

Analysis of the influence of radiators basing errors in the monopulse phased array antenna aperture on its characteristics

Yury Rusov^{1,*}

¹Bauman Moscow State Technical University, Radioelectronic Systems and Devices Department, 105005 2-ya Baumanskaya str. 5, Moscow, Russia

Abstract. The influence of radiators basing errors in the flat monopulse phased array antenna with spatial excitation on the beam forming accuracy is researched. The results of calculations of the deviation of the position of the difference radiation pattern minimum depending on the displacement of the antenna array radiators for antenna arrays with diameters from 10 to 100 wavelengths are presented.

Phased array antenna (PAA) is the main type of antennas with electric beam scanning [1, 2]. When used in radar systems, an important parameter is the accuracy of forming the beam in a given direction. In a monopulse antenna forming both total and difference radiation patterns, the position of the beam is associated with the direction of the minimum of the difference radiation pattern. Of practical interest is the research of the influence on the accuracy of the phased array beam installation of its design features such as the real errors of the radiators basing in the antenna aperture and the size of the aperture.

The article deals with phased array antennas with a flat aperture and spatial excitation by four-horn monopulse irradiators (Figure 1) [1, 3].

The antenna array contains aperture radiators, providing matching with the free space within the sector of the electric beam scanning, and receiving radiators, located on the side of the irradiator and forming the amplitude distribution in the antenna aperture. Such antenna systems have proven themselves well in a number of practical applications due to high manufacturability with acceptable electrical characteristics [4, 5]. As a rule, these antenna arrays have modular design based on integrated elements of phased array antennas containing, for example, Faraday ferrite phase shifters and waveguide-dielectric radiators [4, 6, 7].

The research of the influence of errors in the location of its elements on the accuracy of the phased array beam forming was carried out on the example of antennas with a round aperture.

Difference radiation patterns of aperture antenna array are calculated by the equation [2]

$$F(\theta, \psi) = f_A(\theta, \psi) \sum_{n=1}^N A_n \exp(i \varphi_n) \exp[ik(x_n \cos \psi + y_n \sin \psi) \sin \theta]. \quad (1)$$

* Corresponding author: rusov.yu.s@yandex.ru

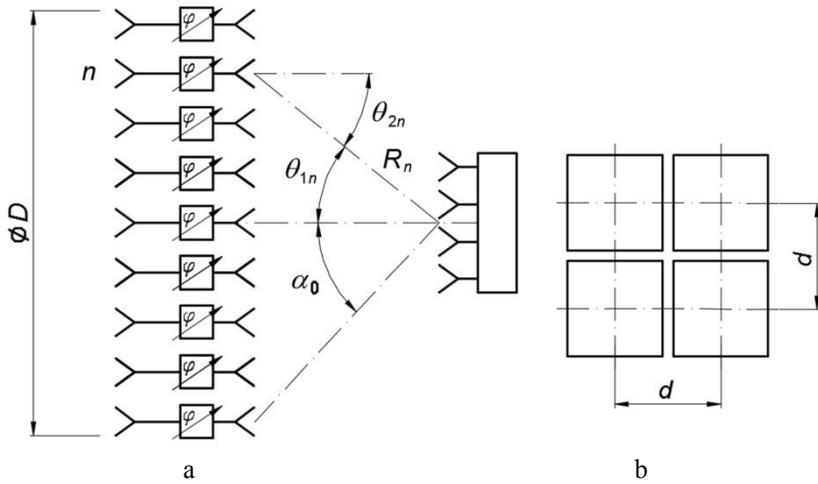


Fig. 1. Schematic of pass-through PAA with spatial excitation (a) and layout of radiators in the monopulse irradiator (b).

In the equation (1) A_n and φ_n are the amplitude and excitation phase of the phased array element with the number n , respectively; N is the total number of elements in the antenna aperture; x, y are the coordinates of the phased array elements in the antenna aperture, taking into account the basing errors; $k = 2\pi/\lambda$; λ is the wavelength; θ, ψ are the angles of the spherical coordinate system; $f_A(\theta, \psi)$ is the radiation pattern of the aperture radiator of the antenna array.

