UDC 621.396.949

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Comprehensive methodology for identifying incompatible radio electronic facilities in a grouping

The study introduces comprehensive methodology for identifying incompatible radio electronic facilities in a grouping, with provision for the effect of radio interference of various types operating in different spatial directions. The research also focuses on the characteristic features of radio wave propagation in the area where radioelectronic facilities are used. In view of the results obtained, it is possible to determine a plan for ensuring electromagnetic compatibility when designing radio electronic facilities. Moreover, findings of the research allow us in real time to receive data on radioelectronic facilities which have harmful interference impact, in the presence of basic data on real electromagnetic environment in the area where radioelectronic facilities are used.

Keywords: electromagnetic compatibility condition, radioelectronic facilities, regional frequency spacing, radio wave propagation, real electromagnetic environment, geographical gap zone.

The radioelectronic facilities (REF) and industrial radio interference sources are ever growing in numbers, with radio-frequency spectrum becoming increasingly crowded. In this respect, the relevance of the problem of ensuring electromagnetic compatibility (EMC) with the surrounding REF grouping increases accordingly. It is necessary to ensure REF functioning with required quality in the specified electromagnetic environment, without posing inadmissible electromagnetic interference to other REF at that [1].

Solving the problem of ensuring EMC is a set of tasks which includes drawing of special maps that represent electromagnetic environment in a given terrain and identifying incompatible REF in a grouping when deploying a new REF in the current REF activity area. The methodology for evaluating REF susceptibility to industrial radio interference sources has been described before [2].

According to the normative documents, REF susceptibility is a specific reaction of REF and its components to radio interference. A susceptibility level is defined as the minimum radio interference level at which inadmissible deterioration of REF functioning quality occurs [1].

This paper presents a methodology for identifying incompatible REF in a grouping, based on determining REF susceptibility to ground sources of radio interference. The term “comprehensive” is understood as a methodology accounting for impact of radio interference of various types operating in different spatial directions, as well as accounting for the conditions of radio wave propagation in the area where REFs are used, with due consideration of the terrain relief.

To identify incompatible REFs, it is necessary to determine the EMC compliance conditions between an REF – recipient of radio interference (hereinafter – recipient) and a grouping of REFs – radio interference sources (hereinafter – source). There are several methods for solving this problem [3]:

1) the *frequency separation method*, implying selection of REF operating (carrying) frequencies for ensuring REF EMC, is the most commonly known and widely used. Calculation of the necessary frequency separation becomes complicated in the presence of a large number of spurious radio emissions of sources and spurious receiving channels of recipients;

2) the *time division method*, under which time intervals of REF operation are selected for ensuring REF EMC. For evaluation of source interference impact on the recipient, information about exposure time is required;

3) the *geographical (spatial) separation method*, making provision for REF arrangement in a territory and/or in space so as to ensure REF EMC.

In addition to the above methods, their combinations are applied (time-frequency separation, frequency-geographical separation, and others). The time division method is implemented under availability of the hardware potential provided for at the REF development stage. This paper focuses on the frequency and geographical separation methods.

We shall introduce the following designations for technical characteristics of the recipient (currently operating facility) and the source (newly introduced facility) of radio interference:

• $P_{прм}(f)$ – radio receiver sensitivity in the main and minority receiving channels at recipient frequency f;

• $G_{прм}(\alpha_{прд}, \beta_{прд})$ – recipient receiving antenna gain factor in the direction towards a source located at $\alpha_{прд}$ in azimuth and $\beta_{прд}$ in elevation;

• $h_{прм}$ – antenna height relative to recipient ground level;

• $P_{прд}(f)$ – radio transmitter output power at the main and spurious emission frequencies at source frequency f;

• $G_{прд}(\alpha_{прм}, \beta_{прм})$ – source antenna gain factor in the direction towards recipient located at $\alpha_{прм}$ in azimuth and $\beta_{прм}$ in elevation;

• $h_{прд}$ – antenna height relative to source ground level.

For solving the problem of determining recipient EMC compliance conditions, we suggest using one of the two approaches.

