

Characteristics of Electromagnetic Environment Created by Communication Low Earth Orbit Satellite Systems Near the Earth's Surface

Vladimir Mordachev^{#1}, Dzmitry Tsyenenka^{#2}, Aliaksandr Svistunou^{#3}

[#]EMC R&D Lab, Belarusian State University of Informatics and Radioelectronics, Belarus

¹mordachev@bsuir.by, ²tsiond@tut.by, ³emc@bsuir.by

Abstract — A technique is proposed for estimating the average intensity of the electromagnetic background (EMB) created near the earth's surface by a system of low earth orbit communication satellites, taking into account the number of satellites in the constellation, the satellite total radiated power and parameters of radiation in the main and side lobes, the orbit altitude and restrictions on the angle of service of ground-based equipment. Estimates of EMB levels at the earth's surface created by these systems indicate that with their full-scale deployment, the average level of artificial EMB of the SHF range at the earth's surface can exceed the average intensity of natural EMB by 10-12 orders of magnitude. Such a significant change in physical characteristics of the operating environment of ground-based technical systems and population habitat requires serious attention and further in-depth analysis.

Keywords — low earth orbit satellites, electromagnetic radiation, total radiated power, electromagnetic background.

I. INTRODUCTION

The observed deployment in the near-earth space of megaconstellations of low earth orbit communication satellites (Starlink, OneWeb, Astra, Kuiper, GuoWang, etc.) will increase by 2-3 orders of magnitude the number of low-orbit sources of SHF electromagnetic radiation (EMR) in the direction of the earth's surface and also will increase in the total density of downlink satellite communication area traffic capacity on the earth's surface, especially when integrating these satellite communication systems, which provide high speeds and relatively low delays in information transmission, with global 5G/6G mobile communication systems.

This alarms specialists who are concerned about both the obvious increase in the probability of collisions of satellites of various affiliations and the problem of "space debris" [1,2], and the expected complication of the electromagnetic environment (EME) near the earth's surface, which may cause interference for the operation of various terrestrial radio services that use frequency bands of satellite systems on a secondary basis, as well as aggravation of problems of electromagnetic safety of the population and electromagnetic ecology of the habitat [3,4].

The goal of this work is to develop a base methodology that makes it possible to analyse the statistical and integral power characteristics of EME presented as an ensemble of radio frequency electromagnetic fields (EMF) created near the

earth's surface by EMRs of megaconstellations of low earth orbit satellites (LEOS).

II. INITIAL MODELS AND ASSUMPTIONS

A. Model of LEOS radiation to the earth's surface

The main LEOS megaconstellations are characterized by layered placement of subsets (separate constellations) of satellites in different orbital planes and with different orbital inclinations, ensuring their uniform quasi-regular distribution above the Earth's surface [5].

From a ground-based observation point (OP), the location of N satellites of the LEOS megaconstellation in n spherical orbital shells of radii $R_i = H_i + R_E$, $i \in [1, n]$ over N_i satellites in the shell can be considered random and uniform over the shell area with an average density ρ_i [LEOS/m²]:

$$N = \sum_{i=1}^n N_i, \quad \rho_i = N_i / [4\pi(H_i + R_E)^2], \quad (1)$$

where $300 \text{ km} \leq H_i \leq 2000 \text{ km}$ is the altitude of the orbit of the i -th LEOS constellation, R_E is the Earth radius.

