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Method of Calculating the Boundaries of the Active Protection Mobile Radio Zone

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Abstract:

The article discusses the need to create active protection of a mobile radio communication channel in the UHF/VHF band using a radio interference generator in the conditions of action of enemy ground-based radio monitoring means. The problem of determining the boundaries of the location area of a directional radio interference generator is formulated, at each point of which the protection of a mobile radio communication channel is provided. An algorithm for determining the boundaries of the radio interference generator location zone is proposed. The dependence of the shape and size of the obtained location zone of the radio interference generator on the current parameters of the mobile radio communication channel model is analyzed.

Keywords:

radio monitoring, directional antenna, signal-to-noise ratio, defensive electronic countermeasures, electromagnetic compatibility

1 Introduction

Modern radio monitoring means provides highly efficient scanning, interception of signals, their finding and analysis, on the basis of which an assessment of the enemy's actions and intentions is made. This results in a problem of suppressing radio monitoring means through the use of active and passive electronic warfare means. One of the passive ways to reduce the effectiveness of radio monitoring is to calculate the Electro-Magnetic Availability (EMA) zone of mobile radio communication systems [1, 2], outside of which the transmitter signal power is insufficient for reception by an enemy monitoring's radio receiver. If such a receiver is inside the EMA zone, then it is possible to apply active suppression of the useful radio signal at the location of the enemy monitoring's radio receiver by placing a source of intentional radio interference

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[3-7]. At the same time, the operation of such a special radio interference generator must ensure compliance with the conditions of Electro-Magnetic Compatibility (EMC) and its radio exchange means [6-8].

The model of active protection of the mobile radio communication channel is shown in Fig. 1.

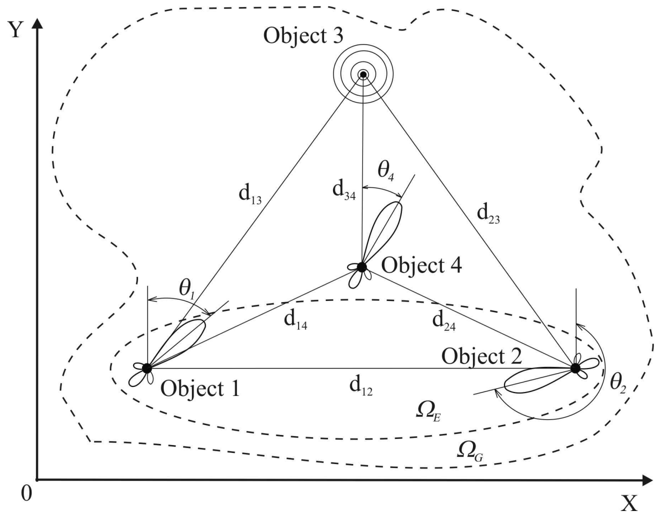

Fig. 1 Model of active protection of mobile radio communication channel

The model contains objects with the following parameters:

- Objects 1 and 2 are ground-based UHF/VHF radio signal receiver/transmitter, located at points with coordinates (x_1, y_1) and (x_2, y_2), with transmitter power P_1 and P_2, respectively. The objects operate with directional antennas, the digitized normalized Radiation Pattern (RP) of which is described by functions $G_1(\theta)$ and $G_2(\theta)$, respectively. The antennas' own azimuths of the objects are angles θ_1 and θ_2. The radio receivers' sensitivity of objects 1 and 2 is E_{s12}.
- Object 3 is ground-based enemy monitoring's radio receiver with coordinates (x_3, y_3). The normalized antenna RP is described by function $G_3(\theta) = 1$. The radio receivers' sensitivity of object 3 is E_{s3}.
- Object 4 is a ground-based generator of additive frequency-concentrated radio interference in the UHF/VHF band with coordinates (x_4, y_4) and transmitter power P_4. The digitized normalized antenna RP is described by function $G_4(\theta)$. The antenna's own azimuth angle is θ_4.

To provide active protection of the mobile radio communication channel, it is necessary to have a zone of possible placement of a radio interference generator Ω_G, from which the region Ω_E, where EMC conditions are not met, should be excluded.

For calculations, it is advisable to use an energy approach based on assessing the power of the useful radio signal and the radio noise signal [9]. With a known limit (threshold) signal-to-noise ratio (SNR_{min}) at the input of the radio receiver, we can set the condition for suppressing the useful radio signal in the form

$$K_{\text{sup}} = \frac{1}{SNR} = \frac{P_N}{P_S} \geq K_{\text{th}} \tag{1}$$

where K_{sup} – the suppression coefficient in power of the useful signal by radio interference at the input of the radio receiver; P_{N} – the radio interference power; P_{S} – the useful radio signal power; $K_{\text{th}} = 1/SNR_{\min}$ – the threshold value of the suppression coefficient for a radio receiver, depending on the type of interference and signal, the conditions of their interaction and the method of processing the sum of the signal and interference.

