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MULTIFUNCTIONAL RADIO MONITORING ANTENNA

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Abstract*—*The theoretical bases of the development of an antennas for monitoring system are presented. Antennas combine the functions of measuring the emissions parameters, directional finding and suppression of the interference waves, close by the frequency to the main radiation. Antenna system includes array 3x2, flat screen and mechanical rotator. Minimum angular separation between direction of a signal and direction on interference wave is obtained.

Index Terms—Antenna array; direction finding; suppression of the interference.

I. INTRODUCTION

Radio monitoring stations use a considerable number of antennas, each of which performs only one of its inherent function [1]. For example, the antenna system measures the field characteristics or determines the angular position of the radiation source of radiation. In the case of mobile radio monitoring systems, it is necessary to limit the number of antennas, since such systems are located on cars and therefore there is a need to use multifunction antennas. Broadband nondirectional antennas in modern cities often receive electromagnetic radiation in conditions of significant interference, which in some cases makes impossible measurements with given accuracy.

II. PROBLEM STATEMENT

The essence of the problem is to synthesize the antenna system, which would combine the possibility of reception the required radiation in an unfavorable electromagnetic environment, creating an electrical signal with the intensity necessary to detect the source of radiation; suppress interference, which operates at a frequency close to the frequency required for radiation monitoring; measurement of the angular position of the radiation source and the value of electric field strength. Such antenna system can be a system consisting of several elements. It should be noted that the most common case of the radiation sources location is at angles near zero, that is, in a horizontal plane. Taking this into account, it is possible to limit the directional finding only to the azimuthal angle and to measure the meridional and azimuthal angles with simplified methods using a turnstile antenna system. In addition, in order to reduce the antenna dimensions it is desirable to apply the linear array of three active dipoles. If necessary accurate measurements of field parameters the flat antenna array 3x2 should be considered.

III. THEORETICAL BASIS

Let's consider the antenna array, the elements of which are three turnstiles antennas (Fig. 1).

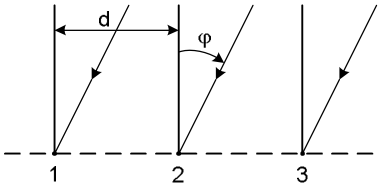


Fig. 1. Three element array

The phase of EMF induced in radiator 2 is assumed zero. The waves fall on the antenna system at an angle φ to the direction perpendicular to the array's axis. The EMF at antenna terminals:

$$\left.\begin{aligned} \dot{\varepsilon}_1 &= \dot{A}e^{-ikd\sin\varphi}, \\ \dot{\varepsilon}_2 &= \dot{A}, \\ \dot{\varepsilon}_3 &= \dot{A}e^{ikd\sin\varphi}, \end{aligned}\right\} \qquad (1)$$

where $\dot{A} = \dot{E}\,\ell_{\partial}F_1(\varphi)$; $\dot{E}$ is field intensity of incident wave; ℓ_{∂} is effective length of radiator; $F_1(\varphi)$ is the pattern of array element; $k = \dfrac{2\pi}{\lambda}$ is the wave number; λ is the wavelength; *d* is a distance adjacent radiators.

Obviously, the received EMF need to be amplified. Therefore, obtained voltages will correspond with the exact accuracy of the EMF (1)

$$\left.\begin{aligned}\dot U_1 &= a\dot A e^{-ikd\sin\varphi},\\ \dot U_2 &= 2a\dot A,\\ \dot U_3 &= a\dot A e^{ikd\sin\varphi},\end{aligned}\right\} \tag{2}$$

where a is a constant factor.