As a model of the LEOS antenna radiation pattern in the direction of the earth's surface, a two-level model with a conical beam of equal width $\Delta\phi$ in azimuth α and zenith angle β can be used, described by the following relations:

$$\left. \begin{aligned} G_{ML} &= \frac{C_P}{(1+C_P)\sin^2(\Delta\phi/4)}, C_P = \frac{P_{ML}}{P_{SL}}, P_{ML} + P_{SL} = P_{TRP}; \\ G_{SLR} &= \frac{G_{SL}}{G_{ML}} = \frac{tg^2(\Delta\phi/4)}{C_P}; G_{SL} = \frac{1}{(1+C_P)\cos^2(\Delta\phi/4)}; \\ g_N(\alpha, \beta) &= \begin{cases} 1, & \alpha, \beta \in \Delta\Omega_{ML}; \\ G_{SLR} = tg^2(\Delta\phi/4)/C_P, & \alpha, \beta \in \Delta\Omega_{SL}, \end{cases} \end{aligned} \right\} (2)$$

where G_{ML} is the gain in the main lobe (ML), G_{SL} and G_{SLR} are absolute and relative levels of side lobes (SL), C_P is the ratios of powers emitted in the ML (P_{ML}) and SLs (P_{SL}), respectively; $\Delta\Omega_{ML}$ and $\Delta\Omega_{SL}$ – solid angles corresponding to the main and side lobes, $g_N(\alpha, \beta)$ – normalized radiation pattern, P_{TRP} – LEOS total radiated power.

$$Z_{\Sigma ML} = N_{ML} \cdot m_1(Z_{ML}), \quad Z_{\Sigma SL} = N_{SL} \cdot m_1(Z_{SL}). \quad (7)$$

f) Determination of the total average EMB level Z_{Σ} in OP as the sum of components formed by ML and SL radiations of the given set of LEOS:

$$Z_{\Sigma} = Z_{\Sigma ML} + Z_{\Sigma SL}. \quad (8)$$

III. ANALYSIS OF LEOS CONSTELLATIONS SPATIAL MODELS AND EARTH IRRADIATION SCENARIOS

Since satellite systems may differ in EMR characteristics in the direction of the earth's surface, an analysis of EMR characteristics for several LEOS EMR implementation scenarios was performed using the above algorithm.

A. LEOS with isotropic EMR, scenario 1 (hypothetic)

A model of the spatial placement of the LEOS constellation with isotropic EMR and OP on the Earth's surface is shown in Fig. 3.

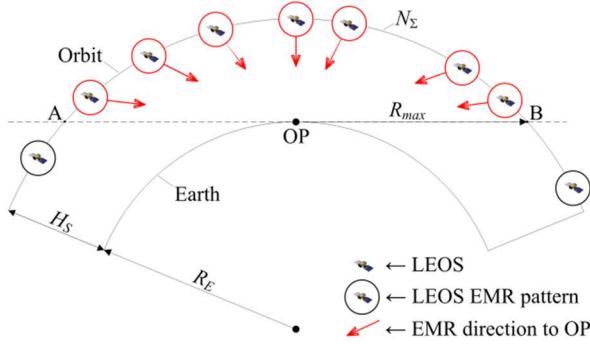


Fig. 3. Spherical model of the distributed above the earth's surface constellation of LEOS with isotropic EMR. LEOS from radio visibility zone capable of OP irradiating are highlighted in red.

If LEOS are distributed uniformly with density $\rho_i = const$ over the i -th orbital shell of height H_S , then their average number in the shell segment limited by the radio visibility zone of radius R_{max} from OP is equal to

$$N_{\Sigma} = 2\pi\rho_i(R_E + H_S)H_S. \quad (9)$$

Using the algorithm described above, for the considered scenario we obtain the following:

a) P.d.d. $w(R)$ of the distance R from LEOS to the OP:

$$w(R) = R / (H_S R_E), \quad H_S \leq R \leq R_{max} = \sqrt{2R_E H_S + H_S^2}. \quad (10)$$

b) P.d.d. of PFD Z created in OP by LEOS with EIRP P_e :

$$w(Z) = \left. \begin{aligned} & Z_{min} Z_{max} / [(Z_{max} - Z_{min}) Z^2], \quad Z_{min} < Z < Z_{max}, \\ & Z_{min} = P_e / (4\pi R_{max}^2), \quad Z_{max} = P_e / (4\pi H_S^2) \end{aligned} \right\} \quad (11)$$

