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Radar station with digital axisymmetric active phased antenna array as a promising direction for the development of surveillance radars

The purpose of the study was to build a surveillance radar station (radar) with an axisymmetric (i.e. cylindrical, conical, etc.), multibeam receiving-transmitting active phased array (APAR) and investigate its characteristics. The radar station makes it possible to shorten the surveillance time, increase the rate of updating information, provide flexibility in changing operating modes, increase the reliability and service life of a radar station as compared to a radar station with mechanical rotation of antenna systems. The radar station is compared with electronic circular scanning based on cylindrical, three- and tetrahedral APAR.

Keywords: radar station, all-round surveillance, axisymmetric antenna array, active antenna array, digital antenna array, multibeam antenna array, phased antenna array, surveillance time, potential measurement accuracy.

Introduction

With emergence of air attack weapons flying at high supersonic speeds, an issue arises of reducing the time required for their detection, lock-on, and tracking.

To improve the rate of information updating in surveillance radars with electromechanical rotation of antenna systems in azimuth, increased rotation speeds are applied: up to 10, 20, 30 or even 60 rpm [1]. An increase of rotation speed leads to aggravation of certain drawbacks inherent in the electromechanical surveillance method, such as low reliability and limited operating life of rotary devices (drive, rotary support device, and current collector). Application of the electromechanical rotation is associated with the energy output ratio, structural complexity of the liquid cooling system of a rotating active phased antenna array (APAA), and other factors. Among the critical weaknesses of a radar with electromechanical antenna rotation is the absence of flexibility in changing the surveillance mode and impossibility to switch from all-round surveillance to the mode of sectoral scanning in the most dangerous directions.

In this respect, a relevant problem is that of building all-round radar surveillance facilities that would be free from the weaknesses inherent in radars with electromechanical rotation of antenna systems.

Also applied are radars with pyramidally arranged planar phased antenna arrays (PAA), ensuring electronic scanning in two planes and forming the number of beams corresponding to the number of faces [2, 3]. Pyramidal PAAs can ensure small time of selected sector surveillance and a high tracking rate; moreover, they feature a dependence of the characteristics of detection and angular coordinates measurement accuracy on the planar PAA normal direction in azimuth.

It is known that axisymmetrical PAAs (cylindrical, conical, etc.) do not feature a dependence of their parameters (directivity factor (DF), beam width) on beam direction in azimuth. In this respect, it is of interest to compare the characteristics of radars with axisymmetrical and pyramidal PAAs. In this paper, such comparison is made for the case of active PAAs.

Radar configuration

Normally, axisymmetrical PAAs have a single beam, formed by radiating elements located in a restricted excited sector of the antenna surface. In the course of scanning, it is necessary to ensure excited sector movement over the antenna surface. Such APAA will knowingly be inferior to a multibeam pyramidal APAA in terms of the total radiated power at an equal number and power of the modules, since in any given moment of time part of its modules are not involved in the radiation process. The surveillance rate of an axisymmetrical APAA will be less than that of a pyramidal APAA, whose number of beams is equal to the number of faces. Besides, it is necessary to provide for excited sector movement over the antenna surface, which leads to complication of the beam-forming arrangement of an axisymmetrical PAA.

These drawbacks can be eliminated by forming, in an axisymmetrical APAA, of a multilobe radiation pattern (RP) for transmission and respective number of beam groups for reception. In the all-round surveillance mode, the maxima of a multilobe RP, which has *K* (2–4) similar main lobes, are oriented relative to one another at an angle of 360°/*K* in azimuth (Fig. 1). For reception, a group of receiving RPs is formed in the direction of each lobe of the transmitting RP, intended for detection of targets and mono-pulse measurement of their angular coordinates. Scanning is performed by simultaneous coordinated movement of all RPs in azimuth and elevation. In the transmission mode, all APAA modules operate for radiation with equal power, which allows to ensure the maximum APAA potential (product of the directivity factor by the radiated power [4]) (see Appendix), as well as eliminate the need to control the position of the excited sector for transmission, since amplitude distribution for transmission is uniform for all the elements. In that case, RP scanning for transmission is provided due to change of phase distribution only.

