TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 4, August 2020, pp. 2070~2079
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i4.15601 ❒ 2070

Assessment of quality indicators of the automatic control system influence of accident interference

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Article Info

Article history:

Received Jan 21, 2020
Revised Mar 18, 2020
Accepted Apr 3, 2020

Keywords:

Active electronically scanned array
Control system
Differential coupling
Mean-square error
Radiation pattern
Repeater

ABSTRACT

This work concentrates the analysis of the system of automatic control of the directive diagram of the moving active electronically scanned array with a limited number of transceiver modules. The analysis revealed a number of shortcomings that lead to a significant increase in standard deviations, quadratic integral estimates, and an increase in transient time. The identified disadvantages lead to a decrease in the efficiency of the antenna system, an increase in the error rate at the reception, the inability of the system to react to disturbances applied to any point of the system in the event of a mismatch of a given signal/noise level. In accordance with the analysis, the mathematical model of the automatic control system of the directional diagram of the moving active electronically scanned array was considered, considering this a new method of estimating the quality indicators of the automatic control diagram of the directional diagram of the active electronically scanned array in a random setting and disturbing action was developed. The difference between the proposed method and the existing method is in the construction of an automatic control system with differential coupling equivalent to the combination due to the introduction of derivatives of the random setting action of the open compensation connection.

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1. INTRODUCTION

Analysis of the technical characteristics of modern antennas and the experience of their use in different radio systems show that the active electronically scanned array (AESA) meets the requirements to the antenna systems of multifunctional radio equipment [1-6]. The use of AESA in mobile and space radio complexes can significantly increase the range of radio communication, quality, efficiency and volumes of transmitted information. As the energy resources of robotic search engines are generally limited, maintaining the high potential of AESA in the scanning sector is associated with minimizing all losses, both in the AESA tract and on the radio link. The fulfillment of these requirements is possible only by optimizing the AESA parameters, taking into account all the factors that affect its operation.

Takashi Iida, Warren L. Stutzman, Gary A. Thiele, Constantine A. Balanis, Enson Change, Rick Sturdivant, Mike Harris and others have devoted themselves to the study of AESA, but they have not consider improving the efficiency of broadcasting information in mobile radio systems at the expense of the antenna system of the translator [5-11]. The task of determining the values of the parameters of system of automatic control (SAC) directional pattern (DP) AESA is reduced to the estimation of the mean-square error (MSE) and quadratic integral estimates (QIE) of the automatic control system with differential feedback.

In order to develop a methodology for assessing the quality of SAC DP AESA, the research was conducted. It can be divided into two stages:

First stage is theoretical analysis:

- Composite a system of equations describing the SAC with differential coupling;
- Check the identity of constituent errors caused by the defining and disturbing actions to the combined system of automatic control with differential coupling for determine the compliance of constructed system;
- Synthesis of parameters transfer function links of differential coupling according to conditions of minimization MSE and QIE, caused by the defining actions - change in the azimuth of the coupler.

Second stage is modeling of system with definite parameters:

- Modeling of the initial and system with differential coupling;
- Input to system the necessary condition for increasing the order of astatism;
- Assessment the MSE and QIE of system an accidental defining action;
- Check the time of the transition process of SAC.

2. RESEARCH METHOD

Analysis of the existing methods of increasing the efficiency of the systems of automatic control of the active electronically scanned array showed that the most simple and transparent are the direct methods, among which are the frequency method, error coefficients, and QIE [12-16]. But the use of direct methods is not always appropriate in cases where it is not possible to determine with maximum precision in which element of the structural scheme of the modeled system there is the disturbing effect, i.e., it is random.

There are two ways to solve this problem, namely: using direct methods; construction of an equivalent system for automatic control of the AESA radiation pattern. Thus, a prematurely modeled system will allow not only to estimate but also to control AESA parameters in real-time by time-limited computational operations. Based on the analysis, the functional diagram of this system while measuring one angular coordinate can be represented in the form shown in Figure 1. Tables and figures are presented center, as shown below and cited in the manuscript.