The first approach is applied when one or two sources are located in the area of recipient operations and is based on determining a geographical gap between radio interference recipient and its source. The geographical gap is understood as the distance between recipient and source in all azimuthal directions of a given terrain area beyond the limits of which the source does not produce interfering radio emissions for the recipient. Hence, to determine the geographical gap it is necessary to find relationship $d(\alpha_{прм})$ under constant values of $P_{прд}$ and $h_{прд}$.

Information on the EMC conditions of the above REFs can be obtained by considering difference q(dB) between the power of radio interference from source, acting at the recipient radio receiver input, and recipient susceptibility threshold:

$$q = P_{прд}(f) + G_{прд}(f, \alpha_{прм}, \beta_{прм}) - L(f, d, \alpha_{прм}, p) - P_{прм}(f) + G_{прм}(f, \alpha_{прд}, \beta_{прд}) + F(\Delta f), \quad (1)$$

where $L(f, d, \alpha_{прм}, p)$ – basic energy losses during radio waves propagation from radio interference source, located at distance d and at azimuth $\alpha_{прм}$ (dB), to its recipient, without accounting for antenna’s directional properties;

p – percentage of time relative to full observation interval (averaged year) during which the basic energy losses $L(d, \alpha_{прм}, p)$ are not exceeded [4];

$F(\Delta f)$ – coefficient determined by frequency separation Δf and radio signal bandwidths of source and recipient, respectively [5].

For studying the impact of radio interference whose frequencies lie outside of the main receiving channel frequency band, we should substitute in expression (1) the values of susceptibility levels by intermodulation, gain locking and spurious receiving channels instead of $P_{прм}(f)$.

Each component in the right-hand part of expression (1) is a function of one or more arguments. It lacks the argument of the functions of antenna gain factors that characterises the polarisation properties, since it is presumed that both antennas are of the same polarisation type, which is the worst case from the viewpoint of REF EMC.

The REF EMC compliance condition is satisfied if $q < 0$. If $q \geq 0$, then, to achieve REF interference-free functioning, it is necessary to change the arguments of functions in expression (1). As it is exactly the geographical gap that is considered in this paper, it is necessary to find such value of d at which $q < 0$. The values of functions $P_{прд}(f)$ and $P_{прм}(f)$ are constant, and $G_{прд}(f, \alpha_{прм}, \beta_{прм})$ and $G_{прм}(f, \alpha_{прд}, \beta_{прд})$ practically do not change depending on d for a given azimuthal direction. Then, assuming $q = 0$ and taking into account expression (1), we can determine the required basic energy losses during radio waves propagation $L_{треб}$ (дБ):

$$L_{треб} = P_{прд}(f) + G_{прд}(f, \alpha_{прм}, \beta_{прм}) + G_{прм}(f, \alpha_{прд}, \beta_{прд}) - P_{прм}(f). \quad (2)$$

| ISSN 2542-0542 Journal of “Almaz – Antey” Air and Space Defence Corporation | No. 4, 2017

The required basic energy losses during radio waves propagation are determined by a given terrain area and can be predicted for a given value of p (%) with the use of recommendations of the International Telecommunications Union (ITU), in particular, ITU-R P.452-16 “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”. The recommendations are applicable to frequencies within a range of 0.1…50 GHz in all zones of the world and for all communication route types, they are sufficiently universal and account for the following mechanisms of radio interference propagation: optical visibility, diffraction, tropospheric scattering, surface waveguides, reflection and refraction from elevated layer, dispersion in precipitation [4].

Hence, it is necessary to determine d value at which $L(f, d, \alpha_{прм}, p) = L_{треб}$, i.e. to express the magnitude of d via expression for $L(f, d, \alpha_{прм}, p)$, as determined in the recommendations and designated as L_b. However, the equation linking d and $L(f, d, \alpha_{прм}, p)$ is a transcendental one and cannot be resolved by algebraic methods. To resolve it, we shall use the graphical method of approximate (in practice, no high accuracy is normally required) solution [6]. Arguments f, $\alpha_{прм}$, and p are not involved in the consideration, therefore we omit them so as to simplify notation. To determine graphically approximated value of real roots of the considered equation, we shall plot a graph of function $L(d)$ and find the abscissae of d_1, d_2, ..., d_j points of this graph intersection with axis $0d$, where j – roots of the equation being resolved. The value of transmission basic losses for a real route does not follow a strong correlation, when with an increase of distance d losses $L(d)$ increase too, and, accordingly, $j = 1$. As a result, the sought value of d at which REF EMC compliance is ensured will be the greatest of the found values of d_j.

