UDC 621.396.677.494 doi: 10.26906/SUNZ.2020.3.124

O. Besova[1] ,V. Karlov[1], O. Lukashuk[1], I. Petryshenko[2]

[1] Kharkiv National Air Force University of Ivan Kozhedub, Kharkiv, Ukraine
[2] Odessa Military Academy, Odessa, Ukraine

DIAGNOSTICS OF HEADLIGHTS FROM NEAR AREA ON PLACE OF BASING

Abstract. Methods of microwave diagnostics of a phased array allow reconstructing the amplitude-phase distribution in the antenna and implement on this basis methods for adapting the lattice control to those found in the amplitude-phase distribution to defects. The methods of microwave diagnostics from the near zone described in the well-known literature are realizable only in anechoic chambers or on specially equipped training grounds. To solve the problems of adapting a phased antenna array to a technical state and increasing its operating time under extreme conditions, it is necessary to have methods of integrated microwave diagnostics of a phased antenna array at its location. **The aim of the article** is to develop a method for microwave diagnostics of a phased array antenna, implemented from the near zone of the antenna at its location, and eliminating the influence of echo signals (ES) on the diagnostic results. The article proposes a method for microwave diagnostics of a phased array antenna from the near field, which allows to exclude the influence on the accuracy of diagnostics of the echo signal present at the measuring site and errors in the positioning of the measuring probe. The proposed method will make it possible to implement microwave diagnostics of the antenna from the near field at its location. The results of microwave diagnostics are supposed to be used to implement various methods of adapting a phased array to a technical condition, significantly increasing its life.

Keywords: antenna measurements, phased array antenna diagnostics, near field , microwave diagnostics

Introduction

The methods of control of phased antenna array (PAA) can conditionally be divided into methods of built-in control and methods of bench (polygon) tests. The first are implemented by control systems for amplitude-phase distribution (APD) control systems integrated into the phased antenna array and built-in factor control systems that distort the amplitude-phase field distribution in the antenna aperture [1].

The methods of stand (ground) tests of aerial include microwave diagnostics of main control nodes PAA – phase shifters (FS) and controlled attenuators (CA). These methods are described in [2-5] and realized both from a near area [2, 3] and from a distant area [4, 5]. The basis of all these methods is the transmission coefficient measurement procedure microwave canal between the generator of the probe signal supplying the phased antenna array in transmission mode and the output of the measuring probe located in the near or far zone of the antenna under study. Methods differ by the plans of management diagnostics and methods of treatment of results of measuring's.

Advantage of methods of built-in control is circumstance that they are realized practically at any time in place of basing of PAA. Failing – methods do not give information about indeed realized in the aperture of aerial of APD. Only the number and channel numbers of the phased array are known, in which microwave devices fail.

Methods of microwave diagnostics of a phased array allow reconstructing the amplitude-phase distribution in the antenna and implement on this basis methods for adapting the lattice control to those found in the amplitude-phase distribution to defects, for example, as in [1, 5]. The methods of microwave diagnostics from the near zone described in the well-known literature [2, 3] are realizable only in anechoic chambers or on specially equipped training grounds.

To solve the problems of adapting a phased antenna array to a technical state and increasing its operating time under extreme conditions, it is necessary to have methods of integrated microwave diagnostics of a phased antenna array at its location.

The aim of the article is to develop a method for microwave diagnostics of a phased array antenna, implemented from the near zone of the antenna at its location, and eliminating the influence of echo signals (ES) on the diagnostic results.

Analysis of literature. Diagnostics of PAA from a near area is described in [2, 3], and from a distant area and in presence ES [6].

Using the method of measuring the transfer coefficient between the investigated phased antenna array and the probe in the near field [2,3] and the method of accounting for ES from [6], it is possible to decide set the problem of diagnostics of PAA from the near zone in the presence of ES.

Main material

The structural diagram of the measuring and computing system and the studied represented by Fig. 1.

The measuring probe is located in the direction normal to the aperture of the phased antenna array under study at a distance r_0 (in the near zone). The selection criterion r_0 is described in [2].