It is obvious that the condition for suppression of Eq. (1) should work for useful radio signals received by object 3 from objects 1 and 2 respectively. For a given threshold value of the suppression coefficient of the monitoring's radio receiver (object 3) K_{th3}, the condition for protecting the radio transmitters of objects 1 and 2 from eavesdropping can be written in the following form:

$$C_{\text{sup}} = C_{\text{sup}\,13} \cap C_{\text{sup}\,23} \tag{2}$$

where $C_{\text{sup13}} = \frac{P_{43}}{P_{13}} \geq K_{\text{th3}}$ – the condition for suppressing the signal of object 1 at the object's 3 location; $C_{\text{sup}\,23} = \frac{P_{43}}{P_{23}} \geq K_{th3}$ – the condition for suppressing the signal of object 2 at the object's 3 location; P_{43} – the radio interference signal power created by object 4 at the object's 3 location; P_{13} – the power of the useful signal of object 1 at the object's 3 location; P_{23} – the power of the useful signal of object 2 at the object's 3 location.

At the same time, to meet EMC conditions, the radio interference generator must create a sufficiently low level of interference for the protected radio means of the communication channel. For a given threshold value of the suppression coefficient K_{th12} of radio receivers of objects 1 and 2, the EMC condition can be written in the following form:

$$C_{\text{EMC}} = C_{\text{EMC12}} \cap C_{\text{EMC21}} \tag{3}$$

where $C_{\text{EMC12}} = \frac{P_{42}}{P_{12}} \leq K_{\text{th12}}$ – the condition for acceptable signal suppression of object 1 at the object's 2 location; $C_{\text{EMC21}} = \frac{P_{41}}{P_{21}} \leq K_{\text{th12}}$ – the condition for acceptable signal suppression of object 2 at the object's 1 location; P_{21} – the power of the useful signal of object 2 at the object's 1 location; P_{12} – the power of the useful signal of object 1 at the object's 2 location; P_{41} and P_{42} – the power of the radio interference signal created by object 4 at the locations of objects 1 and 2, respectively.

The zone of possible placement of a radio interference source Ω_{G} is a part of the entire area Ω, in which conditions Eq. (2) and Eq. (3) must be simultaneously meet:

$$\Omega_{\text{G}} = \left\{ \forall (x, y) \in \Omega \middle| C_{\text{sup}} \cap C_{\text{EMC}} \right\} \tag{4}$$

The task of providing the simultaneous fulfillment of conditions Eq. (2) and Eq. (3) in [6, 7] was solved by orienting the antenna device of the interference source in azimuth using a radio communication channel model. At the same time, only one version of the channel model was considered for the case of an omnidirectional antenna of one of objects 1 or 2. The range of radio communications means and the EMA of the radio channel were not considered, that is, the conditions for protecting the radio exchange channel were obtained under the assumption that all mobile radio communications means, monitoring's radio receiver and radio interference generator are simultaneously relative to each other within electromagnetic availability. However, during tactical calculations, the distances between model objects can increase up to several kilometers, which can lead to the loss of the radio channel functionality, the exit of radio exchange means beyond the coverage area of the enemy monitoring's receiver, or the inability of the radio interference generator to effectively influence the monitoring's receiver. An increase in the size of the Ω_G zone to values comparable to the maximum communication range of mobile radio communications means (5 km) [10]-takes the model used in [6, 7] beyond the scope of its adequacy and leads to the need to consider the EMA of radio means of radio communications channel [1, 2]. In this case, an important issue is the calculation of power losses of the useful radio signal and radio interference along the path of their propagation.

Thus, within the framework of a specific operational task, the existing prerequisites for the use of active protection means of the mobile radio communication channel should first be analyzed. To do this, the fulfillment of the conditions for the operability of the radio communication channel and its availability for eavesdropping by enemy radio monitoring means is checked from the point of view of the EMA of radio means. And only then can we draw a conclusion about the need to apply an active protection model for the mobile radio communication channel and begin solving the problem of choosing the location of the radio interference generator.

Solving tactical problems of protecting radio exchange from eavesdropping, it is desirable to have a method for determining the boundaries of the zone of possible placement of a radio interference generator to suppress enemy radio monitoring means. Existing powerful commercial systems for electronic warfare planning, such as, for example, ATDI's HTZ WARFARE [11], among others, allow us to solve the problem of calculating coverage, interference, EMC and optimizing the location of suppressing stations. At the same time, such software products have a high cost of acquisition, proprietary software, and functions redundancy relative to the particular task under consideration.

The purpose of the study is to develop a fast and convenient method for determining the boundaries of the zone of possible placement of a radio interference source Ω_G, within which protected radio exchange of UHF/VHF band radio communications means of sufficiently good quality is ensured, determined by the conditions of the EMA of the radio channel and its EMC with the radio interference source.

To achieve this aim, it is necessary to solve the following tasks:

- to improve the model of active protection of the UHF/VHF band mobile radio communication channel by considering the EMA of interacting radio means,
- to develop a numerical method for determining the boundaries of the zone of possible placement of a radio interference generator to suppress an enemy monitoring's radio receiver using an improved model of radio communication channel active protection,
- to study the influence of the parameters of the active protection model of the UHF/VHF band radio communication channel on the size and configuration of the radio interference generator location zone.

2 Mathematical Model of Active Protection of a Mobile Radio Communication Channel, Considering the EMA of Interacting Radio Means

Let us consider the interaction of mobile radio communication channel objects (object 1, 2) and enemy radio monitoring means (object 3), presented in Fig. 1, and determine the conditions for using means of active protection of the radio communication channel.

