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Metrological Complex for Electromagnetic Field Forming and Study of Electromagnetic Environment

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Abstract: The article is devoted to the problems of constructing electromagnetic field with given parameters and both to the study of electromagnetic environment. For solving the problems, the corresponding theoretical material is presented. The functional relationships are considered that make it possible to construct the device for generating electromagnetic field with specified parameters in circular orthogonal polarization basis. The block diagram, which can ensure the specified field forming with acceptable errors are synthesized. Measurement of radiation characteristics, including polarization characteristics, requires the appropriate orientation of the receiving antenna to the direction of wave propagation. Corresponding algorithm and antenna system for this purpose is proposed. The study of the field polarization characteristics formed using the ring antenna elements is carried out. It is shown that in the broad frequency band, the ring elements can be replaced with spiral radiators, as well as that the antenna system for electromagnetic waves reception and their subsequent decomposition in circular polarization orthogonal basis, must contain at least eight antenna elements. Applied spiral flat antenna elements ensure the low level of cross-polarization due to the matched load on the spiral end, which is one of the conditions for successful polarization analysis. Besides, a device for polarization analysis of incident electromagnetic waves and the algorithm for measurement of the effective reflection area are considered.

Index Terms: Electromagnetic Wave, Polarization, Field Formation, Antenna System, Errors Analysis, Effective Reflection Area.

1. Introduction

At the current stage of the development of science and technology, the need to take quantitively into account, model and measure the interaction of substances, tissues and, of course, technical systems, especially electronic, with the electromagnetic field is becoming more and more relevant. It is obvious that for this it is at least necessary to generate an electromagnetic field with given parameters, which can be quickly changed according to the task and current situation. Let's imagine that we have a system that, unlike the use of standard generators and antennas, makes it possible to form an electromagnetic field with specified characteristics for multifunctional applications. Where and for what purpose such system is reasonable to be used? Some beneficial applications are discussed below.

The ability to simulate various electromagnetic field configurations allows for complex experiments and research, for example, in physics, enabling the exploration of phenomena that are difficult or impossible to replicate in real-world conditions. Understanding how materials interact with different electromagnetic fields [1] is crucial for developing new materials with unique properties, such as superconductors or materials for stealth technology.

Advanced electromagnetic field manipulation can help to improve medical imaging techniques, such as Magnetic Resonance Imaging (MRI), by providing better image resolution, reducing scan times, or even enabling new types of imaging that can target specific tissues or abnormalities [2]. Moreover, electromagnetic fields are used in various medical treatments, including cancer therapy and pain management. A system that can accurately simulate and apply complex fields could lead to more effective and less invasive treatments.

In the telecommunications sector, the ability to create and manipulate complex electromagnetic fields can lead to more efficient signal transmission, reduced interference, and the development of new communication technologies that can operate in challenging environments. In the field of radar and remote sensing, the development of advanced systems for electromagnetic field formation, particularly those capable of multifunctionality [3] in terms of intensity, polarization [4], and field configuration, can significantly enhance the capabilities and applications of radar and other microwave technologies [5]. Such advancements could impact especially polarimetric and coherent-polarimetric radar development [6] and their applications [7]. By accurately forming and analyzing electromagnetic fields with different polarizations, it becomes possible to distinguish between different types of targets more effectively, improving classification and identification processes [8-10]. For defense applications, such a system could be useful for electronic warfare testing, including jamming enemy communications or protecting friendly communications from interference [11]. Moreover, manipulating electromagnetic fields can also play a role in stealth technology [12], making vehicles or objects less detectable to radar or other detection methods.

The ability to control and analyze complex electromagnetic fields allows for sophisticated signal processing techniques, enhancing the detection of subtle changes in the target or environment [13-15]. The combination of coherence and polarization information enables more effective clutter suppression techniques, improving the radar's ability to detect targets against a background of noise and interference [16] and improve resolution including passive systems [17].

From this far from complete overview it follows that the development of such a multifunctional system transcends traditional limitations, offering high precision and versatility in electromagnetic field manipulation. This opens up new possibilities across diverse fields, from enhancing scientific research capabilities to practical applications in medicine, telecommunications, radar, defense, and beyond. The investment in the theoretical groundwork is justified by the potential to revolutionize how we interact with and utilize electromagnetic fields in technology and science.

Methods for studying the parameters and characteristics of radiation objects, reflection objects or the influence of the environment on electromagnetic waves propagation include the use of radio equipment and measuring processes. The integrated use of such tools is possible only if their external (operational) characteristics ensure the compatibility of mutual functioning and the proper efficiency of the measuring processes. This remark concerns to the metrological characteristics, as well as to the operating frequency range, the radiation power of the transmitters and the receivers' sensitivity, the polarization orthogonal basis of the antennas and other critical parameters.

Based on these considerations, it can be noted that the creation on general principles of the means for the electromagnetic field formation and means for analyzing the electromagnetic situation for joint operation can provide not only greater efficiency of measuring processes, but also expand the range of research. So, for example, the means of electromagnetic field forming agreed with the means of measuring main parameters of electromagnetic waves make it possible to comprehensively measure the reflective properties of objects for various purposes, the characteristics of radio channel, etc.

The technique for creating electromagnetic fields for studying both antennas of various types and the response to irradiation of certain objects is considered in many works devoted to the theory and practice of radio engineering measurements. The choice of equipment for measuring antenna parameters, electromagnetic compatibility (EMC) testing depends on a number of factors and primarily on the problem to be solved and the possibilities of its implementation. In most cases for radiation an electromagnetic field, the standard generators and certain types of antennas are used. For example, this is in Rohde & Schwarz and Keysight papers [18-20], measurements in the near zone [21], EMC testing [22, 23] and etc. Much less is known about scientific and technical studies that consider the complex problems of radiation field formation according to specified characteristics in certain spatial locations, as well as the ability to analyze both the processes of electromagnetic waves scattering in the selected polarization basis and evaluate their energy characteristics and propagation features.

As a result of the analysis of known systems for studying the electromagnetic environment and forming the electromagnetic field, the absence of an integrated structure that would allow a comprehensive solution of the tasks was noted. Existing systems are characterized by a limited set of functionalities. That is why the theoretical substantiation of the fundamentals for constructing the structure of a metrological complex with advanced capabilities is necessary to get a tool for the practical implementation of such systems. As engineering solutions, which use the developed theory, the functional units and devices of the metrological complex should also be synthesized in this research.

Based on the above remarks, the following areas of the work can be identified:

1. It is advisable to consider the theoretical aspects of radiation field formation with certain polarization characteristics at known distance from the radiating system and the possibility of simple control of field energy characteristics. In addition, it is necessary to develop theoretical base for methods for determining the energy characteristics in the chosen polarization basis, to analyze the polarization features and the location of radiation sources.

2. The purpose of this research is to develop the theoretical foundations for constructing a field formation system that would be multifunctional compared to standard solutions, that is, it would allow not only to form a field of a given strength and polarization, but also to simulate various field configurations that may arise in practice.

3. Traditionally, in problems of analysis and formation of electromagnetic fields, the basis of orthogonal linear polarization was more often used. But in many cases, the basis of circular polarization has significant advantages over the basis of linear orthogonal polarization [24]. Therefore, in this research, the orthogonal circular polarization basis is used for creating a unified set of devices to generating a given electromagnetic field, as well as studying electromagnetic waves in a given space. It is reasonable to note that there is no loss of generality of the results, since it is always possible to unambiguously transform a signal from one orthogonal polarization basis to another.

