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Low-Frequency Satellite Communication System Technical Means' Parameters Synthesis by the Requirements for Energetic Concealment and Noise Immunity[1]

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Abstract—The method of technical means parameters synthesis by the requirements for energetic concealment and noise immunity has been developed for satellite communication systems that use reduced (down to 30–100 MHz) carrier frequencies and dual antennae diversity. It allows to calculate the dependence of board transmitter's emitting power, transmission speeds and transmitted signals' carrier frequency on the signal reception error probability allowed values, radio link's energetic reserve and the energetic concealment coefficient.

Keywords: satellite communication system, noise immunity, energetic concealment, lowered frequencies, dual antennae diversity, technical means' parameters

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1. INTRODUCTION

It is known [1, 2] that radio waves with carrier frequency $f_0 > 30$ MHz will pass through Earth's Ionosphere into outer space. However, in satellite communication systems (SCS) much higher frequencies $f_0 = 1$–10 GHz are usually used. This is explained by the fact that lowering f_0 (especially down to $f_0 < 100$ MHz) is followed by the increase of Ionosphere's influence on radio wave propagation (RWP) and by the requirement to increase the minimum allowed signal/noise ratio (h^2_{req}) to provide the required error probability values ($P_{\text{err req}}$) of signals in SCS. The analysis of transionospheric RWP's factors has shown that the most significant impact on lowering the SCS noise immunity (increase of h^2_{req} when $P_{\text{err req}} = \text{const}$) is caused by received signals amplitude fluctuations (fading, flickering) which, in turn, are caused by dispersion of radio waves on Ionospheric inhomogeneity [3–9]. In order to battle fading to increase noise immunity (lowering h^2_{req}) multiple antennae ($n \geq 2$) signal diversity may be used [10]. Where in SCS the application of lowered carrier frequency values (down to $f_0 = 30$–100 MHz) with simultaneous implementation of space-diversity radio signal reception in Artificial Earth Satellite (AES)—Earth region allows to achieve very high energetic concealment (more than 20–30 dB) with closely-placed (less than 10 km) radio interception receiver [11–14]. This is explained by the fact that the radioprospecting receiver (placed closely to the SCS receiver) cannot use several diverse antennae, and with a single antenna reception ($n = 1$) of fading signals, the allowed signal/noise ratio ($h^2_{\text{req 1}}$) may be 20 dB more than with, for example, dual antennae ($n = 2$) signal reception ($h^2_{\text{req 1}}$). Therefore, the actual signal/noise ratio at the radioprospecting receiver may be 20 dB lower than the allowed value, which indicates the possibility of providing energetic concealment of SCS.

Still, to implement the conditions of providing the required noise immunity for low-frequency SCS when using dual antennae ($n = 2$) signal reception, there may be a necessity of choosing the technical

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means with improved characteristics (AES transmitter input power, transmitting and receiving antennae amplification factor, transmission speed, AES—Earth radio link energetic reserve).

The purpose of this research is to develop a method for technical means parameters synthesis by the requirements for energetic concealment and noise immunity when using lowered frequencies and dual antennae signal reception.

2. TECHNICAL MEANS' PARAMETERS SYNTHESIS

The condition of achieving SCS noise immunity ($h^2 \geq h^2_{\text{req}}$) is exceeding the actual signal/noise ratio on the transmitter input (h^2) compared to the allowed value (h^2_{req}) [12–14]. The latter is determined using the functional (ψ) dependence $P_{\text{err}} = \psi(h^2)$ of signal reception error probability on signal/noise ratio on the transmitter's input with the required (allowed) error probability value $P_{\text{err}} = P_{\text{err req}}$ (usually $P_{\text{err req}} = 10^{-5}$ for SCS). The SCS noise immunity condition ($h^2 \geq h^2_{\text{req}}$) may be presented as the equation $h^2 = h^2_{\text{req}}\,\Gamma$, where $\Gamma \geq 1$ is the SCS energetic reserve for non-considered factors (usually $\Gamma = 1$–10 dB).

