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METHOD OF ADAPTING THE RADIO COMMUNICATION SYSTEM OF THE MOBILE COMPONENT OF THE TACTICAL COMMAND AND CONTROL UNIT OF THE NATIONAL GUARD OF UKRAINE TO THE CONDITIONS OF INTENTIONAL INTERFERENCE

The article deals with the issues of interference and intelligence protection of radio communication means of the mobile component of the tactical command and control link in the conditions of active use of electronic warfare. The problems arising from the use of standard radio communication means that do not provide a sufficient level of protection against intentional interference and interception of signals by the enemy are analysed.

The necessity of developing a scientific and methodological apparatus for adapting the radio networks of the National Guard of Ukraine to the conditions of active interference is substantiated. An analysis of modern radio communication equipment used in the military, including portable radios, satellite communication systems, tactical Wi-Fi solutions and software-based radio networks, is carried out. It is determined that the existing communication systems do not provide effective counteraction to enemy radio jammers, especially in direct contact.

A new method of spatial interference rejection based on the optimal location and direction of antenna systems of ground-based transmitters and receivers of UHF/VHF and Wi-Fi radio signals is proposed. The proposed method takes into account the tactical situation, the territorial location of radio network nodes and allows to increase the interference immunity of radio channels by changing the characteristics of antenna systems.

A mathematical model of interaction between the elements of the radio communication system and active radio masking means is substantiated, which allows determining the optimal parameters of antenna systems and radiation power. The threshold values of the suppression coefficient are determined, at which the required quality of signal reception is guaranteed under the conditions of targeted concentrated interference. The concept of a stable radio communication zone is expanded, in particular, the dependence of its area on the shape of the radiation pattern and the distance between the elements of the communication system is substantiated.

For the first time, a comprehensive analysis of the combined effect of intentional interference and active radio jamming on the stability of radio channels is carried out, which allows a reasonable approach to planning radio communications in the conditions of electronic warfare. An algorithm for determining the area of stable exchange for the points of the operational map of combat operations is proposed, which allows to effectively plan the location of communication means and active radio masking means.

The practical significance of the obtained results lies in the possibility of applying the developed method in the creation of adaptive radio communication systems that take into account the real tactical situation, which can significantly increase the efficiency of troop management in the conditions of information influence of the enemy.

Keywords: *information and analytical support, automated control system, weapons and military equipment, communication systems, radio channel, adaptation, deliberate interference, electromagnetic compatibility, active radio masking, radio channel stability, electromagnetic availability zone.*

Statement of the problem. One of the key methods of electronic warfare (EW) is the creation of intentional interference (II), which allows simultaneously to prevent access to radio communications and to violate the integrity of transmitted messages. In the context of active use of electronic warfare, the main task in organising a radio communication system is to achieve the required level of interference resistance and intelligence protection.

The experience of combat operations during the repulsion of the armed aggression of the russian federation has shown that the regular radio equipment of the mobile component of the tactical command and control link of troops (forces) cannot effectively counteract the enemy's radio jamming and radio reconnaissance in a direct engagement (Table 1) [1].

Given that the basis of the radio communication system of mobile units of the tactical command and control link is made up of foreign-made communication equipment equipped with standard antenna devices included in their kit (Table 2) [1, 4].

Table 1 – Main means of radio communication of the mobile component of the tactical command and control of the National Guard of Ukraine

Type	Range	Antenna type / DC shape
Portable radio station Motorola Moto TRBO DP 4800 (4801)	VHF (136–174 MHz;) UHF (403–527 MHz)	Pin / circular
Portable radio station Motorola Moto TRBO DP 4600 (4601)	VHF (136–174 MHz;) UHF (403–527 MHz)	Pin / circular
Portable radio station HARRIS RF-7800V-HH	30–108 MHz	Pin / circular
Portable radio station HARRIS RF-7800S-TR	350–450 MHz	Pin / circular
Portable radio station HARRIS RF-7800H-MP	1.5–60 MHz	Pin / circular
Portable radio station HARRIS RF-7800M-MP	30 MHz–2 GHz	Pin / circular
Armoured vehicles and vehicles VRC-90s	30–88 MHz	Pin / circular