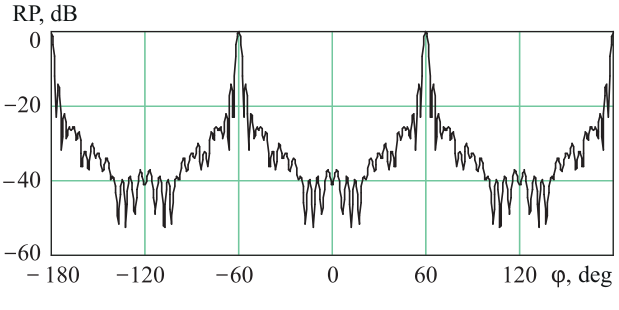

Fig. 1. Three-lobe RP for transmission of a conical APAA with base diameter $2a = 20\lambda$; angle between axis and cone generatrix $\alpha = 12°$; number of elements on the circle – 120; on the generatrix – 20; φ – azimuth angle

Implementation of a multilobe RP operating for transmission is illustrated by a three-lobe RP of a conical PAA, shown in Fig. 1 in the azimuthal plane. The RP calculation is made for uniform amplitude distribution of incident waves at the input of all radiators. Phase distribution within the limits of each 120-degree PAA sector is optimal for sharp beam formation [5]. The obtained level of the first side lobes, equal to 13…14 dB, is acceptable for the transmission mode.

The maximum effective cross-section of a multibeam PAA, when operating for reception, can be obtained in APAA only, since the presence of low-noise amplifiers makes it possible to eliminate beamformer dissipative losses and losses for the non-orthogonality of beams [6]. In so doing, the necessary number of receiving beam groups can be formed when using common radiating elements without reducing S/N ratio. Such receiving APAA with intersecting scanning apertures can hardly be implemented in practice in an analogue configuration because of the beamformer complexity. However, its implementation is quite feasible in case of digital beamforming (DBF) [7], which has been intensively developing in the recent years in radars with planar APAAs.

This paper draws a comparison between the characteristics of surveillance radars with all-round electronic scanning on the basis of pyramidal and axisymmetrical APAAs, with multilobe RP for transmission and multibeam RP for reception. The comparison is drawn as per such criteria as the minimum possible surveillance time in the all-round sector, potential and DF, beam width, potential measurement accuracy of angular coordinates, and APAA overall dimensions.

Theoretical restrictions on the minimum radar surveillance time

In estimation of the minimum possible surveillance time, we assume that, despite the high speeds of targets, the time of target echo-signal integration is not that high so as to require accounting for the effects associated with target’s spatial movement over the integration time.

In this case, surveillance time T can be estimated using the known formula defining detection range during surveillance [8], from which

$$T = \frac{4\pi E_{r\min} R^4 \Omega}{P A_r \sigma}, \tag{1}$$

where $E_{r\min}$ – received signal minimum energy, determined as per specified probabilities of detection and false alarm with the use of known relationships [8];

R – respective detection range;

Ω – surveillance sector (steradian);

P – radiation mean power;

A_r – antenna effective cross-section for reception;

σ – radar cross-section (RCS) of the target.

It is presumed that the values of parameters in formula (1) do not depend on direction in the surveillance sector.

We shall reckon that the losses associated with reflection of a portion of power at the radiating elements’ inputs do not depend on scanning direction and radiator position on the APAA surface. Since the case under consideration is that of simultaneous radiation of all APAA elements with the same power, radiation mean power $P = P_1 N$, where P_1 – mean output power of the active module (per single radiating element); N – number of APAA elements.

