventional method of detection of moving targets is currently being intensively developed, as evidenced by the works [1–5]. However, these and many other works lack both the definition of the background radar method and the definition of the background radar in which the principles of this method are implemented. In addition, the works known to the authors do not have a structural diagram of the background radar. Therefore, the location of the background radar in the hierarchy of some classification of radar equipment is not clear.

The development of the background radar method is connected with the solution of the actual task of detecting drones near the surface area. This method is discussed in many works. In particular, the first application of scientific discovery in radio engineering systems is noted in the works of F.S. Alymov, V.N. Sablin, V.V. Razeviga and V.V. Chapursky [2] in 1984. In these works, in particular, the energy characteristics were calculated for detecting a cruise missile at a range $x$ and a flight altitude $z$ (Figure 1) for the received signal after reflection from the background (Figure 2).

The task of detection of moving objects by the background radar method is set out in [2]. The first experimental and theoretical studies of the background radar method are related to the study of the spectral characteristics of the radio signal reflected from the background (with a moving object in front of the signal) [4, 5] under laboratory conditions. Quite a wide range of questions on the study of the background radar method in the task of detecting air targets of the "plane" and "cruise missile" type, moving at a speed of 200 m/s is presented in [2]. The monostatic effective scattering surface of the above targets does not exceed 0.01 m². A 1 kW radar transmitter emitted sounding radio pulses with a duration of 3 μs at 3 GHz and a repetition period of 4-10 ms. For the specified conditions the authors gave a physical interpretation and derived the equation of the background radar; the energy and frequency ratio of the radio signals reflected from the background was obtained; the problem of detection of a moving target was considered. Based on the background radar equation, the authors estimated the target detection area in the vertical plane, which depends on the shape and width of the main blade of the
target's bistatic target radar cross-section (RCS).

\[ \text{Figure 1. Signal to noise ratio of cruise missile detection by background radar method [2]} \]

\[ U(t), V \]

\[ \text{Figure 2. Receive signal from cruise missile after reflection from the background [2]} \]

In [6] the authors note that in the implementation of the background radar method the main difficulty is the selection of signals scattered by the target among the signals reflected by terrain elements. The authors draw this conclusion from the comparison of the power of these signals by the ratio of the target cross section area (15 ... 25 cm²) to the area of the first Fresnel zone (0.25 m²) equivalent to a two-station radar. To study the possibility of detecting signals from the target in the implementation of the background radar method they conducted an experiment in a building room using a stationary transceiver with a non-scanning antenna.

However, these works lack a clear definition of the background radar and its classification by certain features. There are many patterns for the classification of active radar facilities [5–8]. Active radar equipment is classified by application, purpose, nature of the radar carrier, nature of the received signal, type of the sounding signal, method of action, as well as by the frequency range of the sounding signal. However, these features do not allow unequivocally classify a radar, which uses the background radar method.

The purpose of the article is to define the background radar, formulate the signs of a new classification of active radar facilities and indicate the place of the background radar in this classification.

The solution of this problem, on the one hand, extends the range of existing features of classification of active radar facilities. On the other hand, the classification mentioned below is convenient for selecting the type of the radar in system designing.

The background radar is the technical means of extracting information about a moving target from its modulated reflected signals by terrain objects and related to different elements of resolution.

In the absence of a moving target, the electromagnetic wave propagates from the radar to the target object (background) and back, and in the range strobe corresponding to it there is a radio signal with a priori parameters. When a target moves between the radar and a given object, the electromagnetic wave is dissipated by inhomogeneity (obstacle) as a moving target. That leads to characteristic changes in the
time parameters of the observed radio signal reflected from a given object. Information about a moving target is contained in the amplitude-phase modulation of the given signal.

2. Classification of radar equipment

Let us first consider the place of the background radar among the existing types of active radar equipment, using two classification features: the location in the space of radar transmission and receiving points and the method of formation of an informative radio signal at the receiving point (Figure 3).