Table 2 – The main means of Wi-Fi communication used during the hostilities in Ukraine

Type	Range	Antenna type / DC shape	Purpose
Starlink satellite internet	10.7–12.7 GHz (receive); 14–14.5 GHz (transmit)	Phased array antenna / steered pattern	Provision of broadband communications for units of the Armed Forces of Ukraine and the National Guard of Ukraine
Mesh networks based on MikroTik/Ubiquiti	2.4 GHz, 5 GHz	Panel/pin/sector	Creating local wireless networks in the field
Ruckus tactical Wi-Fi systems	2.4 GHz, 5 GHz	Pin / circular	Setting up wireless networks in command centres
Private military Wi-Fi networks based on EnGenius	2.4 GHz, 5 GHz	Panel / sector	Providing internal communication, UAV control
Software-implemented Wi-Fi solutions based on HARRIS radios	2.4 GHz, 5 GHz	Pin / adaptive	Tactical communication between units

Based on this, it can be argued that currently there is no mechanism for adapting radio networks to effectively protect radio networks from intentional interference.

Thus, there is an objective contradiction between the need to ensure radio communication is resistant to deliberate interference by existing means of communication and the lack of a scientific and methodological apparatus for a reasonable solution to this issue.

Radio network adaptation systems allow for communication in active hostilities, unit management and reconnaissance, including UAV control and ensuring the smooth operation of command posts.

Therefore, the study of the process of active radio-electronic masking of VHF/UHF radio communication channels (RCC) in the presence of ground-based relay radio stations (RRS) with regard to electromagnetic availability zones (EAZ) is relevant and practically necessary.

Analysis of recent research and publications. In [6, 7], a variant of the mobile radio communication channel model in the UHF/VHF bands was studied for the case of using an undirectional antenna of object 1, without taking into account the range of radio communication means and radio channel. It was assumed that all mobile radio communications equipment and the radio interference generator were simultaneously located within the EMI zone.

However, in tactical modelling, the distance between objects can increase to several kilometres, which can lead to loss of radio channel performance [8], radio communication means going beyond the RFI area, or a decrease in the effectiveness of the radio interference generator in suppressing RFI. Expanding the ΩG zone to values commensurate with the maximum communication range of mobile means (approximately 5 km) [9] goes beyond the adequacy of the model presented in [6, 7] and requires taking into account the EMI of radio means in the communication channel [3].

In this context, the key aspect is to estimate the power loss of the useful signal and interference during propagation, taking into account the terrain and characteristics of the area.

When planning military operations and organising the protection of CRS radio communications from interception, it is necessary to have a methodology for determining the boundaries of the ΩG zone for the optimal placement of a radio interference generator, which will ensure effective suppression of enemy radio reconnaissance equipment. Modern commercial electronic warfare software packages, such as HTZ WARFARE from ATDI [10], provide capabilities for calculating coverage, assessing interference, electromagnetic compatibility (EMC), and optimising the location of jamming stations.

However, such software solutions have a number of disadvantages, including high cost, closed source code, and redundant functions that may not be relevant to the specific tasks at hand.

The purpose of the article is developing a method for adapting the radio communication system of the mobile component of the tactical command and control link of the National Guard of Ukraine to the conditions of intentional interference.

Summary of the main material. First, let us formalise the problem of adapting the radio communication system of the mobile component of the tactical command and control link of the National Guard of Ukraine to the conditions of intentional interference.

In accordance with the research objective, which is to increase interference resistance and stealth, the hypothesis is put forward that ensuring stable radio communication in the conditions of the enemy's use of additive targeted frequency-focused interference is possible through the use of antennas with radiation patterns adapted to the location of the relevant radio communication means involved in radio communication, taking into account the peculiarities of the radio networks of the NGU units.