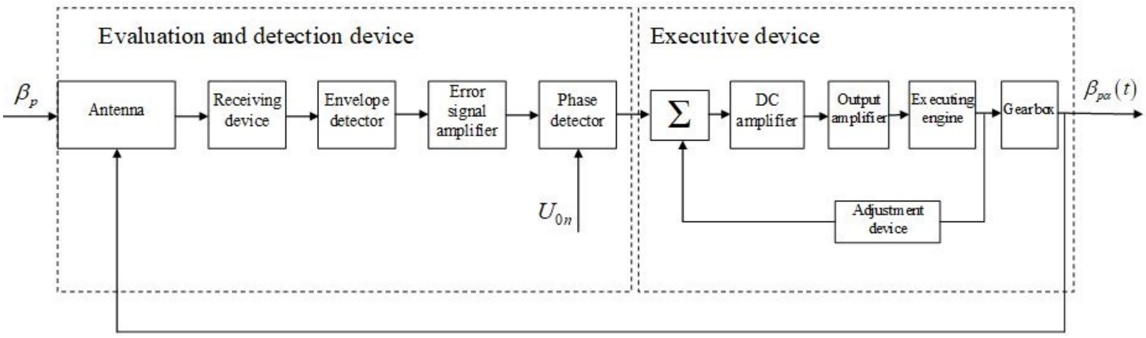


Figure 1. Generalized functional diagram of SAC DP

The input value of the system is the azimuth of the repeater β_p (or the angle of the repeater location) the initial value is the azimuth of the antenna $\beta_{pa}(t)$ (or the azimuth of the repeater). Forasmuch as the signal, proportional to the magnitude and sign of the angular deviation of the repeater from the axis of the antenna-equal to the signal direction, is produced at the output of the phase detector, all elements, from the antenna of the receiving device and ending with the phase detector, are related to the evaluation and detection device. The rest of the elements intended to actuate the output devices and estimate the angular coordinates according to the output of the evaluation and detection device, are referred to the actuator. To compose a mathematical model of a control system, it is necessary to define the transfer functions of its individual elements [16, 17].

On the structural diagram as shown Figure 1, the influence of an accidental moment of changing the position of the antenna web created according to the curvature of the earth surface of the earth station X_c

(disturbing influence) is taken into account by the inclusion in the model of the second channel (K_{DI}) the channel of disturbing influence with the transfer function. Schematic diagram of a system in which an equivalent integral-differential link (consistently adjusting link) with a transfer function $K_{CAL}(p)=K_2(p)$ is included for correction instead of local negative feedback, and is shown in Figure 2.

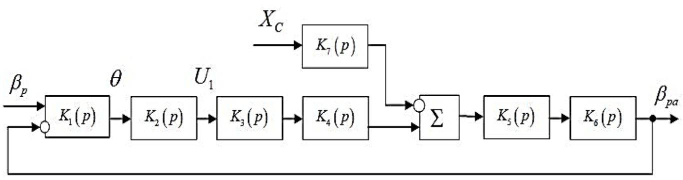


Figure 2. Structural diagram of automatic control of the AESA radiation pattern with integral-differential link

To determine system quality indicators, it is necessary to find the transfer functions of the system with an error in advance. The constituent errors caused by the defining βp and disturbing X_c actions are described by the following equations:

$$\theta_\beta(p) = \frac{1}{1+K_{OlCS}(p)}\beta_p(p), \theta_x(p) = \frac{K_7(p)K_5(p)K_6(p)}{1+K_{OlCS}(p)}X_c(p). \quad (1)$$

According to (1) the transfer functions that connect $\theta_\beta(t)$ with $\beta_p(t)$ and $\theta_x(t)$ with $X_c(t)$ after substituting the values of the transfer functions of the original mathematical model are equal to:

$$K_{\theta\beta}(p) = \frac{\theta_\beta(p)}{\beta_p(p)} = \frac{a_0p^6+a_1p^5+a_2p^4+a_3p^3+a_4p^2+a_5p}{b_0p^6+b_1p^5+b_2p^4+b_3p^3+b_4p^2+b_5p+b_6} = \frac{D_{\theta\beta}(p)}{F_{\theta\beta}(p)}. \quad (2)$$

$$\frac{\grave{a}_0p^4+\grave{a}_1p^3+\grave{a}_2p^2+\grave{a}_3p+\grave{a}_4}{\grave{b}_0p^7+\grave{b}_1p^6+\grave{b}_2p^5+\grave{b}_3p^4+\grave{b}_4p^3+\grave{b}_5p^2+\grave{b}_6p+\grave{b}_7} = \frac{D_{\theta M}(p)}{F_{\theta M}(p)}. \quad (3)$$

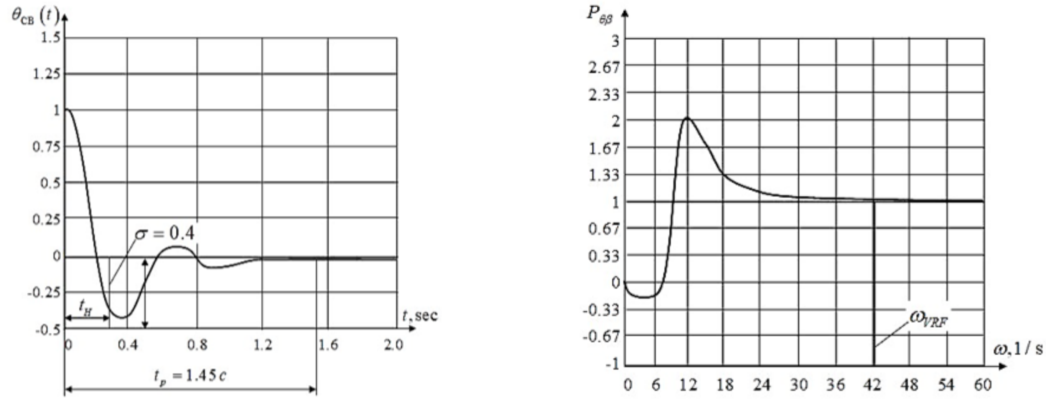
It can be seen from (2) and (3) that the system with respect to the defining action $\beta_p(t)$ is static with the first-order astaticism, and with the disturbing action X_c is static. The permissible MSE of the control system, which shall not exceed the values in the angular and azimuth plane, are defined by the following expressions: $\varepsilon_\beta = \sqrt{\overline{\theta_\beta^2}} = \sqrt{0{,}029} = 0{,}17°$; $\varepsilon_X = \sqrt{\overline{\theta_X^2}} = \sqrt{2{,}286 \times 10^{-9}} = 0{,}00274$grade. In addition to MSE, it is desirable to determine its dynamic errors while evaluating the accuracy of the RP AESA automatic control system. Dynamic errors are calculated CS RP AESA: $\theta_\beta(t) = \lim_{p\to 0}[pK_{\theta\beta}(p)\beta_p(p)]$, $\theta_p(t) = 0{,}09$grade, $\theta_X(t) = \frac{a_4M_0}{b_7}$, where: $a_4 = k_{DI} \times k_{gearbox} = 1{,}17 \times 10^{-3}$; $b_7 = 55{,}3$.