Let us analyse the surveillance time at fixed values of RCS and range in the surveillance sector, taking into account that APAA effective cross-section for reception depends on the direction in space. Then formula (1) will be transformed to the view

$$T = \frac{4\pi E_{r\min} R^4}{P_1 N \sigma} \iint_{\Omega} \frac{1}{A_r} d\Omega. \tag{2}$$

The effective surface of a narrow-beam conformal antenna is easily obtained based on the expression for its DF [5]:

$$A_r = k_a \int_S \cos\vartheta \, dS, \tag{3}$$

where k_a – aperture taper efficiency factor (TEF); under tapered amplitudes, to reduce the level of side lobes for reception $k_a < 1$;

ϑ – angle between scanning direction and normal to the antenna surface in the integration point;

S – surface of conformal antenna illuminated by a plane wave incoming from the direction of receiving beam maximum (or part of it, if a part of the surface is used for reception).

As a result, for the minimum surveillance time, from expressions (2), (3) we obtain

$$T = \frac{4\pi E_{r\min} R^4}{P_1 N \sigma k_a} \iint_{\Omega} \left[\frac{1}{\int_S \cos\vartheta \, dS} \right] d\Omega. \tag{4}$$

Using formula (4), it is possible to compare different radars with APAAs in terms of the space surveillance time.

DF and potential for transmission

Let us split the aperture of an axisymmetrical APAA into K sectors, corresponding to the number of RP main lobes for transmission. Each sector will be forming a single-beam RP, in accordance with polarisation and phase distribution which is optimal for obtaining the maximum DF [5].

To obtain the maximum potential, uniform APAA amplitude distribution for transmission is selected. In this case, from the relationships for DF of a conformal antenna under high-directivity radiation [5], for DF $D_t^{(k)}$ to transmit the k-th sector in a general case of uneven sectors, we have

$$D_t^{(k)} = \frac{4\pi}{\lambda^2 S_k} \left(\int_{S_k} \sqrt{\cos\vartheta} \, dS \right)^2, \tag{5}$$

where S_k – sector area.

Potential Π_k of the APAA is determined by the product of DF by radiation power, and in the considered case, $\Pi_k = P_1 N_k D_t^{(k)}$, where

N_k – number of elements in the k-th sector. For equal sectors

$$\Pi = \Pi_k = P_1 N D_t^{(1)} / K, \qquad (6)$$

and APAA DF for transmission $D_t = \Pi / P_1 N = D_t^{(1)} / K$.

Comparison between cylindrical and polyhedral APAA

Let us draw a comparison between different all-round electronic surveillance systems. For simplicity, we shall consider a cylindrical multibeam APAA and tri- and tetrahedral APAA in the form of a prism (Fig. 2). We assume that the scanning sector in elevation is small, so that it could be possible to consider the characteristics of all APAA types similar and compare them in terms of scanning characteristics in the horizontal plane.

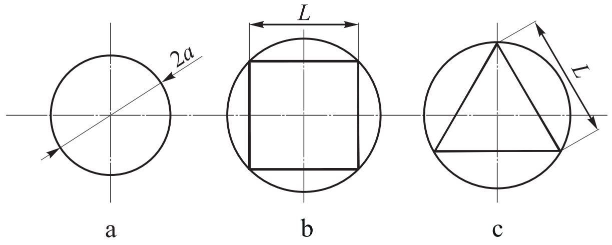

Fig. 2. Contours of cylindrical (a), tetrahedral (b) and trihedral (c) APAA in plan view; a – cylinder radius; L – face horizontal size

In drawing comparison, we shall assume that APAA module mean output power P_1 and the number of elements N is similar for all APAA versions. Factors k_a for reception are also assumed similar in all configurations.

In case of a cylindrical APAA, to obtain the maximum possible effective cross-section for formation of each receiving beam, we shall use the entire illuminated aperture half. For a polyhedral APAA, each receiving beam (or group of beams) is formed by one face only. This is explained by the presence of a gap between the faces, virtually unavoidable due to design considerations, which, when several faces are used jointly, leads to unacceptably high level of side lobes for reception [2]. In this case the minimum surveillance time T (4) for a cylindrical APAA at $K \geq 2$

$$T = \frac{C}{2aH} \int_0^{2\pi} \frac{d\varphi}{\int_0^{\pi/2} \cos\varphi' d\varphi'} = \frac{\pi C}{aH}, \qquad (7)$$

where C – constant;

H – cylinder height;

φ' – azimuthal angle of point on the antenna cylindrical surface.