c) The expectation $m_1(Z)$ is determined by the relation

$$m_1(Z) = \left. \begin{aligned} & \int_{Z_{min}}^{Z_{max}} Z \cdot w(Z) dZ = \frac{Z_{min} Z_{max}}{(Z_{max} - Z_{min})} \ln \frac{Z_{max}}{Z_{min}} \\ & = P_e \ln[(2R_E + H_S) / H_S] / (8\pi H_S R_E). \end{aligned} \right\} \quad (12)$$

d) The average value Z_{Σ} of the EMB in OP:

$$Z_{\Sigma} = N_{\Sigma} \cdot m_1(Z) = \frac{\rho_i P_e (R_E + H_S)}{4R_E} \ln \left[\frac{2R_E + H_S}{H_S} \right] \quad (13)$$

B. LEOS with quasi-isotropic EMR, scenario 2

In Scenario 2 (Fig. 4) LEOS EMRs are isotropic only for OP on the earth's surface; radiations occurs only in the direction of the Earth in the solid angle $\Omega_E = 2\pi(1 - \cos\beta_{max})$, corresponding to $\theta_{min} = 0$ and to the following value of β_{max} :

$$\beta_{max} = \arccos \left\{ \left[(H_S + R_E)^2 + R_{max}^2 - R_E^2 \right] / [2(H_S + R_E)R_{max}] \right\}. \quad (14)$$

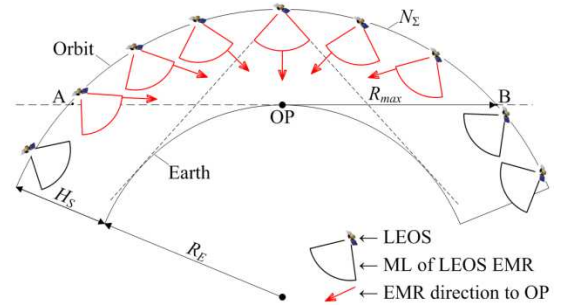


Fig. 4. Spherical model of the distributed above the earth's surface constellation of LEOS with quasi-isotropic EMR. LEOS from radio visibility zone capable of OP irradiating are highlighted in red.

In this case, at a fixed total radiated power P_{TRP} the LEOS EIRP in the direction of the earth's surface will increase relative the previous case (13) by an amount K_P equal to the ratio $4\pi / \Omega_E$, and the average EMB level at the earth's surface will be determined by the following ratio:

$$\left. \begin{aligned} & Z_{\Sigma} = \rho_i P_e K_P (R_E + H_S) \ln[(2R_E + H_S) / H_S] / 4R_E, \\ & K_P = 2(H_S + R_E) / (H_S + R_E - \sqrt{H_S^2 + 2R_E H_S}), \\ & \Omega_E = 2\pi \left[1 - \sqrt{H_S^2 + 2R_E H_S} / (H_S + R_E) \right]. \end{aligned} \right\} \quad (15)$$

C. LEOS with vertical directional EMR, limited size of service area, scenario 3.

If the service area of LEOS with a relatively wide ML is limited by the elevation angle θ_{min} of its observation from the ground OP (Fig. 5), then the following occurs:

a) LEOS EMRs are not isotropic; their antennas with a radiation pattern (2) are oriented vertically down to the nadir and provide service in the range of elevation angles $\theta \in [\theta_{min}, 90^\circ]$. This is determined by the ML conical shape with width $\Delta\phi$, equal to twice the value of the maximum viewing angle from OP: $\Delta\phi = 2\beta_{max}$. The width $\Delta\phi$ of the LEOS EMR ML

turns out to be related to the value θ_{min} and the altitude H_S of the LEOS orbit, which determine the value of the maximum viewing angle β_{max} of OP at the orbital point observed from the OP under the angle θ_{min} .

b) EIRP of LEOS in ML (P_{eML}) and SL (P_{eSL}) are determined by the P_{TRP} value and the antenna gains (2).