The transient component of the error is determined by the expression: $\theta_{C\beta}(t) = A_1e^{p_1t} + A_2e^{p_2t} + A_3e^{p_3t} + A_4e^{p_4t} + A_5e^{p_5t} + A_6e^{p_6t}$. In Figure 3. graphs of the transition function $\theta_{C\beta}(t)$caused by a single step change in the azimuth of the coupler (a) and the valid frequency response (VFR) of system$P_{C\beta}(\omega)$ (b). The transient function of the system of automatic control of the radiation pattern caused by the step change of the inertial moment of the antenna rotation mechanism $X(t)$ is determined by the following formula:

$$\theta_{C\beta}(t) = \frac{2}{\pi}\int_{\omega_{min}}^{\omega_{VF}} \frac{P_{\theta\beta}(\omega)}{\omega}\sin(\omega t)d\omega, \quad (4)$$

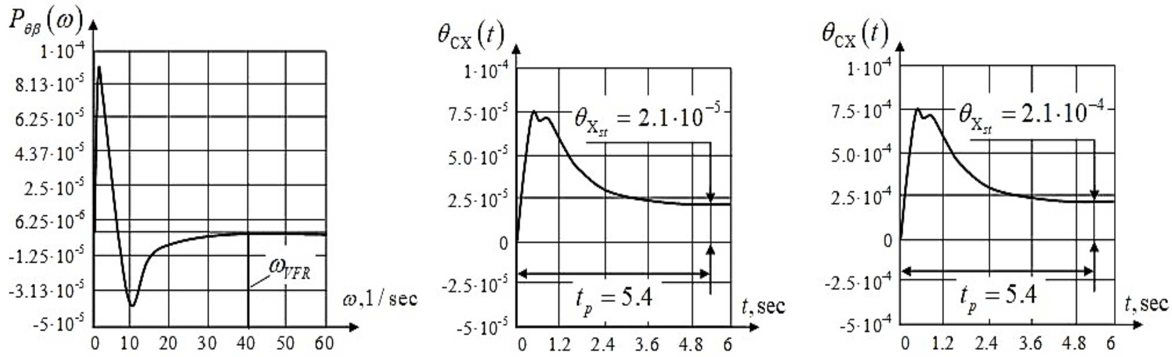
where $P_{\theta\beta}(\omega) = Re[K_{\theta X}(j\omega)]$ valid frequency response (VFR) of the system with error caused by variable $X(t)$.

VFR $P_{\theta\beta}(\omega)$ is shown in Figure 4. The curve of the transition function $\theta_{CX}(t)$ for a single step action $X_0 = 1$ is shown in Figure 4 (b). According to the timing of the transition process $t_p = 5{,}4\ sec.$ is a static error $\theta_{Xst} = 2{,}1 \times 10^{-5}$rad. For the case $X_0 = 1$ of the curve of the transition process $\theta_{CX}(t)$ is shown in Figure 4 (c). According to the graph the statistical error $\theta_{Xst} = 2{,}1 \times 10^{-4}$rad. caused by the inertial effect on the rotating mechanism of the antenna $X_0 = 1$.



(a) (b)

Figure 3. Transient graphs of the function $\theta_{C\beta}(t)$ caused by a single step variable in the azimuth of the coupler (a) and the valid frequency response (VFR) of system $P_{C\beta}(\omega)$ (b)



a) b) c)

Figure 4. Graph of transients of SAC RP caused by disturbing action $X(t)$

Thus, as a result of the analysis, it was established that the original AESA directional control system is a first-order automatic control system with respect to the defining action (azimuth on the relay) and static with respect to the perturbing action (changes in the position of the AESA canvas), and it is characterized by significant root mean square and dynamic errors. The effects of these actions may lead to rejection of the chart orientation in the normal (level signal/noise error rate at the receiver relay). But in cases of non-compliance with these requirements, the task is to evaluate the random perturbations in order to compensate them in the system. Such an assessment is not possible due to the lack of reliable information about the area of the system of automatic control which receives accidental disturbance.

Therefore, in the next step, it is necessary to consider the possibility of evaluating the system of automatic control by introducing derivatives of a random set point action using open compensation. That is, by building a combined system of automatic control with differential coupling, by which such estimation is possible. To compensate the effect of an accidental disturbing action (changing the position of the AESA canvas), applied not at the input of the system, it is necessary to enter a link to this action [18-21]. A block diagram of a mathematical model of the system of automatic control, which was introduced one differential link for indirect measurement $\alpha(t)$ and $X(t)$ is shown in Figure 5.