2. Formation of the Radiation Field According to the Given Parameters

The radiation field in homogeneous lossless medium with the relative permittivity equal to unity is completely determined by the frequency, direction of electromagnetic waves propagation, amplitude and orientation in a given coordinate system of the electric field intensity vector. Thus, in order to create the electromagnetic field for metrological purposes in airspace, it is necessary to choose specific coordinate system (most often this is a spherical system), specify in the selected coordinate system region of space, in which the radiation field meets the desired conditions and formulate these conditions (value and orientation of the electric field intensity vector). Because of that, it can be assumed that the initial data of the radiation field are: the distance from the phase center of the radiating system to the reference point, the power density Π of the electromagnetic wave or the field intensity E, the orientation of the vector E in space. Obviously, the oscillation frequency f (wavelength λ) is set by the generator, which is one of the main elements of the device for generating the radiation field under normal conditions of radio wave propagation at fixed positions of the radiating system and the observation points.

Although the orientation of a vector E in space can be specified using any orthogonal polarization basis, as was mentioned in the introductory section, namely the orthogonal circular polarization basis has important for us advantages over the linear polarization basis. That is why in this article, the basics of field formation are considered in the circular polarization basis, where exist the simple relationship between the antenna power supply and the parameters characterizing the circular polarization.

In [24], it was shown that in an orthogonal circular polarization basis, the ellipticity coefficient is equal to:

$$K_e = \frac{E_R - E_L}{E_R + E_L}, \tag{1}$$

where E_R is the electric field intensity with the right direction of vector rotation; E_L is the electric field intensity with the left direction of vector rotation. Actually, parameter K_e is the inverse to the axial ratio.

The advantage of this parameter (1) over the mathematical expression for determining the axial ratio in a linear polarization basis lies not only in its simplicity for this particular task, but also in the fact that the right side of equation (1) determines both the value of ellipticity coefficient and its sign.

In the antenna theory the formula that relates the electric field intensity E and the power of antenna supply P_A is well known:

$$E = \frac{\sqrt{60 P_A G}}{r} W. \tag{2}$$

Here G is antenna gain; r is distance from the antenna phase center to the reference point; W is the attenuation coefficient of the electric field intensity during propagation.

From expression (2) follows

$$P_A = \frac{E^2 r^2}{60 G W^2} = \frac{4\pi \Pi r^2}{G W^2}, \tag{3}$$

where $\Pi = E^2 / 240\pi$ is power density of the radiation field (modulus of the active component of the Poynting vector).

Formula (3) allows, according to a given electric field intensity, to findthe antenna power supply. Since the total supply powerconsists of two parts: the power of antenna supply P_{AR} of the circular polarization with the right direction of vector rotationand the power of antenna supply P_{AL} with the left direction of rotation, the total power densityis.

$$\mathit{\Pi} = \frac{E_R^2}{240\pi} + \frac{E_L^2}{240\pi} . \tag{4}$$

From equations (1) and (4) it follows that

$$\left.\begin{aligned} \mathit{\Pi}_R &= \frac{E_R^2}{240\pi} = \mathit{\Pi}\frac{(1+K_e)^2}{2(1+K_e^2)}; \\ \mathit{\Pi}_L &= \frac{E_L^2}{240\pi} = \mathit{\Pi}\frac{(1-K_e)^2}{2(1+K_e^2)}. \end{aligned}\right\} \tag{5}$$

Therefore, if the ellipticity coefficient K_e in a small local space and the total power density $\mathit{\Pi}$ are given, then formulas (3) and (5) allow to determine the input powers of the right direction ofrotation P_{AR} and the left direction of rotation P_{AL}.

In the case of given maximum amplitude value of the vector E, then the determination of the values P_{AR} and P_{AL} occurs according to

$$\left.\begin{aligned} \dot{E} &= \dot{E}_R + \dot{E}_L; \\ E &= \max\left|\dot{E}\right| = E_R + E_L; \\ E_R &= \frac{1}{2}(1+K_e)E; \\ E_L &= \frac{1}{2}(1-K_e)E \end{aligned}\right\}$$

and formulas (3).

The inclination angle of the major axis of the polarization ellipse γ is set using the phase shift φ_0 of the currents or voltages at the antenna terminals, which corresponds to the right and left rotation directions of vector E. As follows from the analytical relation between the quantities γ and φ_0 [24], the phase shift φ_0 is equal to

$$\varphi_0 = \arg[I_{AR}(t)] - \arg[I_{AL}(t)] = 2\gamma$$

In case of linear orthogonal polarization basis in order to control process of the field forming the antennas of linear polarization are used, such as turnstile antennas. Analytical relations between the output parameters of the generator and the radiation field are given in [24].

The relative error of the radiation field parameters in a circular polarization basis is determined by the above relations, in particular, from formula (2) it follows that

$$\delta E = \delta r + \delta W + \frac{1}{2}\delta P_A + \frac{1}{2}\delta G \tag{6}$$

or

$$\delta E = \sqrt{(\delta r)^2 + (\delta W)^2 + (0{,}5\delta P_A)^2 + (0{,}5\delta G)^2} ,$$

where δE is the relative error of the electric field intensity value; δr is the relative error of the distance measurement; δW is the relative error of the attenuation factor calculation; δP_A is the relative error in the power supply value; δG is the relative error in the antenna gain estimation.

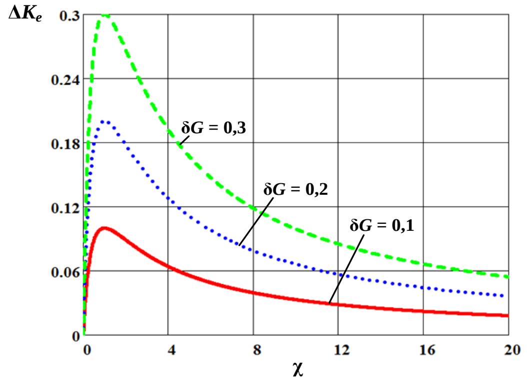
The ellipticity coefficient of the radiation field is characterized by the following error

$$\Delta K_e = 4\frac{\chi}{(1+\chi)^2}\delta E , \tag{7}$$

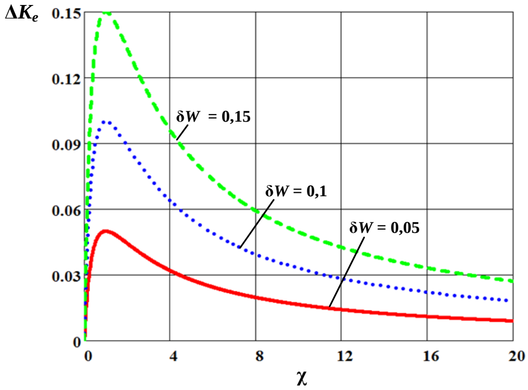
where $\chi = E_L / E_R$.

According to formulas (7) and (6), the dependences of the ellipticity coefficient error from the ratio χ of the field intensity components are presented in Fig. 1. Here it was assumed that the relative errors in measuring the distance and power supply can be neglected.

As can be seen from formula (7), the error in determining the ellipticity coefficient does not exceed the error in determining the electric field intensity.



a



b

Fig. 1. Error of the ellipticity coefficient as a function of the field components ratio of left and right rotation directions of the vector E at: *a* – if $\delta W = 0$; *b* – if $\delta G = 0$.

3. Investigation of the Electromagnetic Environment

3.1. Selecting an Antenna Array Design

Among the significant number of values characterizing the electromagnetic environment in study space, the most significant are the location of radiation sources or the direction of wave propagation if the sources are outside the space under consideration, the energy characteristics of the radiation fields and the orientation of the electric field intensity vector. The numerical characteristics of these quantities are measured using antenna systems supplemented with devices for processing received signals. Methods for measuring such values can be considered on the example of 2x2 antenna array, that is, an antenna system of four identical elements located at the vertices of a square (Fig. 2).