Let's create voltages

$$\left.\begin{aligned}\dot U_{12} &= \dot U_1 + 0.5\dot U_2 = 2a\dot A e^{-i0.5kd\sin\varphi}\cos\left(\frac{kd}{2}\sin\varphi\right),\\ \dot U_{23} &= 0.5\dot U_2 + \dot U_3 = 2a\dot A e^{i0.5kd\sin\varphi}\cos\left(\frac{kd}{2}\sin\varphi\right).\end{aligned}\right\}$$

Their sum is:

$$\dot U_\Sigma = \dot U_{12} + \dot U_{23} = 4a\dot A\cos^2\left(\frac{kd}{2}\sin\varphi\right). \tag{3}$$

Their difference:

$$\dot U_\Delta = \dot U_{23} - \dot U_{12} = i2a\dot A\sin(kd\sin\varphi). \tag{4}$$

Obviously, the voltage (3) is the output voltage of the antenna array with a binomial distribution of excitation currents. Consequently, the pattern (Fig. 2).

$$F_\Sigma(\varphi) = \cos^2\left(\frac{kd}{2}\sin\varphi\right). \tag{5}$$

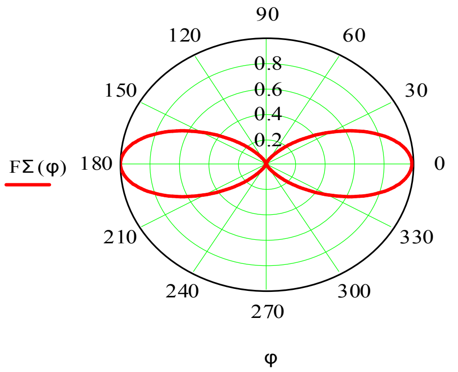


Fig. 2. The pattern in the sum mode

For the same condition ($kd = \pi$) the difference pattern (Fig. 3), which from expression (4) is defined as:

$$F_\Delta(\varphi) = \sin(kd\sin\varphi). \tag{6}$$

It is clear that these two patterns with the use of appropriate technical means will exist simultaneously. Consequently, the antenna array will have two output channels: the total, in which the voltage (3) and the voltage difference (4) can be processed.

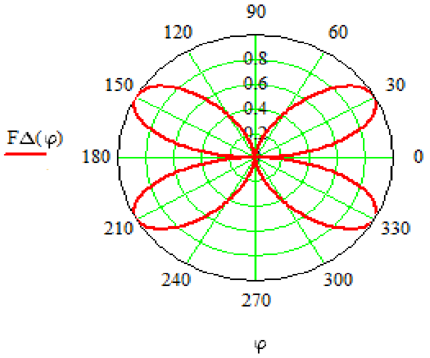


Fig. 3. The pattern in the difference mode

Positive property of difference pattern is high slope near the angles $\varphi = 0°$ and $\varphi = 180°$.

As beamwidth of $F_\Sigma(\varphi)$ at $kd = \pi$ is equal to 42.7°. But at pattern level 0.2 from maximum, that is enough for reception, the beamwidth $2\varphi_{0.2} = 90°$.

For detecting emission in horizontal plane the pattern lobe must have an opportunity to shift. In the case of electrical scanning, two phase shifters can be used in the channels of the array elements 1 and 3. In this case, the voltage in channel 1 will shift to an angle ψ and in channel 3 to $-\psi$,

$$\psi = kd\sin\varphi_q, \tag{6}$$

where φ_q is azimuthal angle on emission source number q.

At phase shifts the patterns in channels 1 and 3 become

$$F_\Sigma(\varphi) = \cos^2\left[\frac{kd}{2}\left(\sin\varphi - \sin\varphi_q\right)\right], \tag{7}$$

$$F_\Delta(\varphi) = \sin\left[kd\left(\sin\varphi - \sin\varphi_q\right)\right]. \tag{8}$$

From (7) and (8) follows that at phase shift (6), which satisfies the equation $\sin\varphi = \sin\varphi_q$ the sum pattern obtain maximal value and the difference pattern approaching zero.