The differential link is constructed accordingly and consists of a section I (a straight chain with a transfer function $p/T_p + 1$ and a section II (positive feedback containing models of links $K_1(p)$ and $K_3(p)$ a link with a transfer function $1/Tp + 1$, the adder $\sum 3$ and the common element with the transfer function $K_B(p)$. The signal $\beta_p(t)$ from the output of the adder $\sum 3$ through the common correction link $K_B(p)$ arrives to the adder $\sum 4$ where it consists of the converted voltage $U_2(t)$of the error signal $\theta(t)$. Let's express the error $\theta(p) = \theta_\alpha(p) + \theta_X(p)$, constituent errors caused by defining $\alpha(t)$ and $X(t)$ disturbing actions.

$$\theta_{\alpha D}(p) = \frac{1-K_3(p)K_1(p)\frac{1}{Tp+1}K_B(p)}{1+K_1(p)K_2(p)K_3(p)\frac{1}{p}}\alpha(p), \tag{5}$$

$$\theta_{XD}(p) = \frac{1-K_3(p)K_1(p)\frac{1}{Tp+1}K_B(p)}{1+K_1(p)K_2(p)K_3(p)\frac{1}{p}}K_5(p)\frac{1}{p}X(p). \tag{6}$$

A structural diagram of a combined SAC RP AESA with open connections on the defining and disturbing action of the equivalent SAC with differential communication is shown in Figure 6. Let's express the error $\theta_K(p) = \theta_{K\alpha}(p) + \theta_{KX}(p)$.

$$\theta_{K\alpha}(p) = \frac{1-K_1(p)K_3(p)\frac{1}{Tp+1}K_B(p)}{1+K_1(p)K_2(p)K_3(p)\frac{1}{p}}\alpha(p),$$

$$\theta_{KX}(p) = \frac{1-K_1(p)K_3(p)\frac{1}{Tp+1}K_B(p)K_5(p)\frac{1}{p}}{1+K_1(p)K_2(p)K_3(p)\frac{1}{p}}X(p).$$

Thus, the equivalence result of the expressions for the determination of errors $\theta_{K\alpha}(p)$ and $\theta_{KX}(p)$ the combined system of automatic control of the radiation pattern were clearly obtained, with the expressions for the determination of errors of the SAC with differential coupling $\theta_{\alpha D}(p)$ and $\theta_{XD}(p)$. This conclusion, in turn, allows using the proposed SAC for the direct evaluation of the random actions and transients of the SAC RP AESA, since the differential connection, as well as the open compensation bonds of the combined system does not affect the stability of the closed system.

Considering that the differential coupling system as shown in Figure 5 is equivalent to the combined system as shown in Figure 6, we will synthesize the differential coupling of the SAC RP AESA due to the lack of influence on the stability of the closed part of the SAC RP AESA. Simultaneous minimization of root mean square and quadratic integral errors of transients caused by defining $\alpha(t)$ and disturbing $X(t)$ actions is carried out in accordance with the method of minimizing root mean square errors and QIE [22, 23]. Reduction of the root mean square errors ε_α and ε_X is carried out by increasing the order of the astaticism of the system with respect to defining action $\alpha(t)$ from the first to the second, and the transformation of a static system of disturbing action $X(t)$ into astatic with the first-order astaticism. To increase the order of astaticism from the first to the second relatively $\alpha(t)$ it is necessary to enter into the system the first derivative of the defining action, and to convert static to astatic relatively $X(t)$, a signal proportional to the disturbing action should be entered into the system.

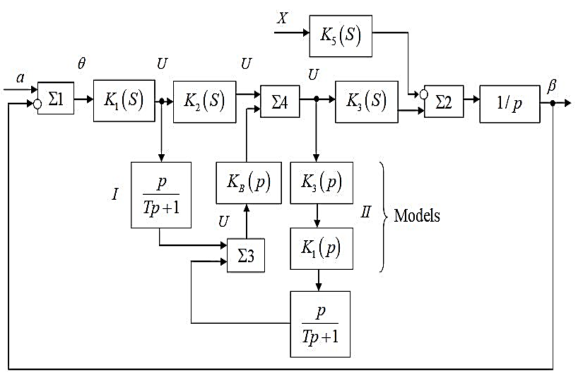


Figure 5. Structural diagram of the system of automatic control of directional AESA diagram with differential coupling for indirect measurement of the setting $\alpha(t)$and disturbing $X(t)$

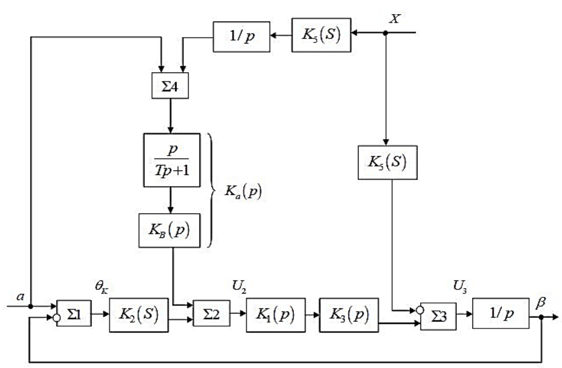


Figure 6. Structural diagram of the combined system of automatic control of the AESA directional diagram with open links on the set $\alpha(t)$ and disturbing action $X(t)$