c) Localization area on the orbital shell of the LEOS set irradiating the OP by MLs, is a spherical segment with height X_m (Fig. 2), determined by the R_m (3), and the base diameter DC in Fig. 5; p.d.d. of the distance R from these LEOS to the OP has the form

$$w(R) = 2R / (R_m^2 - H_S^2), \quad H_S \leq R \leq R_m. \quad (16)$$

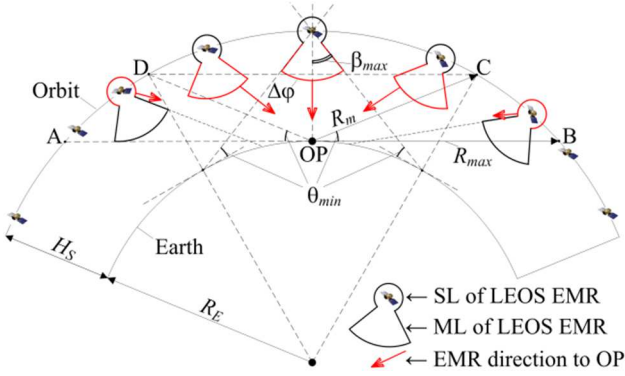


Fig. 5. Spherical model of the distributed above the earth's surface constellation of LEOS with wide conical ML and vertical EMR. Parts of LEOS EMR patterns capable of OP irradiating are highlighted in red.

d) Localization area on the orbital shell of the LEOS set irradiating the OP by SLs, is a spherical belt ABCD in Fig 5; p.d.d. of the distance R from these LEOS to the OP retains the form (16) for $R_m \leq R \leq R_{max}$.

For this scenario, expressions (7) for the average EMB intensity created in the OP by LEOS radiations along the main ($Z_{\Sigma ML}$) and side ($Z_{\Sigma SL}$) lobes, have the following forms:

$$Z_{\Sigma ML} = \frac{\rho P_{TRP} G_{ML} (R_E + H_S) (H_S - R_m \sin \theta_{min})}{R_m^2 - H_S^2} \ln \frac{R_m}{H_S}; \quad (17)$$

$$Z_{\Sigma SL} = \frac{P_{TRP} G_{ML} \rho (R_E + H_S) R_m \sin \theta_{min} \text{tg}^2 \frac{\Delta\phi}{4}}{C_P (R_{max}^2 - R_m^2)} \ln \frac{R_{max}}{R_m}. \quad (18)$$

D. LEOS with inclined narrow ML, scenario 4.

This scenario (Fig. 6) is most adequate to the analysis of Starlink LEOS constellations, the ML width $\Delta\phi$ in which is 3.5° – 5.5° depending on the angle of beam inclination, and many orbit inclinations for many orbital planes allows to consider the ML azimuth of a separate LEOS in the radio visibility zone from OP equal to the random equiprobable with its relatively small constant elevation angle θ_{min} (Fig. 1) which provides the required service zone for the ground-based UE in the LEOS moving direction.

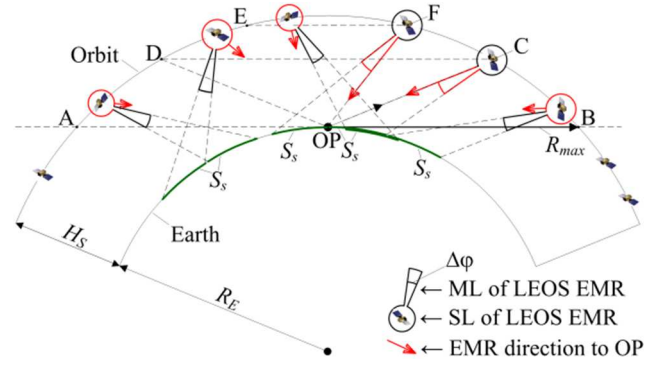


Fig. 6. Model of the distributed above the earth's surface constellation of LEOS with narrow conical ML inclined in different directions. Parts of LEOS EMR patterns capable of OP irradiating are highlighted in red.

