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doi:10.15199/48.2019.04.22

Assessment of information support quality by “friend or foe” identification systems

***Abstract**. Based on the assessment of the aircraft responders and ground-based radio transponders noise immunity it is shown that the identification “friend-or-foe” systems have a low quality of informational support of the air space control system due to the openness of the interrogation channel and, as a consequence, the possibility of the concerned party to influence on the quality of operation of the aircraft responder due to the radiation of simulated interrogation signals of the simulation steady mode.*

***Streszczenie.** W oparciu o ocenę odporności na zakłócenia transponderów statków powietrznych i naziemnych transponderów radiowych wykazano, że systemy identyfikacji "przyjaciel-nieprzyjaciel" mają niską jakość informacyjnego wsparcia systemu kontroli przestrzeni powietrznej ze względu na otwartość kanału zapytania, a w konsekwencji możliwość, aby zainteresowana strona wpłynęła na jakość działania statku powietrznego odpowiadającego na promieniowanie symulowanych sygnałów zapytania w symulacji w trybie ustalonym. (**Ocena jakości informacji za pomocą systemów identyfikacji "przyjaciel czy wróg"**).*

Keywords: noise immunity, friend-or-foe identification system, information support quality, interrogation signals.
Słowa kluczowe: odporność na zakłócenia, system identyfikacji przeciwników, jakość wsparcia informacji, sygnały przesłuchujące.

Introduction

The system of airspace control provides to a large extent the State security and air traffic safety, which determines in itself the level of requirements to protection of information processes of its functioning. Modern systems for monitoring airspace solve, as is known, the following main objectives:

- conducting continuous reconnaissance of the air space;
- assessment of the air situation and identification of violations of the air space use order;
- delivering the results of radar data to the government, administrative, military management and air traffic control management.

Reconnaissance of the air space is realized with the surveillance systems whose main task is to give answers: where is a flying object (FO) and who is it. The systems of primary [1-3] and secondary [2-3] surveillance radar give jointly an answer to these questions. The primary radar systems answer the question “where” and the secondary surveillance radar (SSR) systems i.e. the systems of “friend or foe” identification (IFF), answer the question “who”. The quality of these two surveillance systems information, defined by the interference immunity of the discussed surveillance systems, is determined, to a large extent, by the quality of the information support of the airspace control system. The immunity of the primary radar systems is considered adequately in the existing sources of information, but there is a gap in consideration of the IFF interference immunity. So, the problem of reply signals (RS) processing was raised in [4-6]. However, the SSR are two-channel systems: they contain the interrogation channel and the response channel. This fact should be taken into account when assessing the probability of information support with these surveillance systems[7,8]. The aim of the work is to assess the quality of information support of the airspace control system using the systems of “Friend-or-Foe” identification.

The main part

The SSR information abilities will be characterized by the probability of the FO to detect P_C which is defined as the probability of obtaining the desired number of RS for requests of the considered SSR. Let us consider dependence of this indicator P_C on the intensity of the interrogation signals (IS) flow.

The ground-based radio transponder will receive the RS from the aircraft responder (AR) if and only if two things happen at the same time:

- the AR will receive, correctly decode the IS and form the RS (the probability of this event is equal to the AR availability factor – P_0);
- the AR will receive the RS and detect the ground-based radio transponder (GRT).

Let us consider the probability of these two events in the presence of interferences and analyze the probability of their simultaneous execution.

It should be noted that the AR of the SSR is an open single-channel system of servicing with cancellations. After receiving the IS the AR is closed for the time of paralysis which is long enough for the simulation steady mode of identification. The creation of such a mode of identification made it possible to close the response channel. However, the request channel remains completely open. This gives an opportunity to the interested party to paralyze completely the identification system by introducing interferences, which repeat the existing IS with the desired intensity.

Let us assume that the total flow of interferences is formed by the IS flow of the adjacent SSR, the flow of the intentional correlated interferences from the interested party and the flow of chaotic pulse interferences (intentional and unintentional non-correlated interferences). The calculations will be carried out for the total IS flow of the simulation steady modes of the IFF system and for the existing algorithms for the FO detection. In addition, when estimating the noise immunity let us estimate the contribution of different undesirable situations in the total evaluation of the SSR interference stability.

The IS flow action leads, as shown above, to paralysis of the AR, the duration of which is determined by the IS. Note that, when receiving the IS by the main lobe of the radiation pattern (RP) of the interrogator antenna of the AR is completely paralyzed for the time of servicing, when receiving the IS by the side lobes of the RP of the antenna of the GRT, the AR is paralyzed for the time between the IS pulse (the amplitude of which is remembered) and the pulse of suppression of side lobes (SSL). Chaotic pulse interference (either intentional or unintentional) affects the AR operation in two ways:

- firstly, it suppresses individual pulses of IS, making it impossible to service the given IS;
- secondly, it paralyzes the AR through creation of false IS (a false alarm of the first and second kind).

