Measuring the Effectiveness of a Radio-Identification System

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Abstract—Conducted measurements of qualitative informative features for object recognition determined the most effective methods for measuring them. For this purpose, it is proposed to use the method of digital spectral analysis "thermal noise", which will provide a significant increase in resolution and measurement accuracy of object characteristics. Experimental studies have shown that to increase the likelihood of correct identification of objects by existing radio-technical identification systems, it is necessary to measure the highly informative characteristics of objects - their radar long-range portraits. Measurement of such portraits is proposed to carry out through the use of broadband and especially ultra-wideband signals, with high stability of the complex frequency characteristics of the receiving and transmitting paths of radar stations. In particular, the proposed structure of the construction of an experimental measuring complex and the principle of its operation for measuring radar distance portraits of identification objects.

Index Terms—Identification, filter, noise, radar

I. INTRODUCTION

The need to develop radio-technical identification systems (RTSI) of a new generation necessitates the identification of so-called critical technologies. Critical technologies mean not only the production process of the RTSI, but also a set of scientific and technical measures to identify bottlenecks in the process of creating promising means of measuring the characteristics of the objects being followed - radar stations (RLS) and analyzing ways to eliminate them.

The list of the most critical technologies for creating such radars provides [1], [2]:

- Creation of a unified series of radars of various significance (strategic, operational, tactical), based on various types of carriers: manned and unmanned aerial vehicles (LA) of various range;
- Development of methods for joint processing of information in the composition of multi-point (MP) guidance systems;
- The creation of fundamentally new algorithms for tracking and identifying speed objects with an estimate of not only the first, but also the second and higher derived linear and angular coordinates;
- Development of more advanced decision-making algorithms for ranking objects in order of importance;
- Creation of spherical areas of responsibility with optimization of procedures for their inspection on the basis of active phased antenna arrays;
- Development of ultra-long-range detection modes at the background noise level;
- Integration of all information sensors in the framework of creating integrated radio frequency systems;
- Management of information flows in the MP radar.

Each of these areas entails the need to solve a whole complex of quite complex tasks. The process of creating effective, fundamentally new methods of tracking and identifying objects, as defined in this list, is impossible without having a bank of their reference radar long-range portraits (RLDPs). Measurement of the RLDP is an important and urgent task in the design and creation of modern high-performance RTSI.

The purpose and objectives of the study

The conducted research set the goal of developing a methodology for measuring the qualitative informative characteristics of object recognition to improve the efficiency of radio identification systems [3].

To achieve this goal the following tasks were solved:

- To analyze the width of the spectrum of the receiving and transmitting paths of the existing fleet of radar tracking of the air defense system and to identify existing problems;
- To analyze and justify the method of measurement (simulation) of the quality characteristics of objects of identification;
- Design the structure of construction and develop an experimental measuring complex for measuring the informative characteristics of identification objects using the spectral correlation channel for processing incoming information;
- To conduct a comparative description of the proposed methods of digital spectral analysis to determine the

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most effective from the point of view of their resolution.

II. Analysis of Literature Data and Problem Statement

It is known that as the most informative signs of identification of detected and followed objects are their LFER [4]. The study of the measurement task of such a RLDP showed that their high information content (Fig. 1) is determined by the fact that they contain information about the magnitude (length of objects), the number of maxima and minima on their surfaces, the distances between them, the correlation coefficients between the measured and reference RLP stored in the bank of reference portraits of the identification system [5], [6].

It is shown that measuring the RRLP with the highest information possible due to the use of broadband and especially ultra-wideband signals can only be ensured if the complex frequency characteristics of the receiving and transmitting paths of the tracking radar are high and at a sufficiently high value of the signal-to-noise ratio at the outputs of the receiving radar channels. These conditions are most easily met with the correlation processing of broadband signals in the tracking radar. However, the width of the signal spectrum of the existing tracking radar fleet, as a rule, does not exceed several tens of megahertz, which cannot provide the necessary distinction between local reflection sources (LIO) of tracking objects in range [7].