The actual signal/noise ratio on the SCS transmitter input in the lowered frequencies range $f_0 \approx 30$–100 MHz is determined as [11–14]

$$h^2 = P_t G_t(f_0) G_r(f_0) / L_0(f_0) L_L(f_0) k_{\text{B}} T_e(f_0) R_T, \tag{1}$$

where P_t—signal transmission power, W; $G_t(f_0)$ and $G_r(f_0)$—transmitting and receiving antennae amplification coefficients; $L_0(f_0)$—main transmission losses in free space; $L_L(f_0)$—additional transmission losses caused by adsorption in propagation medium (ionosphere); $k_{\text{B}} = 1.38 \times 10^{-23}$ $(\text{J/K} = \text{W}/(\text{Hz K}))$—Boltzmann constant; $T_e(f_0)$—equivalent noise temperature of the reception system (i.e. of the receiver and of the receiving antenna), measured in Kelvin (K); $R_T = 1/T_S$—transmission speed in bit/s (where T_S—signal duration in seconds, s).

In the frequency range of $f_0 \approx 30$–100 MHz the most commonly used antennas both for reception and transmission are the directional (beam) type ones (wave channel), the amplification coefficient of which is directly proportional to the choice of the carrier frequency f_0 (Hz) and the transmitting L_{At} (m) and receiving L_{Ar} (m) antenna length [15]:

$$G_{t,r} \approx 7 L_{At,r} f_0 / c = k_A L_{At,r} f_0\,, \tag{2}$$

where 3×10^8 m/s—speed of light; $k_A \approx 7/c \approx 2.33 \times 10^{-8}$ s/m.

The main distance transmission losses z_0 in free space are also proportionally dependent on the carrier frequency choice f_0 (Hz):

$$L_0 = (4\pi\ z_0 f_0 / c)^2 = (k_0 z_0 f_0)^2, \tag{3}$$

where $k_0 \approx 4\pi/c \approx 4.19 \times 10^{-8}$ s/m.

Then, considering (1)–(3), when lowering the carrier frequency down to $f_0 \approx 30$–100 MHz and utilizing dual antennae ($n = 2$) signal reception (when $h^2_{\text{req}} = h^2_{\text{req}}(f_0)$, the condition of achieving SCS noise immunity ($h^2 = h^2_{\text{req}}\Gamma$) may be expressed as:

$$h^2(f_0) = \frac{P_t L_{At} L_{Ar} k_A^2 / R_T}{z_0^2 k_0^2 L_L(f_0) k_{\text{B}} T_e(f_0)} = \frac{P_t L_{At} L_{Ar} / R_T}{z_0^2 k_\Sigma L_L(f_0) T_e(f_0)} = h^2_{\text{req}\,2}(f_0)\Gamma, \tag{4}$$

where

$$k_\Sigma = \left(k_0^2 / k_A^2\right) k_{\text{B}} \approx [(4\pi/c)/(7/c)]^2\, 1.38 \times 10^{-23}\ \text{W/(Hz K)} \approx 4.44 \times 10^{-23}\ \text{W}/(\text{Hz K}),$$

constant coefficient with the same dimension as the Boltzmann constant: $\text{W}/(\text{Hz K})$.

Analysis of the SCS noise immunity condition (4) when using lowered frequency and dual antennae signal reception shows that with typical values $h^2_{\text{req}\,2} = 27$ dB; $\Gamma = 1$–10 dB; $R_T \approx 10^5$–10^6 bit/s and typical parameters of the left part of (4) on the frequency $f_0 \approx 60$ MHz [15, 16]: $G_{t,r}(f_0) = k_A L_{At,r} f_0 \approx 5$ dB; $L_L(f_0)$ ~1–20 dB; dB; $T_e(f_0) \sim 10^5$ K it is necessary to provide the board transmitter's transmission power of $P_t \sim 0.5–50$ kW, which is practically unachievable.

Hence, the conclusion about presence of the following practical problem can be made: when using lowered carrier frequency ($f_0 \approx 30–100$ MHz) and space-diverse signal reception on two antennae ($n = 2$) in SCS, the condition of achieving SCS noise immunity $\left(h^2(f_0) = h^2_{\text{req 2}}(f_0)\Gamma\right)$ may not be accomplished with the energetic (system) reserve $\Gamma = 1–10$ dB and the implemented technical characteristics of radio communication means: transmitter power $P_t < 10^2–10^3\ W$, size of the transmitting and receiving director-type antennae $L_{\text{A}t,r} < 10$ m, transmission speed $R_T = 10^5–10^6$ bit/s.