Due to the noted differences of this scenario from the previously considered, at its analysis a different approach was used, based on scalar averaging the set of EMFs PFD radiated by LEOS, along the earth's surface, as well as a probabilistic approach based on the representation of the irradiation of the ground OP by LEOS ML as a rare event and determining the average EMB level in OP using Poisson probabilistic model.

Area S_S of the "spot" on the earth's surface (fig. 1), irradiated by the LEOS narrow conical beam with a width of $\Delta\phi$, is determined by the following expressions:

$$\left. \begin{aligned} S_S &\approx \pi \cdot L_X L_Y / 4; \quad L_Y \approx 2H_S \text{tg}(\Delta\phi/2) / \sin(\epsilon); \\ L_X &= H_S \cdot \frac{\text{tg}(\epsilon + 0.5\Delta\phi) - \text{tg}(\epsilon - 0.5\Delta\phi)}{\text{tg}(\epsilon + 0.5\Delta\phi) \text{tg}(\epsilon - 0.5\Delta\phi)}. \end{aligned} \right\} \quad (19)$$

The relative total average area S_{RA} of irradiation of the earth's surface by the constellation of N_Σ LEOS in the orbital shell with orbit height H_S , will be equal to:

$$S_{RA} = N_\Sigma S_S / S_E \approx \pi L_X L_Y N_\Sigma / (4S_E), \quad S_E = 4\pi R_E^2. \quad (20)$$

Estimates using (18), allow us to conclude that upon completion of the Starlink system ($N_\Sigma \approx 30\,000$ on 10-15 orbital shells with altitudes ranging from 340 to 640 km) [5], a scenario assuming an inclined position of the ML with an elevation angle $\theta_{min} = 25^\circ$, provides almost complete "single-layer" coverage of the entire earth's surface, in which any point on the surface at any given time is in the service area of at least one of the LEOS.

Since the S_{RA} parameter can be interpreted as the average number of LEOS MLs irradiating an OP at an arbitrary moment, we can assume that the probability $p(k)$ of its irradiation at that moment by a specific number k of LEOS is determined by the Poisson distribution:

$$p(k) = S_{RA}^k \exp(-S_{RA}) / k!. \quad (21)$$

The average PFD Z_a created in the "spot" of LEOS ML on the earth's surface is equal to:

$$Z_a \approx (C_P P_{TRP} \sin^2 \varepsilon) / [4\pi H_S^2 (1 + C_P) \sin^2(\Delta\varphi/4)]. \quad (22)$$

At the discrete distribution (21) of the probabilities of an OP falling into the service area of exactly k LEOS MLs, the average EMB intensity created in this OP is equal to:

$$Z_{\Sigma ML} = \sum_{k=1}^{K_m} k Z_a p(k), \quad K_m \gg 1. \quad (23)$$

It is obvious that the adequacy of Poisson model in relation to the considered scenario is limited, since the relative OP and LEOS position cannot be considered completely random, since the relative position of LEOS in the orbital shell of constellation has the regularity necessary to ensure acceptable waiting times and a minimum probability of UE service failure. But taking into account the presence of many orbital shells in constellation, as well as the independence of separate LEOS constellations and relative smallness of S_{RA} , positions of LEOS relative to OP can be considered random, and model (23) can be considered adequate under certain restrictions on k values.