For a K-face prism, the minimum surveillance time will be

$$T = \frac{2CK}{LH} \int_0^{\pi/K} \frac{d\varphi}{\cos\varphi}. \qquad (8)$$

Integral $\int_0^x \frac{d\varphi}{\cos\varphi} = \ln\sqrt{\frac{1+\sin x}{1-\sin x}}$ [9], then we have

$$T = \frac{2CK}{LH} \ln\sqrt{\frac{1+\sin(\pi/K)}{1-\sin(\pi/K)}}. \qquad (9)$$

From the condition of the absence of diffraction lobes, circumferential spacing of cylindrical APAA elements must not exceed $\lambda/2$. Hence, the minimum number of elements

$$N = \frac{4\pi a H}{\lambda d_z}, \qquad (10)$$

where d_z – vertical spacing.

From the condition of the absence of diffraction lobes, horizontal spacing d of the flat-face elements must not exceed $d \leq \lambda / (1 + \sin(\pi/K))$ [2, 4], and then the minimum number of elements

$$N = K \frac{LH}{\lambda d_z} \left(1 + \sin\frac{\pi}{K}\right). \qquad (11)$$

Equating the number of elements (10) and (11), we correlate cylindrical antenna radius and linear dimension of the face:

$$L = \frac{4\pi a}{K\left(1 + \sin\frac{\pi}{K}\right)}. \qquad (12)$$

The values of surveillance time, potential, DF, and other parameters are normalised to respective values for a cylindrical APAA with single-lobe RP for transmission T_0, D_0, etc. In so doing, we shall assume that in a single-beam APAA, only a 180-degree sector of antenna cross-section is used both for reception and transmission.

The minimum surveillance time for a cylindrical APAA, with account of (7)

$$\frac{T}{T_0} = \frac{1}{2}, \tag{13}$$

and for a polyhedral APAA, with account of (9), (12)

$$\frac{T}{T_0} = \frac{K^2}{4\pi^2}\left(1+\sin\pi/K\right)\ln\sqrt{\frac{1+\sin\pi/K}{1-\sin\pi/K}}. \tag{14}$$

Then the transmission potential of a cylindrical APAA, with the use of (5), (6)

$$\frac{\Pi}{\Pi_0} = \left(\frac{\gamma_K}{\gamma_2}\right)^2. \tag{15}$$

Here, integral $\gamma_K = \int\limits_0^{\pi/K}\sqrt{\cos\varphi}\,d\varphi$ is expressed through elliptic integrals, and can be calculated numerically too. For K equal to 2, 3, 4, values of γ_K are, respectively, 1.198; 0.948, and 0.744.

For a polyhedral APAA, with account of (11)

$$\frac{\Pi}{\Pi_0} = \frac{2\pi^2\cos\theta}{K^2\left(1+\sin\pi/K\right)\gamma_2^2}, \tag{16}$$

where θ – angle of beam deflection from normal.

Let us write a mean value of the polyhedral APAA relative potential for the scanning sector in azimuth:

$$\frac{\overline{\Pi}}{\Pi_0} = \frac{\Pi_{\max}}{\Pi_0}\frac{\pi}{K}\int_0^{\pi/K}\cos\varphi\,d\varphi = \frac{2\pi\sin\pi/K}{K\left(1+\sin\pi/K\right)\gamma_2^2}. \tag{17}$$

The effective cross-section for reception of a cylindrical APAA (same as the beam width) does not depend on the number of beams $A_r/A_{r0} = 1$.