More illustrative approach to solving the problem of estimating the quality indicators of the transient process of the system is to calculate a QIE of the system of automatic control RP AESA [24-27]. Transfer function of differential communication on the set action,

$$K_B(p) = \frac{\tau_1(\tau_\alpha p+1)(Tp+1)}{(T_{1\alpha}p+1)(T_{2\alpha}p+1)} = \frac{D_B(p)}{F_B(p)}, \quad (7)$$

$$K_{XT}(p) = \frac{\tau_{1X}p+\tau_{0X}}{T_{1X}p+1} = \frac{\tau_{0X}(\tau_X p+1)}{T_{1X}p+1} = \frac{D_K(p)}{F_K(p)}, \quad (8)$$

where $\tau_X = \tau_{0X}/\tau_{1X}$. According to Figure 6 the transfer function for the disturbing action $X(t)$

$$K_X(p) = K_5(p)\frac{1}{p}K_\alpha(p) = \frac{k_X(\tau_\alpha p+1)}{(T_5p+1)(T_{1\alpha}p+1)(T_{2\alpha}p+1)}, \quad (9)$$

where $k_X = k_5\tau_1$, $T_{1\alpha} = T$.

The obtained transfer function $K_X(p)$ differs from that required $K_{XT}(p)$ by two aperiodic units, but this connection transmits a signal proportional to the disturbing action and its first derivative, that is, the system has become astatic to the disturbing action $X(t)$. Substituting the value of the transfer functions of the system as shown in Figure 6 and founded value of $K_B(p)$ from (7) in formulas (5) and (6) and considering $T_{1\alpha} = T$, we get:

$$\theta_{\alpha D} = \frac{(T_1p+1)[(T_3p+1)(T_{1\alpha}p+1)(T_{2\alpha}p+1)-k_3k_1\tau_1\tau_\alpha p-k_3k_1\tau_1]p}{[(T_1p+1)(T_3p+1)p+k_1k_2k_3](T_{1\alpha}p+1)(T_{2\alpha}p+1)}\alpha(p),$$

$$\theta_{XD} = \frac{(T_1p+1)[(T_3p+1)(T_{1\alpha}p+1)(T_{2\alpha}p+1)-k_3k_1\tau_1\tau_\alpha p-k_3k_1\tau_1]k_5}{[(T_1p+1)(T_3p+1)p+k_1k_2k_3](T_{1\alpha}p+1)(T_{2\alpha}p+1)(T_5p+1)}X(p), \quad (10)$$

The condition of increasing the order of astaticism of the SAC RP AESA from the first to the second relatively defining action $\alpha(t)$ and the transformation of the static system into systems of the first order of astaticism relative to the disturbing action $X(t)$ is the following expression $1 - k_1k_3\tau_1 = 0$. Based on this condition we find $\tau_1 = 1/k_1k_3 = 1/(4 \cdot 1{,}5) = 0{,}16666$.

Let's find the value τ_1 in accordance with the condition of increasing the order of astaticism corresponds to the value τ_{1opt} at which ε_α and ε_X of the system of automatic control of the RP AESA is minimized. Write the transfer functions of the system with an accuracy to determine the parameters τ_2,$T_{1\alpha}$,$T_{2\alpha}$.

$$K_{\theta\alpha D}(p) = \frac{(T_1p+1)[(T_3p+1)(T_{1\alpha}p+1)(T_{2\alpha}p+1)-\tau_\alpha p-1]p}{[(T_1p+1)(T_3p+1)p+k_1k_2k_3](T_{1\alpha}p+1)(T_{2\alpha}p+1)},$$

$$K_{\theta\alpha D}(p) = \frac{(T_1p+1)[(T_3p+1)(T_{1\alpha}p+1)(T_{2\alpha}p+1)-\tau_\alpha p-1]k_5}{[(T_1p+1)(T_3p+1)p+k_1k_2k_3](T_{1\alpha}p+1)(T_{2\alpha}p+1)(T_5p+1)}. \quad (11)$$

The block diagram of the source system is shown in Figure 2 is described by the equations,

$$K_1(p) = \frac{k_1}{T_1p+1}; K_2(p) = k_2; K_3(p) = \frac{k_3}{T_3p+1}; K_4(p) = \frac{k_4}{p}; K_5(p) = \frac{k_5}{T_5p+1}, \quad (12)$$

with parameters $k_1 = 4$; $k_2 = 2$; $k_3 = 1{,}5$; $k_4 = 1$; $k_5 = 1{,}2$; $T_1 = 0{,}003sec$; $T_3 = 0{,}009sec$; $T_5 = T_3 = 0{,}009sec$. From equation of the system with an accuracy $\theta(p) = \theta_\alpha(p) + \theta_X(p)$, where,

$$\theta_\alpha(p) = \frac{1}{1+K_1(p)K_2(p)K_3(p)K_4(p)}\alpha(p), \quad (13)$$

$$\theta_X(p) = \frac{K_5(p)K_4(p)}{1+K_1(p)K_2(p)K_3(p)K_4(p)}X(p), \quad (14)$$

