UDC 621.396.96

2. METHODOLOGICAL APPROACHES TO THE FORMATION OF SIMULATED INPUT SIGNALS FOR A METER-RANGE RADAR STATION

Kozhuhovsky V. L., Master Degree Student, gr. 225941

Belarusian State University of Informatics and Radioelectronics
Minsk, Republic of Belarus

Liakh Y.V. – Senior Lecturer

Annotation. The article deals with methodological approaches to the formation of input signals that describe the background-target situation at the input of the receiving device of a meter-range radar station.

Keywords. Radar station, meter range, input signals, background-target situation, passive interference, active noise interference, radiation, reflected signal, antenna directivity pattern, effective scattering area.

There are many methodological approaches to simulating input signals for radar systems operating in the meter wavelength range. This range is used in various systems designed for air traffic control and remote sensing of the airspace. Simulating input signals for radar systems operating in this wavelength range is associated with several challenges, such as combating interference from other sources, mitigating atmospheric attenuation effects, and minimizing the impact of noise and interference on the received signal.

Many years of experience in the use of meter range radar systems in reconnaissance and air traffic control systems have shown significant advantages over other wavelength systems for these tasks. Meter wavelength radar systems are traditionally characterised by long detection ranges, stable performance in different climatic conditions, the ability to detect objects created using stealth technologies, ease of operation, high reliability, technological efficiency in production, and relatively low cost.

All objects in the radar's surrounding space are determined by their kinematic and radar characteristics. Kinematic characteristics include object coordinates and velocities. Radar characteristics of objects vary depending on the type of object and significantly affect the received signals. Currently, there is a classification of signal sources at the radar input based on their radar properties, including point targets, extended (distributed) targets, passive interference (natural and artificial), and various types of active interference.

There are many methodological approaches to forming simulated input signals of radar, adequate to real reflected radar signals from airborne objects.

The most important characteristic of any radar target is its effective scattering area (ESA). ESA is understood as an equivalent target, normal to the radar beam with an area of σ, which, located at the target's position and isotropically scattering all the power from the radar incident on it, creates the same power density at the location of the radar receiving antenna as the real target. ESA is measured in m^2 and the concept of ESA allows us to obtain the main equations of radar and radio-electronic suppression [1].

ESA of a target can be determined during field trials, as well as by mathematical modeling. Typically, ESA is determined by the relative phases and amplitudes of signals reflected from elementary areas. When the viewing angle changes, the total field will change significantly. In addition, a change in angle will lead to the "shadowing" of some elementary areas and the emergence from shadowing of others. As a result of the joint action of these factors, a total scattered field is formed, which has a multi-lobe structure.

The number of elementary radiators is huge if the object's dimensions are large compared to the wavelength of the incident field and limited from below by the number of degrees of freedom of the field N:

$$N \gg \frac{4\pi L^3}{3\lambda^3}, \tag{1}$$

where L is the characteristic linear size of the object.

The resulting scattered field of the object is a superposition of the scattered fields from the elementary patches:

$$\vec{E} = \sum_{L=1}^{N} \vec{E}_i, \quad (2)$$

The resulting ESA of a complex object represented by a set of elementary rectangular areas with dimensions of λ/2, without taking into account re-scattering between them, is determined by the formula [2]:

$$\sigma = 4\pi \lim_{r\to\infty} r^2 \left|\sum_{n=1}^{N}[\overrightarrow{\rho_e} E^s f]_n + \sum_{m=1}^{M}[\overrightarrow{\rho_e} E^s w]_m\right|^2 / \left|\vec{E}^j\right|^2, \quad (3)$$

When modeling reflected signals, the influence of the antenna radiation pattern (main lobe and side lobes) in the azimuthal and angular planes on the amplitude and phase modulation of the signals in the radio receiving devices of the radar system should be taken into account.

The directional pattern of the transmitting antenna system depends on reflections from the surface of the Earth:

$$g_t[\varepsilon, \varepsilon_0(t)] = g_{tf}[\varepsilon, \varepsilon_0(t)] * \Phi_t[\varepsilon, \varepsilon_0(t)], \quad (4)$$

where $g_{tf}[\varepsilon, \varepsilon_0(t)]$ – elevation pattern of an antenna, disregarding the influence of reflections from the Earth's surface, $\Phi_t[\varepsilon, \varepsilon_0(t)]$ – module of the interference multiplier of the Earth.