In the plane of the antenna aperture, a rectangular coordinate system $\eta 0 \zeta$ is chosen. The perpendicular to the aperture plane with a unit vector $\vec{n}_0$ is drawn through the origin of the coordinate system (Fig. 3). In the pattern of such antenna system, it is easy to ensure the presence of multipliers:

$$\left.\begin{aligned} F_{in}(\alpha) &= \cos(kd \sin\alpha); \\ F_{an}(\alpha) &= \sin(kd \sin\alpha), \end{aligned}\right\} \qquad (8)$$

where α is the angle between the direction of incident wave on the antenna and the vector $\vec{n}_0$ in the plane, including the 0η axis and vector $\vec{n}_0$ or through the 0ζ axis and vector $\vec{n}_0$; $F_{in}(\alpha)$ is the system multiplier of two radiators with in-phase summation of voltages from the outputs of the antenna array (AA) elements, for example $\dot{U}_1 + \dot{U}_2$ and $\dot{U}_3 + \dot{U}_4$, or $\dot{U}_1 + \dot{U}_3$ and $\dot{U}_2 + \dot{U}_4$; $F_{an}(\alpha)$ is the system multiplier of two radiators with antiphase summation of voltages; $2d$ is the distance between AA elements in mutually perpendicular planes (Fig. 2); $k = 2\pi/\lambda$ is wave number; λ is the wavelength.

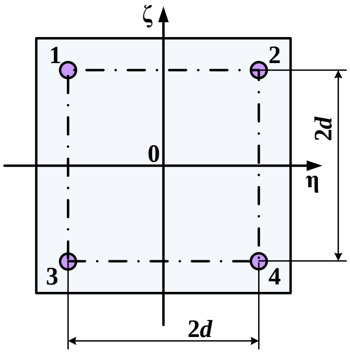


Fig. 2. Location of antenna array elements 2 x 2.

To determine the angular location of radiation sources, the rectangular and spherical coordinate systems are used. Their origin (point 0) is connected to the antenna's own coordinate system η0ζ (Fig. 3).

In the selected coordinate systems (x, y, z and r, θ, φ), the coordinates of the radiation source (point M) are r_M, θ_M, φ_M. Let's align the 0ζ axis with the 0z axis of the main coordinate system. The axis 0η of own coordinate system, as well as the normal $\vec{n}_0$ to the plane of the aperture, lie on the x0y plane. The vector $\vec{n}_0$ is at an angle φ (arbitrarily taken) to the axis 0x. When rotating the aperture around the 0z axis, the vector $\vec{n}_0$ will remain in the x0y plane.

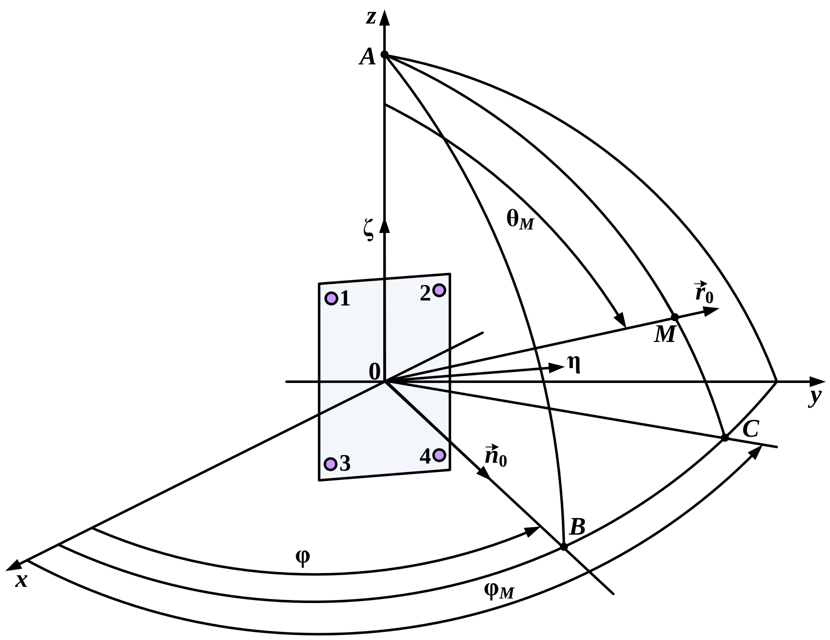


Fig. 3. Antenna array in different coordinate systems.

If the voltages from the outputs of the AA elements are added according to the scheme $\dot{U}'_\Sigma = (\dot{U}_1 + \dot{U}_3) - (\dot{U}_2 + \dot{U}_4)$, then in the meridional plane A0B, drawn through the ort $\vec{n}_0$, a zero of the directivity pattern (8) is formed. Consequently, when the plane A0B is aligned with the meridional plane A0C, in which the radiation source M is located, the voltage $\dot{U}'_\Sigma$ will drop to zero. At this the voltage $\dot{U}''_\Sigma = (\dot{U}_1 + \dot{U}_3) + (\dot{U}_2 + \dot{U}_4)$ increases to a maximum value. At the moment of alignment of the planes A0B and A0C, the angle between the normal $\vec{n}_0$ and the projection of the vector $\vec{r}_0$ in point M on the plane x0y is equal to zero. It is obvious that the process of direction finding along the azimuth angle φ is determined using the angle difference, because

$$\sin\theta_M \cos\alpha = (\vec{n}_0, \vec{r}_0 \sin\theta_M) = \sin\theta_M \cos(\varphi - \varphi_M), \quad (9)$$

where $\vec{n}_0 = \vec{x}_0 \cos\varphi + \vec{y}_0 \sin\varphi$; $\vec{r}_0 = \vec{x}_0 \sin\theta_M \cos\varphi_M + \vec{y}_0 \sin\theta_M \sin\varphi_M + \vec{z}_0 \cos\theta_M$.

In expression (9), the angles θ_M and φ_M do not change if the radiation source occupies a constant position, or changes at a slower rate than the angle φ, which depends on the position of the antenna aperture during its rotation around the 0z axis.

From Fig. 3 it can be seen that for any value of angle θ_M, at condition that meridional planes $A0B$ and $A0C$ coincides as a result of $\varphi=\varphi_M$, the antenna system will not receive waves radiated by the source at point M.

The pattern multiplier of the antiphase system (8) when rotating it around the 0z (0ζ) axis and using expression (9) for the angle α takes the form

$$F_n(\alpha)=\sin[kd\sin\theta_M\sin(\varphi-\varphi_M)]. \quad (10)$$

Therefore, the azimuthal angle of the radiation source according to expression (10) is determined by the antenna system regardless of the angle θ_M.

The meridional angle θ_M is found by rotating the antenna aperture around the 0η axis, provided that the 0ζ aperture axis or the normal $\vec{n}_0$, does not go beyond the same meridional plane $A0B$ (Fig. 4).