It makes sense to solve the problem of creating active protection for a mobile radio communication channel if the following preconditions are met:

- the mobile radio communication channel must be operational, that is, object 1 must be in the EMA area of object 2 and vice versa. The EMA areas of radio channel objects are calculated for the radio receivers' sensitivity E_{s12},
- at least one of the radio channel objects must be accessible for eavesdropping by enemy radio intelligence monitoring means, that is, object 3 must be located in at least one of the EMA areas of objects 1 and 2, calculated for the radio receivers' sensitivity E_{s3}.

The general condition for the operability of a mobile radio communication channel was obtained in [1] and assumes the simultaneous placement of receivers of objects 1 and 2 in the EMA zones Ω_{E1} and Ω_{E2} their transmitters:

$$\begin{cases} (x_1, y_1) \in \Omega_{E_2} \\ (x_2, y_2) \in \Omega_{E_1} \end{cases} \tag{5}$$

$$\Omega_{E_1} = \left\{ \forall (x_2, y_2) \in \Omega \middle| P_{12}(x_2, y_2) \geq P_{\min 12} \right\} \tag{6}$$

$$\Omega_{E_2} = \left\{ \forall (x_1, y_1) \in \Omega \middle| P_{21}(x_1, y_1) \geq P_{\min 12} \right\} \tag{7}$$

$$P_{12} = P_1 + 10\log\left[G_1(\theta_{12} - \theta_1)\right] + 10\log\left[G_2(\theta_{21} - \theta_2)\right] - L_{P12}, \text{ [dB (1 mW)]} \tag{8}$$

$$P_{21} = P_2 + 10\log\left[G_1(\theta_{12} - \theta_1)\right] + 10\log\left[G_2(\theta_{21} - \theta_2)\right] - L_{P21}, \text{ [dB]} \tag{9}$$

$$P_{\min 12} = 10\log\left[\frac{E_{s12}^2}{4R_A}\right], \text{ [dB]} \tag{10}$$

where θ_{12} – the azimuth angle from object 1 on object 2; θ_{21} – the azimuth angle from object 2 on object 1; L_{P12}, L_{P21} – the losses of useful radio signal power along the propagation path from object 1 to object 2 and in the opposite direction [12]; R_A – the matched active input impedance of a radio receiver antenna.

Let us obtain the conditions for the availability of radio means of the mobile radio communication channel for eavesdropping by an enemy monitoring's radio receiver. The minimum power of the useful signal required for reception at the input of the monitoring's receiver of object 3 is

$$P_{\min 3} = 10\log\left[\frac{E_{s3}^2}{4R_A}\right], \text{ [dB]} \tag{11}$$

Powers P_{13} and P_{23} of the useful signal of the radio transmitter of object 1 or 2 at the location of the monitoring's radio receiver of object 3 are calculated as

$$P_{13} = P_1 + 10\log\left[G_1(\theta_{13} - \theta_1)\right] - L_{P13}, \text{ [dB]} \tag{12}$$

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$$P_{23} = P_2 + 10\log\left[G_2\left(\theta_{23} - \theta_2\right)\right] - L_{P23}, \text{ [dB]} \quad (13)$$

where θ_{13} – the azimuth angle from object 1 to object 3; θ_{23} – the azimuth angle from object 2 to object 3; L_{P13} and L_{P23} – the losses of useful radio signal power along the propagation path from object 1 and object 2 to object 3, respectively.

For the object's 1 transmitter, the condition of availability for the eavesdropping by object's 3 receiver to can be written as follows:

$$L_{D13} = P_{13} \geq P_{\min 3} \quad (14)$$

For the object's 2 transmitter

$$L_{D23} = P_{23} \geq P_{\min 3} \quad (15)$$

Generally, the condition of the availability of a mobile radio communication channel for eavesdropping by enemy radio monitoring means L_D suggests the fulfillment of at least one of the conditions Eq. (14) and Eq. (15):

$$L_D = L_{D13} \cup L_{D23} \quad (16)$$

For further calculations, it is necessary to fulfill the operability condition of the mobile radio communication channel Eq. (5-10), as well as the conditions for the availability of this channel for eavesdropping by enemy radio monitoring mean Eq. (16).

The developed model of active protection of a mobile radio communication channel from eavesdropping takes into account EMC conditions, the range of the radio interference generator, radio signal transmitters, as well as the sensitivity of the radio communication channel receivers and the enemy monitoring's radio receiver.

The conditions for protecting radio exchange from eavesdropping depend on the signal-to-noise ratio at the location of the monitoring's radio receiver.

The power of the radio interference signal of object 4 at the location of the object's 3 radio receiver is calculated as

$$P_{43} = P_4 + 10\log\left[G_4\left(\theta_{43} - \theta_4\right)\right] - L_{P43}, \text{ [dB]} \quad (17)$$

where θ_{43} – the azimuth angle from object 4 to object 3; L_{P43} – the power losses of the useful radio signal along the propagation path from object 4 to object 3.

Calculation of the suppression coefficient of the useful radio signal of the object's 1 transmitter of at the location of the object's 3 radio receiver must consider the EMA conditions of the transmitters of objects 1 and 4.

If the condition for receiving an object's 1 useful radio signal at the location of the monitoring's radio receiver Eq. (14) is met, then to protect radio exchange from eavesdropping it is necessary to provide that the condition for receiving a radio interference signal by a monitoring's radio receiver is met

$$L_{D43} = P_{43} \geq P_{\min 3} \quad (18)$$

as well as the level of the suppression coefficient of the useful radio signal

$$K_{\sup 13} = P_{43} - P_{13} \geq K_{\text{th3}} \quad (19)$$

exceeding the threshold value K_{th3} for object 3.