We will analyse the level of influence of spatial and energy parameters on the stability of radio channels under the influence of additive targeted interference focused on the frequency, as well as active radio masking devices with similar interference characteristics.

According to the theory of information, the focus should be on the possibility of increasing the ratio of signal power to interference power (signal/interference).

Given the requirements for the stability of information exchange, for each interference protection means, it is possible to determine the threshold value of the ratio at the input of the receiving path, at which the required level of radio channel stability is still ensured. Thus, for an objective assessment of the effectiveness of interference protection methods, it is advisable to use the minimum allowable ratio of the power of the useful signal $\mathrm{P_c}$ to the power of intentional interference $\mathrm{P_з}$, at which acceptable signal reception quality is guaranteed:

$$\mathrm{K_п} = \frac{\mathrm{P_c}}{\mathrm{P_з}} \leq K_{\text{пор}}, \qquad (1)$$

where $K_{\text{пор}}$ is the threshold value characteristic of a given type of interference and signal, the conditions of their interaction and the method of processing the sum of the interfering signal [2]. The space within which $K_{п}$ is the the suppression coefficient exceeds the specified value $K_{\text{пор}}$ is the defined as the suppression zone of an electronic means. The rest of the operational space will be called the communication zone.

Let us determine the factors that affect the suppression coefficient in the interaction scheme of the system "transmitter-receiver-active radio masking device – intentional jamming device" (Figure 1).

The model of interaction between the transmitter-receiver-active radio jamming device-intentional jamming device system contains objects with the following parameters.

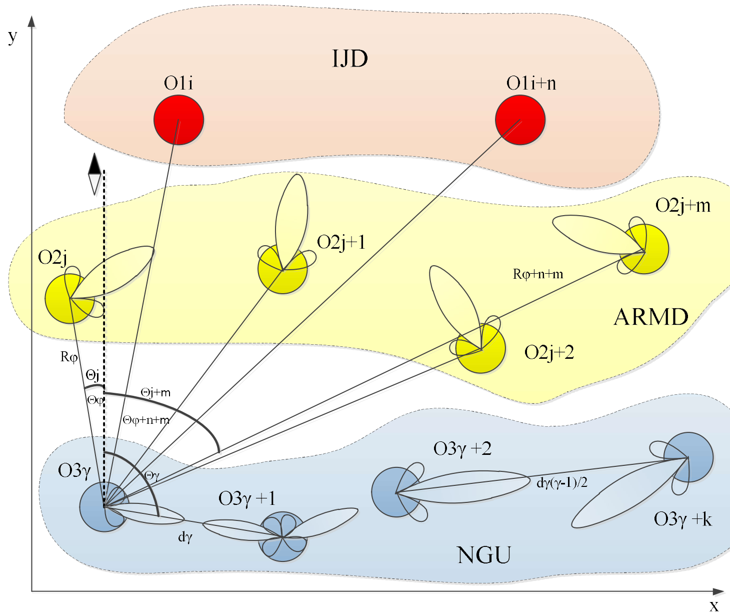

Figure 1 – Diagram of the interaction of the system "transmitter-receiver-active radio masking device – intentional jamming device"

Object 1 ($O1_i$) is the ground-based jamming facility with coordinates (x_i, y_i) and radiation power P_i. The normalised DC of the antenna is described by the function $G_3(\theta) = 1$.

Object 2 ($O1_j$) is the ground-based active radio masking, namely, a generator of additive frequency-concentrated radio interference of the UHF/VHF and Wi-Fi bands with coordinates (x_j, y_j) with transmitter power P_j. The digital normalised DC of the antenna is described by the function $G_j(\theta_j)$.