The number $N_{\Sigma SL}$ of LEOS irradiating the earth's surface by SLs is determined by the number N_{Σ} of LEOS in the radio visibility zone from OP and the ratio of the solid angle Ω_{ML} , corresponding to ML, and the solid angle Ω_H , subtended by the earth's surface along the horizon and corresponding to the angle β_{max} (14) at $\theta_{min} = 0$:

$$\left. \begin{aligned} N_{\Sigma SL} &= N_{\Sigma} (\Omega_H - \Omega_{ML}) / \Omega_H \\ \Omega_H &= 2\pi \left(1 - \sqrt{H_S^2 + 2R_E H_S} / (H_S + R_E) \right) \\ \Omega_{ML} &= 2\pi (1 - \cos(\Delta\varphi/2)) \end{aligned} \right\}; \quad (24)$$

LEOS SL radiations in the direction of the earth's surface are considered isotropic in a solid angle of magnitude $\Omega_H - \Omega_{ML}$, therefore, to determine the average EMB intensity $Z_{\Sigma SL}$ created by these radiations at the earth's surface, we can use relations (12), (13) for isotropic LEOS EMR (scenario 1) by substituting into them P_{eSL} of SL EIRP values:

$$\left. \begin{aligned} P_{eSL} &= P_{TRP} / ((1 + C_P) \cos^2(\Delta\varphi/4)) \\ Z_{\Sigma SL} &= N_{\Sigma SL} P_{eSL} \ln(R_{max}/H_S) / [2\pi(R_{max}^2 - H_S^2)] \end{aligned} \right\}; \quad (25)$$

the average total EMB level Z_{Σ} is determined similarly to (8) as the sum of (23) and (25).

IV. QUANTITATIVE ANALYSIS OF THE AVERAGE EMB INTENSITY AT THE CONSIDERED SCENARIOS

As an example, Fig. 7 shows the following calculated dependences $Z_{\Sigma ML}(N_{\Sigma})$ of the average EMB intensity created by LEOS ML EMRs at the earth's surface on the quantity N_{Σ} of LEOS in the constellation with typical parameters $P_{TRP} = 100$ W, $H_S = 550$ km:

a) dotted brown line 1 corresponds to scenario 1, dotted black line 2 corresponds to scenario 2 (relation (15)), solid

green line 3 corresponds to scenario 3 (relation (17) for $Z_{\Sigma ML}$) at $\theta_{min} = 0^\circ$, $C_P = 1$; dash green line 4 corresponds to scenario 3 for $Z_{\Sigma ML}$ at $\theta_{min} = 0^\circ$, $C_P = 5$;

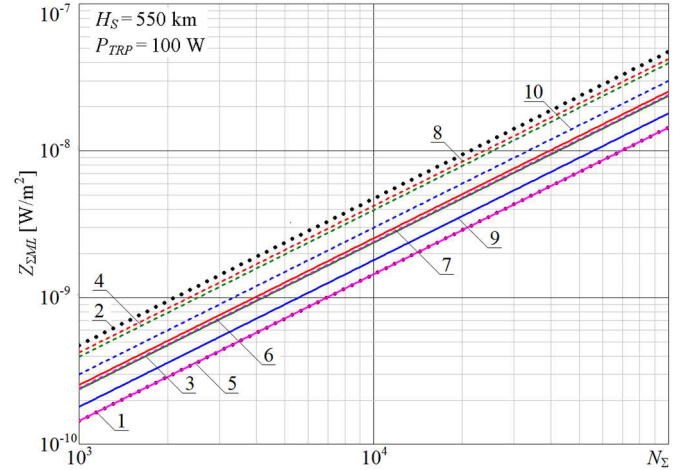


Fig. 7. Calculated dependences $Z_{\Sigma ML}(N_{\Sigma})$ of the average EMB intensity created by LEOS ML EMRs near the earth's surface at various scenarios for the satellite communication system operation

b) lines 5–10 corresponds to scenario 4 (Fig. 6, relation (23) for $Z_{\Sigma ML}$) – solid pink line 5, coinciding with line 1, corresponds to $\theta_{min} = 25^\circ$, $C_P = 1$; dash pink line 6, coinciding with line 3, corresponds to $\theta_{min} = 25^\circ$, $C_P = 5$; solid red line 7 corresponds to $\Delta\varphi = 3.5^\circ$, $\theta_{min} = 0^\circ$, $K_m = 50$, $C_P = 1$; dash red line 8 corresponds to $\Delta\varphi = 3.5^\circ$, $\theta_{min} = 0^\circ$, $K_m = 50$, $C_P = 5$; solid blue line 9 corresponds to $\Delta\varphi = 5.5^\circ$, $\theta_{min} = 25^\circ$, $K_m = 50$, $C_P = 1$; dash blue line 10 corresponds to $\Delta\varphi = 5.5^\circ$, $\theta_{min} = 25^\circ$, $K_m = 50$, $C_P = 5$.