These considerations make it possible to obtain the condition for suppression of the object's 1 useful radio signal at the location of the object's 3 radio receiver, considering the EMA of radio means, in the following form:

$$C'_{\sup 13} = L_{D13} \cap L_{D43} \cap \left(K_{\sup 13} \geq K_{\text{th}3}\right) \tag{20}$$

In a similar way, we obtain the condition for suppressing the object's 2 useful radio signal at the location of the object's 3 radio receiver:

$$C'_{\sup 23} = L_{D23} \cap L_{D43} \cap \left(K_{\sup 23} \geq K_{\text{th}3}\right) \tag{21}$$

where $K_{\sup 23} = P_{43} - P_{23}$.

Then the general condition for protecting radio transmitters of objects 1 and 2 from eavesdropping, taking into account the EMA of radio means, can be written in the following form:

$$C'_{\sup} = C'_{\sup 13} \cap C'_{\sup 23} \tag{22}$$

Let us determine the EMC conditions of a radio interference generator with a radio communication channel, considering the EMA of its radio means. Radio interference signal power of object 4 at the location of the object's 1 radio receiver is:

$$P_{41} = P_4 + 10\log\left[G_1\left(\theta_{14} - \theta_1\right)\right] + 10\log\left[G_4\left(\theta_{41} - \theta_4\right)\right] - L_{\text{P}41}, \text{[dB]} \tag{23}$$

where θ_{14} – the azimuth angle from object 1 to object 4, θ_{41} – the azimuth angle from object 4 to object 1; $L_{\text{P}41}$ – the power losses of the useful radio signal along the propagation path from object 4 to object 1.

The radio interference generator affects the operation of the object's 1 radio receiver if the condition is met

$$L_{D41} = P_{41} \geq P_{\min 12} \tag{24}$$

The EMC conditions of object 1 with a radio interference generator are fulfilled naturally if object 1 is outside the influence zone of object 4, that is, condition Eq. (24) is not met. Otherwise, the suppression coefficient of the useful radio signal received by object 1 from object 2 $K_{\text{EMC}21}$ must be less than a specified threshold $K_{\text{th}12}$:

$$K_{\text{EMC}21} = P_{41} - P_{21} < K_{\text{th}12} \tag{25}$$

Thus, the general EMC condition of the radio interference generator with the object's 1 radio receiver requires the non-fulfillment of condition Eq. (24) or fulfillment of condition in Eq. (25):

$$C'_{\text{EMC}21} = \overline{L_{D41}} \cup \left(K_{\text{EMC}21} < K_{\text{th}12}\right) \tag{26}$$

Radio interference signal power of object 4 at the location of the object's 2 radio receiver is

$$P_{42} = P_4 + 10\log\left[G_2\left(\theta_{24} - \theta_2\right)\right] + 10\log\left[G_4\left(\theta_{42} - \theta_4\right)\right] - L_{\text{P}42}, \text{[dB]} \tag{27}$$

where θ_{24} – the azimuth angle from object 2 to object 4; θ_{42} – the azimuth angle from object 4 to object 2; $L_{\text{P}42}$ – the power losses of the useful radio signal along the propagation path from object 4 to object 2.

Similar to Eq. (26) we write the EMC condition of the radio interference generator with the object's 2 radio receiver as

$$C'_{\text{EMC}12} = \overline{L_{D42}} \cup \left(K_{\text{EMC}12} < K_{\text{th}12}\right) \tag{28}$$

where $L_{D42} = P_{42} \geq P_{\min 12}$ – the condition for the influence of the radio interference generator on the operation of the object's 2 radio receiver; $K_{\text{EMC12}} = P_{42} - P_{12}$ – the suppression coefficient of the useful radio signal received by object 2 from object 1.

The general EMC conditions of the radio interference generator with radio communication channel means, taking into account the EMA of radio means, can be written in the following form:

$$C'_{\text{EMC}} = C'_{\text{EMC12}} \cap C'_{\text{EMC21}} \tag{29}$$

The zone of possible placement of a radio interference source, considering the EMA of radio means, Ω'_{G} is part of the entire area of the operational map in which conditions Eq. (22) and Eq. (29) must be simultaneously met:

$$\Omega'_{\text{G}} = \left\{ \forall (x, y) \in \Omega \middle| C'_{\text{sup}} \cap C'_{\text{EMC}} \right\} \tag{30}$$

At each point in the zone Ω'_{G} there must be at least one azimuth angle θ_4 of the interference generator antenna device, giving such a set of values P_{41}, P_{42}, P_{43} that provides the simultaneous fulfillment of condition Eq. (29). The set of such azimuth angles θ_4 can be denoted as

$$\text{M}(\theta_4) = \left\{ \exists \theta_4 \in [0°, 360°] \middle| C'_{\text{sup}} \cap C'_{\text{EMC}} \right\} \tag{31}$$

In practice, due to its small dimension, the task of determining the elements of the set Eq. (31) can be solved by simply enumerating the values of θ_4.