the images of the components of the system accuracy caused by the defining $\alpha(t)$and disturbing $X(t)$ actions. According to (13) and (14), the transfer functions of the system that associate $\theta_\alpha(t)$with $\alpha(t)$ and $\theta_X(t)$ with $X(t)$ (after substituting the values of the transfer functions of (14), given that $T_3 = T_5$), we obtain,

$$K_{\theta\alpha}(p) = \frac{\theta_\alpha(p)}{\alpha(p)} = \frac{(T_1p+1)(T_3p+1)p}{(T_1p+1)(T_3p+1)p+k_p} = \frac{a_0p^3+a_1p^2+a_2p}{b_0p^3+b_1p^2+b_2p+b_3}.$$

$$K_{\theta X}(p) = \frac{\theta_X(p)}{X(p)} = \frac{k_4k_5(T_1p+1)}{(T_1p+1)(T_3p+1)p+k_p} = \frac{\grave{a}_0p+a_1}{b_0p^3+b_1p^2+b_2p+b_3}, \quad (15)$$

where $a_0 = T_1T_3 = 2{,}7 \times 10^{-5}$; $a_1 = T_1 + T_3 = 1{,}2 \times 10^{-2}$; $a_2 = 1$; $b_0 = T_1T_3 = 2{,}7 \times 10^{-5}$; $b_1 = T_1 + T_3 = 0{,}012$; $b_2 = 1$; $b_3 = k_1k_2k_3k_4 = 12$; $a_0 = k_4k_5T_1 = 0{,}0036$; $a_1 = k_4k_5 = 1{,}2$.

From comparisons (11) and (15), it follows that the differential coupling parameters are not included into the characteristic equation of the closed circuit of the system $(F_{\theta\alpha} = 0, F_{\theta X} = 0)$, and therefore do not affect its stability. But the introduction of differential coupling in the SAC leads to the formation of new roots in the characteristic equation of $F_{\theta\alpha D} = 0, F_{\theta XD} = 0$, equal to $p_{1\alpha} = -1/T_{1\alpha}$, $p_{2\alpha} = -1/T_{2\alpha}$. These roots will be matched by the new components $A_{1\alpha}e^{p_{1\alpha}t}$, $A_{2\alpha}e^{p_{2\alpha}t}$, $A_{1X}e^{p_{1\alpha}t}$, $A_{2\alpha}e^{p_{2\alpha}t}$, leading to an additional phase shift of the SAC RP. Thus, in order that these components do not have a significant effect on the transient functions of the SAC RP, that is $I_{C\alpha}$, I_{CX}, we find the roots of the characteristic equation according to (15).

$$F_{\theta\alpha}(p) = 2{,}7 \times 10^{-5}p^3 + 0{,}012 \times p^2 + p + 12 = 0,$$

When the parameters of the system are equal $p_1 = -14{,}411$; $p_2 = -90{,}95$; $p_3 = -339{,}083$, and the transient component of the system accuracy is caused by a change in the setting action $\alpha(t)$.

$$\theta_C(t) = A_1e^{p_1t} + A_2e^{p_2t} + A_3e^{p_3t} = A_1e^{-14{,}411t} + A_2e^{-90{,}95t} + A_3e^{-339{,}083t}. \quad (16)$$

From the three components of the transient component of the error, the slowest decaying first component $A_1e^{-14{,}411t}$corresponds to the smaller absolute value of the root $p_1 = -14{,}411$. That is, the new components of the transient components of the error $A_{1\alpha}e^{p_{1\alpha}t}$, $A_{2\alpha}e^{p_{2\alpha}t}$can be attenuated much faster $p_{1\alpha} = 10 \times (-14{,}411) = -144{,}11$; $p_{2\beta} = 15 \times (-14{,}411) = -216{,}165$. From $T_{1\alpha} = -1/p_{1\alpha} = 6{,}939 \times 10^{-3}$, $T_{2\alpha} = -1/p_{2\alpha} = 4{,}626 \times 10^{-3}$, $d_1 = T_{1\alpha} + T_{2\alpha}$, $d_2 = T_{1\alpha}T_{2\alpha}$.

The smallest absolute root $p_1 = -14{,}411$ of the characteristic equation$F_{\theta\alpha}(p)$ is also the smallest for the original SAC equation $F_{\theta\alpha}(p) = 0$, so the new components $A_{1X}e^{p_{1X}t}$, $A_{2X}e^{p_{2X}t}$of the transition function $X(t)$will also attenuate faster than its first component $A^1_{1\alpha}e^{p_1t}$. Let's define τ_2 of the transfer function (13) of the differential coupling by which the QIE of the transition function caused by $\alpha(t)$ is minimized. According to the Raleigh formula [16], the QIE of a transition function caused by a single stepping action $\alpha(t)$.

$$I_{C\alpha D} = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\left|K_{\theta\alpha D}(j\omega)\frac{1}{j\omega}\right|^2 d\omega, \quad (17)$$

Or substituting from (15) $K_{\theta\alpha D}$ we have:

$$I_{C\alpha D} = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\left|\frac{a_0(j\omega)^5 + a_1(j\omega)^4 + a_2(j\omega)^3 + a_3(j\omega)^2}{b_0(j\omega)^5 + b_1(j\omega)^4 + b_2(j\omega)^3 + b_3(j\omega)^2 + b_4(j\omega) + b_5}\right|^2 d\omega, \quad (18)$$