The phased antenna array radiators are located in the nodes of the hexagonal grid with a step $d_{PAA} = 0,68\lambda$ (Figure 2 a), providing a sector of single-beam electric beam scanning with a maximum angle of deviation from the normal to the aperture of at least 45° . The calculations take into account the same for all PAA falling to the edges of the aperture amplitude distribution of the field obtained taking into account the radiation patterns of the PAA irradiator and the radiator of the receiving antenna array and angle of the receiving antenna array irradiation α_0 . The excitation amplitude of the PAA element with the number n is determined by the equation

$$A_n = f_\Delta(\theta_{1n}, \psi_{1n}) f_R(\theta_{2n}, \psi_{2n}) / R_n \quad (2)$$

In the equation (2) $f_\Delta(\theta_{1n}, \psi_{1n})$ – difference radiation pattern of PAA monopulse irradiator; θ_{1n}, ψ_{1n} – angles of a spherical coordinate system aligned with the PAA irradiator centre of the radiation; $f_R(\theta_{2n}, \psi_{2n})$ – radiation pattern of the antenna array receiving radiator; θ_{2n}, ψ_{2n} – angles of a spherical coordinate system aligned with the receiver radiator centre of the radiation that is part of the PAA element with the number n ; R_n is the distance between the centres of radiation of the monopulse irradiator and receiving radiator of the PAA element with the number n .

The difference radiation pattern of the monopulse irradiator is calculated by the equation

$$\begin{aligned} f_\Delta(\theta_{1n}, \psi_{1n}) = & \\ = f_1(\theta_{1n}, \psi_{1n}) \sum_{p=1}^2 \sum_{m=1}^2 \exp[i\pi(p-1)] \exp\{ik [d(p-1,5) \cos\psi_{1n} + & \\ + d(m-1,5) \sin\psi_{1n}] \sin\theta_{1n}\}. & \end{aligned} \quad (3)$$

In the equation (3) $f_1(\theta_{1n}, \psi_{1n})$ is the radiation pattern of a single radiator in the aperture of the monopulse irradiator, instead of which the radiation pattern of the open end of the

square waveguide is used in the calculation; d is the distance between the centres of radiation of radiators in the monopulse irradiator aperture.

The excitement phase φ_n of each PAA element is calculated based on the formation of the differential radiation pattern of the antenna array with the coordinates of the minimum θ_s and ψ_s . In this case, the calculation of the excitation phases is carried out taking into account the nominal coordinates of the radiators, and when calculating the antenna pattern, the coordinates of the PAA elements are used, obtained by shifting the elements from the specified positions by the permissible deviation. The calculations are performed for the limiting case when all radiators shifted by the amount specified error Δ , with each half of the PAA aperture, the shift occurs to the side edge of the aperture (Figure 2 b).

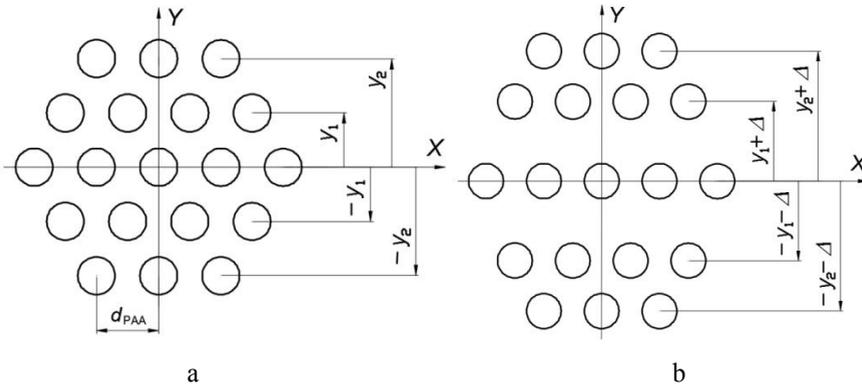


Fig. 2. Placement of radiators in the antenna array in the absence of basing errors (a) and presence of basing errors (b).

The radiation pattern of the waveguide-dielectric radiator $f_A(\theta, \psi)$ optimized for operation in the sector of electric beam scanning with a maximum angle of deviation from the normal to the aperture of 45° was used in the calculations of the PAA radiation patterns [4]. The following PAA radiation patterns are calculated at a value of $\psi = 90^\circ$.

Figure 3 shows the calculated in the region of the minima difference radiation patterns of PAA of different diameters. In Figure 3, the curve 1 corresponds to the difference pattern of the PAA with a diameter $D = 10\lambda$ when the beam is deflected by an angle of 45° from the normal to the aperture and there are no errors in the location of the PAA elements. The curve 2 corresponds to the radiation patterns calculated for the same aperture diameter and the displacement of the radiators by $\Delta = 0,01\lambda$ relative to the initial position. Curve 3 corresponds to the difference radiation pattern calculated at the same displacement, but for an aperture with a diameter of 100λ .

Figure 4 shows the generalized dependence of the angle of displacement of the PAA difference radiation pattern minimum $\Delta\theta$ from the aperture diameter D/λ for a given deflection of the beam $\theta_s = 45^\circ$ with a PAA elements basing error $\Delta = 0,01\lambda$. By increasing the diameter of the aperture there is a decrease in the displacement of the beam relative to the given position.