Relative effective cross-section for reception of a polyhedral APAA

$$\frac{A_r}{A_{r0}} = \frac{2\pi\cos\theta}{K\left(1+\sin\pi/K\right)}. \tag{18}$$

Then a mean value of the relative effective cross-section of a polyhedral APAA in the scanning sector

$$\frac{\overline{A}_r}{A_{r0}} = \frac{2\sin\pi/K}{\left(1+\sin\pi/K\right)}. \tag{19}$$

Relative beam width of a polyhedral APAA for horizontal reception is determined by the ratio of the lengths of equivalent apertures

$$\frac{\Delta\theta}{\Delta\theta_0} = \frac{2a}{L\cos\theta}, \tag{20}$$

mean value of relative width in the scanning sector as per the formula

$$\frac{\Delta\overline{\theta}}{\Delta\theta_0} = \frac{2aK}{\pi L}\ln\sqrt{\frac{1+\sin\pi/K}{1-\sin\pi/K}}. \tag{21}$$

The parameters of radar with a cylindrical APAA, with a different number of RP lobes for transmission, as well as with a tri- and tetrahedral APAA, calculated as per relationships (13)–(21), are given in Table 1.

As follows from the results given in Table 1, a radar with cylindrical APAA has the minimum possible surveillance time less by 12…22 % and the APAA potential higher than that of tri- and tetrahedral APAAs at the scanning sector edge, as well as less average beam width for reception and smaller overall dimensions.

It stands to mention that the comparison was drawn under excitation of a polyhedral APAA by distribution which is optimal with regard to the potential maximum criterion, whereas for a cylindrical APAA, distribution is only optimal for independent excitation of the cross-section area sectors. Given an optimal excitation of a cylindrical APAA, some additional increase in potential can be expected.

Table 1

Parameters of active phased antenna arrays (APAA)

Parameters	Cylindrical APAA			Polyhedral APAA	
Number of RP maxima for transmission, K	2	3	4	3	4
Minimum surveillance time, T/T_0	0.5	0.500	0.500	0.560	0.610
Potential for transmission, Π/Π_0:					
• maximum;	1	0.626	0.386	0.819	0.503
• average in azimuth;	1	0.626	0.386	0.677	0.453
• minimum	1	0.626	0.386	0.409	0.356
Effective cross-section for reception, A_r/A_{r0}:					
• maximum;	1	1	1	1.122	0.920
• average in azimuth;	1	1	1	0.928	0.828
• minimum	1	1	1	0.561	0.651
Beam width for reception, $\Delta\theta/\Delta\theta_0$:					
• maximum;	1	1	1	1.782	1.537
• average in azimuth;	1	1	1	1.120	1.220
• minimum	1	1	1	0.891	1.087
Diameter of circumscribed circle	1	1	1	2.250	1.300

Remarkably, the minimum surveillance time for a radar with cylindrical APAA does not depend on the number of beams for transmission (2, 3, or 4), as with a greater number of beams more time is required for detection of target in each spatial direction, with the probabilities of detection and false alarm remaining the same.

Let us compare the systems under consideration for potential measurement accuracy of target angular coordinates, which is defined by noise RMSE [10]:

$$\sigma_\theta = \frac{c\Delta\theta}{\sqrt{W}}, \qquad (22)$$

where c – a certain constant;

W – S/N ratio at receiver input.

The S/N ratio for the APAAs being compared differs, due to the differences in potential and effective cross-section for reception, in such a way that the relative error of angular coordinates measurement

$$\frac{\sigma_\theta}{\sigma_{\theta 0}} = \frac{\Delta\theta}{\Delta\theta_0}\sqrt{\frac{\Pi_0 A_{r0}}{\Pi A_r}}. \qquad (23)$$

Given in Table 2 are the calculation results of relative noise error of azimuth measurements as per APAA parameters (see Table 1).

Table 2

Noise error in azimuth measurement

APAA	Relative noise angular error in all-round surveillance sector, $\sigma_\theta / \sigma_{\theta 0}$	
	average	maximum
Cylindrical:		
• two-beam;	1.00	1.00
• three-beam;	1.26	1.26
• four-beam	1.61	1.61
Trihedral	1.41	3.72
Tetrahedral	1.99	3.19

The overall dimensions of a cylindrical APAA are smaller than those of a polyhedral one. With radiating elements of the neighbouring faces being adjacent, prism diameter (see Fig. 2) turns out to be larger than the diameter of a cylindrical APAA. According to the assemblability conditions of a polyhedral APAA, considering its thickness, its dimensions have to be larger still.