Objects 3 ($O3_\gamma$) are ground-based transmitters/receivers of UHF/VHF and Wi-Fi radio signals located at points with coordinates (x_γ, y_γ), with transmitter power P_γ. The facilities operate with directional antennas, the digital normalised radiation pattern of which is described by the functions $G_\gamma(\theta_\varphi)$. The natural azimuths of the objects' antennas are the angles θ_γ. The sensitivity of the radio receivers of objects $O3_\gamma$ is E_γ.

Based on the proposed model, the task is to implement spatial interference rejection by optimising the location and direction of antenna systems for terrestrial transmitters/receivers of UHF/VHF and Wi-Fi radio signals while adapting the radiation power and direction of antennas of active radio masking equipment.

Taking into account the work of predecessors [12–17], we will develop existing methods for adapting the radio communication system of the mobile component of the tactical command and control link of the National Guard of Ukraine to the conditions of intentional interference.

Suppose that the signal and interference propagate in free space, then the power of the useful signal at the input of any transceiver will be $P_{c\gamma}$:

$$P_{c\gamma} = \frac{P_\gamma G_{c\gamma}(\theta_\gamma) G_c(\theta_c) \lambda^2}{4\pi d_\gamma^2}, \quad (2)$$

where P_γ is the power of the transmitter of the useful radio signal, $G_c(\theta_c)$ is the gain of the radio signal transmitter antennas in the direction of the receiver, $G_{c\gamma}(\theta_\gamma)$ is the gain of the receiving antenna in the direction of the radio transmitter of the relevant unit of the National Guard of Ukraine (NGU), d_γ is the distance of the radio signal propagation route between the NGU transceivers.

Let's calculate the power generated by the interfering transmitter at the receiver using the superposition principle:

$$P_{3\gamma} = \frac{\varphi\lambda^2}{4\pi} \sum_{\varphi=1}^{m+n} \frac{1}{R_\varphi^2} \sum_{i=1}^{n} P_i \sum_{j=1}^{m} P_j \sum_{\varphi=1}^{m+n} G_c(\theta_\varphi) G_3(\theta_\varphi), \quad (3)$$

where P_i is the power of the means of intentional jamming, P_j is the power of the means of active radio jamming, $G_c(\theta_\varphi)$ and $G_3(\theta_\varphi)$ are the gain of the jamming transmitter antennas in the direction of the receiver and the receiving antenna in the direction of the jamming radio transmitter, respectively, R_φ^2 is the distance of the jamming path (set depending on the a priori data obtained at the planning stage or during the operation).

It follows from formulas (1), (2), (3) that the ratio of signal and interference powers under conditions of radio electronic countermeasures to the information transmission system is obtained by the principle of superposition:

$$К_{п} = \frac{P_{c}}{Р_{з}} =$$

$$= \frac{\frac{P_{\gamma} G_{c\gamma}(\theta_{\gamma}) G_{c}(\theta_{c}) \lambda^{2}}{4\pi d_{\gamma}^{2}}}{\frac{\varphi \lambda^{2}}{4\pi} \sum_{\varphi=1}^{m+n} \frac{1}{R_{\varphi}^{2}} \sum_{i=1}^{n} P_{i} \sum_{j=1}^{m} P_{j} \sum_{\varphi=1}^{m+n} G_{c}(\theta_{\varphi}) G_{з}(\theta_{\varphi})}. \quad (4)$$

From the formula obtained, it follows that to solve the problem of ensuring stable radio communication, which requires an increase in the area of stable communication with protection S_n, the following parameters can be manipulated to reduce the suppression factor:

P_{γ} is the power of the APG payload radio signal transmitter;

P_j is the transmitter interference power from active radio jammers;

P_i is the the power of the interfering transmitter;

R_{φ} is the the distance between the APG transmitter and the APG radio receiver;

d_{γ} is the the distance between the APU radio receiver and the transmitter;

θ_{γ} is the angle of direction of the directional antenna to the APG transmitter;

θ_{c} is the is the angle of the directional antenna to the APG receiver;

θ_{φ} is the angle of the directional antenna towards the interfering transmitter.