3 Algorithm for Determining Zone Boundaries of Possible Placement of a Radio Interference Generator

The operation of the algorithm for determining the zone boundaries Ω'_{G} where a radio interference generator is located, is based on the procedure of a complete enumeration of Region of Interest (ROI) points – a rectangular area on the operational map Ω, which includes Ω'_{G}. Faster wave algorithm [1] in problem Eq. (29) is not applicable since the area Ω'_{G} in many cases consists of several non-adjacent fragments.

The algorithm developed by the authors is shown in Fig. 2.

We will consider the pixel matrix of the operational map image in the ROI area as a discrete working field limited by the coordinates $x_{\min}$, $x_{\max}$, $y_{\min}$, $y_{\max}$. The status of ROI cells is determined by the Mask array as array [$x_{\min}$ .. $x_{\max}$, $y_{\min}$ .. $y_{\max}$] of Boolean. A free cell in the field corresponds to the state Mask [x, y] =False.

The algorithm consists of three stages: initialization of the Mask array, scanning of ROI points and formation of the Border array of zone boundary coordinates Ω'_{G} boundary coordinates.

The initialization stage. All the Mask array elements are set to value False (block 1).

The ROI point scanning stage. In blocks 2...9, for each point (x, y) of the map belonging to the range $x \in [x_{\min}, x_{\max}]$, $y \in [y_{\min}, y_{\max}]$, the elements of the set Eq. (31) are searched. If at least one such azimuth angle is found, that is, condition $\text{M}(\theta_4) \neq \varnothing$ is met, the array element Mask [x, y] takes on the value True (blocks 4 and 5).

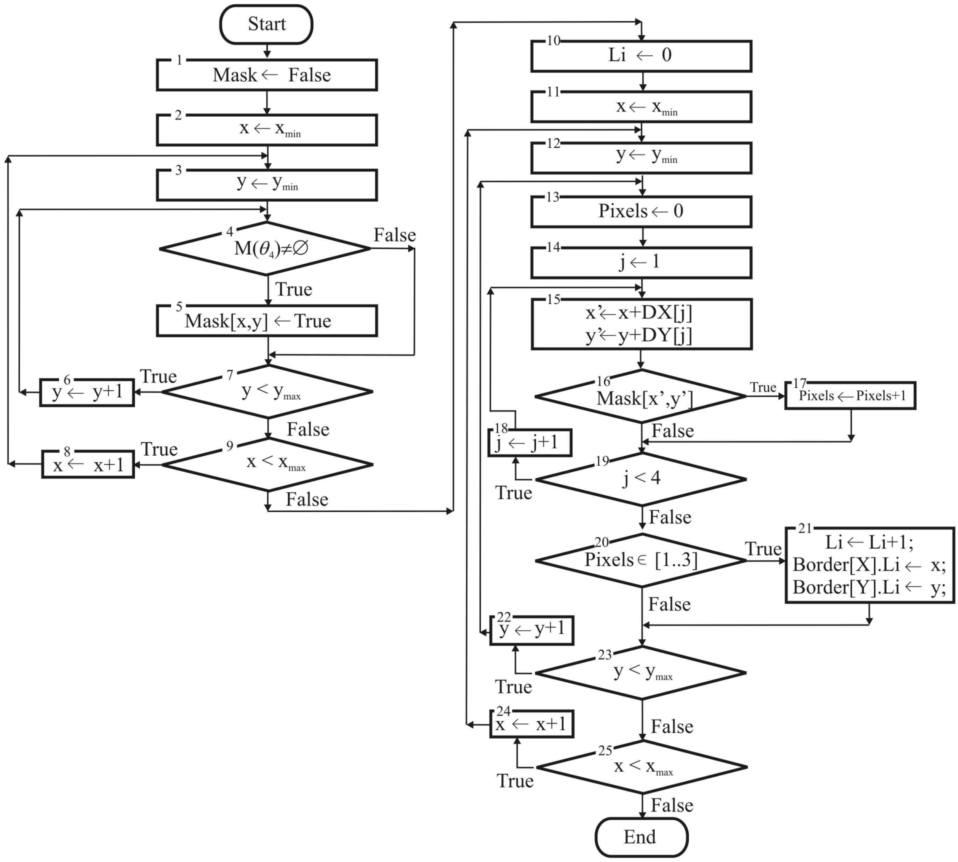

Fig. 2 Algorithm for calculating zone boundaries of possible placement of a radio interference generator

The stage of laying the zone boundaries. After resetting the counter of zone boundary points Li (block 10), the bit mask in Mask array is scanned (blocks 11...25). For each ROI point, the Pixels parameter is calculated – the number of neighboring points whose bitmask has the value True (blocks 16 and 17). If for the current point (x, y) the Pixels parameter lies in the range of values from 1 to 3, this point belongs to the zone boundary and is stored in the Border array – the array of coordinates of the zone boundary points (blocks 20 and 21).

By counting the number of bitmask cells with the True state and referring to the map scale, we can additionally estimate the area of the resulting zone Ω'_G.

4 Influence of the Model Radio Communication Channel Parameters on the Size and Configuration of the Radio Interference Generator Location Zone

The algorithm discussed above for determining the zone boundaries where a radio interference source is located and implemented in the program makes it possible to analyze the dependence of the shape and size of the resulting zone Ω'_G on the current parameters of the model of a secure mobile radio communication channel on a terrain map.