![Classification of active radar stations by space and received signal formation](image)

**Figure 3.** Classification of active radar stations by space and received signal formation

Let us consider the first classification feature. Let us consider a point with transmitting equipment - a transmitting point, a point with receiving equipment - a receiving point, a point with transmitting/receiving equipment - a transmitting/receiving point. Then by positions we mean transmitting, receiving or transmitting/receiving points. We will consider the radar positions different if it requires a synchronization channel or a communication line for transmitting the reference (in the particular case: the transmitted "copy") signal from the transmitting position to the receiving one, or if there is a generator of the reference signal in the receiving position. In this case, the background radar is the development of bistatic "forward-scattering" radars for single position cases. Let us consider the classification of active radars from the point of view of placing transmitting, receiving or transmitting/receiving points at some position. For a single position radar, the probing signal is generated by a generator and at the same point the received signal is generated at the output of the receiving antenna. For two-position radars, the sounding signal is formed at one (transmitting) point, and the received signal is formed at another (receiving) point, and in coherent radars to process the received signal it is necessary to transmit a copy of the sounding signal or synchronous signals over the communication line from the transmitting point to the receiving point. In a multi-position radar, the probing signals are formed at several (transmitting or receiving) points, and the received signals are formed at the same or other (receiving or transmitting) points, with the transmitting, receiving and transmitting/receiving points united by a communication line between themselves and the central information processing point.

Let us consider the second feature of the classification. In a single position radar, the received signal is generated at the antenna output when the radio wave propagates from the transmitting antenna to the target, and after scattering - back to the receiving antenna. If changes in the target scattering indicator within the angle from the target to the transmitting and receiving antenna phase centres are negligible, the effective target scattering surface can be considered monostatic, and the corresponding single position radar can be considered monostatic. If changes in the target scattering indicator within the angle from the target to the transmitting and receiving antenna phases are significant, the effective target scattering surface can be considered bistatic, and the corresponding single position radar – bistatic. However, for real spatial differences of transmitting and receiving antennas of a single position radar, the target scattering indicator in the far zone can be considered constant within the angle from the target to the phase centers of the transmitting and receiving antennas. Therefore, in practice, a single-position variant of a bistatic radar can be implemented, in particular, at relatively short ranges when operating at the central frequencies of the terahertz range. In the microwave range, a single position bistatic radar is
practically not considered.

In general, the output of the receiving antenna of a two-position radar received signal is the result of interference of two beams:

For the first beam (antenna-target-antenna):
- the radio wave from the transmitting antenna reaches the target and dissipates it;
- the scattered wave from the target reaches the receiving antenna and forms the first beam.

For the second beam (antenna-antenna):
- the radio wave from the transmitting antenna reaches the receiving antenna and forms a second beam.

At the output of the receiving antenna interference of these signals is observed in the case when the radio signals of these beams are not resolved in time. Otherwise, the interference of these radio signals is not observed.

If the angle from the target to the transmitting and receiving antennas is close to 180 degrees, then a two-position "forward-scattering" radar is used, and the signal, all other things being equal, is determined by the effective scattering surface in the forward scattering. If the non-zero angle from the target to the transmitting and receiving antennas differs from 180 degrees, then the classical variant of the bistatic two-position radar is used, and the signal, all other things being equal, is determined by the bistatic effective scattering surface. The amplitude of the second beam is smaller than in the case of the "forward-scattering" radar and is determined by the level of the side petals, the mutual orientation of the main petals of the directional charts of the transmitting and receiving antennas. If the transmitting and receiving point are separated by distance and located on the same line of sight with the target so that the target scattering indicator is almost constant, a monostatic two-position radar is used. The amplitude of the second beam is negligibly small than in previous versions of the two-position radar and is determined by the level of the rear petal of the directional diagram of the transmitting antenna.

Thus, the background radar is a variant of the two-position bistatic "forward-scattering" radar, which is obtained from it when placing a given object in place of the receiving point and the transfer (combination) of this point in one position along with the transmitting point. In such a single position radar at the antenna output the output of the receiving antenna is the result of interference of four beams:

For the first beam (antenna-target-object-target-antenna):
- the radio wave from the transmitting antenna reaches the target and dissipates it;
- the target scattered radio wave reaches a given object that scatters it into the surrounding space;
- the scattered wave from a given object reaches the target and is scattered by it;
- the scattered target radio wave reaches the receiving antenna and forms the first beam.