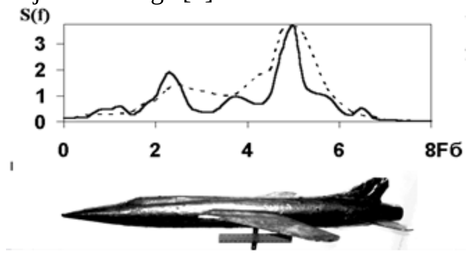
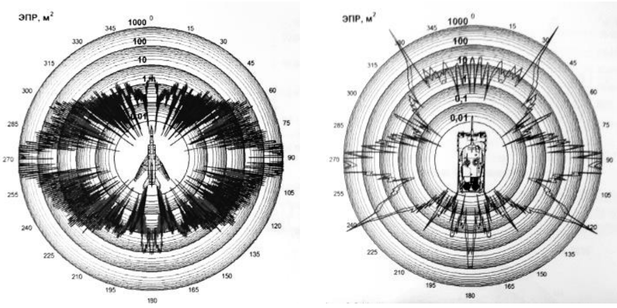


Fig. 1. Snapshot on clearance on the plane and nevovaty RLDP.

Measurement of the RLDP for replenishing the bank of reference portraits of objects is possible either by directly measuring them with real radar, or by conducting a simulation process. At the same time, a large number of works are known, both by our compatriots and by foreign authors, dedicated to the processes of modeling the secondary characteristics of objects of detection and tracking [8], [9]. The current stage of development of methods for measuring the RLPP of objects involves two main methods for modeling them: mathematical and physical.

When solving problems of mathematical modeling, the basis for the study are numerical methods. To obtain RLPP objects of complex shape, prone to random actions or having a stochastic structure, it is necessary to use high-speed computers, which is associated with the reproduction of both different angles of the air object and its electrodynamic interaction with the electromagnetic field of the probing signal.

As an example, Fig. 2 shows the pie scatter diagrams of aerial a) and ground b) objects [9].



a) b)

Fig. 2. Statistical characteristics: a) erial objects; b) ground.

The main disadvantages that manifest themselves in the machine implementation of the methods of mathematical modeling of the measurement process of RLPP objects are:

- Limited accuracy of the representation of the surface of simulation models, and in some cases complete uncertainty in the mathematical description of these surfaces;
- The complexity and ambiguity of the solution of the electrodynamic problem of the interaction of simulation models of objects with a flat electromagnetic wave of probing signals, especially in the case of moving models.

During physical modeling, the studied processes or objects are reproduced with preservation of their physical nature (natural modeling), or using similar physical phenomena (scale modeling).

Large-scale modeling is characterized primarily by the fact that research is carried out on physical models that have physical similarity, that is, they retain fully or at least mainly the nature of the phenomena. An example is the ultrasonic test site (hydroacoustic modeling) or the use of anechoic chambers of ultra-high frequencies (microwave BEC) (electrodynamic modeling) to study radio propagation processes [9], [10].

Full-scale simulation of the RLPP measurement process requires the creation of rather expensive radar models that irradiate objects. To measure the RLPP of objects from different angles, one needs either to fly around these objects around the radar or to move the radar model around the object located on the ground. In the first case, measuring the LLDP will be a very expensive process, while in the second, the task of suppressing reflections of an interfering signal from the ground and local objects is practically not solved.

Therefore, there is reason to believe that the inadequate adequacy and high cost of the above modeling methods determine the need for research in this direction.

III. Matirials and Methods for the Measurement of Qualitative Informative Signs of Recognition

The studies were carried out using the method of electrodynamic modeling, which is the main method of obtaining reliable LDLP models of various objects in a wide frequency range. When the requirements of electrodynamic similarity are met, the measured results take into account the nonlinearity of the signal transmission path and the effects of its reflections, the contribution of which is almost impossible to evaluate by other methods.

As models apply exact reduced copies of the studied objects. At the same time, the dimensions of the model $\ell_{\text{м}}$ and the object $\ell_{\text{о}}$, as well as the wavelengths of the signals that distinguish the radar models λ_M and the real radar λ, must be such that the condition [11] is fulfilled:

$$\frac{\ell_{\text{о}}}{\ell_{\text{м}}} = \frac{\lambda_{\text{м}}}{\lambda} \tag{1}$$

Then the effective scattering surface (EPR) of a real object after obtaining the EPR of its model will be $\sigma_{\text{о}} = \sigma_{\text{м}}\lambda^2/\lambda_{\text{м}}^2$.

In addition, in order to reduce errors in measuring the RLDP, it is necessary, first, to provide a flat wave front that irradiates the model, that is, the model should be located from the transmitting antenna at a distance of at least [11]:

$$r_{\min\ \text{пер}} = \frac{D}{4} + \frac{D}{2\dfrac{D}{\lambda}} \tag{2}$$

where $r_{\min\ \text{пер}}$ - he minimum allowable distance from the transmitting antenna to the object of irradiation; D is the size of the transmitting antenna aperture; λ - wavelength that irradiates the object.