Response factors of channels to change angles φ, φ_q are also different

$$K_\Sigma(\varphi) = \frac{kd}{2}\cos\varphi_q\sin\left[kd(\sin\varphi - \sin\varphi_q)\right].$$

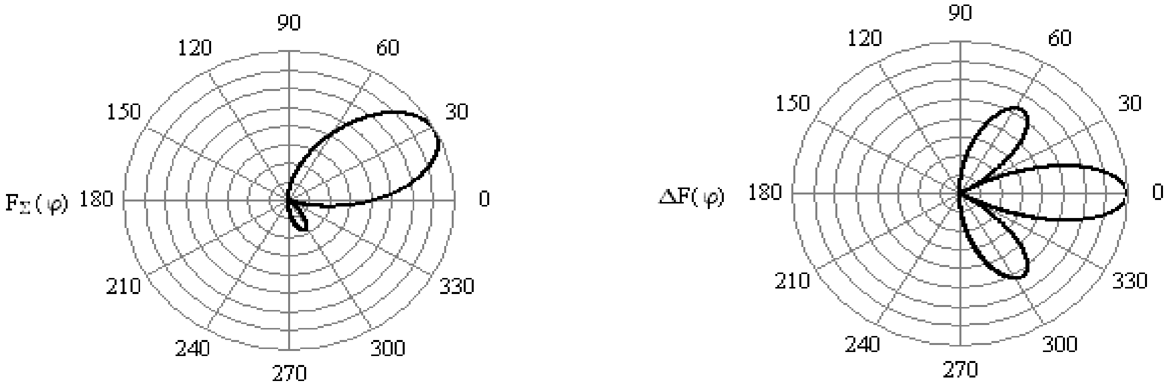
$$K_\Delta(\varphi) = kd\cos\varphi_q\cos\left[kd(\sin\varphi - \sin\varphi_q)\right].$$

From these relationships follows that the direction of radiation sources should be found using used (7). The survey sector in space is limited by directions in which the value of the patterns decreases to the admissible level. For example, it can be taken $F_\Sigma(\varphi) = 0.5$. For $\varphi_q = 0$ and $kd = \pi$ the survey sector lies in borders $\varphi = \pm 30°$. At phase shifts $\psi = \pm 45°$, that correspond to angles $\varphi = \pm 30°$ the patterns $F_\Sigma(\varphi) = \cos^2[90°(\sin\varphi \pm 0.5)]$, have four lobes with maximums at angles 30°; 210°; $-30°; -210°$. For unambiguous determination of the position of radiation sources, it is necessary to a difference pattern (8), whereas detecting the source of radiation, the mode of the sum pattern should be use antenna array with a reflector – a flat screen. In this case, the patterns (7) and (8) are supplemented by the screen multiplier [2] (Fig. 4).

$$F_\Sigma(\varphi) = \cos^2\left[\frac{kd}{2}\left(\sin\varphi - \sin\varphi_q\right)\right]\sin(kh\cos\varphi), \quad (10)$$

$$F_\Delta(\varphi) = \sin\left[kd\left(\sin\varphi - \sin\varphi_q\right)\right]\sin(kh\cos\varphi), \quad (11)$$

where h is a distance between the screen and array's plane.



(a) (b)

Fig. 4. The patterns of array with flat screen: (a) is a sum pattern; (b) is a difference pattern (Fig. 4 at $kd = 180°$, $\sin\varphi_q = 0.5$ and $kh = 90°$)

When using the antenna's mechanical rotation, space review in the azimuth plane can be made from six fixed positions: 0°; 60°; 120°; 180°; 240°; 300°. The patterns will intersect at the level of 0.49, which allows the identification of the radiation source. The advantage of mechanical rotation in comparison with the electric changing of lobe position lies in the fact that in all six antenna positions, its pattern is not distorted and remains unchanged, while in the case of electric scanning the pattern beam width increases and its form becomes asymmetric. Besides when adjusting the minimum of the pattern to the direction $\varphi \approx 90°$ using electric scanning the sensitivity to the change of angle φ approaches zero, which will lead to significant errors in the direction finding.