Also, as an example, for the same typical LEOS parameters and scenario 4, Fig. 8 shows the calculated dependences $Z_{\Sigma}(N_{\Sigma})$ of the average EMB intensity and its components $Z_{\Sigma ML}(N_{\Sigma})$ and $Z_{\Sigma SL}(N_{\Sigma})$ on the quantity of satellites N_{Σ} in the constellation for $K_m = 50$ and for different θ_{min} , $\Delta\varphi$ and C_P ; the calculated worst-case dependence (15) for scenario 2 (dash red line 1) is also shown here:

a) lines 2, 3 and 4 correspond to $\theta_{min} = 0^\circ$, $\Delta\varphi = 10^\circ$, $C_P = 1$ – solid blue line 2 corresponds to the dependence $Z_{\Sigma}(N_{\Sigma})$ of the total average EMB intensity, dash blue line 3 corresponds to the dependence $Z_{\Sigma ML}(N_{\Sigma})$ of average EMB intensity (23) created by ML EMRs; dotted blue line 4 corresponds to the dependence $Z_{\Sigma SL}(N_{\Sigma})$ of the average EMB intensity (25) created by the SL EMRs;

b) lines 5 and 6 correspond to $\theta_{min} = 25^\circ$, $\Delta\varphi = 5.5^\circ$, $C_P = 1$ – solid green line 5 corresponds to the dependence $Z_{\Sigma}(N_{\Sigma})$, dash green line 6 corresponds to the dependence $Z_{\Sigma ML}(N_{\Sigma})$, the dependence $Z_{\Sigma SL}(N_{\Sigma})$ calculated for these parameters, coincides with line 4;

c) lines 7 and 8 correspond to $\theta_{min} = 25^\circ$, $\Delta\varphi = 5.5^\circ$, $C_P = 5$ – solid brown line 7 corresponds to the dependence $Z_{\Sigma}(N_{\Sigma})$, dash brown line 8 corresponds to the dependence $Z_{\Sigma ML}(N_{\Sigma})$, EMB component created by SL EMRs is practically absent (dependence $Z_{\Sigma SL}(N_{\Sigma})$ is beyond the bottom of Fig. 8);

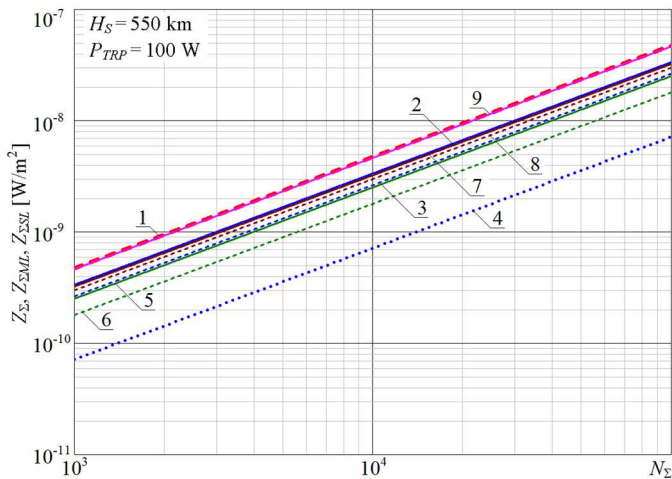


Fig. 8. Calculated dependences of $Z_{\Sigma}(N_{\Sigma})$ of the average EMF intensity and its components $Z_{\Sigma ML}(N_{\Sigma})$ and $Z_{\Sigma SL}(N_{\Sigma})$ on the number of satellites N_{Σ} in the constellation at different C_P , θ_{min} and $\Delta\phi$ (scenario 4)

d) solid pink line 9 corresponds to the dependence $Z_{\Sigma}(N_{\Sigma})$ of the total average EMB intensity at $\theta_{min} = 0^\circ$, $\Delta\phi = 10^\circ$, $C_P = 5$.

