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DEVELOPMENT OF A METHOD FOR CALCULATION OF THE ELECTROMAGNETIC COMPATIBILITY REGION OF A RADIO MASKING SOURCE

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Abstract. *This work is devoted to the problem of determining the electromagnetic compatibility region of a radio transmitter of a radio communication channel in the UHF/VHF range on a terrain map. To solve this problem, mathematical models of radio signal propagation were used, taking into account the characteristics of a particular area. A method is proposed for calculating the boundaries of the electromagnetic compatibility region from a digitized radiation pattern of radio facilities, which is based on the wave algorithm. The results of calculations show that the use of the proposed method is quite effective in solving problems of assessing the performance of a mobile radio communication channel and its security during local combat operations in the conditions of operation of reconnaissance radio receivers or an enemy's intentional radio interference system.*

Keywords: *electromagnetic compatibility region, radio masking source, radio communication system, local combat operations, terrain, mobile radio communication channel, wave algorithm.*

I. INTRODUCTION

When conducting local combat operations by tactical units, taking into account the range of the UHF/VHF radio emission source is an important issue in the tasks of organizing the operation of a mobile radio communication channel. These tasks include [1-4]: analysis of the radio communication channel performance conditions, reducing the effectiveness of enemy radio reconnaissance, protecting the radio channel from the intentional radio interference system. Here, the concept of the electromagnetic compatibility (EMC) region of a radio masking source is used as a set of points in space at which this transmitter provides the minimum required radio signal power at the input of the corresponding receiver, depending on the receiver sensitivity.

II. LITERATURE ANALYSIS

A mathematical model of the EMC of a military radio communication system was proposed in [3-4]. It is based on the representation of the simulated object as a quasi-crystal, based on the provisions of the electromagnetic field theory and the theory of tensor calculus. The authors of [3-4] also give a geometric interpretation of the EMC of a separate military radio station as an indicator of the level of its radio masking. The presented results do not yet have practical application in solving problems of organizing the operation of mobile radio communication systems.

The paper [5] proposes a method for estimating the EMC region by radio monitoring facilities in the conduct of local combat operations by tactical level subunits in conditions of rugged terrain. This method allows modeling with sufficient accuracy various options for constructing regional radio frequency monitoring subsystems. At the same time, the parameters of the calculated EMC region of radio monitoring facilities depend on the power and radiation pattern of the transmitter antenna, the distance between the receiver and the transmitter, the terrain and the sensitivity of the receiver. The algorithm for calculating the boundaries of the EMC region of radio monitoring facilities in [5] allows to determine the points of intersection of lines of equal heights with the current azimuth on the terrain map and iteratively refines the boundary of the EMC region. Such an algorithm is highly labor-intensive: it takes 15-120 minutes to calculate one EMC region, depending on the terrain, locality buildings and discreteness of readings in azimuth.

As shown in [6], when the subunits of the tactical level conduct combat operations on rough terrain, the mobile radio communication channel is characterized by a short range (up to 5–6 km) due to low transmitter powers (1–5 W). Therefore, to calculate the average value of the attenuation of the radio signal (depending on the characteristics of a particular area), simpler mathematical models of radio signal propagation can be used. This will also speed up the calculation of the boundaries of the EMC region of the radio masking source.

For example, in ideal conditions of free space, the Friis propagation model [7] can be used to estimate the power loss of a radio signal:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2 \qquad (1)$$

where P_R – the power [W] of the receiving antenna at a distance d [m],

P_T – the power of the radio signal transmitter [W],

G_T – the antenna gain of the radio signal transmitter in the direction of the receiver,

G_R – the gain of the receiving antenna in the direction of the transmitter,

λ – the wave length [m].

For isotropic antennas, when changing to a logarithmic scale, the relation (1) will look like:

$$P_R = P_T - L_P \text{, [dB]} \qquad (2)$$

where L_P – the loss of radio signal power transmission, which in free space [8] is calculated by the formula

$$L_P = 32.44 + 20\log F_{MHz} + 20\log D_{km} \text{, [dB]} \qquad (3)$$

where F_{MHz} – the frequency of the radio signal [MHz],

D_{km} – the distance between transmitter and receiver [km].