This condition is easier to achieve on higher frequencies ($f_0 > 100$ MHz), where, due to inverse proportionality to f_0, the losses on wave absorption in ionosphere [9, 12] $L_L(f_0) \sim 1/f_0^2$, noise temperature of external noises [16] $T_e(f_0) \sim 1/f_0^{2.4}$ and the allowed signal/noise ratio [14, 17] $h^2_{\text{req 2}}(f_0) \sim 1/f_0$ on the SCS receiver's input may be significantly lower. However, increasing the SCS carrier frequency lowers its energetic concealment. This is caused by the following considerations.

Communication system's energetic concealment from radio interception is characterized by the relation $\gamma_e = h^2_{\text{req p}}/h^2_{\text{p}}$ of the allowed signal/noise ratio on the radio interception receiver's input ($h^2_{\text{req p}}$) to the actual signal/noise ratio (h^2_{p}) [11, 12]. Wherein, energetic concealment in the communication system is provided if the actual signal/noise ratio on the radio interception receiver's input is lower than the allowed ratio ($h^2_{\text{p}} < h^2_{\text{req p}}$ or $\gamma_e = h^2_{\text{req p}}/h^2_{\text{p}} > 1$). Energetic concealment coefficient for SCS using lowered frequencies and dual antennae signal reception diversity ($n = 2$) may be presented as $\gamma_e = h^2_{\text{req p}}/h^2_{\text{p}} = h^2_{\text{req 1}}/h^2_{\text{req 2}}\Gamma$, where $h^2_{\text{req p}} = h^2_{\text{req 1}}$ – allowed signal/noise ratio on the single antenna ($n = 1$) radio interception receiver's input; $h^2_{\text{p}} \approx h^2 = h^2_{\text{req 2}}\Gamma$ – actual signal/noise ratio on the radio interception receiver's input, which is closely placed (less than 10 km) to the dual antennae ($n = 2$) SCS receiver with the actual signal/noise ratio of $h^2 = h^2_{\text{req 2}}\Gamma$.

Considering the dependence on the carrier frequency choice, energetic concealment coefficient of the SCS, which uses dual antennae signal reception diversity, is determined as $\gamma_e(f_0) = h^2_{\text{req 1}}(f_0)/h^2_{\text{req 2}}(f_0)\Gamma$. Analysis of this expression shows [12] that with the lowest carrier frequency $f_0 \approx 30$ MHz, which causes almost Rayleigh fading of the received signals, the allowed signal/noise ratio on the incoherent receiver with single antenna is $h^2_{\text{req 1}}(f_0) \approx 50$ dB, and with two antennae $h^2_{\text{req 2}}(f_0) \approx 27–30$ dB. On traditional SCS for the carrier frequencies $f_0 \gg 100$ MHz fading of received signals is absent and utilization of dual antennae signal reception diversity provides 3 dB more than allowed signal/noise ratio on the receiver's input compared to single antennae incoherent signal reception ($h^2_{\text{req 2}}(f_0) \approx 10$ dB; $h^2_{\text{req 1}}(f_0) \approx 13$ dB). Thereby, as the carrier frequency increases, the allowed signal/noise ratio on the interception receiver's input $h^2_{\text{req 1}}(f_0)$ decreases faster than on the SCS receiver's input $h^2_{\text{req 2}}(f_0)$. Therefore, as the carrier frequency increases, SCS energetic concealment coefficient $\gamma_e(f_0) = h^2_{\text{req 1}}(f_0)/h^2_{\text{req 2}}(f_0)\Gamma$ decreases (while SCS noise immunity increases). This exact contradiction has led to formulation of the aforementioned purpose of the research.

When utilizing lowered frequencies and dual antennae signal reception diversity, the core of SCS technical means' parameters synthesis method consists of the developed technique of choosing lowered frequency and parameters of technical means by the requirements for SCS energetic concealment and noise immunity. The point of this technique is presented in the following:

(1) The condition of providing low-frequency SCS energetic concealment, consisting in exceeding the energetic concealment coefficient ($\gamma_e = h^2_{\text{req p}}/h^2_{\text{p}} = h^2_{\text{req 1}}/h^2_{\text{req 2}}\Gamma$) over the allowed value ($\gamma_e \geq \gamma_{e\ \text{req}}$), is presented in decibels as:

$$\gamma_e(f_0)_{\text{dB}} = h^2_{\text{req 1}}(f_0)_{\text{dB}} - h^2_{\text{req 2}}(f_0)_{\text{dB}} - \Gamma_{\text{dB}} \geq \gamma_{e\ \text{req dB}}. \tag{5}$$