The minimum distance to the object under study should be ensured by the implementation of the inequality:

$$r_{\min\ \text{пр}} \geq \frac{\ell_{\text{м}\max}}{4} + \frac{\ell_{\text{м}\max}}{2\dfrac{\ell_{\text{м}\max}}{\lambda}} \tag{3}$$

where $r_{\min\ \text{пер}}$ - the minimum allowable distance from the object of irradiation to the radar receiving antenna; $\ell_{\text{Мmax}}$ - the maximum size of a model element.

Practically, in the case of a combined radar, the distance from the antennas to the object model is chosen significantly more than two values $r_{\min\ \text{пер}}$ and $r_{\min\ \text{пр}}$.

To reduce measurement errors due to spurious reflections, as a rule, the model is placed in an anechoic microwave oven. The main objective of the microwave BEC is to attenuate the reflections from the surfaces that limit its volume to the required magnitude. This is how the conditions of "free space" are created inside a closed volume, under which the source field is not distorted by reflections.

To measure RLDPs that have a significant difference in the levels of signals reflected from LIOs, it is advisable to make the lining of the inner surface of the BEC microwave radio absorbing material, providing the maximum amount of electromagnetic wave absorption in a wide range of frequencies and angles of incidence.

Fig. 3 shows the inner surface of the BEC UHF, which has a curved cushion-shaped wall with dimensions (8.3 × 5.2 × 4) m, covered with radio-absorbing pyramids in the amount of 8400 pieces. Such pyramids are radio-absorbing materials of the scattering type, which are characterized by significant transverse heterogeneity and can be conventionally combined by a class of spinous or scattering materials. The absorption of electromagnetic waves in such materials occurs when they are multiple reflections from the walls of the pyramidal radio-absorbing material. The height of the pyramids 320mm., The angle at the top of 30 degrees. With such dimensions in the range of angles of incidence of electromagnetic waves 0 ... 40 degrees. The number of beam re-reflections to the middle of the pyramids is at least five and the absorption at each multipath is about 5 ... 12

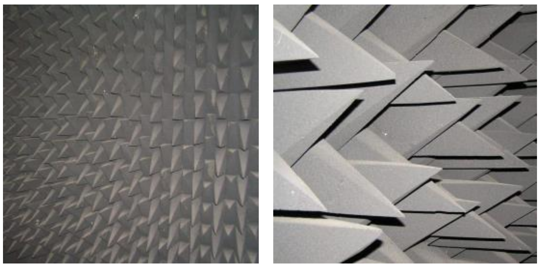


Fig. 3. Internal surface BEC UHF.

The analysis of the theoretical and experimental studies made it possible to conclude that it is possible and necessary to carry out the measurement and replenishment of a bank of standard RELP object models for RTSI using the method of electrodynamic modeling using BEC microwave [12]. For a more qualitative measurement of the RLDP object models, a method of digital spectral analysis (CSA) - thermal noise (4) [13], [14] has been proposed:

$$S(\Omega) = \left[X^*(\Omega) \times \Psi^2 \times X(\Omega)\right]^{-1}, \tag{4}$$

where $X(\Omega) = \left\{1,\ e^{-j\Omega\Delta t},\ e^{-j2\Omega\Delta t}, \ldots\ e^{-j(M-1)\Omega\Delta t}\right\} = \left\{x_i(\Omega)\right\},\ i = 1, \ldots M$, M - measuring measuring vector inspection; $\Psi\left\{\omega_{i,j}\right\} = \Phi^{-1},\ i, j = 1, \ldots M$, $M \times M$ Hermitian matrix, inverse of the correlation matrix $\Phi = \left\{f_{i,j}\right\} = \overline{Y \cdot Y^*},\ \ i, j = 1, \ldots M$ correlation matrix M - dimensional vector of calculations of complex amplitudes

$Y = \{y_i\},\ i = 1,...M$, the process being analyzed; Ω - current frequency value; the sign (*) and the risk from above are the symbols of Hermitian conjugation and statistical averaging, respectively.

The specified algorithm in terms of the signal-to-noise ratio q>12 dB makes it possible to K>2 increase the frequency (range) resolution by a factor of comparison with the classical Fourier method. The authors of this paper proposed an experimental measuring complex (EIC) and a methodology for performing such measurements [15], [16] for measuring the RLDP of object mockups.

Fig. 4 shows the block diagram of the EEC, in which the method of CSA - thermal noise is used to measure the radar characteristics of the models of objects.