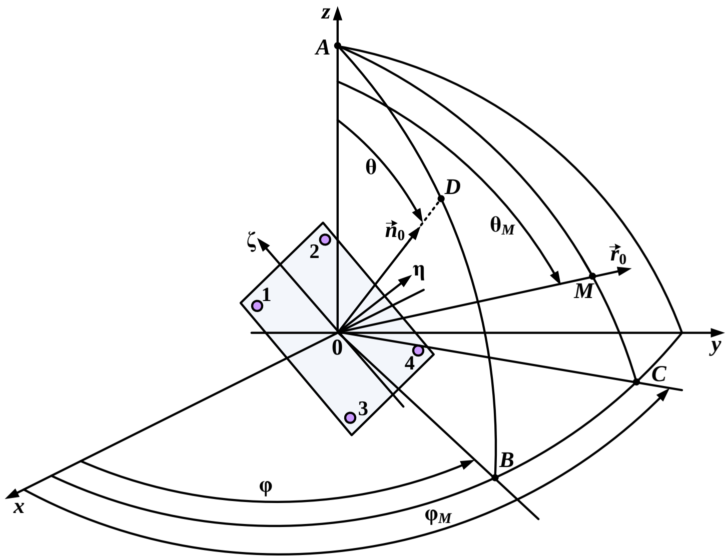


Fig. 4. The direction-finding process of the antenna system by the meridional angle.

If the voltages from the outputs of the AA elements are summed up as $(\dot{U}_1+\dot{U}_2)-(\dot{U}_3+\dot{U}_4)$, then in the plane with axis 0η and normal $\vec{n}_0$, zero of the radiation pattern is formed. The plane with zero radiation changes its position in space when the AA aperture is tilted. At this the angle α in formulas (8) is determined fromthe scalar product of two-unit vectors

$$\alpha=\arccos(\vec{n}_0,\vec{r}_0). \quad (11)$$

Using the relationship between rectangular and spherical coordinate systems, the projections of vector $\vec{n}_0$ for arbitrarily selected position of the antenna aperture are determined as

$$\vec{n}_0=\vec{x}_0\sin\theta\cos\varphi+\vec{y}_0\sin\theta\sin\varphi+\vec{z}_0\cos\theta. \quad (12)$$

By substituting $\vec{n}_0$ (12) and $\vec{r}_0$ (9) into the right-hand side of the equation (11) it is obtained:

$$\alpha=\arccos[\sin\theta\sin\theta_M\cos(\varphi-\varphi_M)+\cos\theta\cos\theta_M]. \quad (13)$$

If at the first stage of direction finding it is established that $\varphi=\varphi_M$ and the $A0B$ plane was aligned with the $A0C$ plane, then the right-hand side of the equation (13) becomes independent of the variable φ and is simplified.

$$\alpha=\theta-\theta_M. \quad (14)$$

By changing the tilt of the antenna aperture and moving the normal $\vec{n}_0$ in the meridional plane, aligned with the $A0C$ plane, can be found aposition with the maximum voltage at the antenna terminals (8) or zero valueof the received signal. That is, the condition $\alpha=0$ is met. Thus, by equating the left side of equation (14) to zero, the second angular coordinate of the radiation source is determined.

In this way, one of the necessary tasks when studying the electromagnetic environment is solved, namely: the orientation of the antenna array towards the device under test or the direction of wave propagation.

3.2. Selecting an Antenna Array Elements

To analyze the polarization characteristics of electromagnetic waves, antennas with clear polarization properties are used as the main tool. By such a way, for example, it is possible to decompose the electromagnetic wave in a circular orthogonal polarization basis by an antenna system built on ring antennas [25, 26], or on helical antennas. The ring element of AA is a metal ring, which, using supply unit provides simultaneous radiation or reception and decomposition of electromagnetic waves with rotating polarization. One of the possible circuits for implementation of the ring antenna with wave separation device, built on square bridges is shown in Fig. 5.

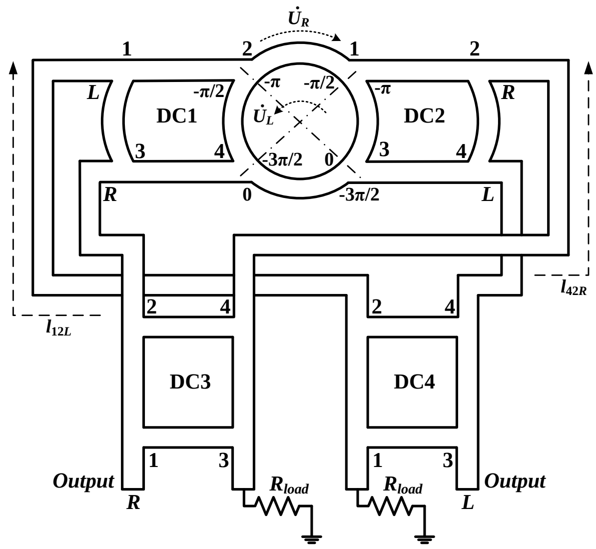


Fig. 5. Design of microstrip ring antenna with device for separating waves by a branch-line directional coupler ($l_{42R}= l_{23R}+ \Lambda/2$ and $l_{12L}= l_{14R} + \Lambda/2$).

Parts of the ring, namely arcs of length Λ/4, where Λ is the wavelength in the ring strip, from arm 2 to arm 4 of the branch-line directional coupler DC1 and from arm 1 to arm 3 of the coupler DC2 are used additionally as elements of these bridges. Branch-line directional couplers DC3 and DC4 are both 3dB power dividers and fixed phase shifters. The necessary phase relationships for voltages at equidistant points of the ring (1, 2, 3 and 4) are achieved by lines length of quarter wavelength. Phase shifts of voltages for the right rotation wave are indicated on the outer side of the ring (Fig. 5), and for the left rotation wave are on the inner side of the ring. The free arms of directional couplers DC3 and DC4 are loaded with matched resistances. With good matching of all strip circuit elements, no electrical power should be dissipated on these resistances.

Only four ring elements are enough to build the antenna system. The disadvantage of such antenna system is the narrow bandwidth, since each element of the AA must have the length that is multiple of quarter wavelength.

Broad bandwidth and low level of cross-polarization are able to provide spiral elements of AA. This is especially true for flat arithmetic helix ($\rho = a\varphi$, where ρ is the radius of a point on the helix in the polar coordinate system; *a* is the speed of helical deployment; φ is the polar angle). Since the helix unwinds only in one direction, the radiation field can have only one rotation direction. Therefore, the antenna system built on helical elements must have at least eight elements (Fig. 6).

Four AA elements (1-4) form the subsystem *R* of the vector *E* right rotation direction, and four more elements (5-8) form the subsystem *L* of the left rotation direction. The antenna system (Fig. 6) is at least twice the dimensions of the antenna panel with ring radiators. This disadvantage of the helical AA is somewhat compensated by the fact that the separation of the *R* and *L* subsystems by some distance *D* can provide better polarization separation, which is important for reducing the systematic errors of the polarization analysis of the radiation field.

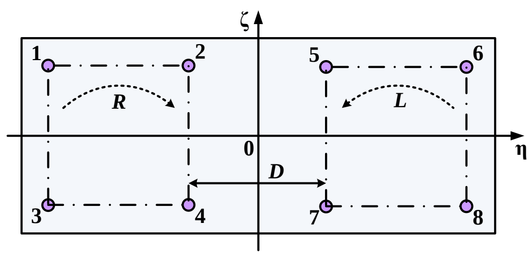


Fig. 6. Schematic arrangement of helical elements on the AA panel 4x2.

4. Measurement of the Effective Reflection Area

The ability of any object to reflect electromagnetic waves can be characterized by the effective reflection area S_{0e}. In radar terminology this parameter corresponds to the radar cross section (RCS). Obviously, the properties of reflected wave from an object depend on many factors, in particular, the wavelength λ, the shape of the wave front, the incident angle, the structure and material of the irradiated surface, etc. At study the object reflection propertiesit is considered equivalent surface, which is ideally conducting, flat, square shape, with dimensions depending only on the wavelength, wave front shape and the position of the object relative to the wave front.