Comparison between cylindrical, conical, and paraboloid APAAs

The shape of PAA axisymmetric surface generatrix can be different. Among the known designs are cylindrical, conical, spherical PAAs and PAAs on the surface of paraboloid of revolution [5, 11]. Let us consider the dependence of the maximum DF of a cylindrical, conical, and paraboloid antenna vs. scanning angle (RP) in the elevation plane at the same antenna height *h* and equivalent flat aperture area under radiation in the direction of horizon (Fig. 3).

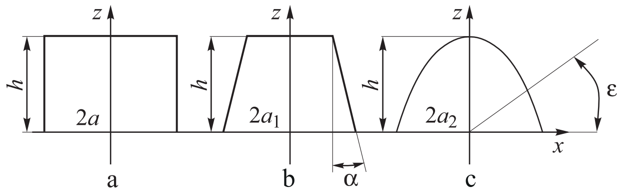

Fig. 3. Vertical cross-section of axisymmetric cylindrical (a), conical (b), and paraboloid (c) PAAs

It is presumed that the radiating elements are arranged only on the side surface of the cylinder and cone.

Based on the formula (2.21) [5] for the maximum DF of a paraboloid antenna, it is easy to obtain

$$D=\frac{4\pi a_2}{\lambda^2}\left[a_2\sin\varepsilon\left(\frac{\pi}{2}+\beta+\frac{1}{2}\sin(2\beta)\right)+\frac{2}{3}h\cos\varepsilon\left(2+3\sin\beta-\sin^3\beta\right)\right], \tag{24}$$

where a_2 – base radius (see Fig. 3),

ε – elevation angle from the horizon;

$$\beta=\begin{cases}\arcsin\left(\dfrac{a_2}{2h}\operatorname{tg}\varepsilon\right), & \operatorname{ctg}\varepsilon>\dfrac{a_2}{2h};\\[2ex] \dfrac{\pi}{2}, & \operatorname{ctg}\varepsilon\le\dfrac{2h}{a_2}.\end{cases} \tag{25}$$

Expressions for the maximum DF of a cylindrical and conical antennas are given in [5]. The calculation results of normalised DF D/D_0 (where D_0 – DF value, similar for all antennas, at $\varepsilon=0$) for height/radius ratio of a cylindrical antenna $a=h$ are given in Fig. 4.

By selecting surface shape, it is possible to ensure a required law of DF variation depending on elevation angle ε (see Fig. 3). A cylindrical PAA is suitable for scanning in a limited sector of elevation angles. At a change of elevation angle, DF of a conical PAA, with angle between axis and generatrix $\alpha=15°$, changes insignificantly.

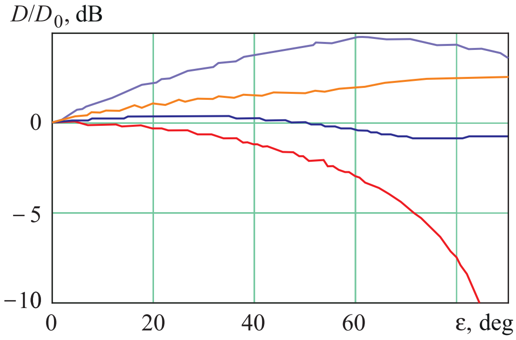

Fig. 4. Dependencies of axisymmetrical PAA DF vs. scanning angle for:
— – paraboloid; — – cone $\alpha=30°$;
— – cone $\alpha=15°$; — – cylinder;

The given dependencies of DF vs. scanning angle relate to a PAA with controllable polarisation of radiators. Under fixed polarisation of radiators, DF can decrease much faster with the increase of the elevation angle. However, for a cylindrical and conical PAA with radiators in the form of slots or vibrators, whose axes are arranged along PAA surface generators, the losses associated with non-optimal polarisation of radiators are small at cone angles $\alpha\le 30°$ [5].