Imagine the transmission coefficient of the emitter paths (from the output of the probe signal generator to

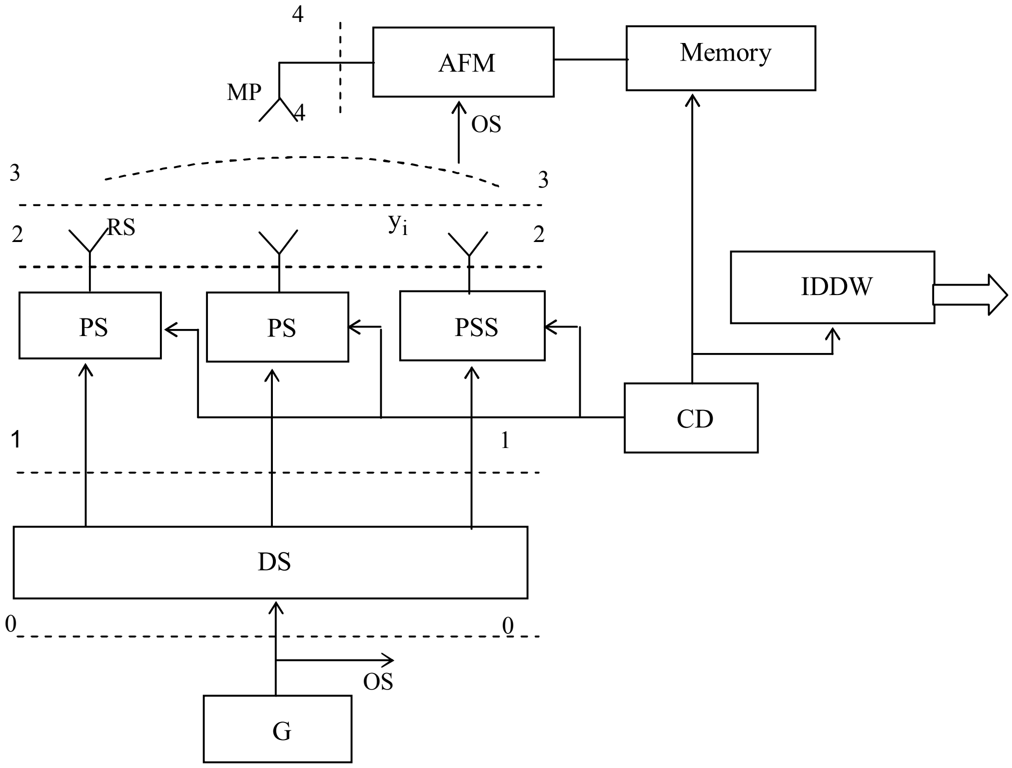

Fig. 1. Block diagram of the measuring and computing system of the integrated PAA control by the DPU method (G - generator; DS - distribution system; PS - phase shifter; RS - radiating system; MP - measuring probe; AFM - amplifazometr; Memory - storage device; IDDW - inverse DDW;CD - control device)

the emitter input) $I_{ei}(\theta_\phi)$ as the ratio of the excitation current to the complex amplitude (CA) of the PS, Fig.1:

$$I_{ei}(\theta_\phi)=K_{pi}\Phi_i(\theta_\phi)\left[1-\Gamma_i(\theta_\phi)\right] \; , \quad i\in 0,N-1 \; ; \quad (1)$$

where θ_ϕ – grating phasing direction; K_{pi} – TC of the distributive system; $\Phi_i(\theta_\phi)$ – TC phase shifter when the beam is oriented in the direction θ_ϕ ; $\Gamma_i(\theta_\phi)$ – reflection coefficient in the path of the i-th emitter due to the mutual coupling of emitters [7]; N – a number of emitters in PAA.

In default of ES in MP pointed EMF [2, 3]:

$$X(\theta_\phi)=\sum_i I_{ei}(\theta_\phi)G_i(\theta_i)\rho_i(\theta_i), \quad i\in 0,N-1 \; ; \quad (2)$$

where $G_i(\theta_i)$ – counting the complex amplitude of the radiation pattern of the i-th emitter in the direction of the vector $\vec{r}_i$, connecting an i-th emitter with MP; $\rho_i(\theta_i)$ – TC from the output of i-th emitter to the exit MP; numeral, concordantly [2]:

$$\rho_i(\theta_i)=\frac{\sqrt{K_z}}{2k_0 r_i}\exp(-\gamma k_0 r_i)\,g_z(-\theta_i) \; , \quad (3)$$

where r_i – distance between an i-th by an emitter and MP; K_z, g_z –an amplification factor and rationed radiation pattern MP; $k_0=2\pi\lambda^{-1}$ – wave number.

In the presence of an echo of the signal (2) can be represented as:

$$X_z(\theta_\phi)=\sum_i I_{ei}(\theta_\phi)G_i(\theta_i)\rho_i(\theta_i)M_i \; , \quad (4)$$

where $$M_i=1+\mu_i=1+\sum_u \rho_{ui}R_{ui}G_{ui}\Big/\rho_i G_i \; , \quad (5)$$

$u\in 1,U$ – numbers of sources of ES; ρ_{ui} – TC from the source of u-th ES to MP; R_{ui} – reflectivity PS of *i*-th channel from the source of u-th ES; G_{ui} – numeral value radiation pattern i-th emitter in the direction of source of u-th ES.