The case of irradiation of an object by plane wave front is the simplest; that means that the object under study is located in the far field of antenna. In the general case, the transmitting antenna A_1 (transmitter) and the receiving antenna A_2 (receiver) are separated by the certain distance ($d_1 + d_2$) from each other (Fig. 7).

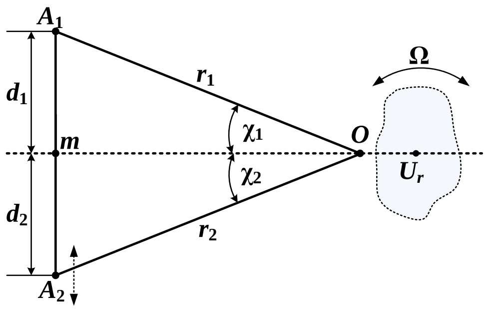


Fig. 7. Determination of the effective reflection area.

Let us assume that the depolarized (cross-polarized) component of the reflected wave is much smaller than the polarized (principally polarized) component. In this case, reflection from the object O can be considered as reemission of the incident wave in the direction A_1O. With mirror reflection, the effective reflection area (RCS) is perpendicular to the straight line mO. At this $\chi_2 = \chi_1 = \chi$; $r_1 = r_2 = r$; $d_2 = d_1 = d$.

The virtual field distribution on the area S_{0e} will be uniform with linear phase shift, which, at the boundary of the effective reflection area acquires the following value

$$\psi_0 = \frac{ka}{2}\sin\chi_0,$$

where a is the dimension of the equivalent area S_{0e} in the plane A_1A_2O (Fig. 7); $\sin\chi_0 = d/r$.

Let the geometric area S_{0e} be a square. Then the field intensity of the reflected wave, depending on the angle χ, is defined as

$$E_{ref} = \frac{E_{inc}a^2}{\lambda r}\frac{\sin\left[\frac{ka}{2}(\sin\chi - \sin\chi_0)\right]}{\frac{ka}{2}(\sin\chi - \sin\chi_0)}, \tag{15}$$

where E_{inc} is the field intensity of the incident wave.

By moving antenna A_2 along the line A_1mA_2, one can find the point with maximum value of reflected wave intensity. In this antenna position the condition $\chi = \chi_0$ is satisfied. Then the expression (15) takes the form

$$E_{ref\max} = \frac{E_{inc}a^2}{\lambda r}, \text{ where } S_{0e} = a^2.$$

From the obtained expression, the effective reflection area (RCS) is equal to

$$S_{0e} = \lambda r \frac{E_{ref\max}}{E_{inc}}.$$

Obviously, for more complete information about the characteristics of object's ability to reflect waves, it is necessary to irradiate it from different sides. For this, the object is placed on a platform that can rotate in one or another direction Ω relative to the point U_r.

5. The Device for the Field Formation

The structural diagram of the device for the electromagnetic field forming is based on functional connections, considered in the theoretical part of the work (Fig. 8).

Input data about the local volume of space in the selected coordinate system, frequency, electric field intensity and the ellipticity coefficient are entered into the computer (C). The local oscillator (LO) output voltage is divided into two equal parts by the voltage divider (VD). One of these voltages $\dot{U}_R$ is directly supplied to power amplifier P_{AR} of the right rotation direction. The second part of the voltage $\dot{U}_L$ is applied to the phase shifter (PS), the phase shift of which is set according to the required inclination angle of the major axis of the polarization ellipse γ. Then voltage $\dot{U}_R$ is amplified by the power amplifier P_{AL}. Computer controls gains of the amplifiers due to the given ellipticity factor.

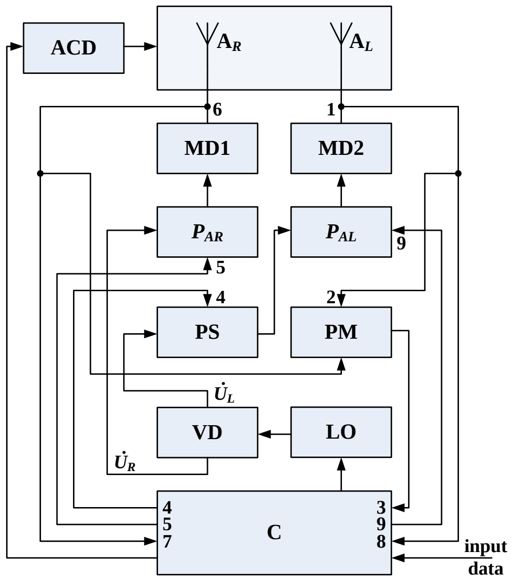


Fig. 8. Device for field forming according to the given energy and polarization parameters.

From the outputs of the power units P_{AR} and P_{AL} the signals are fed to the antenna inputs through the matching devices (MD). Also, the MD blocks, if necessary, balance the antenna currents, distribute the power among the AA. MD outputs are used for control the phase shift with a phase meter (PM) and control powers P_{AR} and P_{AL}. At this the loops are formed: for automatic adjustment of the phase shift (1, 2, 3, 4), power control P_{AR} (5, 6, 7) and power control loop P_{AL} (8, 9). Since the measurement of φ_0 (phase shift), P_{AR} and P_{AL} are carried out practically at the terminals of the antenna system, the built-in control and automatic adjustment of the phase shift and power levels can provide minimal errors in setting the parameters of the radiation field.

The antenna system A_R and A_L is made in the panel form, set in the required position by the control device (ACD) using coordinate angles θ and φ. The angles θ and φ may be fixed or variable due to the data on the position in the local space in the selected coordinate system. Antennas can be quite simple, for example, one ring antenna, two helical antennas, or turnstile antenna. In order to concentrate electromagnetic energy in narrow spatial sector the antennas can be built as AA.

6. Antenna System with Primary Signal Processing for Studying the Electromagnetic Environment

As noted earlier, the main tool for the wave polarization analysis and sources' location is the antenna array (AA). The number of the AA elements must be at least four. This applies to such radiators as ring or turnstile antennas. That is, the AA elements must be able to allocate voltages that are proportional to the field intensity vectors of the right and left rotation directions, at their terminals. Therefore, the antenna system will have eight outputs. The same number of outputs can be provided by the AA 4 x 2, consisting of two subsystems 2 x 2. One of these subsystems allocates voltages induced by waves of the right (*R*) rotation direction, the second – the left (*L*) rotation direction. The AA consisting of the two subsystems has simpler supply circuits and larger frequency band. For example, the helix antenna can have input impedance equal to wave impedance of the feeder that ensuresgood matching and at the same time provide wide operating frequency band.

The primary processing of the voltages at antenna terminals includes the measurement of the polarization parameters of the incident wave, determination of the angular position of the radiation sources, and formation for the subsequent analysis voltages $\dot{E}_R$, $\dot{E}_L$, $\dot{E}$ that represent radiation field. In the structure of the primary processing device (Fig. 9) the antenna system 4x2 of helical elements is used.