In the case of combat operations on a flat hilly terrain with an average height of irregularities up to 15 m, it is advisable to use the Egli statistical model [9]. It does not take into account the diffraction loss that occurs due to the propagation of a radio signal over rough terrain, and also does not take into account the presence of trees and shrubs. In this case, the losses of radio signal power transmission here [10] are calculated by the formula:

$$L_{\mathrm{P}} = 20\log F_{\mathrm{MHz}} + 40\log D_{\mathrm{km}} - 20\log h_{\mathrm{T}} + \begin{cases} 76.3 - 10\log h_{\mathrm{R}}, & h_{\mathrm{R}} \le 10 \\ 85.3 - 20\log h_{\mathrm{R}}, & h_{\mathrm{R}} > 10 \end{cases}, \ [\mathrm{dB}] \quad (4)$$

where h_{T} – the effective transmitter antenna height [m],

h_{R} – the effective receiver antenna height [m].

When conducting local combat operations in the conditions of urban development and suburbs, it is advisable to use more complex models of Okumura, Hata, and others [10-12].

In this study, to construct a method for calculating the boundaries of the EMC region of a radio masking source as part of a mobile radio communication channel, simpler relations (1), (3), (4) are used to calculate the loss of radio signal power.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The aim of the study is to develop a method for calculating the boundaries of the EMC region of radio masking sources as part of a UHF/VHF mobile radio communication channel with reference to a topographic map of the area with a tactical situation.

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

– to obtain mathematical relationships for determining the EMC regions of radio masking sources, taking into account the losses of the radio signal power;

– to build a fast, simple and reliable algorithm for determining the boundaries of the EMC region of transmitters as part of a mobile radio communication channel;

– to check the feasibility of applying the method for calculating the boundaries of the EMC region of radio masking sources for organizing the operation of a mobile radio communication channel by practical calculations on a topographic terrain map with a tactical situation.

The object of the study is the process of functioning of the radio communication system in the conditions of the use of radio masking facilities.

The subject of the study is the influence of location parameters of active radio masking on the functioning of the radio communication system.

When solving the problems of this study, the following methods were used: the basics of the theory of radio reception – for an analytical description of the interaction of a radio communication system with active radio masking; simulation methods – to analyze the EMC conditions and the effectiveness of the interaction of passive and active radio masking facilities; numerical optimization methods – to optimize the parameters of the system elements by active radio masking facilities; methods for modeling surfaces and solving spatial problems of computational geometry, graph theory – to create algorithms for constructing the boundaries of the EMC region and the zones for the location of active radio masking facilities.

IV. RESULTS

4.1 Determination of the EMC region of radio masking sources in the mobile radio communication channel

Let us consider the interaction of radio facilities of a mobile radio communication channel, taking into account the range of radio masking sources. Let Ω be an area of a topographic terrain map with a tactical situation. Then the proposed model of a mobile radio communication channel in the general case contains the following objects (Fig. 1).

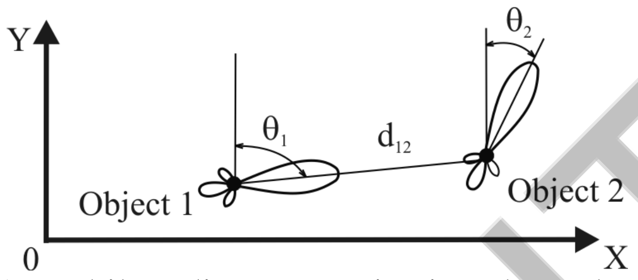


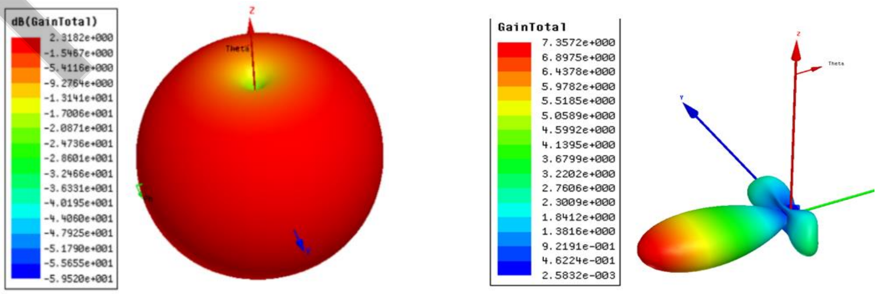
Fig. 1. Mobile radio communication channel model

Object 1 is a ground-based receiver/transmitter of UHF/VHF radio signals with transmitter power P_1 at the point with coordinates $(x_1, y_1) \in \Omega$. The digitized normalized antenna radiation pattern is described by the function $G_1(\theta)$, and the own azimuth of it is the angle θ_1.