As an investigated plot of terrain, an area was selected and, using a topographic database (according to Google mapping data for 2017), terrain elevations (above the mean sea level) were determined along the route from recipient to source along the great-circle arc within a radius of 300 km, arranged in all azimuthal directions with an angular increment of 1°.

Fig. 1 shows a graph of $L(d)$ dependence, plotted for one of the terrain segments. As an example, the value $p = 0.001$ % of time is used. The abscissae of the points of graph intersection with axis are $d_1 = 210$ km, $d_2 = 211$ km, $d_3 = 243.5$ km, $d_4 = 250$ km, $d_5 = 256.5$ km, $d_6 = 267$ km (see Fig. 1). The sought distance, i.e. a distance at which there will knowingly be no radio interference effects, for a given $\alpha_{прм}$ is $d = d_6 = 267$ km. The magnitude $p = 0.001$ % shows the percentage of time in relation to the full interval of observations (averaged year) during which the value of

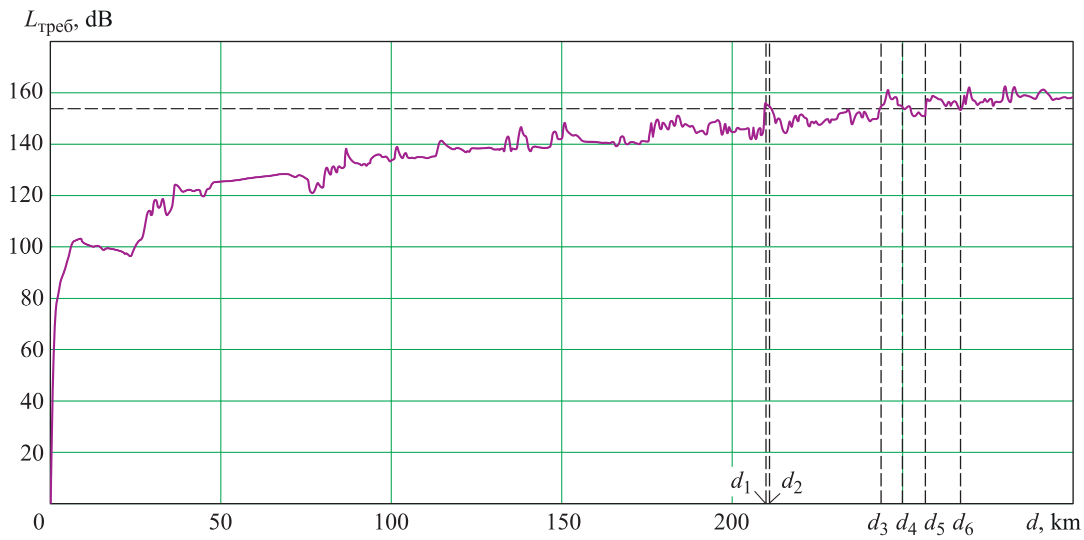

Fig. 1. Dependence of the magnitude of basic energy losses in radio waves propagation from source on distance d

basic energy losses in radio waves propagation $L(d)$ does not exceed the magnitude of 154 dB indicated on the ordinate axis.

Similar calculations have to be repeated for all azimuthal directions $\alpha_{прд}$. Fig. 2 shows the found dependence for a given terrain segment in the polar coordinates system. The coordinate origin is aligned with the recipient location point. The radial coordinate corresponds to d, distance between recipient and source. The angular coordinate, reckoned clockwise, corresponds to the value of azimuth $\alpha_{прд}$.