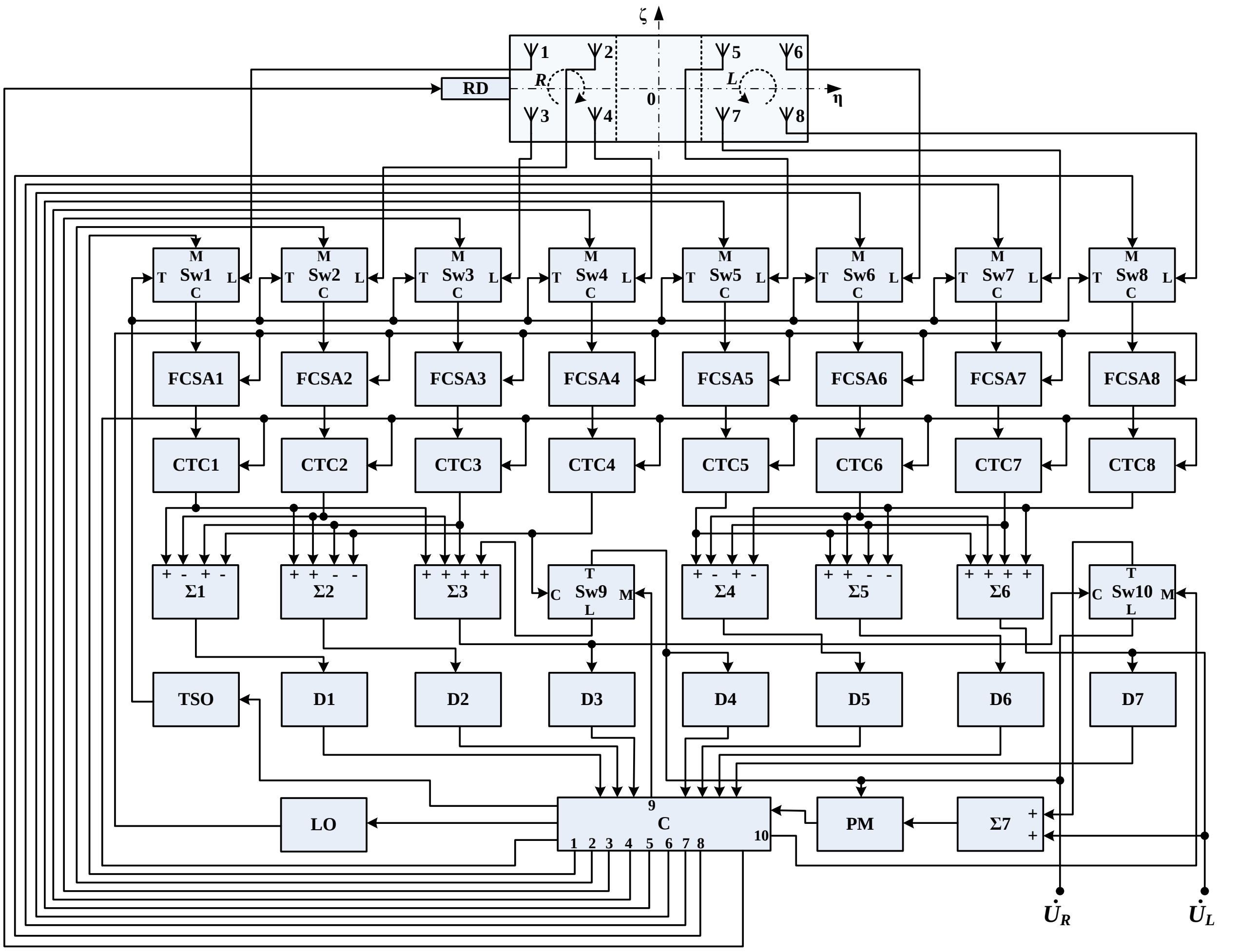


Fig. 9. Structural diagram of the antenna array with primary signal processing device.

The directivity characteristic of each AA subsystem consists of three factors:

$$\left.\begin{aligned} F(\varphi) &= F_1(\varphi)F_{sc}(\varphi)F_2(\varphi); \\ F(\theta) &= F_1(\theta)F_{sc}(\theta)F_2(\theta), \end{aligned}\right\} \tag{16}$$

where $F_1(\varphi)$, $F_1(\theta)$ are the patterns of the AA elements (helical radiator) in the azimuth and meridional planes, respectively; $F_{sc}(\theta)$ is the screen multiplier; $F_2(\varphi)$, $F_2(\theta)$ are the multipliers (array factor) of two radiators system (8); θ, φ are the angular coordinates of spherical coordinate system.

Each factor F_2 from (16) can take either maximum value when the wave falls in normal direction $\vec{n}_0$, or zero value. Therefore, for each of the AA subsystems, it is possible to create four radiation patterns (RP), which significantly differ from each other. For detection radiation sources, determination their angular location and generation the voltage proportional to the field intensity $\dot{E}_R$ or $\dot{E}_L$, three types of RP are enough. For this purpose, the structure of the signal processing device (Fig. 9) provides eight channels for amplifying and frequency conversion to the band, which is convenient for certain metrological transformations.

The input of each channel begins with the switch Sw*s*, where $s = 1 \ldots 8$ is the corresponding number of the AA element. Elements 1…4 refer to the AA subsystem, which receives waves with the right (*R*) rotation, and numbers 5…8 refer to the AA subsystem with the left (*L*) rotation. The switch diagram is shown in Fig. 10. In normal operation, the switch terminal marked L is connected to the terminal C to which the channel input is connected. The switch control signal is applied to the terminal M from the computer. The terminal T is used only in the mode of control and correction of channel transmission coefficients.

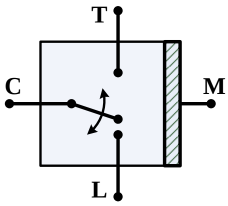


Fig. 10. Switch of channels.

The first functional unit of each channel is the frequency conversion and signal amplification unit (FCSA). All mixers are fed from the local oscillator LO with the given frequency stability and phase noise level.

To ensure the identity and stability of the channel transmission coefficients, the channel transmission correction units (CTC) are used. The amplified signals from the CTC units enter the adders Σ*s*, where *s* = 1…3 for the subsystem *R* and *s* = 5…7 for the subsystem *L*. At the direction finding of radiation sources, the output voltages of the adders 1, 2, 5 and 6 are used as indicators of tuning the normal to the antenna aperture to the direction of wave arrival. So, at the output of the adder Σ1, the next voltage is formed:

$$\dot{U}_{\varphi 1} = \left(\dot{U}_1 + \dot{U}_3\right) - \left(\dot{U}_2 + \dot{U}_4\right), \tag{17}$$

where $\dot{U}_s$ (*s*= 1…4) is the output voltage of the *s*-th channel.

From equation (17) it follows that array factor $F_2(\theta,\varphi)$ takes the form

$$F_{21}(\theta,\varphi) = F_{in1}(\theta)F_{an1}(\varphi).$$

Therefore, the output voltage of the adder Σ1 can be used to determine the azimuth angle φ of the radiation source, since with the argument φ = 0 or $\varphi - \varphi_M = 0$ of the antiphase multiplier $F_{an1}(\varphi)$, the meridional plane is obtained with zero voltage at the terminals of the antenna system.

The output voltage of the adder Σ2 has a similar dependence on the angles φ and θ:

$$\dot{U}_{\theta 2} = \left(\dot{U}_1 + \dot{U}_2\right) - \left(\dot{U}_3 + \dot{U}_4\right),$$

but in this case, the plane of zero reception passes through the axis 0η of its own coordinate system and the unit vector $\vec{n}_0$. Therefore, the voltage $\dot{U}_{\theta 2}$ is used for direction finding of the meridional angle θ.

The voltage at the output of the third adder Σ3 is the sum of the in-phase voltages induced on the four spirals of the antenna system

$$\dot{U}_R = \dot{U}_1 + \dot{U}_2 + \dot{U}_3 + \dot{U}_4.$$

It is advisable to use it when detecting radiation sources and measuring the amplitude and phase of the field intensity formed by the wave component $\dot{E}_R$ with the right rotation direction. It is assumed that $\dot{U}_R = \tilde{a}\dot{E}_R$, where $\tilde{a}$ is the constant, determined by the gain of the helical elements and the channel transmission ratio module and phase.