Thus, the vector of parameters for solving the problem of ensuring stable radio communication is as follows:

$$X = (P_i, P_j\ P_{\gamma}, R_{\varphi}, d_{\gamma}, \theta_{\gamma}, \theta_{c}, \theta_{\varphi}). \quad (5)$$

Since the powers of intentional jamming transmitters can be considered fixed, it is possible to manipulate the distances, powers of jamming transmitters from active radio cloaking devices and by choosing for the antennas of transmitters and receivers of the useful signal and antennas of active radio cloaking devices at each point of the optimal space – S_z angles $\theta_{\gamma}, \theta_{c}, \theta_{\varphi}$ from the ratio (4) such that

$$K_{п}(P_j, P_{\gamma}, R_{\varphi}, d_{\gamma}, \theta_{\gamma}, \theta_{c}, \theta_{\varphi}) = \min K_{п}. \quad (6)$$

Summarising the above, let us formulate a rule for determining the area of a stable exchange with protection S_z for the points of the operational map $x, y \in \Omega$ (Ω is the set of points of the operational map belonging to the area of hostilities):

$$S_z = \{\forall(x,y) \in \Omega | K_s(x, y, P_j, P_{\gamma}, R_{\varphi}, d_{\gamma}, \theta_{\gamma}, \theta_{c}, \theta_{\varphi}) = \min K_{п} \le K_{пор}; \quad (7)$$

$$K_{пор} \ge K_{п} = \begin{cases} \dfrac{\frac{P_1 G_{c1}(\theta_1) G_{c}(\theta_{c})}{d_1^2}}{\varphi \sum_{\varphi=1}^{m+n} \frac{1}{R_{\varphi}^2} \sum_{i=1}^{n} P_i \sum_{j=1}^{m} P_j \sum_{\varphi=1}^{m+n} G_{c}(\theta_{\varphi}) G_{з}(\theta_{\varphi})} \\ \dfrac{\frac{P_{k} G_{ck}(\theta_{k}) G_{c}(\theta_{c})}{d_{k}^2}}{\varphi \sum_{\varphi=1}^{m+n} \frac{1}{R_{\varphi}^2} \sum_{i=1}^{n} P_i \sum_{j=1}^{m} P_j \sum_{\varphi=1}^{m+n} G_{c}(\theta_{\varphi}) G_{з}(\theta_{\varphi})} \end{cases}; \quad (8)$$

$$K_{пор} \le 10 \text{ dB}. \quad (9)$$

From expression (8), it follows that the area of stable exchange with protection depends on the shape of the directional diagram and distance, therefore, to confirm the proposed hypothesis that that in the conditions of the enemy's use of additive targeted frequency-concentrated jamming and the simultaneous use of active radio masking means, it is possible to ensure stable radio communication by applying the proposed method of spatial jamming by optimising the location and direction of antenna systems of ground-based transmitters/receivers of radio signals UHF/VHF and Wi-Fi when adapting the radiation power and direction of antennas of active radio masking means. The initial data for the system construction should be the tactical situation on the map, namely the territorial location of the UHF/VHF and Wi-Fi radio network nodes.

Conclusions

A simple and effective method for adapting the radio communication system of the mobile component of the tactical command and control link of the National Guard of Ukraine to the conditions of intentional interference is proposed. The method takes into account the presence of communication zones of mobile radio communication systems and the range of the radio interference generator with simultaneous fulfilment of EMC conditions with radio means of the communication channel.