The red line in Fig. 2 designates a geographical gap zone around recipient (currently active REF) beyond the limits of which a source (newly deployed REF) does not produce interfering radio emissions exceeding tolerable level. It means that the REF EMC compliance condition $q < 0$ is satisfied there. Source arrangement

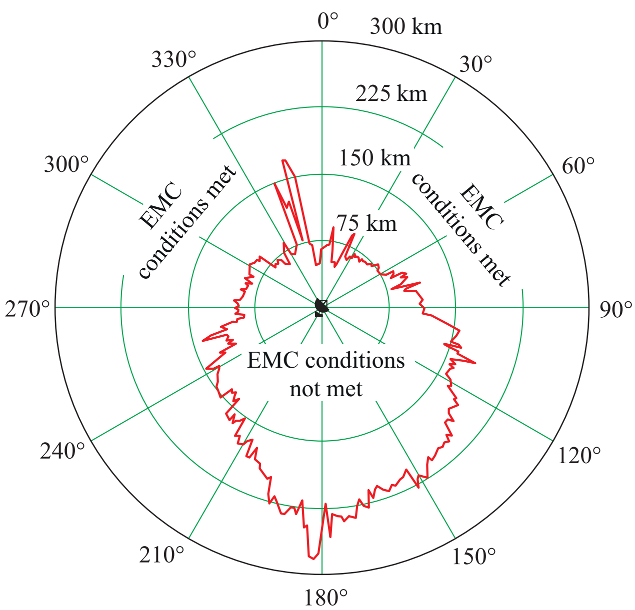

Fig. 2. Dependence of distance d between recipient and source on azimuthal direction $\alpha_{прд}$ for a given terrain segment

in azimuthal directions $\alpha_{прд}$ is approximately 105°…240° and must be at the maximum distance from recipient, which corresponds to the main lobe area of recipient's antenna radiation pattern (ARP); in the azimuthal directions of 270°…360° and 0°…90° – at the minimum distance, which corresponds to the area of recipient's ARP back lobes. In this way, the geographical gap zone is determined, in the first instance, by the recipient's ARP, which corresponds to formula (2). Function $G_{прм}(f, \alpha_{прд}, \beta_{прд})$ is determined by means of ARP.

To determine dependence $d(\alpha_{прд})$ for any other i-th source, it is necessary to rewrite expression (2) as follows:

$$L_{треб\_i} = P_{прд\_i}(f) + G_{прд\_i}(f, \alpha_{прм}, \beta_{прм}) - P_{прд}(f) - G_{прд}(f, \alpha_{прм}, \beta_{прм}) + L_{треб}. \quad (3)$$

For clarity, we shall distinguish in expression (3) the magnitudes that represent the equivalent isotropically radiated power (EIRP). Then

$$L_{треб\_i} = EIRP_i(f, \alpha_{прм}, \beta_{прм}) - EIRP(f, \alpha_{прм}, \beta_{прм}) + L_{треб}, \quad (3')$$

where $EIRP_i(f, \alpha_{прм}, \beta_{прм})$ – EIRP of the i-th source (dBW);

$EIRP(f, \alpha_{прм}, \beta_{прм}) = P_{прд}(f) + G_{прд}(f, \alpha_{прм}, \beta_{прм})$ – EIRP of a source for which dependence $d(\alpha_{прд})$ (dBW) was determined.

Fig. 3 shows dependence $d(\alpha_{прд})$ for different sources with different EIRP. With source EIRP increase (decrease), the geographical gap zone increases (decreases), but not proportionally. It is associated with the fact that dependence $L_{треб}(d)$ has several "local" maxima across the d_j interval (see Fig. 1).

Fig. 4 shows dependence $d(\alpha_{прд})$ for p equal to 50 %, 1 % and 0.001 %. With a decrease of time percentage, the magnitude not exceeded by the basic energy losses during radio waves propagation decreases too and, accordingly, the necessary distance $d(\alpha_{прд})$ increases. Moreover, in some azimuthal directions (from 150° to 190°) the necessary distance increases from 150 to 300 km. For guaranteed compliance with the REF EMC conditions it is recommended to take the minimum value of p (%).