After calculations we get the value of the optimal one $\tau_{2aopt} = 0{,}00303$. Substituting $K_{\theta XD}$ according to (17) we have:

$$I_{CXD} = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\left|\frac{a_0^1(j\omega)^4 + a_1^1(j\omega)^3 + a_2^1(j\omega)^2 + a_3^1}{b_0^1(j\omega)^6 + b_1^1(j\omega)^5 + b_2^1(j\omega)^4 + b_3^1(j\omega)^3 + b_4^1(j\omega)^2 + b_5^1(j\omega) + b_6^1}\right|^2 d\omega\,. \quad (19)$$

After calculations we get the value of the optimal one $\tau_2 = \tau_{2Xopt} = 0{,}003451$. Comparing the obtained values we can conclude that the value τ_{2Xopt} is almost indistinguishable from $\tau_{2\alpha opt}$. That allows asserting the possibility of direct estimation of SAC parameters by means of the built system of automatic control of the AESA directional diagram with differential coupling as shown in Figure 5.

3. RESULTS AND ANALYSIS

In order to confirm the conclusions about the possibility of increasing the quality indicators of the SAC DP AESA with use of one differential link modeling was implemented at Matlab. The simulation model of SAC DP AESA is shown in Figure 7.

The simulation model was synthesized to determine the main characteristics of an automatic control system. Characteristics were defined as error of defining action β_p (t); mean square errors $\varepsilon_\beta(t)$; transition process $\theta_{S\beta}(t)$. The description and course of the research process is described below.

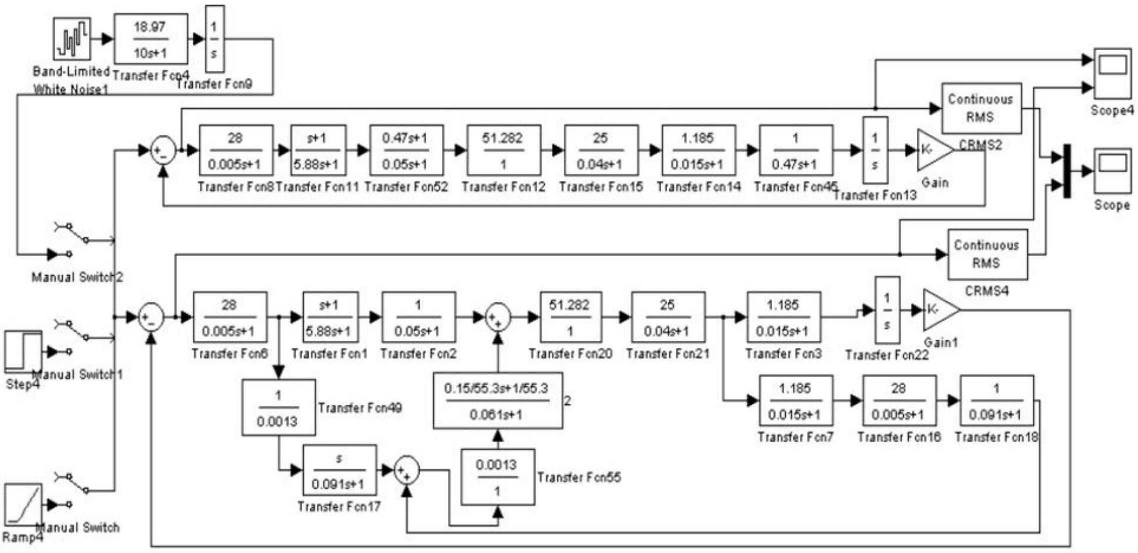


Figure 7. Simulation models initial system of SAC DP AESA and system with differential coupling without channel of disturbing action $X(t)$

3.1. Simulation models

Parameters of simulation models are according to the parameters consideration before. The first and second derivatives of the setting action has injected into the system by the differential coupling. The first derivative (parameter τ_{2aopt}) is synthesized to according the condition of increasing the order of the astaticism of the system from the first to the second, the second derivative (parameter τ_{2Xopt}) – accordingly to condition of minimization of quadratic integral errors of transients function caused by defining actions $\beta_p(t)$.

When the Switch 1 is closed, an intermittent random defining action is inputted to the system in parallel, the spectral density of which is $S_\beta(\omega) = \frac{2\beta\overline{\Omega^2}}{\omega^2+\beta^2}$, and shaped by lag element and integrator. Oscillogram of error of defining action $\beta_p(t)$ is shown in Figure 8. To quantify the impact of differential coupling to the MSE errors of both systems through computing devices 1 and 2, which determine the MSE according to the formula $\varepsilon_\beta = \sqrt{\theta_\beta^2}$, are supplied at the oscilloscope. The curve $\varepsilon_\beta(t)$ as shown in Figure 9 correspond to MSE value of error initial system, the curve $\varepsilon_{\beta D}$ is to the MSE error of system with differential coupling.