Conclusion

In the proposed configuration of an all-round surveillance radar with a multibeam axisymmetrical APAA for transmission, a multilobe radiation pattern is formed. The maximum radiation power and energy potential in each beam are provided due to equal radiation power of all APAA elements. In the receiving mode, respective number of receiving beams is used, with the maximum effective cross-section ensured due to digital beamforming in an APAA with intersecting apertures corresponding to different beams. Such radar makes it possible to reduce the time required for space surveillance. In so doing, the minimum surveillance time does not depend on the number of beams (2 or more), which can be selected, for example, with account for the duration of a coherent burst of radio pulses necessary for moving target selection.

It is shown that with equal power of the modules and equal number of elements, an axisymmetrical APAA has the minimum surveillance time less by 12…22 % and a higher potential as compared with the minimum potential of a polyhedral APAAs in the scanning sector, as well as less average beam width for reception, up to 2–3 times lower target azimuth measurement error, and smaller overall dimensions.

Due to selection of axisymmetrical PAA generatrix shape, it is possible to ensure a required form of DF and surveillance zone dependence on the scanning angle in the elevation plane. Use of a cylindrical PAA is relevant when the scanning sector is up to 60° in elevation. A conical PAA with cone angle of 15° makes it possible to ensure a virtually constant gain factor when scanning in elevation. Application of radiators in the form of slots or vibrators, whose axes are directed along PAA surface generators, allows to do without control of a conical and cylindrical PAA during scanning, with small losses in DF.

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Appendix. Maximum potential of an arbitrary APAA

Potential of an arbitrary APAA [6]

$$\Pi = \left|\sum_{n} a_n f_n(\theta_0, \varphi_0)\right|^2, \tag{A.1}$$

where a_n – amplitude of incident wave at the n-th radiator input;

$f_n(\theta_0, \varphi_0)$ – value of element's partial pattern in the direction of radiation pattern maximum.

Here, partial RP is understood as an RP with one element excited by an incident wave with the unit power, at matched loads at the inputs of all other elements, and with common phase origin point for all elements.

Power of an individual transmitting module of the APAA is limited by its technical capabilities, therefore it can be considered that the amplitudes of incident waves shall satisfy the inequalities

$$|a_n| \le 1. \tag{A.2}$$

Using the known inequality

$$\left|\sum_n x_n\right| \le \sum_n |x_n|, \tag{A.3}$$

with consideration of (A.2), we obtain

$$\Pi \le \left(\sum_n |a_n||f_n|\right)^2 \le \left(\sum_n |f_n|\right)^2. \tag{A.4}$$

Equality (A.4) is achieved at

$$a_n = e^{-j\arg(f_n)}. \tag{A.5}$$

In this way, an optimal distribution, such that delivers the maximum of APAA potential, is defined by (A.5) and corresponds to equal (maximum) output power of all transmitting modules of the APAA.

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Science research interests: radar, theory and technology of surveillance radar stations.

Радиолокационная станция с цифровой осесимметричной активной фазированной антенной решеткой как перспективное направление развития радиолокационных станций кругового обзора

Предложено построение и исследованы характеристики радиолокационной станции (РЛС) кругового обзора с осесимметричной (цилиндрической, конической и др.) многолучевой приемо-передающей активной фазированной решеткой (АФАР). Такая РЛС позволяет сократить время обзора, увеличить темп обновления информации, обеспечить гибкость изменения режимов работы, повысить надежность и ресурс РЛС по сравнению с РЛС с механическим вращением антенных систем. Проведено сравнение РЛС с электронным круговым сканированием на основе цилиндрической, трех- и четырехгранной АФАР.

Ключевые слова: радиолокационная станция, круговой обзор, осесимметричная антенная решетка, активная антенная решетка, цифровая антенная решетка, многолучевая антенная решетка, фазированная антенная решетка, время обзора, потенциальная точность измерения.

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