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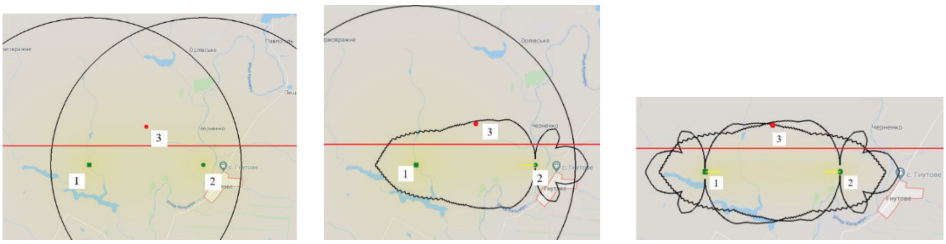
The mobile communication radio channel (Fig. 1) is built on MTP3000 Series radio means [10] with the following parameters: $P_1 = P_2 = 1$ W, $E_{s12} = 0.25$ µV, $E_{s3} = 0.25$ µV. The functionality of the mobile radio communication channel is provided and it is possible to eavesdrop to the mobile radio communication channel, which makes it advisable to use an active radio interference generator.

Calculations were carried out for three cases of combination of types of antenna RP of objects 1 and 2 in the same operational situation. An analysis of the influence of the radio interference generator power on the shape and size of the zone, where it is located, was carried out for omnidirectional RP of objects 1, 2 (option 1), combined RP (option 2) and directional RP (option 3). The EMA zones boundaries of objects for all three options are shown in Fig. 3.



a) *b)* *c)*

Fig. 3 Options for combinations of RP types for objects 1 and 2:
a) omnidirectional RP, b) combined RP, c) directional RP

In the figures of the resulting placement zones for interference generator, there is a conventional horizontal front line dividing the zone Ω'_G into two parts. The area of the upper part, where the enemy monitoring's receiver is located (object 3), will be denoted as S_3. The lower part of the zone Ω'_G, where objects 1 and 2 are located, with an area of S_{12} is used for the placement of a radio interference generator from a safety point of view. The total area of the interference generator placement zone Ω'_G is $S_G = S_{12} + S_3$. The incorporation of a conditional line helps to understand the nature of the redistribution of the area parts sizes Ω'_G as the parameters of the radio channel model change.

Case 1. Objects 1 and 2 have omnidirectional antenna devices. The results of calculating the zone boundary of possible placement of a directional radio interference generator for power values $P_4 = 1$, 2 and 5 W are shown in Fig. 4.

a) *b)* *c)*

Fig. 4 Results of calculating the zone boundary Ω'_G depending on the power of the interference generator for omnidirectional RP of objects 1 and 2: a) $P_4 = 1$ W b) $P_4 = 2$ W c) $P_4 = 5$ W

When P_4 = 1W (Fig. 4a), the placement zone Ω'_G has the shape of an irregular circle with a center at the object's 3 placement point and a radius that varies in the range of 2.7-3.2 km. Characteristic changes in the shape of the area Ω'_G are deformation regions A and B, where conditions Eq. (30) associated with object 1 are not met. Deformation areas C and D have a similar origin, where conditions of Eq. (30) associated with object 2 are not met.

The area of zone Ω'_G is S_G = 12.03 % of the entire area of the operational map Ω, the area S_{12} = 3.2 %, which is 2.75 times less than the area S_3 = 8.83 % occupied by the enemy.

It should be emphasized that by placing a radio interference generator with a directional antenna at any point located inside the zone Ω'_G, we can always find the azimuth angle θ_4, which provides the conditions for channel protection Eq. (22) and EMC Eq. (29). One of the many options for placing a directional radio interference generator (object 4) in the area Ω'_G at P_4 = 1 W, $\theta_4 = 0^0$ is shown in Fig. 5.

With an acceptable suppression level of the useful signal $K_{th12} = -5$ dB in the mobile radio communication channel, EMC conditions Eq. (29) are met: $K_{12} = -10$ dB, $K_{21} = -10$ dB. The conditions of channel protection Eq. (22) are also met for a given level $K_{th3} = 0$ dB: $K_{13} = 1$ dB, $K_{23} = 1$ dB.

As the power of the radio interference generator increases, the limitations associated with EMC conditions increase, the zone shape Ω'_G becomes more irregular and breaks up into parts (Fig. 4b, c).

Fig. 6 shows the dependence of the relative zones size S_{12} and S_3 on the power of the radio interference generator.

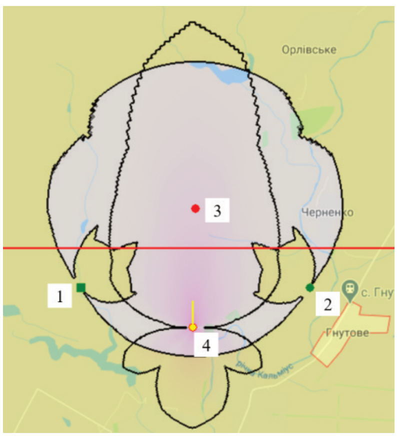


Fig. 5 Option for placing a radio interference generator for P_4 = 1 W

With an increase in generator power in the range from 1 to 20 W, the size of zone S_3 exceeds the area of zone S_{12} by 2.8 to 3.8 times. It should be noted that the dynamics of the decrease in zone S_{12} is less pronounced compared to S_3. The best power values are P_4 = 1 W and P_4 = 2 W, providing the maximum sizes of S_{12}. Working with large P_4 values gives worse results. Thus, in practice, it is necessary to provide the correct choice of not only the radio interference generator location, but also of its power P_4, which provides the maximum area of the S_{12} zone.