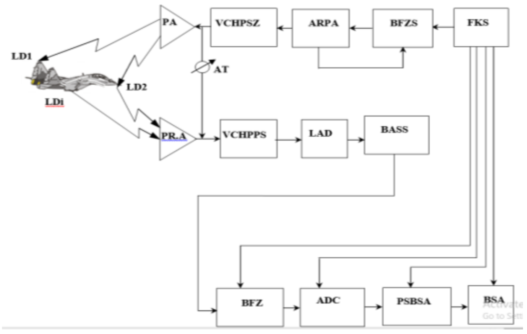


Fig. 4. EIC structural diagram.

The structure of the main EIC units includes:

FKS - driver control signals;

BFZS - block formation of chirp sounding signals;

ARPA - automatic power control system

VCHPSZ - high-frequency amplifier probing signals;

PA - transmitting antenna;

PR.A - receiving antenna;

AT - attenuator;

VCHPPS - low-noise high-frequency amplifier of the received signal;

LAD - linear amplitude detector;

БПВС - block amplification of the selected signal;

BFZ - phase shift unit and messages with analog-to-digital converter;

ADC - analog-to-digital converter;

PSBSA - a device for interfacing with a spectral analysis unit;

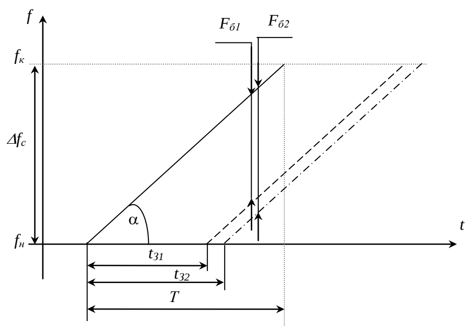


Fig. 5. The principle of measurement of RLP objects in the spectral region.

BSA is a spectral analysis unit. The measurement principle of the RLDP of observation object mock-ups is explained in Fig. 5, where the solid, dashed and dashed-dashed lines show the laws of the frequency of the probing and reflected from two local sources of reflection (LIO) of the chirp signal object. Doppler frequency shift of the reflected signals in the fixed mock objects is missing, which corresponds to the compensation of the value of the system of automatic tracking speed radar SAM.

In Fig. 5, the following notation is used:

-duration of the radio frequency pulse;

Δf_c - frequency deviation of the probing chirp signal;

$f_н$ и $f_к$ - the initial and final frequencies of the probing chirp signal;

$tg\alpha = \Delta f_c / T$ - the slope of the frequency change of the chirp signal;

$t_{з1(2)}$ - the delay time of the reflected signal from the first (second) LIO relative to the probing chirp signal;

$F_{б1(2)}$ - difference frequency of beats between the frequency of the probing signal and the reflected signal from the first (second) LIO.

IV. The Results of Studies Measuring the Qualitative Informative Signs of Recognition

The work of the measuring complex was carried out as follows [17]. The device for the formation of chirp signals (driver control signals (FCC) and block the formation of probe signals (BFZS)) due to the presence of the automatic power control system (ARPA) generates a periodic sequence of probing signals of constant power (Fig. 4).

The generated chirp sounding signal with the initial frequency $f_н$ and frequency deviation Δf_c after amplification of about 30 dB in the high-frequency amplification module of the probing signals (HFPS) is radiated into space by means of a transmitting antenna (PA).

Thus, the generated chirp signal reaches the object surface, is reflected from the LIO located on it (LD1, LD2, ..., LDi) and returns to the receiving antenna (Fig. 4). At the same time, from the output of the VCHPZS to the input of the low-noise high-frequency amplifier of the received signal (HFPS), a signal comes through the attenuator, playing the role of a heterodyne signal. After amplification in power (about 30 dB), the penetrating and reflecting signals in the HFPS block are detected and the harmonic oscillations selected at the amplitude detector (BP) with beating frequencies $F_{б1(2)}$ (Fig. 5) are amplified by the selected signal amplification unit (BITS).

Next, in the phase shift block (BFZ), the signal is divided into the main and quadrature channels, after which it is digitized in the analog-to-digital converter (ADC) unit. The digitized signal from the ADC unit enters the interface device with the spectral analysis unit (PSBSA), in which the incoming digitized signal is redirected to the corresponding address and data buses of the computer of the spectral analysis unit (BSA). In the BSA block, spectral estimation of digitized signals is carried out in accordance with the CSA method - thermal noise (4).

The measured values of the RLDP of the objects in the spectral region $S(\Omega)$ are recorded in the reference portraits bank (long-term EIC memory), and the spectrograms obtained are displayed on the monitor of the experimental measuring complex.