At action on the responder input of the at the same time interferences and the RSS will be observed the following unwanted phenomena, which leads to the impossibility of forming a RQS:

- suppressing the RQS of the given requester and the PI requests due to the obstruction of the preemptive RQS (false alarms of the first kind) causing the emission of the RS or triggering of the sidelobes suppression circuit;
- suppressing the RQS of the given requester due to the emergence of outrunning RQS of their requester, as well as the requesters of the interested party, which unauthorized uses the responder;
- high-frequency suppression of RQS pulses of the given requester in case of coincidence in time of impulses of interference and RSS in unfavorable phase proportions;
- suppression of the RQS of the given requester due to the appearance of precursor false RQSs formed as a result of the interaction of the first RQS impulse of the given requester with the outgoing (based on the code) impulses of interference or RSS and causing the radiation of the RQS or the triggering of the SLS scheme (false alarm of the second kind);
- suppression of the RQS as a result of the decoder's inputs formers inertia and responders load restriction.

Let's determine the probability of these events in the assumption that the impulses of interference and RSS acts on the inquiring codes of the given requester independently of each other [13,14].

Let at the responders input is present: intentional uncorrected interference with the total intensity λ_0, RSS causing the radiation of the corresponding codes in stable and unstable to imitation modes and mode of flight information transmission λ_1, as well as RSS triggering the SLS scheme, with intensity λ_2. Assume that the duration of impulses flows of interference and RSS is the same and is equal the duration of the useful signal pulses τ_0.

The combined effect of interference and RSS results in high-frequency suppression of individual RSS impulses with unfavorable phase proportions, resulting in a decrease in the intensity of the RSS. The probability that at least one impulse of interference will coincide with the momentum of the RSS and suppress it, can be determined from the following ratio

$$P_p = \gamma\left(1 - e^{-\lambda_0 \tau_0}\right). \tag{1}$$

Proceeding from this, the RQS stream, taking into account the high-frequency suppression causing the emission of response codes, can be defined as:

$$\lambda_{11} = \lambda_1 \left(1 - P_p\right)^n, \tag{2}$$

but causing the triggering of the SLS scheme

$$\lambda_{12} = \lambda_2 \left(1 - P_p\right)^n. \tag{3}$$

As noted above, the RQS cannot be served at the time when the defendant is engaged in the servicing of another RQS, therefore, the probability of suppression or the impossibility of servicing another request will be determined by the time of paralysis of the defendant employed by the servicing of another RQS. The time to paralyze AR will depend on the operating modes of the system.

The probability that at least one RQS will fall into the ahead interval and suppress the request of the requester due to the time of paralysis of the AR t_1 and when the response code is emitted, are determined accordingly:

- under the influence of the formation from a false RQS (FRQS) in the mode of unstable to imitation [15,16,17],

$$P_{11} = 1 - e^{-\lambda_p t_1}, \tag{4}$$

where t_1 - the time of paralysis of the requester in servicing the RQS in the mode of unstable to imitation,

- in forming of the FRQS due interferences in the mode of unstable to imitation,

$$P_{12} = 1 - e^{-\lambda_p t_2}, \tag{5}$$

where λ_p - the average number of false RQS, formed from the interferences and cause radiation of RS, we define as:

$$\lambda_p = n \lambda_0^n \left(\tau_0 - \tau_c\right)^{n-1}, \tag{6}$$

where n - the number of impulses RQS; τ_c - the given value of the selection of pulses in duration; t_2 - time of paralysis of the defendant in servicing the RQS in the mode of stable to imitations [18,19],

- under the influence of RSS in unstable to imitation mode

$$P_{13} = 1 - e^{-\lambda_{11} q_1 t_1}, \tag{7}$$

- under the influence of RSS in stable to imitation mode

$$P_{14} = 1 - e^{-\lambda_{11} q_2 t_2}, \tag{8}$$

where q - coefficient, characterizing the contribution to the total flow of RQS of the appropriate mode RQS. The total probability that at least one RQS will fall in the leading interval and suppress the request of the requester due to the time of the paralysis of the respondent in the radiation of the RS t_1 in unstable to imitation mode is defined as:

$$P_{1n} = 1 - \left(1 - P_{11}\right)\left(1 - P_{14}\right). \tag{9}$$

The total probability that at least one RQS will fall into the ahead interval and suppress the request of the requester due to the time of the paralysis of the respondent t_2 in the radiation of the RS in stable to imitation mode, is defined as:

$$P_{1i} = 1 - \left(1 - P_{12}\right)\left(1 - P_{14}\right). \tag{10}$$

The probability that at least one RQS will fall into the ahead interval and suppress the request of this requester at the expense of the time of paralysis $t_3 \approx t_4$ in the triggering of the SLS scheme are determined, respectively:

- when formed from interference FRQS in unstable to imitation mode

$$P_{21} = 1 - e^{-\lambda_p t_3}, \tag{11}$$

- when formed from interference FRQS in stable to imitation mode

$$P_{22} = 1 - e^{-\lambda_p t_4}, \tag{12}$$

- under the influence of RSS in unstable to imitation mode

$$P_{23} = 1 - e^{-\lambda_{12} q_1 t_3}, \tag{13}$$

- under the influence of RSS in stable to imitation mode

$$P_{24} = 1 - e^{-\lambda_{12} q_2 t_4}, \tag{14}$$

where t_3, t_4 - the time of paralysis of the requester during the operation of the SLS scheme in stable and unstable to imitation modes [20.21].

The total probability of suppressing the RQS of the given requester, caused by the time of paralysis of the requester during the triggering of the SLS scheme in unstable to imitation mode, is

$$P_{2n} = 1 - (1 - P_{21})(1 - P_{23}), \tag{15}$$

in stable to imitation mode

$$P_{2i} = 1 - (1 - P_{22})(1 - P_{24}). \tag{16}$$

The probability that at least one flight information request will fall into the ahead interval and suppress the request of the requester at the expense of the time during t_5 the flight information transmission are determined accordingly when formed FRQS from interferences [22,23]

$$P_{31} = 1 - e^{-\lambda_p t_5}, \tag{17}$$

under the influence of RSS

$$P_{32} = 1 - e^{-\lambda_{11} q_3 t_5}. \tag{18}$$

The total probability of suppressing the RQS of this requester due to the time of the paralysis of the respondent during the flight information transfer is determined as:

$$P_3 = 1 - (1 - P_{31})(1 - P_{32}). \tag{19}$$

The probability that at least one impulse from the stream of intentional uncorrelated interference and RSS will be superimposed on the pulse of the RQS of the given requester and suppress it, is

$$P_{10} = \gamma \left(1 - e^{-\lambda_c \tau_0}\right), \tag{20}$$

and the value of the total stream is defined as:

$$\lambda_c = \lambda_{11} + \lambda_{12} + \lambda_0. \tag{21}$$

Taking into account the n impulses of RQS, the probability of RQS suppressing will be

$$P_4 = 1 - (1 - P_{10})^n. \tag{22}$$

The probability of suppressing the RQS of the given requester due to the appearance of advanced false RQSs, formed as a result of the interaction of the first RQS impulse of the given requester with advanced impulses of interference or the RQS stream, and causing the radiation of the RS or the triggering of the SLS circuit, is defined as:

$$P_5 = (1 - P_{10})^n \left[1 - (1 - P_{10})^{n-1}\right], \tag{23}$$

the second plural in this expression takes into account the possible situations of the formation of false forward-looking RQS: n-following pulses of RQS leading to the emission of AR, and $n-1$ pulses of RQS, which lead to the radiation of the RS or the triggering of the SLS circuit.

The probability of occurrence at the position of the signal of the false impulse of the suppression formed from the interference is defined as:

$$P_6 = (1 - P_{10})^n P_{01}^{n-1}, \tag{24}$$

where P_{01} in turn can be defined as:

$$P_{01} = 1 - e^{-\lambda_0 \tau_0}. \tag{25}$$

The probability of suppressing RQS due to the inertia of the respondent's input formers can be defined as:

$$P_7 = \left(1 - P_f\right)^n, \tag{26}$$

where P_f - the probability of suppressing a single impulse of the RQS due to the inertia of the former.

When the AR flows of RQS streams and chaotic impulse noise (CPI) are received by the respondent, the respondent will not form a RS if at least one of the following unfavorable situations occurs:

- the RQS of the given requester is suppressed through the formation of CPI ahead of the false RQS (false alarms of the first kind), which lead to the radiation of the RS or the operation of the SLS scheme (we denote the probability of this situation P_1);
- the query signal of the requester is suppressed through the ahead RQS of the neighboring requesters or interested party requesters (we will indicate the probability of this situation P_2).