Complex coefficients μ_i unknown and depend on the number and coordinates of discrete points of formation of ES, as well as reflection coefficients in them R_{ui} . Such presentation M_i is comfortable that a size M_i does not depend on amplitude and phase of PS (it remained in a multiplier $I_{ei}(\theta_\phi)$).

From (4) it is necessary that the presence of ES on a measuring ground results in distortion of response of probe. The combined action of ES can be compared to appearance on an entrance MP a modulating hindrance M_i , distorting the response of probe on a radiation from every channel of PAA. The purpose of diagnostics is determination of TC phase shifter $\Phi_i(\theta_\phi)$, reflectivities in highways emitters $\Gamma_i(\theta_\phi)$ and integral TC each of microwave paths

$$K_i\left(\theta_\phi\right)=K_{pi}\Phi_i\left(\theta_\phi\right)\left[1-\Gamma_i\left(\theta_\phi\right)\right]G_i\left(\theta_\phi\right)= \\ =I_{ei}\left(\theta_\phi\right)\ G_i\left(\theta_\phi\right). \quad (6)$$

If there is a priori information about K_{pi} and $G_i(\theta)$ numeral values $K_i\left(\theta_\phi\right)$ can be reconstructed by measurement $\Phi_i\left(\theta_\phi\right)\left[1-\Gamma_i\left(\theta_\phi\right)\right]$ for each of the phasing directions.

Consider a diagnostic management plan that allows from the total response of the probe $X_z\left(\theta_\phi\right)$ to select $K_i\left(\theta_\phi\right)$.

It consists in the organization of measurement experiments, representing a consistent in time application of the direct discrete Walsh transform (DDW) to radiated PAA to the soundings signals [4, 5]

$$Y_r(\theta)=\sum_i I_{ei}\left(\theta_\phi\right)G_i\left(\theta_i\right)w_{ri}\rho_i\left(\theta_i\right)M_i, ; \quad (7)$$

where $r\in 0,N-1$; $Y_r(\theta)$ – respond MP on r-th direct DDW; w_{ri} – walsh functions ordered by Hadamard or Paley and taking only two values (+1) or (-1), [8]; n_r – CA noise (including measuring errors) at measuring Y_r. The functions w_{ri} of PS PAA will be realized w_{ri}, thus (+1) corresponds the change of phase in an i-th channel on 0°, and (-1) – to the phase shift on 180°.

Numeral values $Y_r(\theta)$ must be fixed in storages of data (ZU, fig.1).

After completing N direct procedures DDW to the vector $Y_r(\theta)$ it is necessary to apply procedure of inverse DDW. The result is a vector of estimates

$$\hat{y}_i(\theta)=N^{-1}\sum_i Y_r(\theta)w_{ri}= \\ =I_{ei}\left(\theta_\phi\right)G_i\left(\theta_i\right)\rho_i\left(\theta_i\right)M_i+\hat{n}_i, \quad (8)$$

where $\hat{n}_i=N^{-1}\sum_r n_r w_{ri}$.

For a selection from (8) an interesting us multiplier $I_{ei}\left(\theta_\phi\right)$ a next reception is offered. All of PS of grate simultaneously translated in one of $n\in 0,L-1$ (where $L=2^m$, m – number of digits of PS) the states. This means phasing the antenna in the direction $\theta_\phi=0$, but all of PS here are in n-th the state. Estimates of the responses of the measuring probe

$$\hat{y}_i(0,n)=I_{ei}(0,n)G_i\left(\theta_i\right)\rho_i\left(\theta_i\right)M_i . \quad (9)$$

Consider the relationship $\hat{y}_i(0,n)$ to $\hat{y}_i(0,0)$, where $\hat{y}_i(0,0)$ respond MP when zeroed (de-energized) PS, will get

$$\gamma_{i,n}=\frac{\hat{y}_i(0,n)}{\hat{y}_i(0,0)}=\frac{I_{ei}(0,n)}{I_{ei}(0,0)}= \\ =\Phi_i(0,n)\left[1-\Gamma_i(0,n)\right]\big/\left(\Phi_i(0,0)\left[1-\Gamma_i(0,0)\right]\right). \quad (10)$$

Reflection coefficients (RC) $\Gamma_i(0,n)$ and $\Gamma_i(0,0)$ characterize reflections in the PAA when the beam is oriented normal to the antenna aperture. In this position of the beam, as a rule, emitters with their paths are matched $\Gamma_i(0,n)$ = $\Gamma_i(0,0)\approx 0$. Therefore, from (10) we obtain that the desired TC PS:

$$\Phi_i(0,n)=\Phi_i(0,0)\gamma_{i,n} . \quad (11)$$

In relation (11) $\gamma_{i,n}$ – measured response relationship MP, and TC PS $\Phi_i(0,0)$ stored in processor memory of CSL. This means that unknown TC PS in all their states and in each channel $\Phi_i(0,n)$ can be reconstructed and also stored in processor memory CSL.