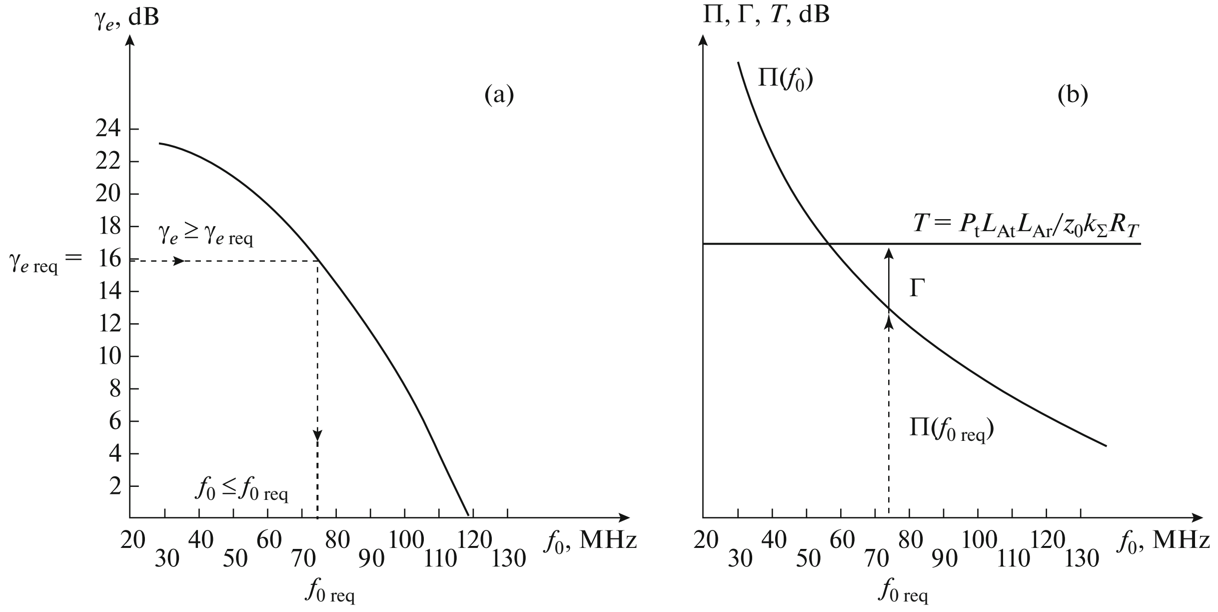

Fig. 1. Choosing lowered carrier frequency ($f_{0\,\rm req}$) and technical means parameters (T) by the requirements for satellite communication system energetic concealment (a) and noise immunity (b).

(2) In conformity with the frequency dependencies $h^2_{\rm req\,1}(f_0)_{\rm dB}$ and $h^2_{\rm req\,2}(f_0)_{\rm dB}$ a graph can be composed that shows the dependence $\gamma_{e\,\rm dB} = \psi(f_0)$ of SCS energetic concealment coefficient on choosing the carrier frequency with respect to energetic reserve Γ (its qualitative aspect is shown on the Fig. 1a, which depicts the formally justified dependency between lowering γ_e and raising f_0).

(3) By the requirements for SCS energetic concealment ($\gamma_{e\,\rm req}$) it is possible to determine (see the Fig. 1a) the maximum allowed carrier frequency value ($f_{0\,\rm req}$) and the range of lowered frequencies ($f_0 \leq f_{0\,\rm req}$), in which the requirements for energetic concealment are fulfilled ($\gamma_e \geq \gamma_{e\rm req}$).