The second approach to solving the problem of determining compliance conditions of recipient EMC with a source is applied when the number of sources is more than two. When using this approach, the maximum tolerable EIRP of a source (newly deployed REF) is determined, depending on the distance to recipient (currently

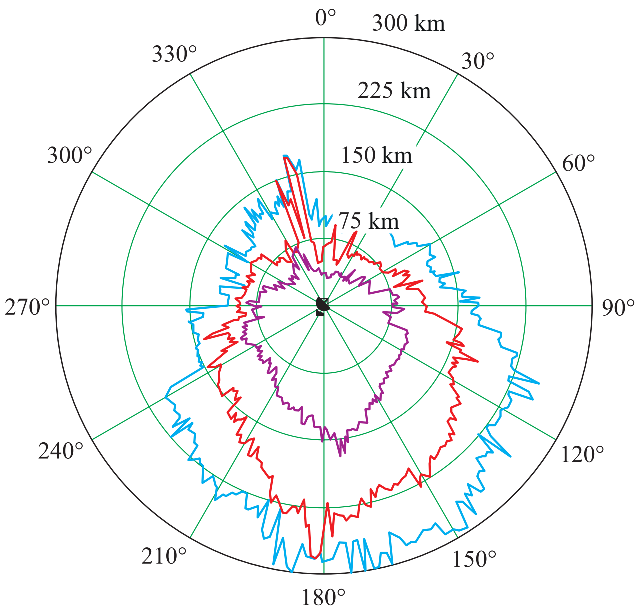

Fig. 3. Dependence of distance d between recipient and the i-th source on azimuthal direction $\alpha_{прд}$ for a given terrain segment:
— – $EIRP_1$ = 0 dBW; — – $EIRP_2$ = 10 dBW;
— – $EIRP_3$ = 16 dBW

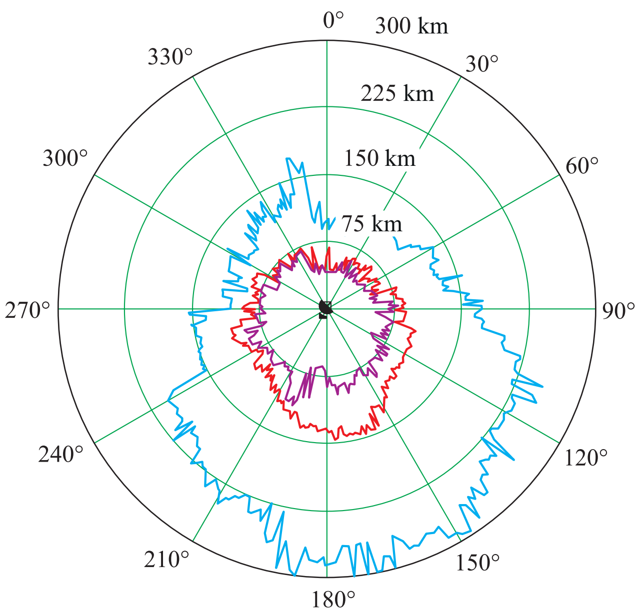

Fig. 4. Dependence of distance d between recipient and source on azimuthal direction $\alpha_{прд}$ for a given terrain segment:
— – p = 50 %; — – p = 1 %; — – p = 0.001 %

active REF), for a certain azimuthal direction in a given terrain segment, at which EIRP no interfering radio emissions for the recipient are produced. It is necessary to determine dependence $EIRP(d)$ at constant values of $\alpha_{прд}$ and $h_{прд}$. For that, assuming $q = 0$, we rewrite expression (1) as follows:

$$EIRP(f, \alpha_{прм}, \beta_{прд}) = P_{прд}(f) - G_{прм}(f, \alpha_{прд}, \beta_{прд}) + L(f, d, \alpha_{прм}, p), \quad (4)$$

where $EIRP(f, \alpha_{прм}, \beta_{прм}) = P_{прд}(f) - G_{прд}(f, \alpha_{прм}, \beta_{прм})$.