Let us consider the case when two sources of radiation in the survey sector operate at such close frequencies that frequency selective circles do not allow them to be separated. The voltages on the antenna system terminals will be determined as:

$$\left.\begin{aligned} \dot{U}_\Sigma &= \dot{U}_1^\Sigma F_\Sigma(\varphi_1) + \dot{U}_2^\Sigma F_\Sigma(\varphi_2), \\ \dot{U}_\Delta &= \dot{U}_1^\Delta F_\Delta(\varphi_1) + \dot{U}_2^\Delta F_\Delta(\varphi_2), \end{aligned}\right\} \quad (12)$$

where $\dot{U}_\Sigma, \dot{U}_\Delta$ are the voltages on the outputs of sum and difference channels; $\dot{U}_1^\Sigma = A_\Sigma \dot{E}_1 \ell_\partial$ and $\dot{U}_2^\Sigma = A_\Sigma \dot{E}_2 \ell_\partial$ are complex amplitudes of components voltage $\dot{U}_\Sigma$, caused by radiation of array elements 1 and 2; $\dot{E}_1$ and $\dot{E}_2$ are field intensities; $\dot{U}_1^\Delta = A_\Delta \dot{E}_1 \ell_\partial$ and $\dot{U}_2^\Delta = A_\Delta \dot{E}_2 \ell_\partial$ are complex amplitudes of voltage $\dot{U}_\Delta$ components ; A_Δ is a transfer factor of difference; φ_1 and φ_2 angular position of sources 1 and 2.

After linear detection the modules of complex voltages:

$$\left.\begin{aligned} U_\Sigma &= \sqrt{[U_1^\Sigma F_\Sigma(\varphi_1)]^2 + [U_2^\Sigma F_\Sigma(\varphi_2)]^2 + 2[U_1^\Sigma F_\Sigma(\varphi_1)][U_2^\Sigma F_\Sigma(\varphi_2)]\cos\Phi_\Sigma}, \\ U_\Delta &= \sqrt{[U_1^\Delta F_\Delta(\varphi_1)]^2 + [U_2^\Delta F_\Delta(\varphi_2)]^2 + 2[U_1^\Delta F_\Delta(\varphi_1)][U_2^\Delta F_\Delta(\varphi_2)]\cos\Phi_\Delta}, \end{aligned}\right\} \quad (13)$$

where Φ_Σ is a phase shift of complex amplitudes $\dot{U}_1^\Sigma$ and $\dot{U}_2^\Sigma$; Φ_Δ is a phase shift of complex amplitudes $\dot{U}_1^\Delta$ i $\dot{U}_2^\Delta$.

It is impractical to use the voltage U_Δ for detecting sources of radiation [3], [4], because the system's sensitivity of difference channel twice as low as for sum channel. This assertion follows from formulas (3) and (4), also from the patterns depicted in Fig. 2 and Fig. 3 (the width of each lobe of the pattern $F_\Delta(\varphi)$ is narrower than the main lobe of $F_\Sigma(\varphi)$. On the other hand, it is inappropriate to use voltage U_Σ for direction finding of emission source, since the width of the pattern at the level 0.25 by field intensity reaches $2\varphi_{0,25} \approx 80°$ (Fig. 2). So, for voltage sources, we use voltage U_Δ (13).

The second equation of system (11) will be written in the time region as follows:

$$\dot{U}_\Delta = U_1 F_\Delta(\varphi_1) e^{i(\omega_1 t + \psi_1)} + U_2 F_\Delta(\varphi_2) e^{i(\omega_2 t + \psi_2)} \qquad (14)$$

where ω_1 and ω_2 are circular frequency oscillations from sources 1 and 2; ψ_1 and ψ_2 are initial phase angels. From the formula (14):

$$\Phi_\Delta = (\omega_1 - \omega_2)t + \psi_1 - \psi_2 .$$

Since sources 1 and 2 are independent , the waves radiated by them are incoherent. Consequently, even assuming that $\omega_1 \approx \omega_2$, their difference will be significantly different from zero. In addition, the frequency values may change over time, which is regulated by state and international standards [3], [4]. In connection with this, the third component under the root in the expression U_Δ (11) will be a value that changes in time by law

$$\cos\Phi_2 = \cos[(\omega_1 - \omega_2)t + \psi_1 - \psi_2].$$

This circumstance can be used to create an effective direction finder. Bringing the voltage (13) to the square:

$$U_{\Delta \mathrm{R}} = B_Q U_\Delta^2 = B_Q \Big[\big[U_1^\Delta F_\Delta(\varphi_1)\big]^2 + \big[U_2^\Delta F_\Delta(\varphi_2)\big]^2$$

$$+ 2\big[U_1^\Delta F_\Delta(\varphi_1)\big]\big[U_2^\Delta F_\Delta(\varphi_2)\big]\cos\Phi_2 \Big],$$

where B_Q is a transfer factor by voltage of a squarer.