Object 2 is a ground-based receiver/transmitter of UHF/VHF radio signals with transmitter power P_2 at the point with coordinates $(x_2, y_2) \in \Omega$. The digitized normalized antenna radiation pattern is described by the function $G_2(\theta)$, the own azimuth of it is the angle θ_2.

Let us assume that the sensitivity of the receivers of both objects is the same and equal to E_s, [μV].

To calculate the digitized antenna radiation pattern of the mobile radio communication facility $G(\theta)$, it is possible to apply the program for modeling three-dimensional electromagnetic fields [13]. Examples of such a calculation of the radiation patterns of omnidirectional and directional antennas of mobile radio communication facilities from [2] are shown in Fig. 2.



a b

Fig. 2. Examples of shapes of digitized antenna radiation patterns in the mobile radio communication channel model [2]:
a – for an omnidirectional antenna, b – for a directional antenna.

Let's move on to solving the first of the study tasks – we will obtain a mathematical relationship to determine the boundaries of the EMC region of the transmitter of object 1, which interacts with the receiver of object 2 when organizing the operation of a mobile radio communication channel. In the case when a matched antenna in mobile radio communication facilities is connected directly to the receiver input with sensitivity E_s and matched active input impedance R_A, the following dependence takes place [13]:

$$P_{\min} = \frac{E_s^2}{4R_A} \qquad (5)$$

The $P_{\min}$ value determines the minimum power of the useful signal that provides high-quality reception at the input of the receiver of object 2. For example, in radio stations Mototrbo™ DP4000 radio stations the receiver sensitivity is 0.25 μV, and for the standard value $R_A = 75$ Ohm, the minimum value of the radio signal power $P_{\min} = -126.8$ dBm [6]. It is logical to assume that at the boundary of the EMC region of the transmitter of object 1, the power of the radio signal at the input of the receiver of object 2 should be at least $P_{\min}$.

According to relation (1), we determine the power of the useful signal of the radio transmitter of object 1 at the location of the radio receiver of object 2, taking into account the functions of the digitized antenna radiation patterns:

$$P_{12}(x_2, y_2) = P_1 G_1(\theta_{12} - \theta_1) G_2(\theta_{21} - \theta_2) \left(\frac{\lambda}{4\pi \mathrm{d}_{12}} \right)^2 \qquad (6)$$

where P_{12} – the signal power of the receiving antenna of the radio receiver of object 2 [W],

P_1 – the signal power from the transmitter of object 1 [W].

According to relation (3), on a logarithmic scale, we calculate the signal powers P_{12} and P_1 as:

$$P_{12}(x_2, y_2) = P_1 + 10\log\left[G_1(\theta_{12} - \theta_1)\right] - L_{\mathbf{P}} \text{ , [dBm].} \qquad (7)$$

Thus, with the minimum required power of the useful signal $P_{\min}$, it is possible to determine the EMC region of the transmitter of object 1 for the receiver of object 2 as

$$\Omega_{E_1} = \left\{ \forall (x_2, y_2) \in \Omega \mid P_{12}(x_2, y_2) \geq P_{\min} \right\} \qquad (8)$$

and the EMC region of the transmitter of object 2 for the receiver of object 1 as:

$$\Omega_{E_2} = \left\{ \forall (x_1, y_1) \in \Omega \mid P_{21}(x_1, y_1) \geq P_{\min} \right\} \qquad (9)$$

where

$$P_{21}(x_1, y_1) = P_2 + 10\log\left[G_2(\theta_{21} - \theta_2)\right] - L_{\mathrm{P}} \text{ , [dBm]} \qquad (10)$$

To ensure the operability of the mobile radio communication channel, a necessary condition is the simultaneous placement of the receivers of objects 1 and 2 in the adjacent EMC regions of the radio channel transmitters:

$$\begin{cases} (x_1, y_1) \in \Omega_{\mathrm{E}_2} \\ (x_2, y_2) \in \Omega_{\mathrm{E}_1} \end{cases} \tag{11}$$

Thus, from the relations (7)-(11) obtained, it follows that the size of the EMC region and the fulfillment of the conditions for the operability of a mobile radio communication channel depend on their power, the orientation of the antenna radiation pattern, power losses in the signal propagation path and the sensitivity of the radio signal receiver.