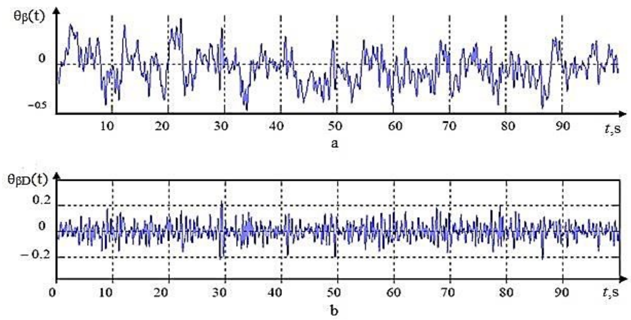


Figure 8. Oscillogram of error of defining action $\beta_p(t)$:
(a) – $\theta_\beta(t)$ initial system; (b) – $\theta_{\beta D}(t)$ system with differential coupling

The results of experimental values and calculation values of MSE for two system are submitted at the Table 1. When the Switch 2 is closed, a single step action $\beta_{Sp}(t) = 1(t)$ is inputted to the systems. The curves of the transition functions are shown in Figure 10. When the Switch 3 is closed, a defining action that varies according to linear principle $\beta_{Lp}(t) = \beta_1 t$, where $\beta_1 = 5\frac{grad}{s}$ as shown in Figure 11.

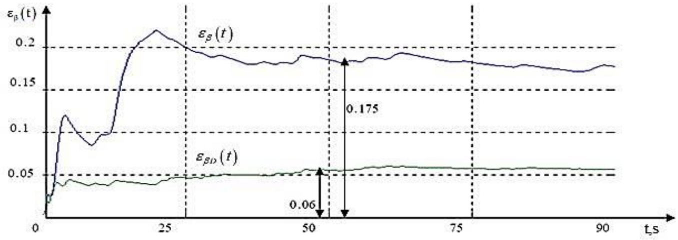


Figure 9. Plots of mean square errors of SAC: $\varepsilon_\beta(t)$ – initial system; $\varepsilon_{\beta D}$ – system with differential coupling

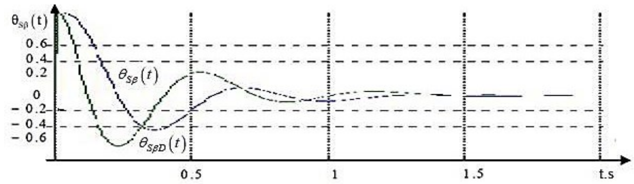


Figure 10. Plot of the transition process at single step action $\beta_{Sp}(t)$: $\theta_{S\beta}(t)$ - initial system; $\theta_{S\beta D}(t)$ - system with differential coupling (10)

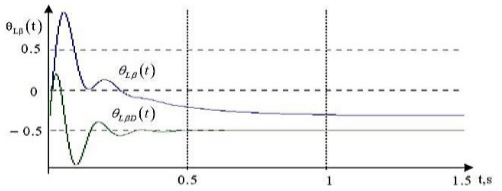


Figure 11. Plot of the transition process at defining action that varies according to linear principle $\beta_{Lp}(t) = \beta_1 t$: $\theta_{L\beta}(t)$ - initial system; $\theta_{L\beta D}(t)$ - system with differential coupling

Table 1. Calculation values and experimental values of MSE SAC DP AES

MSE of system and theirs relation	Calculation values	Simulation results
ε_β	0.17	0.175
$\varepsilon_{\beta D}$	0.059	0.06
$\varepsilon_\beta/\varepsilon_{\beta D}$	2.881	2.91
ε_X	4.781×10^{-5}	5.5×10^{-5}
ε_{XD}	$9.581\ 10^{-6}$	1×10^{-5}
$\varepsilon_X/\varepsilon_{XD}$	4.99	5.5

3.2. The results of research

Quality assessment of impact differential coupling to playback error of random defining action is shown in Figure 8. Comparison the results may prove the using of differential coupling is able to reduce reproduction error of random defining action. According to the Table 1, the calculated mean square errors, caused by random error of defining action, for two systems are exactly meets data obtained at the simulation. According to the Figure 10, the basic quality parameters of transition process at system with differential coupling are better than at initial system. In particular, the transitory period has decreased by 1.84 times.

The transition functions of SAC DP AESA obtained from the simulation coincide with the calculated ones. The constant errors of both systems are zero, which corresponds to their calculated values. According to the Figure 11, we conclude that with a linear change of the azimuth of the repeater in the initial system, a constant dynamic error occurs $\theta_\beta(t) = 0{,}09$ grad, corresponding to the calculated value. So the quality of the transition process at the system with differential coupling has improved significantly. The constant error of system with differential coupling is zero, which corresponds to the theoretical calculations.

4. CONCLUSION

The use of the proposed method makes it possible to evaluate the dynamic characteristics of the system of automatic control of the radiation pattern of the active electronically scanned array, and to improve the quality of the system. The conditions of increasing the order of astaticism for the built system of automatic control of the AESA radiation pattern with differential coupling for the setting action (τ_{2aopt}=0,00303) and (τ_{2Xopt}=0,00345) for the random disturbance action were obtained, and their approximate equality shows the equivalence of this system to the combined one. The results of the modeling of the control system with high reliability confirmed the validity of the theoretical calculations obtained and convinced that the quality indicators of control system of directional AESA diagram could be significantly improved by means of input to the system a differential coupling. The application of the proposed method could improve the basic quality parameters of transition process and also the energy efficiency of the active phased antenna array at the disturbing action. Thus, the solved partial interrelated tasks are indicating the achievement of the goal of the research.

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