The module of the interference multiplier of the Earth for the transmitting antenna system at time t for the direction by elevation angle ε, with the position of the radiation pattern by elevation angle $\varepsilon_0(t)$, is determined by the equation [3]:

$$\Phi_t[\varepsilon, \varepsilon_0(t)] = \sqrt{1 + \Gamma^2(\varepsilon)\frac{g_{tf}{}^2[-\varepsilon, \varepsilon_0(t)]}{g_{tf}{}^2[\varepsilon, \varepsilon_0(t)]} + +2\Gamma(\varepsilon)\frac{g_{tf}{}^2[-\varepsilon, \varepsilon_0(t)]}{g_{tf}{}^2[\varepsilon, \varepsilon_0(t)]} * \cos\left[\frac{4\pi h}{\lambda} * sin\varepsilon + \psi(\varepsilon)\right]}, \quad (5)$$

where $\Gamma(\varepsilon)$ is the magnitude of the specular reflection coefficient, $\psi(\varepsilon)$ is the phase of the complex reflection coefficient, h is the height of the radar antenna above the surface of the Earth, and λ is the wavelength of the probing signal.

The azimuthal antenna pattern can be described as [3]:

$$g_{tf}[\beta, \beta_0(t)] = \begin{cases} e^{-\frac{\pi[\beta-\beta_0(t)]^2}{2(\Delta\theta_{\beta t})^2}}, \text{если } \beta_{t1} \le \beta \le \beta_{t2}, \\ p_{t\beta} * e^{-m_t(\beta-\beta_{t1})^2} * \cos[f_t * (\beta-\beta_{t1})^2], \text{если } \beta < \beta_{t1}, \\ p_{t\beta} * e^{-m_t(\beta-\beta_{t2})^2} * \cos[f_t * (\beta-\beta_{t2})^2], \text{если } \beta > \beta_{t2} \end{cases} \quad (6)$$

where β_{t1} and β_{t2} are the boundary azimuth values where the approximating functions converge.

Most existing radar systems used for air space surveillance employ probing signals that do not allow the implementation of the super-resolution mode for the elements of the radar observation space. Therefore, the majority of observed targets are so-called concentrated objects, which are located within the limits of just one resolution element (Fig. 1).

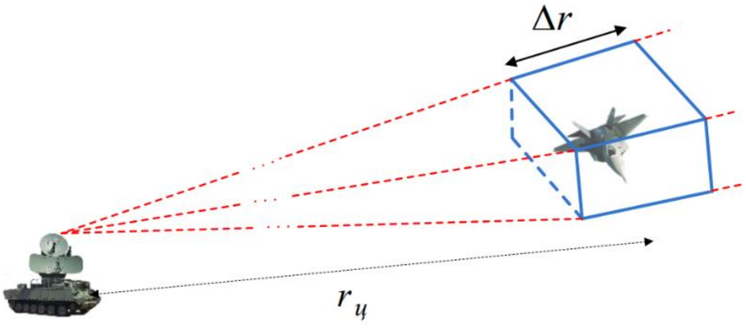

Figure 1 – Observation of a concentrated target

At the same time, it should be noted that most surface ships, whose geometric dimensions exceed the size of the resolution element, are distributed objects based on the principle of forming the structure of the reflected signal. Distributed targets occupy several resolvable volumes in the space of radar observation.

The resulting field of secondary radiation at the receiving point is a vector sum of the fields excited by each of the reflecting surface elements of the target. The approach discussed assumes the representation of the temporal structure of the reflected signal as a result of the interference of several signals reflected from individual elements of the target's structure:

$$m(t) = \sum_{x=1}^{N_x} m_x(t) = \sum_{x=1}^{N_x} E_x(t) U_L(t - t_{r_x}) e^{j[(\omega_0 + \Omega_{\partial_x})t + \varphi_x(t)]} \quad , \qquad (7)$$

where N_x is the number of local reflection areas on the object surface, $m_x(t)$ is the temporal structure of the reflected signal from the χ-th local reflection area, $U_L(t - t_{r_x})$ is the complex modulation law of a limited sequence of L single radio pulses, ω_0 is the circular carrier frequency of the probing signal, t_{r_x} is the delay time of the reflected signal from the χ-th "glittering" point, Ω_{∂_x} is the circular Doppler shift due to the radial velocity of the χ-th "glittering" point, $\varphi_x(t)$ is the phase of the reflected signal from the χ-th reflection area.

When implementing algorithms for modeling the air environment, it is important to take into account passive and active noise interference. Passive interference does not use electronic means to modify the incoming radar signal or to create a jamming signal. The idea is to reflect the radar signal in such a way as to mask the target, create false targets, disrupt the radar signal, or otherwise disorient the radar system.