The spectral analysis unit, made on the basis of a personal computer, functions according to a specially developed program, which allows measuring the RLDP of object models in the spectral domain.

V. Discussion of the Results of the Study of Measurment the Qualitative Informative Signs of Recognition

Fig. 6 shows the LDEL of aircraft mockups, which are measured by the Fourier method and the proposed thermal noise method. The dashed and solid lines in Fig. 6 show the LDEL of aircraft of various sizes when applying the Fourier method and the thermal noise method, respectively.

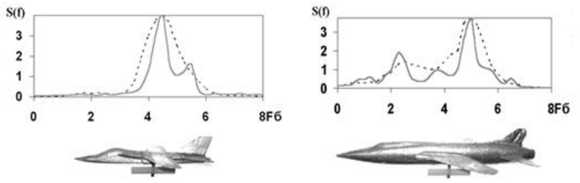


Fig. 6. RLPD models of airplanes of various sizes measured by EIC in BEC UHF.

Metal models of airplanes with dimensions of 34 cm and 72 cm were used as the objects under study. The aircraft models under investigation were placed in turns at the BEC UHF at a distance of 4.5 meters from the receiving-transmitting antennas of the experimental measurement complex.

The conditions of the experiment were as follows. The frequency deviation of the chirping signal of the EVC signal is selected, based on conditions (1-3), approximately the same as in real-world radar tracking of the air defense system. In this case, the dimension of the correlation matrix Φ is M=30. The number of samples was 120. For a set of statistics for each of the course angles, 250 measurements were taken. With the help of the noise generator built into the EIC, the signal-to-noise ratio was set, which was chosen based on the maximum approximation to the real conditions of tracking objects in difficult interference conditions and was approximately 14 dB.

From Fig. 6 it can be seen that for the same measurement conditions for the LLDP of aircraft mock-ups, there is a significant increase in the informativeness of the signs of the portraits when using the CSA algorithm for thermal noise compared to the classical Fourier method.

Fig. 7 shows the options for measuring the LDEL of an airplane mockup with angular courses of 0 and 10 degrees.

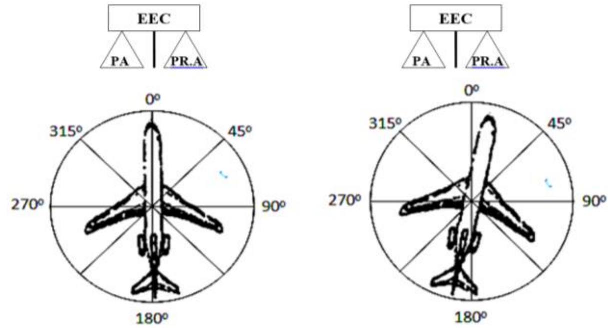


Fig. 7. Measurements in the BEC UHF RLPD of the aircraft mock-up at different viewing angles.

The change in the course angle was carried out with a resolution of 0.5 degrees due to a special radio-absorbing rotator.

VI. Conclusions

Studies have found that a narrow range of signals of the receiving and transmitting paths of the existing fleet of radar tracking of the air defense system is not able to provide the necessary resolution in range. The solution to this problem should be the introduction of a spectral-correlation identification channel into the radar air defense system using modern methods for processing incoming information. For this purpose, it is proposed to use the CSA thermal noise method, which will provide a significant increase in the resolution and accuracy of measuring the characteristics of objects, without a significant re-equipment of the receiving and transmitting paths of the existing radar fleet of tracking air defense systems.

In order to increase the likelihood of correct identification of objects by existing RTSIs, it is proposed in the work to measure the highly informative characteristics of objects - their LDLE. Measurement of such RLDP is proposed to be implemented through the use of broadband and especially ultra-wideband signals, with high stability of the complex frequency characteristics of the radar receiving and transmitting paths.

A structure for constructing the EIC and the principle of its functioning for measuring the LDLP objects are proposed, which allows such measurements to be carried out when creating and replenishing the bank of reference portraits of objects in the RTSI.

Thus, using the developed experimental measuring complex using the methods of digital spectral analysis - thermal noise, it became possible in the spectral field to measure the highly informative signs of the identification of objects, namely their RLDP, when creating or replenishing a bank of reference radar remote sensing systems for radio identification systems.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Oleksi Bichkov, Volodymyr Nakonechnyi, conducted the research; Oleksi Bichkov, Volodymyr Nakonechnyi, Nataliia Lukova-Chuiko, Victoria Zhebka analyzed the data; Galina Panayotova, Dimitar Dimitrov wrote the paper. All authors had approved the final version.

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