In the resulting equation on the right side there are three components, two of which are constant values. This gives an opportunity to filter the variable

$$U_{AC} = 2B_{Q\Phi} \Big\{ \big[U_1^\Delta F_\Delta(\varphi_1)\big]\big[U_2^\Delta F_\Delta(\varphi_2)\big]\cos\Phi_2 \Big\},$$

where $B_{Q\Phi}$ is a transfer factor of serious connection of squarer and filter.

The rectified voltage

$$U_{DC} = D\big[U_1^\Delta F_\Delta(\varphi_1)\big]\big[U_2^\Delta F_\Delta(\varphi_2)\big], \qquad (15)$$

where D is the coefficient of the converter to the constant voltage and serves as an indicator of the orientation of the difference pattern to the direction of radiation source. The expression (15) for electric scanning of the beam, using formulas (8), (11), (12), is written as:

$$U_{DC} = D A_\Delta^2 l_\partial^2 E_1 E_2 \sin\big[kd(\sin\varphi_1 - \sin\varphi_q)\big]$$

$$\cdot \sin\big[kd(\sin\varphi_2 - \varphi_q)\big],$$

with mechanical filing:

$$U_{DC} = 4a^2 l_\partial^2 D E_1 E_2 \sin\big(kd\sin\varphi_1\big)\sin\big(kd\sin\varphi_2\big).$$

At the direction finding of the source 1, we change phase shifts with phase shifters so as to obtain $\sin\varphi_1 = \sin\varphi_q$ and at a mechanical turn of the antenna combine the position of the pattern zero direction with the angle φ_1. As a result of this setting the angular position φ_1 of the radiation source is obtained and the voltage U_Δ at $F_\Delta(\varphi_1) = 0$ using equation (13) is equal

$$U'_\Delta = A_\Delta E_2 \ell_\partial F_\Delta(\varphi_2). \qquad (16)$$

Obviously, at the direction finding of the second source of radiation the angle φ_2 is found and obtain voltage at $F_\Delta(\varphi_2) = 0$

$$U''_\Delta = A_\Delta E_1 \ell_\partial F_\Delta(\varphi_1). \qquad (17)$$

An important characteristic of such antennas is the minimum angular spacing between the two sources, which ensures the correct reception of electromagnetic waves with suppression of interference. Obviously, in order to suppress the interference signal, a difference pattern is used, the zero value of which must coincide with the direction of interference wave arrival. In this case, the arises the question about the voltage on antenna terminals, sufficient for the further processing at separation angle $\Delta\varphi = \varphi_1 - \varphi_2$.

Angular separation $\Delta\varphi$ at a given level of useful voltage δ can be found using equations (7) and (5). Expression (7) is transformed into the following form:

$$\Delta\varphi = \mathrm{arc}\left(\frac{\arcsin\delta}{kd} + \sin\varphi_2\right) - \varphi_2. \qquad (18)$$

But the expression (5) takes simpler form, which follows from formula (16)

$$\Delta\varphi = \mathrm{arc}\left(\frac{\arcsin\delta}{kd}\right). \qquad (19)$$

Using formulas (18) and (19) the graps of dependence $\Delta\varphi = f(\delta)$ were built. Figure 5 shows the dependences of the minimum angular separation of the 1st and 2nd radiation sources from the angular position of the 2nd source at the minimum value of the relative voltage induced by the first source using the electric displacement of the pattern zero. Figure 6 depicts the same dependence as Fig. 5 but using the mechanical antenna turn.