(4) The condition of achieving SCS noise immunity (4) may be presented in decibels through difference of actual and allowed signal/noise ratio on the SCS receiver's input, or through difference of generalized technical (T) parameter, which does not depend on the carrier frequency, and frequency-dependent (Π) parameter:

$$h^2(f_0)_{\rm dB} - h^2_{\rm req\,2}(f_0)_{\rm dB} = T_{\rm dB} - \Pi(f)_{\rm dB} = \Gamma_{\rm dB}, \tag{6}$$

where generalized technical and frequency-dependent parameters are determined as

$$T = P_t L_{At} L_{Ar} \Big/ z_0^2 R_T k_\Sigma\,, \tag{7}$$

$$\Pi(f_0) = L_L(f_0) T_e(f_0) h^2_{\rm req\,2}(f_0). \tag{8}$$

Wherein, the allowed signal/noise ratio on the SCS receiver's input with dual antennae ($n = 2$) signal reception diversity depends on the requirements to noise immunity ($P_{\rm err\,req}$), Rician fading distribution $\gamma^2(f_0)$ of the received signals and their correlation coefficient $R(f_0, \Delta\rho)$ in receiving antennae, which is determined by the frequency choice (f_0) and the antennae diversity ($\Delta\rho = \Delta\rho_A$) [17]:

$$h^2_{\rm req\,2}(f_0) = \Psi\left[P_{\rm err\,req},\ \gamma^2(f_0),\ n = 2, R(f_0, \Delta\rho_A)\right]. \tag{9}$$

(5) According to the expression (8), a graph can be composed that shows the dependence of the parameter $\Pi_{\rm dB}$ on the carrier frequency choice f_0 (its qualitative aspect is shown on the Fig. 1b).

(6) For the found allowed carrier frequency value ($f_{0\,\mathrm{req}}$) and the required energetic reserve (Γ), the following values are determined (see the Fig. 1b): allowed frequency-dependent parameter value $\Pi(f_{0\,\mathrm{req}})$ and generalized technical parameter value: $T = P_t L_{\mathrm{A}t} L_{\mathrm{A}r} \big/ z_0^2 R_r k_\Sigma$.

(7) By the generalized technical parameter value the technical means parameters are chosen (P_t, L_{At}, L_{Ar}, R_T).

Based on the developed technique a method for technical means parameters synthesis by the requirements for energetic concealment and noise immunity when using lowered frequencies and dual antennae signal reception diversity has been explained.

The required scientific result is to obtain the functional dependence of technical means parameters (P_t, L_{At}, L_{Ar}, R_T), antennae diversity ($\Delta\rho_A$) with dual antennae ($n = 2$) signal reception and lowered carrier frequency (f_0) on the requirements to SCS energetic concealment ($\gamma_{e\,\mathrm{req}}$) and noise immunity ($P_{\mathrm{err\,req}}, \Gamma$)

$$\{P_t, L_{At}, L_{Ar}, R_T, n = 2, \Delta\rho_A, f_0\} = \psi(\gamma_{e\,\mathrm{req}}, P_{\mathrm{err\,req}}, \Gamma). \tag{10}$$

Method for technical means parameters synthesis by the requirements for energetic concealment and noise immunity when using lowered frequencies and dual antennae signal reception diversity with the purpose of obtaining the scientific result (10) consists of 5 stages:

On the first stage the dependence of low-frequency, dual antennae signal reception diversity SCS energetic concealment coefficient on the carrier frequency choice $\gamma_e(f_0) = h^2_{\mathrm{req}\,1}(f_0) \big/ h^2_{\mathrm{req}\,2}(f_0)\,\Gamma$ is concretized in the following form:

$$\gamma_e(f_0) = \left[\frac{1 - R^2(f_0)}{3P_{\mathrm{err\ req}}}\right]^{0.5} \exp\left[-\frac{\gamma^2(f_0)R(f_0)}{1 + R(f_0)}\right]\Gamma^{-1}, \tag{11}$$

where $\gamma^2(f_0)$ and $R(f_0)$—dependencies the on Rician fading distribution of the received signals carrier frequency choice and on the fading correlation coefficient in diverse antennae.

On the second stage by the requirement of achieving SCS energetic concealment no worse than allowed ($\gamma_e \geq \gamma_{e\,\mathrm{req}}$), the lowered frequencies range is determined ($f_0 \leq f_{0\,\mathrm{req}}$). With this purpose, the condition $\gamma_e(f_0) \geq \gamma_{e\,\mathrm{req}}$, according to (11), while maintaining the allowed fading correlations in diverse antennae $R(f_0) = R_{\mathrm{req}}$ is expressed as:

$$\gamma_e(f_0) = \left(\frac{1 - R^2_{\mathrm{req}}}{3P_{\mathrm{err\,req}}}\right)^{0.5} \exp\left[-\frac{\gamma^2(f_0)R_{\mathrm{req}}}{1 + R_{\mathrm{req}}}\right]\Gamma^{-1} \geq \gamma_{e\,\mathrm{req}}, \tag{12}$$

where the Rician fading distribution in low-frequency SCS is determined only by the dispersions phase fluctuations in wave front on the output of inhomogeneous ionosphere $\sigma^2_\phi(f_0)$ as [2, 5, 11–14, 17]

$$\gamma^2(f_0) = \left\{\exp\left[\sigma^2_\varphi(f_0)\right] - 1\right\}^{-1}. \tag{13}$$