For the second beam (antenna-target-object-antenna):
- the radio wave from the transmitting antenna reaches the target and dissipates it;
- the target scattered radio wave reaches a given object that scatters it into the surrounding space;
- the scattered wave from a given object reaches the receiving antenna and makes a second beam.

For the third beam (antenna-object-target-antenna):
- the radio wave from the transmitting antenna reaches a given object that scatters it into the surrounding space;
- the scattered wave from a given object reaches the target and is scattered by it;
- the scattered wave from the target reaches the receiving antenna and forms a third beam.

For the fourth beam (antenna-object-antenna):
- the radio wave from the transmitting antenna reaches a given object that scatters it into the surrounding space;
- the scattered wave from a given object reaches the receiving antenna and forms a fourth beam.

Under certain conditions, it is possible to imagine the background radar as a two-position bistatic "forward-scattering" radar, counting the given object as a repeater of radio waves propagating from the transmitting antenna and from the target in the direction of the receiving point. The observed signal at the output of the receiving antenna of the background radar will be accurate to a constant multiplier and the delay will match the output signal of the receiving antenna of the two-station bistatic "forward-
scattering" radar under the following conditions:

- for the diffuse nature of radio wave reflections from the target and a given object, when the amplitude of the first ray is approximately 30 dB below the amplitude of the other rays and the first, second and fourth rays make the main contribution to the received signal;
- when the linear sizes of aperture of the receiving antenna of a bistatic "forward-scattering" radar are comparable to the geometrical sizes of the set object;
- when the directional characteristics of the receiving antenna coincide with the scattering indicator of the given object.

If those conditions are violated, the representation of the background radar as a two-station bistatic radar is incorrect. In particular, this is true for the resonance over-radiation of the signal by the target (for example, if the target is a semi-wave dipole at the resonance frequency), when the amplitude of the first beam is commensurate with the amplitudes of other beams.

3. Comparison of background and bistatic radar methods

The background radar method is similar to the methods of coherent-pulse radars with external coherence. The difference between them is that in coherent-pulse radars with external coherence, a moving target and a fixed object that re-reflects the radio wave and generates a reference signal at the antenna output are in the same range strobe. In the background method, the distance to a moving target and to an object varies more than the range resolution, so their beating signals correspond to different strobes in terms of range.

It should be noted that the background radar can be implemented in a two-position version, or it can be part of a multi-position (multistatic) radar system and provide information to a central processing point along with monostatic, bistatic and "forward-scattering" radars [6–9].

The structural diagram of the single position background radar includes: a transmitting path, transmitting and receiving antennas, digital signal processing unit, indicator, as well as a reflector of natural or artificial origin, forming a background radio signal. The receiving and transmitting tracts of single position background radar are located at one point, and the corresponding receiving and transmitting antennas are so close that their spatial difference is caused by the final dimensions of the antennas.

The detection of a small unmanned aerial vehicle is conducted by processing and analysis of the total background radio signal. The total background radio signal is formed by interference of signals observed in the range strobe of the reflector (background). An example of specified objects that form a background radio signal can be: the underlying surface or the ground and above-ground objects located on it, as well as other terrain elements, including their combinations. Such specified objects will be called background objects or background, and radio signals reflected from these objects - background radio signals or radio signals from the background.

Usually in one range strobe the background radio signal is observed with the radio signal reflected by the underlying surface. Such a background object is complex, as the background radio signal is formed by reflected signals of different spatially spaced objects.

In such a case, for the background radar, the radio wave propagation path is formed by a moving straight line target with a small effective scattering surface (a small unmanned aerial vehicle) to be detected, and by a surface of natural (forest, underlying surface or terrain elements protruding above it) or artificial origin (walls or roofs of civil works, buildings). After the radar emits the sound signal, the radio waves reach the specified surfaces and form the background radiation of the radio waves as a result of diffuse scattering.

4. Conclusion

The following conclusions can be drawn from the materials presented.

1. The background radar is the technical means of extracting information about a moving target from its modulated reflected signals by terrain objects and related to different elements of resolution.
The background radar method can be implemented in single-position, two-position and multi-position radar systems. Under certain conditions, the background radar is a kind of two-position "forward-scattering" radar. In particular, when the target scatters the radio wave diffusely.

The difference between the background radar method and coherent-pulse methods is that the first moving target and a stationary object forming the reference radio signal have different range strobes.

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