Active jamming produces signals at the input of the radar, which hinder the detection and recognition of useful signals against the background of the surrounding environment. This leads to a decrease in the probability of detecting air targets, a decrease in the accuracy of measuring their coordinates, and an increase in the probability of false alarms (Fig. 2) [4].

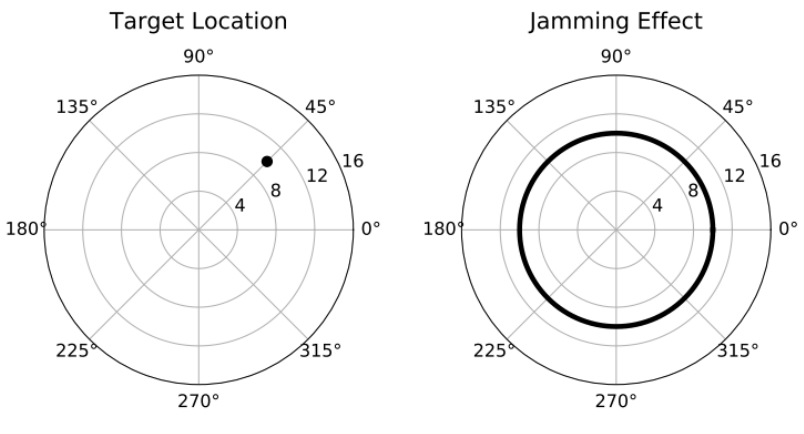

Figure 2 - Inverse gain jamming technique

The effectiveness of continuous jamming is characterised by the ratio of the power of the interference to the power of the signal in the receiver's bandwidth. The power of the interference received by the radar is often expressed in decibels (dB) and is determined as follows [4].

$$J = \frac{P_j G_j \lambda^2 G_r}{(4\pi r_j)^2 B_j L_j}, \qquad (8)$$

where P_j is the power of the j-th source of interference (Watt), G_j is the gain coefficient of the ADP in the direction of the j-th source of interference when transmitting signals, G_r is the gain coefficient of the ADP in the direction of the j-th source of interference when receiving signals, r_j is the distance from the j-th source of interference to the radar, B_j is the bandwidth of the receiver of the j-th source of interference, and L_j is the power losses in the j-th source of interference.

For the completeness of the described model, it is necessary to take into account the inherent noise of the radar itself. The noise generated in the receiver is random, and statistical techniques are used to characterise its effect. The noise level at the input to the receiver is primarily determined by the antenna noise temperature and its associated loss.

The noise generated by the radar is a combination of the noise of the antenna itself and the internal noise of the receiver:

$$T_s = T_a + T_r = T_a + L_r T_0 (F - 1), \tag{9}$$

where T_s is the total noise temperature in the system, T_a is the antenna noise temperature, T_r is the receiver noise temperature, L_r is the power loss in the receiver, T_0 is the receiver operating temperature, and F is the receiver noise figure.

The noise due to the receiver is typically small compared to the noise input to the receiver. Therefore, receiver noise only has a small effect on the total system noise temperature. This is important when calculating parameters such as signal-to-noise ratio (SNR) as the SNR referenced to the receiver noise can be very different from the SNR referenced to the total system noise

Thus, the basic principles of simulating input signals for a meter-range radar have been considered, based on which the algorithmic part of the target environment simulator is currently being developed. Modeling physical processes in the digital computing system of the radar based on these approaches, performed at the stage of developing the algorithms for the operation of the radio-electronic device, allows obtaining necessary information at an early stage about how well the proposed digital signal processing algorithms meet the requirements set for them. With this information, researchers can make decisions about the need to make changes to the device's operating algorithms during its development stage, rather than during testing of the finished device. This approach can significantly reduce the time and costs associated with creating software for the computing system of the developed radar.

References

Bassem, R. Mahafza. Radar Systems Analysis and Design Using MATLAB / Chapman and Hall/CRC, 4th edition, 2022. – 666 p.

Sveshnikov, O.V. Synergy of the invisible objects. Radar of Stealth-objects / Balt. state tech. un-t., 2015. – 122 p.

Skolnik, M. Handbook of radiolocation / M. Skolnik. - New York, 1970. – 376 p.

Harrison, A. Introduction to Radar Using Python and MATLAB / Library of Congress Cataloging-in-Publication Data, 2020. – 491 p.