Since the antenna subsystem *R* is decoupled by polarization from the waves of the left circular polarization and cannot detect the radiation sources with the left circular polarization, the voltages from the elements of the subsystem *L* are also summed up by the units Σ4, Σ5, Σ6 in a similar way, that is

$$\left.\begin{aligned} \dot{U}_{\varphi 4} &= \left(\dot{U}_5 + \dot{U}_7\right) - \left(\dot{U}_6 + \dot{U}_8\right); \\ \dot{U}_{\theta 5} &= \left(\dot{U}_5 + \dot{U}_6\right) - \left(\dot{U}_7 + \dot{U}_8\right); \\ \dot{U}_L &= \dot{U}_5 + \dot{U}_6 + \dot{U}_7 + \dot{U}_8. \end{aligned}\right\} \tag{18}$$

Output constant voltages from detectors D1, D2, D3, D5, D6, D7 (Fig. 7) are proportional to the amplitudes of alternating voltages $\dot{U}_{\varphi 1}$, $\dot{U}_{\theta 2}$, $\dot{U}_R$, $\dot{U}_{\varphi 4}$, $\dot{U}_{\theta 5}$, $\dot{U}_L$. Dependence of voltages $U_{\varphi 1}$ and $U_{\varphi 4}$ on the angle φ (18) is used in the computer for angular displacement of the antenna aperture until the zero voltage appears. The commands from the computer are transmitted to the rotating device (RD). RD rotates the antenna panel around the 0*z* axis in the direction of the azimuth angle φ, at which the values $U_{\varphi 1}$ and $U_{\varphi 4}$ decrease to zero. When this position is reached, the computer fixes the azimuth coordinate of the radiation source ($\varphi = \varphi_M$). In order to reduce the error of coordinate finding the higher voltage is used ($U_{\varphi 1}$ or $U_{\varphi 4}$).

Voltages $\dot{U}_{\theta 2}$ and $\dot{U}_{\theta 5}$ are used in the same way. When these voltages decrease to zero, as a result of the antenna aperture rotation around the 0η axis, the meridional angle of the radiation source is found ($\theta - \theta_M = 0$).

After the direction-finding process is completed, that is, the antenna aperture is set so that the directions $\vec{n}_0$ and $\vec{r}_0$ coincide, there are opportunities for polarization analysis. The antenna system divides the received wave into two components with circular polarization: right *R* and left *L*. Due to this, voltages $\dot{U}_R$ and $\dot{U}_L$ are formed at the outputs of adders Σ3 and Σ6 respectively. The amplitudes of these components taken from the detectors D3 and D7 determine the ellipticity coefficient:

$$K_e = \frac{U_R - U_L}{U_R + U_L}. \quad (19)$$

Formula (19) determines not only the ellipticity coefficient value, but also its sign, which favorably distinguishes the circular polarization basis from the linear orthogonal polarization basis.

The major axis of the polarization ellipse is defined by the phase shift between the voltages $\dot{U}_R$ and $\dot{U}_L$. The voltage $\dot{U}_R$ from the output of the adder Σ3 through the switch Sw10 enters the phase meter (PM). The other input of the PM receives the voltage $\dot{U}_L$ passing through the adder Σ7 with two inputs. No signals are received at the second input of the adder Σ7 in the normal operation mode. Therefore, with the transmission coefficient of Σ7 equal to unity, the voltage $\dot{U}_L$ without any distortion serves to measure the phase shift. The start of the phase shift φ_0 count down depends on the chosen coordinate system in the wave front, the spiral configuration, the wavelength, and the spiral beginning relative to the axis 0η. The inclination angle of the polarization ellipse major axis with respect to the axis 0η is calculated as

$$\gamma = 0{,}5\varphi_0.$$

In addition, the resulting voltages $\dot{U}_R$ and $\dot{U}_L$ go to the output of the signal processing device and can be used for other purposes.

In the correction mode of channel transmission ratio all switches connect the terminals C to the terminals T. The fourth channel is used as an exemplary one, therefore, with the help of the switch Sw9 it is separated and the voltage from its output T is applied to the detector D4 and the PM. The rectified voltage from the D4 serves to set the same transmission ratio for all channels, and the output signal from the PM allows the computer to correct the transmission ratio phase of each channel. The test signal oscillator (TSO) is connected in turn to the inputs of the channels, and their output voltages are taken from the outputs of the adders Σ3 and Σ6.

In order to compare the phase angle of the transmission ratio in the fourth channel with the phases of the remaining seven channels the adder Σ7 is used, the inputs of which are alternately supplied with the output voltages of the seven channels. The modules of the channel transmission ratio are corrected according to the voltages of the detectors D3 and D6. When the modules or phases of the channel transmission ratio deviate from the module and the phase of the fourth channel, the necessary commands are generated to configure the CTC units.

7. Further Directions of Research

In further research, it is planned to determine the requirements for the electrodynamic and design parameters of the units of the measuring complex for testing antennas of rotational and linear polarization in the meter, decimeter and centimeter wavelength ranges. It is necessary to analyze in detail the electrical and other characteristics of manufacturers' devices and instruments to ensure that their performance meets the requirements for the structure of the proposed metrological complex.

Attention will also be focused on choosing the type and design of the antenna system, which, on the one hand, will ensure the measurement of the necessary parameters of the electromagnetic field with sufficient accuracy, and on the other hand, will be able to form the desired structure of the electromagnetic field in a quiet zone. One of the main criteria for selection is the bandwidth of the measuring antenna. This condition serves to minimize the number of replaceable antenna panels.

8. Conclusion

In this article the theoretical foundations for constructing a multifunctional field formation system that allow to form the electromagnetic field of a given strength and polarization, creating various field configurations have been developed. Some possible implementations of the suggested system and examples of their specific applications have been proposed and described.

The considered functional relationships between the energy quantities of the oscillator and the radiation field make it possible to construct the device for generating electromagnetic field with parameters that are specified in circular orthogonal polarization basis. The synthesized block diagram is quite simple and can ensure the specified field forming with acceptable errors.

It has been shown that the antenna system for receiving electromagnetic waves and their decomposition into components in circular polarization orthogonal basis must contain at least eight antenna elements.

The presented metrological complex allows solving problems of assessing the electromagnetic environment, testing antenna systems, assessing electromagnetic compatibility, etc. Instead of using highly specialized measuring systems, it is proposed to use a multifunctional complex that provides the specified accuracy characteristics and research efficiency.

The structure of the proposed metrological complex allows measurements in any frequency range. The required bandwidth is ensured by the choice of antenna array elements and signal processing circuits. It is also possible to use replaceable antenna panels.

In addition, the following conclusions can be drawn from the results of this research.

1. The study of the field polarization characteristics can be successfully carried out using ring antenna elements. In the broad frequency band, the ring elements can be replaced with spiral radiators.

2. The use of spiral elements in the antenna system creates conditions for the construction of metrological equipment with an ultra-wide range of operating frequencies.

3. Spiral flat antenna elements can provide very low level of cross-polarization due to the load of the end of the spiral on a matched resistance, which is of great importance in polarization analysis.

4. Spacing the right (R) and left (L) subsystems of a circularly polarized antenna by a certain distance increases polarization isolation and reduces polarization errors.

5. The theoretical studies presented in the work have been shown how it is possible to implement in the proposed system an algorithm for aligning the antenna array to the given object. In addition, among many other applications, the system can measure the effective reflection area, that is RCS, of different objects.

References

[1] M.M. Bait-Suwailam, “Electromagnetic Field Interaction with Metamaterials”, Electromagnetic Fields and Waves. Intech Open, May 15, 2019. DOI: 10.5772/intechopen.84170.