Determine the probability of these events in the assumption that the streams of RQS and CPI affect the query codes of the given requester independently of each other and the number of sources forming the total flow of RQS is sufficiently large to characterize the flow as Poisson.

Let the respondent enter the entrance:

- CPI stream with intensity λ_0;
- RQS stream of with intensity, which includes the flow of RQSs of neighboring inquirers and the RQS stream simulated by the interested party λ_1;
- stream of RQS, which cause the operation of the scheme of suppression of the side lobes, with intensity λ_2.

Assume that the duration of the pulses of the RQS stream is the same, unchanged in time and coincides with the duration of the impulses of a useful signal. We also assume that the common flows of RQS consist of k parts of unstable to imitation mode and $(1-k)$ parts of stable to imitation mode [24,25].

The combined effect of CPI and the RQS stream leads to a high-frequency suppression of individual RSS impulses in unfavorable phase proportions, which results in a decrease of the RQS stream intensity.

The probability that at least one impulse of the CPI will coincide with the impulses of the RQS and suppress it, is

$$P_p = \gamma \left(1 - e^{-\lambda_0 \tau_0}\right), \tag{27}$$

where γ - the interference suppression factor, which determines the probability of interference suppression of the received RQS impulse at its time convergence with interference impulse.

Because of high-frequency suppression decreases the RQS intensity of the radiation that causes radiation of the RS:

$$\lambda_1^1 = \lambda_1 \left(1 - P_p\right)^n, \tag{28}$$

and the intensity of the RSS that triggering of the SLS scheme:

$$\lambda_2^1 = \lambda_2 \left(1 - P_p\right)^n, \tag{29}$$

where n - number of impulses in RQS.

The probability that at least one RQS will fall into the ahead interval and suppresses the RQS of this IFF system due to the time of paralysis t_1 of the AR in unstable to imitation mode when the radiation of the RS is determined, respectively:

from CPI:

$$P_1^1 = 1 - e^{-\lambda_x t_1}, \tag{30}$$

from RSS:

$$P_1^2 = 1 - e^{-k \lambda_1 t_1}, \tag{31}$$

where λ_x - the average number of false n-pulse codes that lead to the emission of RS.

The average number of false n-pulse codes that lead to the emission of RS can be determined by the formula

$$\lambda_x = n \tau_0^n \lambda_0^{n-1} \left(1 - \tau_s / \tau_0\right), \tag{32}$$

where τ_s - specifies the duration of pulse selection by time.

The probability that at least one RQS will fall into the ahead interval and suppress RQS from this IFF system due to the time of paralysis t_2 of AR in the mode of stable to imitation, in the emission of RS, is determined, respectively:

from CPI:

$$P_1^3 = 1 - e^{-\lambda_x t_2}, \tag{33}$$

from RSS:

$$P_1^4 = 1 - e^{-(1-k)\lambda_1 t_2}. \tag{34}$$

The resulting probability of suppressing the RQS of the given responder through the paralysis of the respondent in the radiation of the AR is

$$P_1 = \prod_{i=1}^{4}\left(1 - P_1^i\right). \tag{35}$$

Here and further the calculations are carried out provided that the intensity of the RSS emitted from the side lobes of the antenna of the requesting is three times greater than the intensity λ_0 of the RSS emitted from the main lobe of antenna pattern of the requester.

The probability that at least one RQS will fall into the ahead interval and suppresses the RQS of this ISS due to the time of paralysis t_3 of the AR in the triggering of the SLS scheme in the mode of unstable to imitation, is determined, respectively:

from CPI:

$$P_2^1 = 1 - e^{-\lambda_x t_3}, \tag{36}$$

from RSS:

$$P_1^4 = 1 - e^{-(1-k)\lambda_1 t_2}. \tag{37}$$

The probability that at least one RQS will fall into the ahead interval and suppresses the RQS of this ISS due to the time of paralysis of the AR in the triggering of the SLS scheme in the mode of stable to imitation, is determined, respectively:

from CPI:

$$P_2^3 = 1 - e^{-\lambda_x t_4}, \tag{38}$$

from RSS:

$$P_2^4 = 1 - e^{-(1-k)\lambda_2 t_4}. \tag{39}$$

The resulting probability of suppressing the RQS of the given requester of the ISS through the paralysis of the respondent at the receipt of the RQS emitted from the side lobes of the antenna of the requester is [26,27]

$$P_2 = \prod_{i=1}^{4}\left(1 - P_2^i\right). \tag{40}$$

If the average number of the IS exceeds the allowable load of the transponder λ_m, then the probability of response with the operation of the circuit of the AR loading constraints is reduced and is equal to $P_{1v} = \lambda_m / \lambda_3$, where $\lambda_3 = \lambda_1 + \lambda_2$.