Shown in Fig. 5 in the polar coordinate system are the found values of $EIRP(d)$ for a given terrain segment. The EIRP values are represented by the colours: blue – for the minimum values, red – for the maximum ones. Also, zone shown in Fig. 3 for $EIRP_2$ = 10 dBW is outlined in the figures with a dashed line.

It should be noted that, apart from the recipient's ARP, specific relief features of a given terrain segment are revealed (see Fig. 5). Source locations in azimuthal directions $\alpha_{прд}$ from 285° to 360° are most appropriate for meeting the EMC conditions. This is due with the fact that the given area has an undulating relief with elevation changes, with such mechanisms

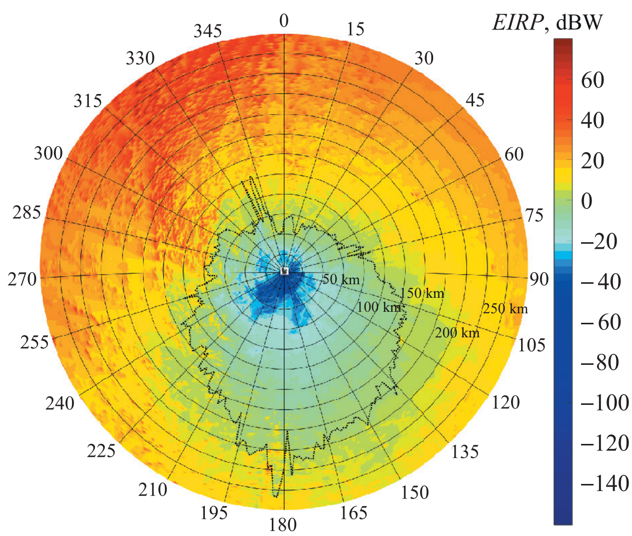

Fig. 5. Dependencies of $EIRP(d)$ for a given terrain segment

of radio interference propagation as diffraction prevailing. Within a pre-determined interference impact zone, there are small areas where compliance with the EMC conditions is possible, which testifies to non-homogeneity of the radio wave propagation environment due to the terrain relief influence.

The proposed comprehensive methodology for identifying incompatible REFs in a grouping has found practical application and proved its effectiveness. Using the findings obtained, it can be feasible to determine:

• required parameters of the frequency-geographical separation;

• basic data for a plan of ensuring REF EMC for state and military management systems at the federal level (central plan), plans of ensuring EMC of REFs used by the federal executive power bodies within the boundaries of military command regions (regional plans), as well as a yearly plan of introducing temporary prohibitions (restrictions) on using radioelectronic facilities at the time of carrying out works and activities of high importance;

• a necessity for REF upgrade so as to improve frequency selectivity characteristic and raise interference resistance degree.

Given the availability of dynamic data on the real electromagnetic environment in REF operations area, it can be possible to obtain in real time information on REFs producing intolerable interference effects.

The materials of the presented work will be used in subsequent promising directions of research:

• development of 3D models for determining REF EMC conditions with account for impacts from aerodynamic and outer space sources of radio interference;

• evaluation of the degree of REF combat potential deterioration under various electronic countermeasures;

• development of efficient models for enemy's REF suppression.

Part of the research for this paper was carried out by A. V. Pilkov with support by the grant of the President of the Russian Federation NSh-6831.2016.8.

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Submitted on 05.12.2017

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Комплексная методика выявления несовместимых радиоэлектронных средств в группировке

Представлена комплексная методика выявления несовместимых радиоэлектронных средств в группировке, которая учитывает влияние радиопомех различного типа, действующих с разных пространственных направлений, и особенности распространения радиоволн в районе использования радиоэлектронных средств. При учете полученных результатов представляется возможным определять план обеспечения электромагнитной совместимости при проектировании радиоэлектронных средств, а также в реальном времени получать данные о радиоэлектронных средствах, оказывающих недопустимые помеховые воздействия при наличии исходных данных о реальной электромагнитной обстановке в районе использования радиоэлектронных средств.

Ключевые слова: условие электромагнитной совместимости, радиоэлектронные средства, частотно-территориальный разнос, распространение радиоволн, реальная электромагнитная обстановка, зона территориального разноса.

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