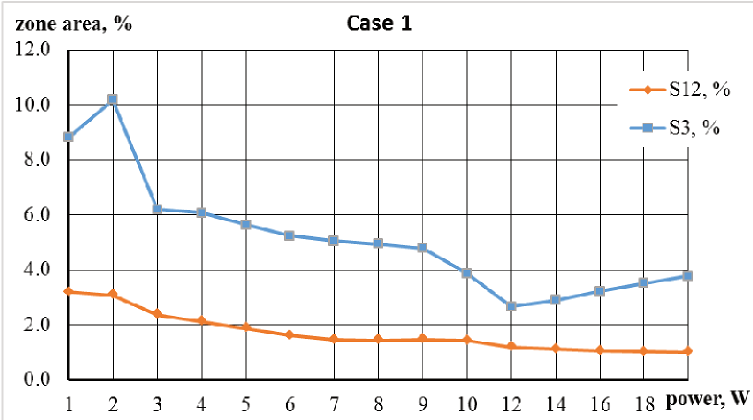


Fig. 6 Dependence of relative zones size S_{12} and S_3 on radio interference generator power P_4 (Case1)

Case 2. Object 1 has an omnidirectional antenna, and object 2 has a directional antenna device oriented towards object 1. The results of calculating the zone's boundary of possible placement of a directional radio interference generator for power values $P_4 = 1$, 5 and 12 W are shown in Fig. 7.

At $P_4 = 1$ W (Fig. 7a), characteristic changes in the shape of the zone Ω'_G are deformation regions A and B, where conditions of Eq. (30) are not met associated with object 1. The deformation region C associated with object 2 has a similar origin. The presence of a directional RP of object 2 causes a smaller area of the deformation region C compared to A and the absence of deformation region D (Fig. 4a).

a) *b)* *c)*

Fig. 7 Results of calculating zone boundary Ω'_G depending on power of interference generator for combined RP of objects 1 and 2: a) $P_4 = 1$ W b) $P_4 = 5$ W c) $P_4 = 12$ W

The area of the zone Ω'_G is $S_G = 12.69$ % of the entire area of the operational map Ω, the area $S_{12} = 3.63$ %, which is 2.5 times less than the area $S_3 = 9.06$ %, occupied by the enemy.

Fig. 8 shows the dependence of the relative zones size S_{12} and S_3 on the radio interference generator power. With an increase in generator power in the range from 1 to 20 W, the size of zone S_3 exceeds the area of zone S_{12} by 2.5 to 0.6 times.

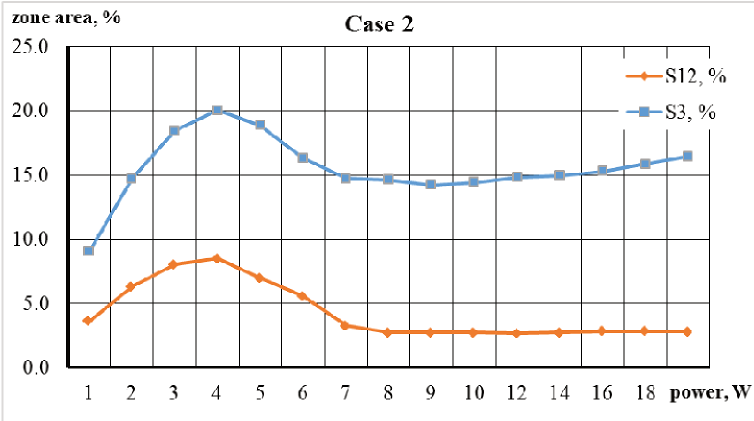
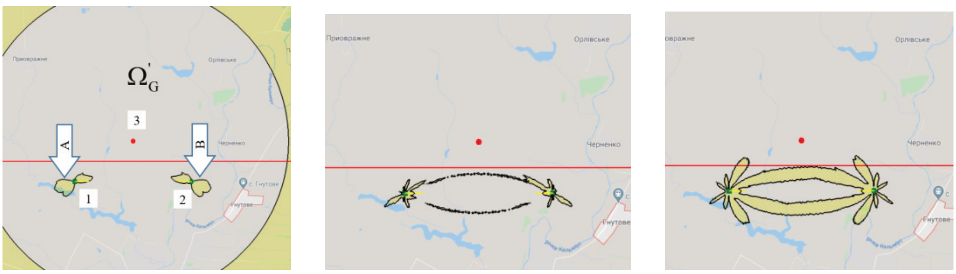


Fig. 8 Dependence of relative zones size S_{12} and S_3 on radio interference generator power P_4 (Case 2)

In this embodiment, we can talk about the optimal power value of the radio interference generator $P_4 = 4$ W, for which the area S_{12} has a maximum value.