The probability of response radiation by the aircraft transponder to the request of the given CC is:

$$\text{with } \lambda_3 < \lambda_m \qquad P_0 = \prod_{i=1}^{2}\left(1 - P_i\right), \tag{41}$$

$$\text{with } \lambda_3 > \lambda_m \qquad P_0 = P_{1v}\prod_{i=1}^{2}\left(1 - P_i\right). \tag{42}$$

Fig.1 demonstrates the calculations according to the given expressions. In this case it was assumed that the intensity of the CPI flow $\lambda_0 = 0; 2\cdot10^4; 4\cdot10^4$, and the intensity λ_1 of the ISS which lead to the RS radiation is five times less than the intensity λ_2 of the IS flow that cause the action of the side lobes suppression circuit.

Results and discussion

From the presented results we can draw the following conclusions:

- Increase in the intensity of the IS flow results in the decrease in the availability factor of the aircraft responder, that indicates low interference stability of the FO. Indeed, Fig. 1 shows that formation of the intentional correlated interference of intensity of 5000 leads to a decrease in the FO availability factor from 1 to 0.3.
- Uncorrelated interferences (CPI) have relatively little effect on the FO availability factor.

Therefore, the given estimation of the AR interference stability demonstrates the AR low resistance to the effects of intentional correlated interferences and makes it possible to estimate the throughput of the IFF systems of the AR.

Let us carry out the assessment of the interference stability of the IFF systems in general [28,29,30,32].

Let us assume that the transponder processing instrument implements a two-stage algorithm for quasi-optimal detection of the RS packet and the AR availability factor is constant within the entire RS packet. The RS flow arrives to the input of the GRT receiver.

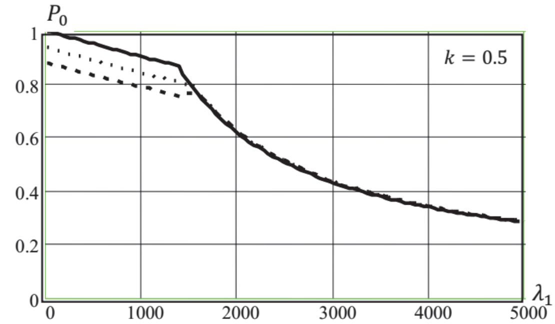

Fig. 1. Estimation of the AR availability factor

In the absence of interferences the probability of the RS packet detection, i.e. the IFF system, when applying the logic of "k out of M", is determined by the formula

$$P_{io} = \sum_{i=k}^{M} C_M^i P_0^i \left(1 - P_0\right)^{M-1}. \tag{43}$$

where $C_M^i = \dfrac{M!}{i!(M-i)!}$ – are the binomial coefficients.

Fig.2 demonstrates dependence of the FO Pio detection probability, using the IFF system, on the intensity λ1 of the ISS, which result in the RS radiation [31].

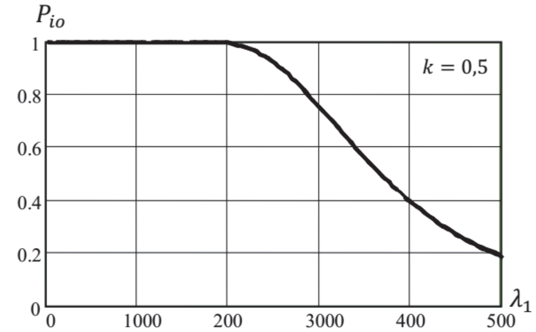

Fig. 2. Probability of the FO identification

When calculating, it was assumed that the intensity λ_1 of the IS flow, which lead to the radiation of the RS, was five times less than the intensity λ_2 of the IS flow, causing the SRP circuit action [8,12]. Fig. 2 shows that the increase in the RS flow volume, when using unauthorized responders, results in a significant decrease in the probability of the FO detection with the IFFF system. So, for the coefficient of non-simulation stability $k = 0{,}5$ the increase in the ISS intensity λ_1 up to 5000 results in the decrease in P_{io} to 0.2. Practically, this points to the possibility of a total paralysis of the existing SSR at unauthorized use of responders by the interested party. Such approaches are possible and quite promising for solving problems in decision-making systems for medical diagnostics [9,10,11].

Conclusions

The given calculations have shown a low quality of the users' information support of the "Friend-or-foe" identification system due to the possible impact of the intentional correlated interferences on such a system. This is possible due to the openness of the IFF system request channel.

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