Standard deviation (SD) of phase fluctuations in the output wave front is described by the expression [18, 19]

$$\sigma_\varphi \approx 80.8\pi\sigma_{\Delta N_T} \big/ cf_0 \ (\mathrm{rad}), \tag{14}$$

where 80.8—coefficient with the dimensionality $\left[\mathrm{m}^3 \big/ \mathrm{s}^2\right]$; $c = 3 \times 10^8$ m/s—speed of light; $\sigma_{\Delta N_T}$—SD of ionosphere total electron content (TEC) [el/m^2] small-scale variations; carrier frequency f_0 is expressed in [Hz].

According to (12), the condition of achieving SCS energetic concealment no worse than allowed may be expressed as:

$$\gamma^2(f_0) \leq \frac{1 + R_{\mathrm{req}}}{R_{\mathrm{req}}} \ln\left[\left(\frac{1 - R^2_{\mathrm{req}}}{3P_{\mathrm{err\,req}}}\right)^{0.5} (\Gamma\gamma_{e\,\mathrm{req}})^{-1}\right] = C_{\mathrm{req}}, \tag{15}$$

i.e. as non-exceedance of the Rice parameter $\gamma^2(f_0)$ over some maximum allowed value

$$C_{\text{req}} = \frac{1+R_{\text{req}}}{R_{\text{req}}}\ln\left[\left(\frac{1-R_{\text{req}}^2}{3P_{\text{err req}}}\right)^{0.5}\left(\Gamma\gamma_{e\text{ req}}\right)^{-1}\right]. \tag{16}$$

Since frequency-dependent Rice parameter $\gamma^2(f_0)$, according to the expression (13), is completely determined by wave front phase fluctuations dispersion with the carrier frequency f_0 on ionosphere exit $\sigma_\varphi^2(f_0)$, the condition (15) $\gamma^2(f_0) \le C_{\text{req}}$ takes the following form:

$$\exp\left[\sigma_\varphi^2(f_0) - 1\right] \ge C_{\text{req}}^{-1} . \tag{17}$$

This inequation may be expressed in form of exceeding SD for phasic wave front fluctuations at inhomogeneous ionosphere exit σ_φ over some allowed value $\sigma_{\varphi\text{ req}}$, which is determined by the coefficient C_{req}:

$$\sigma_\varphi(f_0) \ge \sqrt{\ln\left(C_{\text{req}}^{-1}+1\right)} = \sigma_{\varphi\text{ req}}, \tag{18}$$

which depends, according to the functional dependency (16) $C_{\text{req}} = \psi\left(\gamma_{e\text{ req}}, P_{\text{err req}}, \Gamma\right)$, on the noise immunity (i.e. the allowed signal reception error probability $P_{\text{err req}}$ and the radio link energetic reserve Γ) and the SCS energetic concealment ($\gamma_{e\text{ req}}$) requirements.

Considering the dependence (14) $\sigma_\varphi \approx 80.8\pi\sigma_{\Delta N_T}/cf_0$ of SD for phasic wave front fluctuations at inhomogeneous ionosphere exit σ_φ on the carrier frequency choice f_0, the requirement for SCS energetic concealment (18) may be expressed as the requirement to choose the carrier frequency lower than the allowed value ($f_0 \le f_{0\text{ req}}$):

$$f_0 \le 80.8\pi\sigma_{\Delta N_T}/c\sigma_{\varphi\text{ req}} = f_{0\text{ req}}. \tag{19}$$