4.2 Algorithm for determining the boundaries of the EMC region of the source of radio masking as part of a mobile radio communication channel

Let us take as a basis the modification of the wave algorithm from [2].

A topographic terrain map with a tactical situation in the form of a pixel matrix can be represented as a discrete workspace, which is limited by the coordinates $x_{\min}$, $x_{\max}$, $y_{\min}$, $y_{\max}$. The Mask array is used to describe the state of the cells of this workspace (as Mask array is array [$x_{\min}$ .. $x_{\max}$, $y_{\min}$ .. $y_{\max}$] of boolean). In it, a free workspace cell with coordinates (x, y) corresponds to the Mask[x, y] = False state, and a non-free workspace cell with coordinates (x, y) corresponds to the Mask[x, y] = True state. The coordinates of the points of the old and new wave fronts are accumulated respectively in the Front array (as array[1…L_f] of record x, y: integer end) and Fnew array (as array[1…Lfnew] of record x, y: integer end).

The algorithm for calculating the boundaries of the EMC region of the radio masking source is shown in Fig. 3 and consists of three stages: initialization (block 1), wave propagation (blocks 2-14) and formation of an array of coordinates of the region boundary (8) (blocks 15-30).

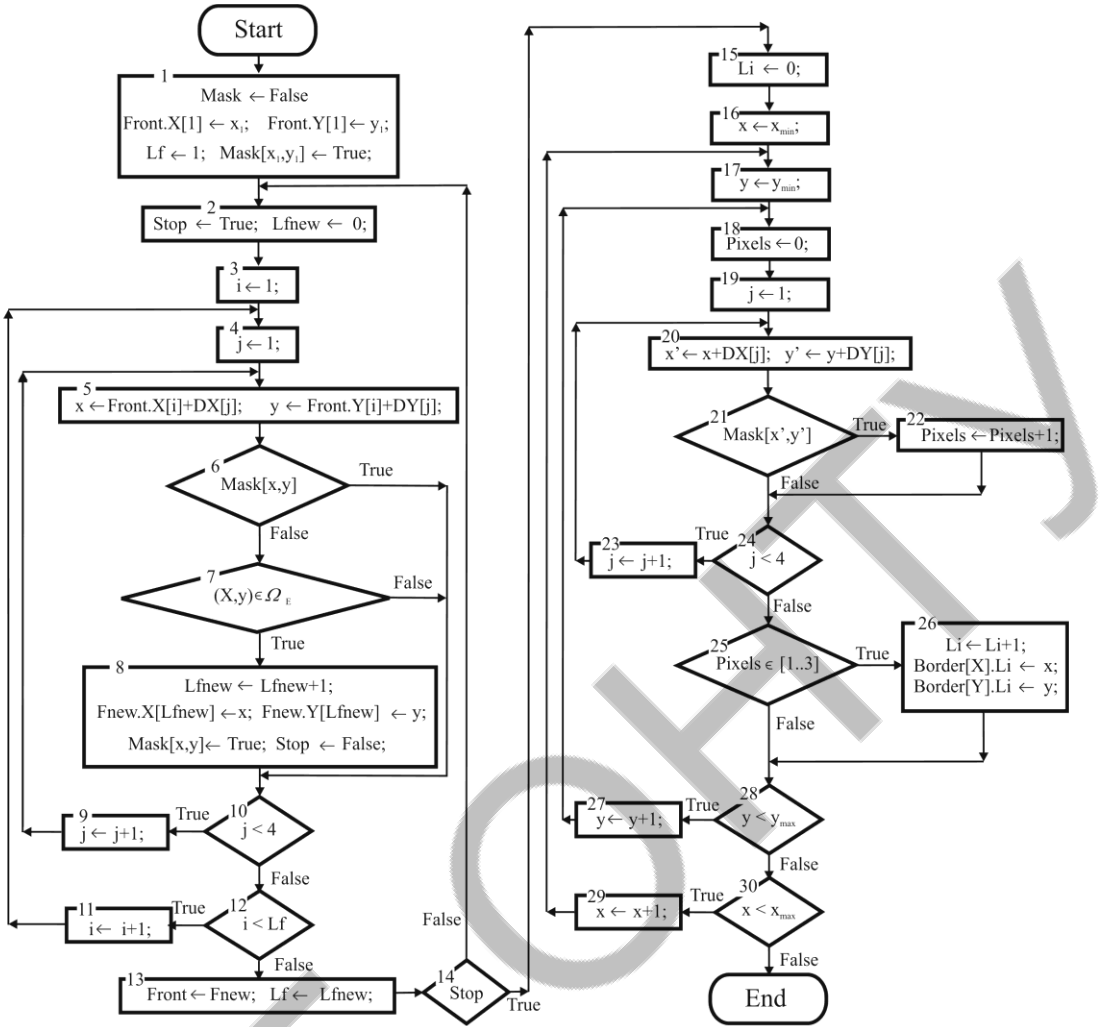


Fig. 3. Algorithm for calculating the boundaries of the EMC region of a radio masking source

At the initialization stage, it is assumed that all cells of the discrete workspace are free, therefore, all elements of the Mask array are set to False. The transmitter location point (x_1, y_1) is chosen as the starting cell, so the corresponding element of the mask array changes its value to Mask[x_1, y_1] = True. The coordinates of the starting cell are also written to the Front array. Wave front length Lf = 1.

At the stage of wave propagation, the arrays Fnew, Front, and Mask are updated cyclically. For each point of the old wave front, using the working arrays DX (0,1,0,-1) and DY (-1,0,1,0), the coordinates of adjacent points are calculated (block 5). If the candidate point with coordinates (x, y) is free (block 6) and the condition (8) is satisfied (block 7), then the candidate point with coordinates (x, y) is included in the new front (block 8). The corresponding element of the Mask[x, y] array is set to True.