When phasing the antenna in the direction θ_ϕ PS of every channel will be translated in one of great number of L of the states, i.e. $I_{ei}=I_{ei}\left(\theta_\phi,n\right)$. Then

$$\gamma_{i,n}\left(\theta_\phi\right)=\frac{\hat{y}_i\left(\theta_\phi,n\right)}{\hat{y}_i(0,0)}=\frac{\Phi_i\left(\theta_\phi,n\right)}{\Phi_i(0,0)}\left[1-\Gamma_i\left(\theta_\phi,n\right)\right] . \quad (12)$$

From this relation it is easy to determine the reflection coefficient in the channels when phasing the antenna in the direction θ_ϕ

$$\Gamma_i\left(\theta_\phi\right)=1-\gamma_{i,n}\left(\theta_\phi\right)\frac{\Phi_i(0,0)}{\Phi_i\left(\theta_\phi,n\right)} . \quad (13)$$

A remarkable property of the proposed diagnostic method is that the accuracy of the estimates of the transmission coefficients of the phase shifters and reflection coefficients in the channels is practically independent of the presence of an echo signal at the measuring site, the accuracy of positioning with a measuring probe, and the accuracy of the information about the radiation pattern of the emitters in the grating $G_i\left(\theta_i\right)$. The method is implemented in gratings agreed in the direction normal to its aperture and in the presence of a priori information about the phase shifter transmission coefficient in the initial (de-energized) state.

In the presence of a priori information about the radiation pattern of emitters $G_i(\theta)$, (obtained from another experiment, for example [9-16]), it becomes possible to reconstruct the integral TC i-th canal from the input of the distribution system to the output of the emitter

$$K_i\left(\theta_\phi,n\right)=I_{ei}\left(\theta_\phi,n\right)G_i\left(\theta_\phi\right), \quad (14)$$

where $I_{ei}\left(\theta_\phi,n\right)=\Phi_i\left(\theta_\phi,n\right)\left[1-\Gamma_i\left(\theta_\phi,n\right)\right]$.

Availability of information on $\Phi_i\left(\theta_\phi,n\right)$, $\Gamma_i\left(\theta_\phi\right)$, $K_i\left(\theta_\phi,n\right)$ allows you to implement the adaptation of the phased antenna array to the technical condition according to the criterion of maximum approximation of the realized and desired amplitude-phase distribution in the aperture of the array.

Conclusion

Thus, a methodology for controlling microwave diagnostics of a phased antenna array is proposed, which eliminates the influence on the accuracy of diagnosis of the echo signal. Analyzing the results of microwave diagnostics, the proposed technique can be used to implement various methods of adapting a phased antenna array to a technical condition. In this case, the life of the antenna array will increase significantly.