Analysis of these dependencies, as well as, in general, detailed quantitative analysis of the considered scenarios using (9)-(25) indicates the following:

1) EMB level at the earth's surface significantly depends on the C_P parameter, which characterizes the loss of EMR power due to the SLs, which reduces the part of the LEOS total radiated power P_{TRP} that reaches the earth's surface. At an increase in C_P and a decrease in θ_{min} , the dependences $Z_{\Sigma}(N_{\Sigma})$ tend to the pessimistic one peculiar to scenario 2 (relation (15)), in which all energy radiated by LEOS falls on the earth's surface. At the same time, for values of $0.5 \leq C_P \leq 2$, corresponding to real antennas [8], LEOS SLs can make a noticeable contribution to the EMB level.

2) In scenarios 3, 4, with a fixed P_{TRP} and excluding MLs from falling beyond the earth's surface ($\theta_{min} - \Delta\phi/2 > 0$), a change in ML width is accompanied by a corresponding change in G_{ML} and ML EIRP with practical constancy of the covering total radiated power - the P_{TRP} fraction, emitted in solid angle Ω_H (24) [7]. Therefore, for given N_{Σ} , θ_{min} , P_{TRP} and C_P , the average EMB intensity at the Earth's surface is practically independent of ML width $\Delta\phi$ and on LEOS orbit height H_S . At multi-beam LEOS EMR, an increase in the number of beams is accompanied by a decrease in the radiated power of each beam in such a way that the total radiated power P_{TRP} remains constant, limited by LEOS energy capabilities, which can be interpreted as an expansion of the equivalent single ML, under the accepted restrictions does not affecting on the average intensity of the created EMB.

3) The very weak dependence of the average EMB intensity created by the LEOS constellation at the earth's surface on the orbital altitude H_S , noted above in relation to scenarios 3, 4, indicates the applicability of (17)-(25), at least for analyzing the EMB intensity created by the entire constellation of non-geostationary satellite communication and navigation systems,

in particular, global navigation satellite systems GPS, GLONASS, Galileo, Beidou, etc.

4) Pessimistic estimates of the average EMB levels created by LEOS constellations (worst case estimates) can be performed using relation (15), and a more detailed analysis using (17) - (19), (23), (25) allows to assess the impact on the average EMB levels of the power efficiency and directionality of LEOS EMR (parameters C_P , $\Delta\phi$), orbit altitudes H_S , restrictions on the elevation angle θ_{min} of the served LEOS, etc.

V. CONCLUSION

Comparison of the average level of natural EMB in SHF frequency band, which is of about $10^{-20} \dots 10^{-19}$ W/m² according to [9], with the average levels of artificial EMB created by the LEOS megaconstellations indicates that these levels can exceed the level of natural EMB by 10-12 orders of magnitude. And although, in general, levels of artificial EMB created by the radiation of LEOS megaconstellations remain quite low, such a quantitatively significant change in physical characteristics of the operating environment of ground-based technical systems and the habitat of the population requires very serious attention and analysis.

The above relations (9)-(19), (23), (25), obtained as a result of the analysis of several operation scenarios for the LEOS constellations, provide the possibility of a preliminary multivariant pessimistic (worst-case) quantitative analysis of the average intensity of the EMB created by these systems near the earth's surface. The results obtained using probabilistic schemes (6) and (21)/(23) are practically identical, which in general can be considered as evidence of the adequacy of these different approaches and methods for analyzing the average EMB intensity created by LEOS constellations.

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