At the end of the cycle of polling adjacent points and the cycle of scanning the points of the current wave front (blocks 11, 12), the Fnew array is rewritten to the Front array (block 13). The process of wave propagation ends at the boundary of the region, when the condition (8) ceases to be satisfied for any candidate points. In this case, the Stop flag switches to the next stage of the algorithm.

Attention should be paid to the rule for determining whether the current point of the discrete working field belongs to the EMC region of the radio masking source in block 7. The transition from the Friis radio signal propagation model to the Egli model in this block is easy to do, taking into account relations (3) or (4), respectively, in equations (7) and (8).

Next comes the stage of laying the boundaries of the region. After resetting the counter of boundary points of the region L_i (block 15), the points of the working area of the map $x_{\min}$, $x_{\max}$, $y_{\min}$, $y_{\max}$ are scanned using the Mask array (blocks 16...30). For each point with coordinates (x, y), the Pixels parameter is calculated – the number of adjacent points whose bit mask is set to True (blocks 21 and 22). If for the current point (x, y) the Pixels parameter lies in the range of values from 1 to 3, then this point is included in the region boundary (8) and stored in the array of coordinates of the region boundary points – Border (blocks 25 and 26).

On Fig.4 shows the visualization of the results of the phased operation of the algorithm when calculating the boundaries of the transmitter EMC region with reference to the terrain map; the map was taken from Google Maps at a scale of 19 m/pixel.

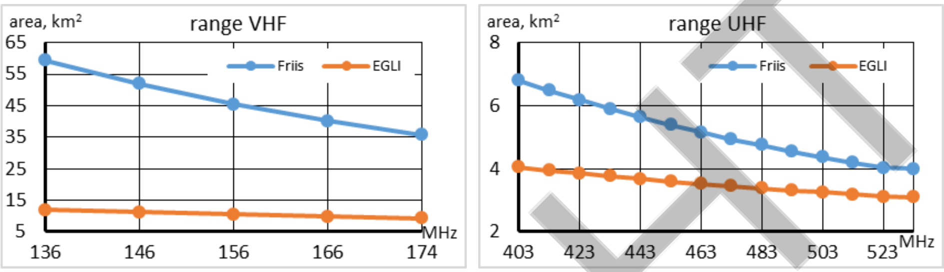
Wave propagation starts from the transmitter location point $(x1, y1)$; map points (x, y) for which Mask[x, y] is set to True are shown in yellow (see Fig. 4a). The wave stops propagating when the Stop flag is set to True (see Fig. 4b). Next, the region boundaries Ω_E are drawn (see Fig. 4c). These results of the phased operation of the algorithm for calculating the boundaries of the EMC region of the radio masking source were obtained for a transmitter with a power of 1 W (when operating at a frequency of 446 MHz) and for a receiver sensitivity of 0.25 μV.