[2] P.S. Fuchs, Electromagnetic Fields in MRI: Analytical Methods and Applications. [Dissertation (TUDelft), Delft University of Technology], 2020. https://doi.org/10.4233/uuid:78d96af2-fb96-4a6e-a51e-ea4236fdf2d7.

[3] F.J. Yanovsky, "Evolution and Prospects of Airborne Weather Radar Functionality and Technology," 2005 18th Int. Conf. on Applied Electromagnetics and Communications, ICECom 2005, Dubrovnik, Croatia, 2005, pp. 349-352. DOI: 10.1109/ICECOM.2005.204987.

[4] Y. Averyanova, A. Averjanov, and F. Yanovsky, "Doppler polarization radar methods for meteorological applications," IEEE Aerospace and Electronic Systems Magazine, 2014, 29(7), pp. 64–73. DOI: 10.1109/MAES.2014.130143.

[5] A. I. Nosich et al. "Microwaves in Ukraine," IEEE Microwave Magazine, vol. 3, no. 4, pp. 82-90, Dec. 2002, DOI: 10.1109/MMW.2002.1145680.

[6] F.J. Yanovsky, H.W.J. Russchenberg, and C.M.H. Unal, "Retrieval of information about turbulence in rain by using Doppler-polarimetric radar," IEEE Transactions on Microwave Theory and Techniques, 2005, 53(2), pp. 444–449. DOI: 10.1109/TMTT.2004.840772.

[7] A. Pitertsev and F. Yanovsky, "Polarimetric method for remote predicting a zone of icing-in-flight in clouds and precipitation," 2011 Microwaves, Radar and Remote Sensing Symposium, Kyiv, Ukraine, 2011, pp. 220-223, DOI: 10.1109/MRRS.2011.6053640.

[8] D.N. Glushko and F.J. Yanovsky, "Analysis of differential Doppler velocity for remote sensing of clouds and precipitation with dual-polarization S-band radar," International Journal of Microwave and Wireless Technologies, 2010, Vol. 2, issue 3-4, pp. 391-398. DOI: https://doi.org/10.1017/S1759078710000504.

[9] Y.P. Ostrovsky, F.J. Yanovsky, and H. Rohling, "Turbulence and precipitation classification based on doppler-polarimetric radar data," 2nd Microwave and Radar Week in Poland - International Radar Symposium, IRS 2006, Proceedings, 2006, pp. 1-4, DOI: 10.1109/IRS.2006.4338026.

[10] Y. Averyanova, A. Rudiakova, and F.J. Yanovsky, "Segregating deformation of scattering rain-drops using several receive antennas with different polarization angles," 2017 18th International Radar Symposium (IRS), 2017, pp. 1-6, DOI: 10.23919/IRS.2017.8008260.

[11] Electronic Warfare Test and Evaluation. RTO AGARDograph 300, Flight Test Technique Series, AG-300-V28. NATO, Research and Technology Organisation, Dec, 2012, 314 pp. https://www.sto.nato.int › RTO-AG-300-V28

[12] I. Jeffrey and B. Brooking, "A Survey of New Electromagnetic Stealth Technologies," W.R. Davis Engineering Ltd.Ottawa, Ontario, Canada, 7 pp. https://davis-eng.com/docs/papers/New_Electromagnetic_Stealth.pdf.

[13] R.B. Sinitsyn and F.J.Yanovsky, "MIMO radar copula ambiguity function," European Microwave Week 2012: "Space for Microwaves", EuMW 2012, Conference Proceedings – 9th European Radar Conference, EuRAD 2012, 31 Oct.-2 Nov. 2012, Amsterdam, Netherlands, pp. 146-149.

[14] Z.M. Bokal, R.B. Sinitsyn, and F.J.Yanovsky, "Generalized copula ambiguity function application for radar signal processing," 2011 Microwaves, Radar and Remote Sensing Symposium, MRRS-2011 - Proceedings, 2011, pp. 313-316. DOI: 10.1109/MRRS.2011.6053663.

[15] F.J. Yanovsky, V.E. Ivashchuk, and V.P. Prokhorenko, "Through-the-wall surveillance technologies," 2012 6th International Conference on Ultrawideband and Ultrashort Impulse Signals, UWBUSIS 2012 - Conference Proceedings, 2012, pp. 30–33, DOI: 10.1109/UWBUSIS.2012.6379723.

[16] F. Yanovsky, I. Prokopenko, H. Rhee, A. Pitertsev, and A. Dmytruk, "Robust Algorithm for Signal Digital Detection on the Background of Non-Gaussian Passive Interferences," Proceedings, Workshop on Microwave Theory and Techniques in Wireless Communications, MTTC-2022, Riga, Latvia, October, 2022, pp. 199-203. DOI: 10.1109/MTTW56973.2022.9942539.

[17] R.L. Panteyev, F.J.Yanovsky, A.M. Mykolushko, V.M. Shutko, "Radio Receiver with Internal Compression of Input Signals Using a Dispersive Delay Line with Bandpass Filters," International Journal of Image, Graphics and Signal Processing (IJIGSP), Vol.15, No.6, pp. 1-12, 2023. DOI: 10.5815/ijigsp.2023.06.01.

[18] Demystifying over-the-air (OTA) testing − important antenna parameters, test system setup and calibration. Industry white paper. Munich: Rohde & Schwarz, 2020. https://www.allaboutcircuits.com/industry-white-papers/demystifying-over-the-air-ota-testing-important-antenna-parameters-test-system-setup-and-calibration/

[19] Massive MIMO. Eight things to consider when testing antenna arrays. Munich: Rohde & Schwarz, 2018. https://www.everythingrf.com/whitepapers/details/4423-massive-mimo-eight-things-to-consider-when-testing-antenna-arrays

[20] Antenna Test. Selection Guide. Keysight Technologies, 2017. - 82 p. https://www.keysight.com/us/en/assets/7018-06818/technical-overviews/5968-6759.pdf

[21] S. Gregson, J. McCormick and C. Parini, Principles of Planar Near-Field Antenna Measurements. 2nd Edition, Verlag: Institution of Engineering and Technology, 2023.

[22] Vincent Lascoste. 5GNR-OTAtest&measurement aspects standards&regulations, EMC Europe 2020. - 52 pp.

[23] IEC 61000-4-3. Electromagnetic Compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radio-frequency electromagnetic field immunity test, Edition 4.0, 2020 -09.

[24] L. Ilnitsky, O. Shcherbyna, F. Yanovsky, M. Zaliskyi, O. Holubnychyi and O. Ivanets, "Comparison of Circularand Linear Orthogonal Polarization Bases in Electromagnetic Field Parameters Measurement," International Journal of Image, Graphics and Signal Processing (IJIGSP), vol.14, no.3, 2022, pp. 58-72, doi: 10.5815/ijigsp.2022.03.06.

[25] L.Ya. Ilnitskyi, L.V. Sibruk, I.I. Mykhalchuk and A.P. Slobodian, "Forming Electromagnetic Field for Antenna Testing. Telecommunications and Radio Engineering," Vol. 81, No.2, 2020, pp. 13-24, doi: 10.1615/TelecomRadEng.2022042836.

[26] L.Ya. Ilnitskyi, O.A. Shcherbyna, M.Yu. Zaliskyi, I.I. Mykhalchuk and O.V. Kozhokhina, "Power Supply of Ring Antenna using Directional Couplers," Radio Electronics, Computer Science, Control, No 3, 2023, pp. 6-16, doi:10.15588/1607-3274-2023-3-1.

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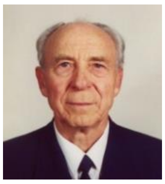

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