Here the allowed carrier frequency value $f_{0\text{ req}} \sim \sigma_{\Delta N_T}/\sigma_{\varphi\text{ req}}$ is determined by SD of ionosphere TEC small-scale variations $\sigma_{\Delta N_T}$ (the amount of which may be measured using GPS-monitoring data for small-scale ionosphere inhomogeneity [19]) and by the allowed value for SD of phasic wave front fluctuations on inhomogeneous ionosphere exit ($\sigma_{\varphi\text{ req}}$), which depends, according to (16), (18), on the requirements for noise immunity ($P_{\text{err req}}$, Γ) and on SCS energetic concealment ($\gamma_{e\text{ req}}$):

$$\sigma_{\varphi\text{ req}} = \sqrt{\ln(C_{\text{req}}^{-1}+1)} = \psi(P_{\text{err req}}, \Gamma, \gamma_{e\text{ eq}}).$$

The expressions (16), (18), (19) allow to determine the maximum allowed carrier frequency value $f_{0\text{ req}}$ not with a graphical way (as shown on Fig. 1a), but with an analytical approach based on the given requirements for noise immunity ($P_{\text{err req}}$, Γ) and energetic concealment of the SCS, and on the ionosphere's inhomogeneity monitoring results ($\sigma_{\Delta N_T}$). Attention should be paid to the fact, that according to the derived expressions (16), (18), (19), as the allowed signal reception error probability ($P_{\text{err req}}$), the radio link energetic reserve (Γ) and the allowed SCS energetic concealment ($\gamma_{e\text{ req}}$) grow, the allowed SD for phasic wave front fluctuations at inhomogeneous ionosphere exit ($\sigma_{\varphi\text{ req}}$) also grows, but the minimum allowed carrier frequency value $f_{0\text{ req}} = \sigma_{\Delta N_T}/\sigma_{\varphi\text{ req}}$ declines.

On the third stage of the method a frequency-dependent parameter is determined by known dependencies of its three factors [9, 13, 14, 16], according to the expression (8) $\Pi(f_0) = L_L(f_0)T_e(f_0)h_{\text{req 2}}^2(f_0)$.

On the fourth stage, according to the SCS allowed noise immunity provision condition (6), which may be expressed as $T_{\text{dB}} = \Gamma_{\text{dB}} + \Pi(f_0)_{\text{dB}}$ using the frequency-dependent parameter $\Pi(f_0)$, its value on the allowed lowered frequency $\Pi\left(f_{0\text{ req}}\right)$, is found, and with required energetic reserve $\Pi\left(f_{0\text{ req}}\right)$, a generalized technical parameter $T_{\text{dB}} = \Gamma_{\text{dB}} + \Pi\left(f_{0\text{ req}}\right)_{\text{dB}}$ is determined, as shown on Fig. 1b.

On the fifth stage, by the generalized technical parameter value (7) $T = P_tL_{At}L_{Ar}/z_0^2R_Tk_\Sigma$, with determined communication distance $z_0 = 10^6–4\times10^7$ m, antennae diversity ($\Delta\rho_A$), and lowered carrier frequency ($f_{0\text{ req}}$), the SCS technical means parameters: (a) transmitter power (P_t); (b) transmitting and receiving antennae characteristics ($L_{At}L_{Ar}$); (c) transmission speed (R_T) are chosen.

3. CONCLUSION

The method, which allows to achieve the sought dependency for low-frequency ($f_0 \approx 30$–100 MHz), dual antennae signal reception diversity ($\Delta\rho_A$; $n = 2$) SCS technical means parameters (transmitter power P_t, transmitting L_{At} and receiving L_{Ar} directional antennae size, transmission speed R_T) synthesis has been developed by the specified requirements for energetic concealment ($\gamma_{e\,\mathrm{req}}$) and noise immunity ($P_{\mathrm{err\,req}}$, Γ).

The advantage of the suggested synthesis method compared to similar procedures is in the fact that the core of this method consists of the developed technique of choosing SCS lowered carrier frequency and technical means parameters by the contradicting requirements for energetic concealment and noise immunity. The core of the technique is in the fact that, firstly, the lowered frequency range is determined ($f_0 \le f_{0\,\mathrm{req}}$), in which the requirements for SCS energetic concealment ($\gamma_e \ge \gamma_{e\,\mathrm{req}}$) are fulfilled. Secondly, for the found allowed carrier frequency value ($f_{0\,\mathrm{req}}$), the generalized technical parameter value ($T = P_t L_{At} L_{Ar} / R_T$) is determined, which provides the means to fulfill the SCS noise immunity requirements ($P_{\mathrm{err\,req}}$, Γ).

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