a b c

Fig. 4. The results of the phased work of the algorithm for calculating the boundaries of the EMC region of the radio masking source:
a – the beginning of wave propagation, b – the ending of wave propagation, c – laying the region boundaries

The maximum distance from the transmitter location to the EMC boundary points is 3.629 km, which corresponds to the main lobe of the antenna radiation pattern. It is also possible to estimate the area of the received region Ω_E of the transmitter by calculating the number of cells in the Mask array with the True state (with reference to the map scale). So, for example, in the given example (Fig. 4), the area of the region Ω_E turned out to be 5.56 km2, which is 3% of the total area of the topographic terrain map with the tactical situation Ω. An analysis of the results of the calculations allows us to state that the area of the EMC region increases by a factor of 1.56 with an increase in the sensitivity of the radio receiver by 0.05 μV.

During the study, the dependences of the area of the EMC region of the Mototrbo^{TM} DP4000 radio station [6] on the signal frequency in the VHF (136–174 MHz) and UHF (403–527 MHz) bands were obtained, which are shown in Fig. 5. Analysis of the calculation results allows us to conclude that with a decrease in the frequency of the radio signal, the size of the EMC region increases: for the Friis signal propagation model – by 1.7 times, and for the Egli signal propagation model – by 1.3 times. There is also a tendency for the sizes of the EMC region to converge for different models with increasing frequency in the UHF range



a b

Fig. 5. Dependence of the size of the EMC region of the radio masking source on the signal frequency:
a – VHF band, b – UHF band

By calculating the EMC regions, it is also possible to assess the fulfillment of the conditions for the operability of a mobile radio communication channel (11). On Fig. 6 shows two options for calculating adjacent EMC regions of an operable radio channel for omnidirectional and directional antennas, which were carried out for a radio transmitters power of 1 W and a radio receivers sensitivity of $E_{s1} = E_{s2} = 0.25$ μV. For both options, the conditions for the operability of the mobile radio communication channel (11) are satisfied.

a b

Fig. 6. Examples of calculation of EMC regions of radio facilities of a mobile radio communication channel:
a – for omnidirectional antennas, b – for directional antennas

The presence of EMC regions of radio facilities of a mobile radio communication channel should also be taken into account when they operate in the presence of reconnaissance radio receivers or a enemy's intentional radio interference system.

V. CONCLUSIONS

As a result of the study, mathematical relationships were obtained to determine on the terrain map with the tactical situation of EMC regions of radio masking sources as part of a mobile radio communication channel, taking into account the loss of radio signal power. For this, Friis and Egli's mathematical models of radio signal propagation were used, taking into account the characteristics of a particular area.

The proposed method for determining the boundaries of the EMC region of transmitters of a mobile radio communication channel is characterized by simplicity, high speed and reliability of calculations. According to the research results, the duration of calculating the EMC region of radio masking sources on a topographic terrain map, taking into account the tactical situation, is on average 0.8..1.5 seconds.

The shape of the EMC region is determined by the digitized radiation pattern of the transmitter antenna obtained using special software.

The size of the EMC region depends on the power and frequency of the radio transmitter, the power loss along the signal path, and the sensitivity of the radio signal receiver. An analysis of the results of the calculations shows that the area of the EMC region increases by a factor of 1.56 with an increase in the sensitivity of the radio receiver by 0.05 μV. With a decrease in the frequency of the radio signal, the size of the EMC region increases: for the Friis signal propagation model – by 1.7 times, and for the Egli signal propagation model – by 1.3 times. There is also a tendency for the sizes of the EMC region to converge for different models with increasing frequency in the UHF range.

Practical calculations on a topographic terrain map with a tactical situation have shown the feasibility of using the method of calculating the boundaries of the EMC region of radio masking sources in the tasks of organizing the operation of a mobile radio communication channel.

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