Figures 5-7 present the results of research of the angle of displacement of the PAA difference radiation pattern minimum at different values of the maximum deviation of the coordinates of the elements from the nominal values, as well as when changing the size of the PAA aperture. Curves of Figure 5 illustrate the changes the difference radiation pattern in the region of its minimum for an antenna array with a diameter of 10λ when the deflection of the beam by 45° in dependence on a value of the radiators basing error in the aperture: 1 – difference radiation pattern with the absence of errors ($\Delta=0$); 2 – with the basing error $\Delta = 0,03\lambda$; 3 – with the basing error $\Delta = 0,05\lambda$.

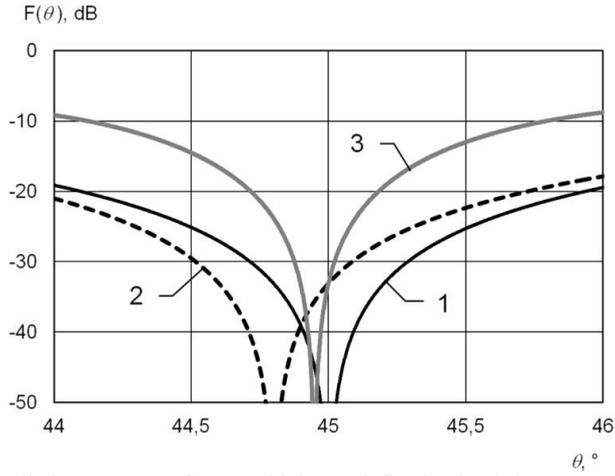


Fig. 3. Difference radiation patterns of PAA with beam deflection by 45°.

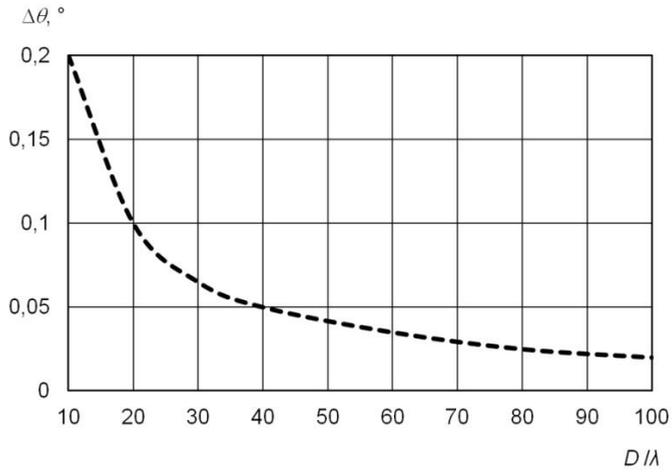


Fig. 4. The value of the angular displacement of the difference radiation pattern minimum depending on the diameter of the PAA aperture.

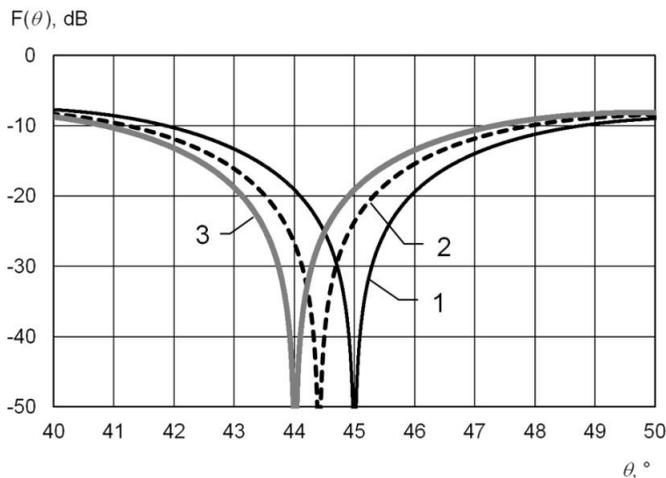


Fig. 5. Difference radiation patterns with a PAA diameter of 10λ near the direction of the deflected beam minimum.

Figure 6 shows the dependence of the value of the angular displacement $\Delta\theta$ of difference radiation pattern minimum from the radiators basing error Δ/λ , calculated for PAA different diameters: 1 – $D = 10\lambda$; 2 – $D = 50\lambda$; 3 – $D = 100\lambda$. The calculation is performed with the beam deviation angle $\theta_s = 45^\circ$.

Figure 7 shows the calculated dependence of the angular displacement $\Delta\theta$ of difference radiation pattern minimum of the angle of beam deflection θ_s , with the radiators basing error $\Delta = 0,01\lambda$ for PAA of various diameters: 1 – $D = 10\lambda$; 2 – $D = 50\lambda$; 3 – $D = 100\lambda$.