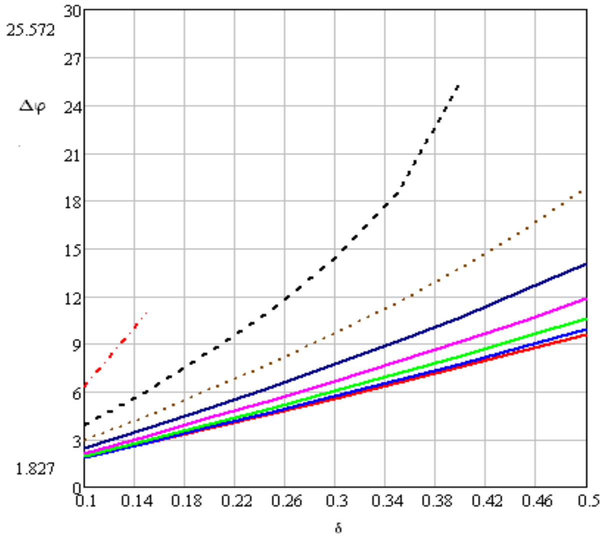


Fig. 5. Dependences of the minimum angular separation of the 1st and 2nd radiation sources from the angular position of the 2nd source at electric shift of antenna pattern

Based on the theoretical considerations, the mechanical method for the antenna turn is chosen.

Consequently, the antenna array can with the help of rotary device change the position of the major lobe in the azimuthal plane discretely through 60° and continuously within ± 45°.

The antenna array 3x2 consists of three turn style radiator in the upper row and three vertical dipoles in the lower row.

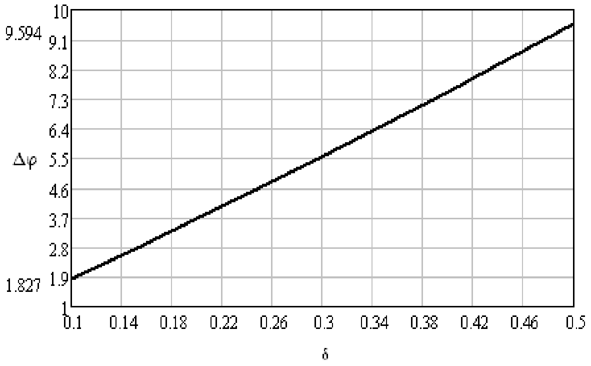


Fig. 6. Dependences of the minimum angular separation of the 1st and 2nd radiation sources from the angular position of the 2nd source at mechanical turn of antenna

V. CONCLUSIONS

When the antenna pattern is electrically scanning in order to prevent interference, the minimum angular separation of signal source and interference source increases with increasing azimuthal angle of the interference source position. This is due to the deformation main lobes of pattern at deviation of the pattern zero direction from the perpendicular to the antenna aperture of the antenna system.

At mechanical turn of antenna the pattern does not change, that provides a steady separation capability for all positions of the interference source.

Formulas (16) and (17) after the determination angles φ_1 and φ_2 on emission sources give an opportunity to calculate the field intensity in the point of reception from these sources.

Next work will describe the antenna and processing blocks, which constructing on the presented theoretical basis.

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Л. Я. Ільницький, Л. В. Сібрук, І. І. Михальчук. Багатофункціональна антена радіомоніторингу

Представлено теоретичні основи розробки антенної системи моніторингу, яка суміщає функції вимірювання параметрів радіовипромінювання, пеленгації та придушення завад, близьких за частотою до основного випромінювання. Антенна система включає в себе масив 3x2, плоский екран і механічний ротатор. Отримано мінімальне кутова відстань між напрямком сигналу і напрямом на интерференционную хвилю.

Ключові слова: антенна решітка; радіо пеленгування; придушення завади.

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Л. Я. Ильницкий, Л. В. Сибрук, И. Михальчук. Многофункциональная антенна радиомониторинга

Представлены теоретические основы разработки антенной системы мониторинга, которая совмещает функции измерения параметров радиоизлучения, пеленгации и подавления помех, близких по частоте к основному излучения. Антенная система включает в себя массив 3x2, плоский экран и механический ротатор. Получено минимальное угловое расстояние между направлением сигнала и направлением на интерференционную волну.

Ключевые слова: антенная решетка; радио пеленгования; подавление помехи.

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