REFERENCES

1. Shishov, Yu.A., Golik, A.M. (1990), "Adaptacyya upravlenyya FAR po rezultatam vstroennogo kontrolya" [Adaptation of the PAR control according to the results of the built-in control], Foreign Electronics, No. 9, p. 699.
2. Bubnov G.G., Nikulin, S. M., Seryakov, Yu. N. (1988), "Kommutacyonnij metod y`zmereny`ya xaraktery`sty`k FAR"[The switching method of measuring the characteristics of the PAR], Radio and communications, 120 p.
3. Voronin, E.N., Nechaev, E.E., Shashenkov, V.F.(1995), "Rekonstruktivnyie antennyie izmereniya" [Reconstructive antenna measurements], Moscow, 352 p.
4. Shifrin, Ya.S., Liepin U.R.(2000), "Besfazovyie metodyi diagnostiki fazirovannyih antennyih reshetok" [Phaseless diagnostic methods for phased antenna arrays], Antennas, No. 1 (44), pp. 84-99.
5. Voskresensky, D.I., Kanaschenkova, A.I. (2004), "Aktivnyie fazirovannyie antennyie reshetk" [Active phased antenna arrays], Radio engineering, p.351-370.
6. Nikolsky, V.V., Nikolskaya, T.I. (1989), "Elektrodinamika i rasprostranenie radiovoln" [Electrodynamics and radio wave propagation], Nauka, 544 p.
7. Voskresensky, D.I. et al (1988), "Avtomatizirovannoe proektirovanie antenn i ustroystv SVCH"[Computer-aided design of antennas and microwave devices], Radio and Communications, 240 p.
8. Harmut, H. (1980),"Teoriya sekventnogo analiza. Osnovyi ee primeneniya" [Theory of sequential analysis. The basics of its application.], Moskow, Mir, 574 p.
9. Karlov, V. D., Lukashuk, O.V. (2008), "K voprosu ob ispolzovanii antennyih sistem v nazemnyih stantsiyah sputnikovoy svyazi" [On the use of antenna systems in satellite ground stations], Information Processing Systems, No. 2(69), pp.57 - 62.
10. Kovalenko, A. and Kuchuk H. (2018), "Methods for synthesis of informational and technical structures of critical application object's control system", *Advanced Information Systems*, 2018, Vol. 2, No. 1, pp. 22–27, DOI: https://doi.org/10.20998/2522-9052.2018.1.04
11. Sviridov, A., Kovalenko, A. and Kuchuk, H. (2018), "The pass-through capacity redevelopment method of net critical section based on improvement ON/OFF models of traffic", *Advanced Information Systems*, Vol. 2, No. 2, pp. 139–144, DOI: https://doi.org/10.20998/2522-9052.2018.2.24
12. Kuchuk, G.A., Kovalenko, A.A. and Lukova-Chujiko, N.V. (2017), "A method for minimizing the average latency of packets in the virtual connections of the cloud service support network", *Control, navigation and communication systems*, PNTU, Poltava, No. 2 (42),- pp. 117–120.
13. Donets V., Kuchuk N., Shmatkov S. Development of software of e-learning information system synthesis modeling process. *Сучасні інформаційні системи*. 2018. Т. 2, № 2. С. 117–121. DOI: https://doi.org/10.20998/2522-9052.2018.2.20
14. Mozhaiev, M., Kuchuk, N. and Usatenko, M. (2019), "The method of jitter determining in the telecommunication network of a computer system on a special software platform", *Innovative technologies and scientific solutions for industries*, (4 (10), pp. 134-140. doi: 10.30837/2522-9818.2019.10.134
15. Nechausov A., Mamusuĉ I., Kuchuk N. Synthesis of the air pollution level control system on the basis of hyperconvergent infrastructures. Сучасні інформаційні системи. 2017. Т. 1, № 2. С. 21 – 26. DOI: https://doi.org/10.20998/2522-9052.2017.2.04
16. Liepin, U.R., Svitenko, N.I. (2005), " Metod izmereniya diagramm napravlennosti izluchateley v sostave FAR " [The method of measuring the radiation patterns of emitters in the headlamp], Successes of modern radio electronics, No. 7, pp. 10-14.

Received (Надійшла) 19.05.2020
Accepted for publication (Прийнята до друку) 22.07.2020

Діагностика фазованих антенних решітки з ближньої зони на місці базування

О. В. Бєсова, В. Д. Карлов, О. В. Лукашук, І. М. Петрушенко

Анотація. Актуальність. Методи мікрохвильової діагностики фазованого рентгенівського випромінювання дозволяють реконструювати амплітудно-фазовий розподіл в антені та реалізувати на цій основі методи адаптації управління гратами до тих, що знаходяться в амплітудно-фазовому розподілі, до дефектів. Методи мікрохвильової діагностики з ближньої зони реалізовуються лише в безехових камерах або на спеціально обладнаних тренувальних майданчиках. Для вирішення проблем адаптації фазованої антенної решітки до технічного стану та збільшення часу її роботи в екстремальних умовах необхідно мати методи інтегрованої мікрохвильової діагностики фазованої антенної решітки на її місці. **Метою статті** є розробка методу мікрохвильової діагностики фазованої решіткової антени, реалізованої з ближньої зони антени в її розташуванні, та усунення впливу exoсигналів на результати діагностики. **Результати**. У статті пропонується метод НВЧ діагностики фазованої антенної решітки з ближньої зони, що дозволяє виключити вплив на точність діагностики відлуння сигналу, присутніх на вимірювальної майданчику, і похибок в позиціонуванні вимірювального зонда. **Висновки.** Запропонований метод дасть можливість реалізувати НВЧ діагностику антени з ближньої зони, на місці її базування. Результати НВЧ діагностики передбачається використовувати для реалізації різних способів адаптації фазованої антенної решітки до технічного стану, помітно збільшуючи термін її експлуатації.

Ключові слова: антенні вимірювання, діагностика ФАР, ближня зона, НВЧ.