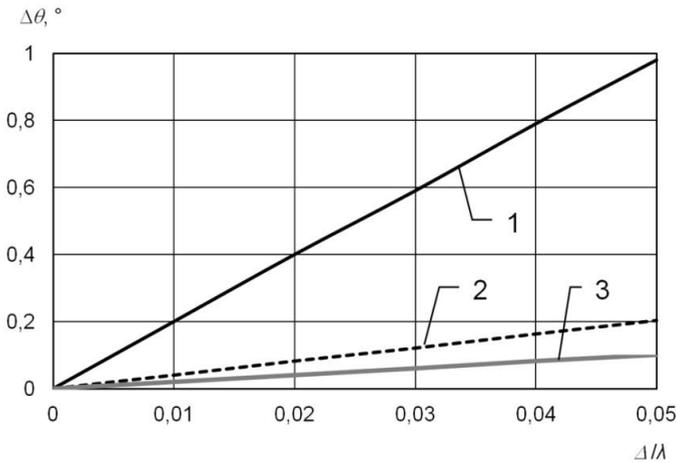


Fig. 6. Angular displacement of PAA difference radiation pattern minimum from a given direction of the deflected beam depending on the radiators basing error.

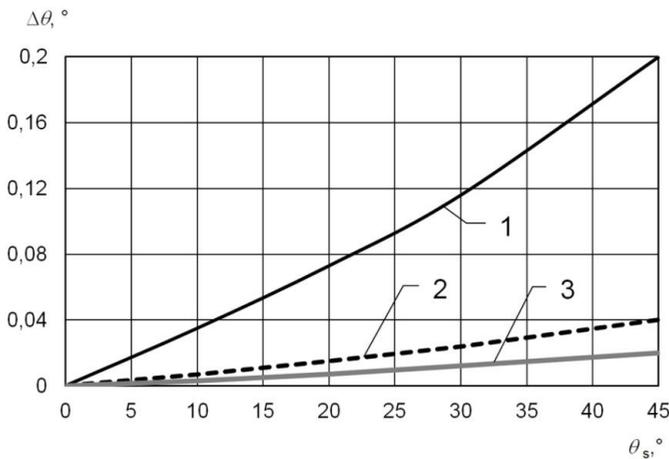


Fig. 7. Angular displacement of PAA difference radiation pattern minimum from a given direction depending on the angle of deflection of the beam for PAA with different diameters.

Thus, the increase in the angular displacement of PAA difference radiation pattern minimum is observed with increasing angle of the beam deflection and the allowable radiators basing error, and if you reduce the size of antenna aperture.

Summary

Research the effect on the accuracy of the forming beam of the phased array antenna such design parameters as the real radiators basing error in the aperture and the size of its aperture allow making following conclusions.

1. An increase in the numerical values of the allowable radiators basing error leads to an increase in the error of the PAA beam forming.

2. The value of the angular displacement of PAA difference radiation pattern minimum from a given direction increases with increasing angle of deflection of the antenna beam in the scanning sector.

3. An increase in the aperture diameter leads to a monotonous decrease in the angular displacement of PAA difference radiation pattern minimum.

4. The numerical results can be used for the reasonable assignment of tolerances for the displacement of the PAA elements in the aperture in the design of multi-element flat antenna arrays with spatial excitation.

References

1. Merrill I. Skolnik Editor in Chief, *Radar Handbook, Third Edition* (McGRAW-HILL, 2008)
2. D.I. Voskresenskiy, *Microwave devices and antennas. Design of phased array antennas* (Moscow, Radiotekhnika Publ., 2012)
3. V.I. Obrazumov, V.M. Krekhtunov, O.Yu. Shevtsov, Yu.S. Rusov, M.Ye. Golubtsov, *Monopulse aerial, Patent RF № 2370863* (Appl. 04.08.2008, publ. 20.10.2009)
4. V.M. Krekhtunov, M.Ye. Golubtsov, Yu.S. Rusov, E.V. Komissarova, *Vestnik MGTU im. N.E. Bauman. Series Instrumentation. Special issue. Antennas and devices of radio and optical bands*, pp. 105-117 (2009)
5. I.B. Federov, G.P. Slukin, V.N. Mitrohin, V.M. Krekhtunov, *Antennas*, v. **8(228)**, pp.84-98 (2016)
6. Yu.S. Rusov, M.Ye. Golubtsov, V.M. Krekhtunov, S.I. Nefedov, *Pass-through phased array antenna module, Patent RF № 2461930* (Appl. 30.12.2010, publ. 20.09.2012)
7. M.Ye. Golubtsov, Yu.S. Rusov, V.M. Krekhtunov, S.I. Nefedov, *Element of the pass-through phased array antenna, Patent RF № 2461931* (Appl. 30.12.2010, publ. 20.09.2012)