Case 3. Objects 1 and 2 have antenna devices aimed at each other. The results of calculating the zone's boundary of possible placement of a directional radio interference generator for power values $P_4 = 1$, 2 and 12 W are shown in Fig. 9.



a) b) c)

Fig. 9 Results of calculating the zone boundary Ω'_G depending on the power of the interference generator for directional RP of objects 1 and 2: a) $P_4 = 1$ W b) $P_4 = 2$ W c) $P_4 = 12$ W

When $P_4 = 1$ W (Fig. 9a), the placement zone Ω'_G has a shape of an irregular circle with a center at the object's 3 placement point and a radius that varies in the range of 6 400 to 6 660 m. Characteristic changes in the shape of the zone Ω'_G are deformation regions A and B, where EMC conditions are not met with objects 1 and 2, respectively. The area of the zone Ω'_G is $S_G = 53.44$ % of the entire area of the operational map Ω, while the area $S_{12} = 21.32$ %, which is much larger than the sizes of the areas in the previous cases (Case 1 and Case 2).

Fig. 10 shows the dependence of the relative zones size S_{12} and S_3 on the radio interference generator power.

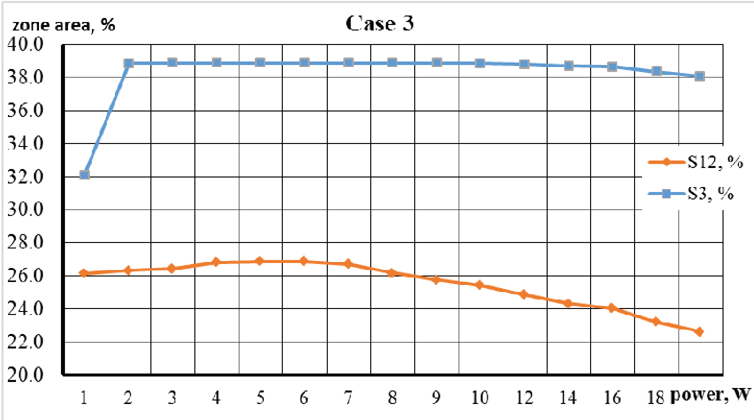


Fig. 10 Dependence of relative zones size S_{12} and S_3 on radio interference generator power P_4 (Case 3)

As the power of the radio interference generator increases, the shape of the deformation regions A and B changes significantly, where the EMC conditions are not met (Fig. 9b, c). With an increase in the power of the radio interference generator in the range from 1 to 20 W, the size of zone S_3 exceeds the area of zone S_{12} by 1.2 to 1.7 times. From graph S_{12} in Fig. 10 it follows that the optimal range of power values P_4 is 3…8 W, for which the area of the S_{12} zone has a maximum value.

Based on the results obtained, we can conclude that Case 3, in which objects 1 and 2 have directional antenna devices mutually oriented towards each other, is the most preferable option for organizing the radio channel operation, since in this case the area of the S_{12} zone is of greatest importance compared with Case 1 and Case 2.

5 Conclusions

A simple and effective method is proposed for determining the zone boundaries of possible placement of a radio interference generator to protect mobile radio communication means in the UHF/VHF range from being eavesdropped by an enemy ground monitoring's radio receiver. The method takes into account the presence of EMA zones of mobile radio communication systems and the range of the radio interference generator.

It is shown that the use of an active radio interference generator is advisable if the operability of the mobile radio communication channel is provided, and the enemy monitoring's radio receiver has the ability to eavesdrop to the mobile radio communication channel. At each point in the radio interference generator location zone, by orienting its antenna device in azimuth, suppression of the useful radio signal at the input of the enemy monitoring's radio receiver is provided while simultaneously meeting the EMC conditions with the radio communication channel means.

The problem of orienting the antenna device of a radio interference generator is solved using an improved model of the UHF/VHF mobile radio communication channel, which makes it possible to calculate the signal-to-noise ratio considering the spatial location and EMA of interacting radio means.

To determine the coordinates of the boundary points of the radio interference generator location zone, an algorithm is used that uses a complete enumeration procedure for ROI points, including the solution region. The faster wave algorithm, used earlier by the authors, is not applicable to the problem under consideration, since the solution region in many cases consists of several non-adjacent fragments.

The influence of the types of antenna RP of radio communication channel means and of the power of the radio interference generator on the size and configuration of the deployment zone have been studied.

For low power values of the radio interference generator (1 W), the shape of its placement zone is close to a circle. As the power increases, the shape of the zone becomes irregular and falls apart. In this case, the most severe deformation is experienced by that part of the solution region in which the mobile communication channel radio means are located (the so-called preferred zone). The area of this part is significantly less than the area of the part where the enemy monitoring's receiver is located (2.8 to 3.8 times for the case of omnidirectional antennas, 2.5 to 6 times for the case of combined antennas, 1.2 to 1.7 times for the case of directional matched antennas).

The dependence of the area of the deployment zone on the power of the radio interference generator for all combinations of types of antenna devices RP of radio communication channel, as a rule, has a region of maximum values. The location and nature of the maximum region here depends on the combination of types of antenna devices RP. This allows us to talk about the range of the most effective power values of the radio interference generator in each specific task. The most pronounced zone is the maximum area of the solution region, in which the mobile communication channel radio means are located, in the case of combined antennas. Thus, in practice, it is desirable to provide the correct choice of not only the coordinates of the location of the radio interference generator, but also its power, providing the maximum area of the preferred location zone.

The most preferable option for organizing the operation of a radio channel, which opens up wide opportunities for its active protection using a radio interference generator, is the presence of directional antenna devices on both radio means of the mobile communication channel, mutually oriented towards each other. In this case, the area of the preferred zone for placing the radio interference generator is of greatest importance compared to other combinations of types of antenna devices RP of the radio communication channel.

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