The scientific novelty of the method is as follows:

– a method of spatial interference rejection based on the optimal location and direction of antenna systems of ground-based transmitters and receivers of UHF/VHF and Wi-Fi radio signals in the conditions of intentional interference and active radio masking by the enemy;

– for the first time, an approach to the adaptation of the radio communication system of the mobile component of the tactical command and control link of the National Guard of Ukraine is proposed, which takes into account the tactical situation and the territorial location of radio network nodes to improve interference resistance;

– a mathematical model of interaction between the elements of the radio communication system and active radio masking means is substantiated, which allows determining the optimal parameters of antenna systems and radiation power to ensure stable communication;

– the threshold values of the suppression coefficient are determined, at which the required signal reception quality is guaranteed to be maintained in the conditions of targeted concentrated interference;

– the concept of a stable radio communication zone is expanded, in particular, the dependence of its area on the shape of the radiation pattern and the distance between the elements of the communication system is substantiated;

– for the first time, an analysis of the combined effect of intentional interference and active radio masking on the stability of radio channels was carried out, which allows a reasonable approach to planning radio communications in the conditions of electronic warfare.

The direction of further research is to develop a methodology for the optimal location of radio interference generators that ensures effective jamming of enemy radio reconnaissance equipment without disrupting EMC with own communications.

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МЕТОД АДАПТАЦІЇ СИСТЕМИ РАДІОЗВ’ЯЗКУ МОБІЛЬНОЇ КОМПОНЕНТИ ТАКТИЧНОЇ ЛАНКИ УПРАВЛІННЯ НАЦІОНАЛЬНОЇ ГВАРДІЇ УКРАЇНИ ДО УМОВ ВПЛИВУ НАВМИСНИХ ЗАВАД

Розглянуто питання завадо- та розвідзахищеності засобів радіозв’язку мобільної компоненти тактичної ланки управління в умовах активного застосування засобів радіоелектронної боротьби. Проаналізовано проблеми, що виникають під час використання стандартних засобів радіозв’язку, які не забезпечують достатнього рівня захисту від навмисних завад та перехоплення сигналів противником.

Обґрунтовано необхідність розроблення науково-методичного апарату для адаптації радіомереж підрозділів Національної гвардії України до умов впливу активних завад. Проведено аналіз сучасних засобів радіозв’язку, що використовуються у військах, охоплюючи портативні радіостанції, супутникові системи зв’язку, тактичні Wi-Fi рішення та програмно-реалізовані радіомережі. Визначено, що наявні системи зв’язку не забезпечують ефективної протидії засобам радіопридушення противника, особливо в умовах безпосереднього зіткнення.

Запропоновано новий метод просторової режекції завад, що базується на оптимальному розташуванні та спрямуванні антенних систем наземних передавачів і приймачів радіосигналів UHF/VHF та Wi-Fi діапазону. Зазначено, що цей метод ураховує тактичну обстановку, *територіальне розташування вузлів радіомережі і дає змогу підвищити завадозахищеність радіоканалів унаслідок зміни характеристик антенних систем.*

Обґрунтовано математичну модель взаємодії елементів системи радіозв'язку та засобів активного радіомаскування, що дає змогу визначати оптимальні параметри антенних систем і потужність випромінювання. Визначено порогові значення коефіцієнта придушення, за яких гарантовано зберігається необхідна якість прийому сигналу в умовах дії прицільних зосереджених завад. Розширено поняття зони стійкого радіообміну, зокрема обґрунтовано залежність її площі від форми діаграми спрямованості та відстані між елементами системи зв'язку.

Уперше проведено комплексний аналіз сумісного впливу навмисних завад і засобів активного радіомаскування на стійкість радіоканалів, що дає змогу обґрунтовано підходити до планування радіозв'язку в умовах радіоелектронної боротьби. Запропоновано алгоритм визначення площі стійкого обміну для точок оперативної мапи бойових дій, що дає можливість ефективно планувати розташування засобів зв'язку та засобів активного радіомаскування.

Практичне значення отриманих результатів полягає у можливості застосування розробленого методу під час створення адаптивних систем радіозв'язку з огляду на реальну тактичну обстановку, що дає змогу значно підвищити ефективність управління військами в умовах інформаційного впливу противника.

Ключові слова: *інформаційно-аналітичне забезпечення, системи зв'язку, радіоканал, адаптація, навмисні завади, електромагнітна сумісність, активне радіомаскування, стійкість радіоканалів, зона електромагнітної доступності.*

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