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Total levels of anthropogenic and natural microwave electromagnetic background in areas with intensive information servicing by constellations of low-orbit communication satellites

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***Abstract* — A technique for analyzing the averaged intensity of the electromagnetic background (EMB) created at the earth's surface by subscriber terminals of communication systems using constellations of low-orbit satellites has been developed. Using previously obtained results of the analysis of EMb created by radiation from the space segment of these systems, estimates have been made of the total levels of the ground anthropogenic and natural EMB. The results indicate that the radiation from subscriber terminals of these systems makes the main contribution to the ground EMB intensity, exceeding by several orders of magnitude other EMB components formed by both natural sources of microwave radiation and radiation from multitude of low-orbit satellites, changing the physical characteristics of the habitat and ground electromagnetic environment.**

***Key words* — low-orbit communication satellite, subscriber terminal, gateway station, electromagnetic radiation, electromagnetic background, natural radio noise.**

I. INTRODUCTION

The development of mega-constellations of low-orbit communication satellites (LOCS) in near-Earth space (Starlink, OneWeb, Astra, Kuiper, GuoWang, etc.) increases 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, while simultaneously increasing by orders of magnitude the area density of ground-based sources of SHF EMR, which are the subscriber terminals (ST) of these satellite communication systems (SCS). Intensive developments of these systems create problems for several radio services, but for the radio astronomy service it already today poses the greatest danger [1].

Previously, authors developed a technique for analyzing and evaluating the intensity of electromagnetic background (EMB) created by the space segment of similar SCS near the earth's surface, using the LOCS registration data (total radiated power, EMR directivity characteristics, orbital altitudes, etc.) and their number in mega-constellation [2]; the obtained calculated average EMB levels created by this SCS segment in the frequency band of 10–20 GHz exceed the levels of natural EMB [3] by 2–3 orders of magnitude.

The goal of this work is to use the approaches of [3] to develop a technique for analyzing the average levels of EMB created at the earth's surface by radiations of STs of the SCS of the considered type, and to estimate the total EMB levels in the frequency band of 10–20 GHz, taking into account EMB components, both anthropogenic and natural, based on [2, 3].

II. COMPONENTS OF THE EMF NEAR THE EARTH'S SURFACE IN THE LOCS FREQUENCY BANDS

A. EMB Component Created by Subscriber Stations

Typical scenarios for the implementation of communications using LOCS mega-constellations are usually focused on low-rise suburban development, rural areas and sparsely populated areas where high-speed data transmission cannot be provided via fiber-optic communication lines, and assume the ST placements at a relatively low altitude (1 - 5 m) above the earth's surface. Analysis of characteristics of the electromagnetic environment (EME) created by ST radiations at the observation point (OP) located at the height of H_{OP} [m] above the earth's surface (Fig. 1) was performed under the following conditions, which ensure a pessimistic nature of estimates of levels of STs electromagnetic fields (EMF) in OP:

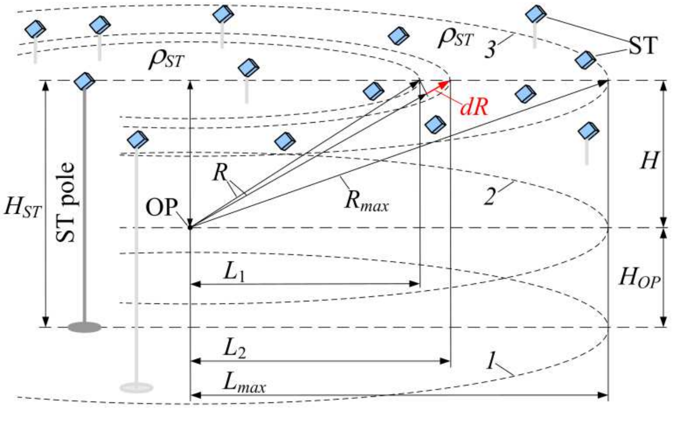

Fig. 1. ST and OP spatial placement in typical scenarios of communication implementation in SCS using LOCS: 1 - earth's surface, 2 - plane of OP placement, 3 - plane of STs placement.

- the earth's surface is considered flat, its sphericity and morphology (heterogeneity of relief, presence of vegetation and buildings) are not taken into account;

- the conditional plane of STs spatial placement with an average density ρ_{ST} [ST/m^2] is located above the earth's surface at a height H_{ST} [m] of the ST suspension, so that the distance between this plane and the plane of random OP placement is equal to $H = H_{ST} - H_{OP}$;
- the space around the OP, STs in which are taken into account at EME forming in the OP, is limited by the size of the area of ST radio visibility from the OP. As a criterion for the radio visibility of the ST – the EMR source with equivalent isotropically radiated power (EIRP) P_e in the OP direction, a certain threshold value of the EMF power flux density (PFD) Z_0 is accepted, corresponding, for example, to the "by field" susceptibility of objects - possible receptors of interference, and associated with the radius R_{max} of radio visibility area of the considered EMR source from the OP at radio wave propagation (RWP) in free space:

$$Z_0 = \frac{P_e}{4\pi R_{max}^2}, \quad R_{max} = \sqrt{L_{max}^2 + H^2} \; ; \tag{1}$$

- STs have narrow-beam antennas with a main lobe (ML) width of several degrees, directed upward at an elevation angle of at least 25°, therefore the ST EIRP in the OP direction is determined by levels of the side lobes (SL) of ST radiations.

As an EME in an OP we will represent a certain ensemble of N ST EMFs present in it with levels exceeding the threshold value (1). The investigated integral characteristic of EME in the OP is the EMB intensity Z_Σ, determined as a scalar sum of PFDs $Z_1, Z_2, \ldots, Z_N$ of N presented EMFs:

$$Z_\Sigma = \sum_{n=1}^{N} Z_n, \quad Z_n \geq Z_0 . \tag{2}$$

If the spatial density of ST – point sources of EMF on a conditional plane raised to a height H above the plane of OP placement, is constant (ρ_{ST} = const), then their average number $N_{\Sigma ST}$ in a circular region above the OP, limited by a certain radius R_{max}, is equal to

$$N_{\Sigma ST} = \rho_{ST}\pi L_{max}^2 = \rho_{ST}\pi\left(R_{max}^2 - H^2\right) \approx \rho_{ST}\pi R_{max}^2 \; ;$$

L_{max} corresponds to the location area of STs, the contribution of the EMFs of which is taken into account in estimates (2) of the EMB level in the OP.

STs – point sources of EMF, the distance of which from the OP does not exceed R, are distributed uniformly over a circular area with a radius L_1 of the plane at a height H; their average number N_1 is equal to

$$N_{1ST} = \rho_{ST}\pi L_1^2 = \rho_{ST}\pi\left(R^2 - H^2\right).$$

STs, the distance of which from OP does not exceed $R+dR$, are located in a circle of radius L_2; their average number N_{2ST} is equal to

$$N_{2ST} = \rho_{ST}\pi L_2^2 = N_{1ST} + \rho_{ST}\pi\left(2RdR + (dR)^2\right).$$

STs falling within an elementary interval dR of distance values from the OP, located at a distance R from this point, are located in a narrow annular region limited by radii L_1 and L_2; their average number in this region will be equal to

$$dN = N_{2ST} - N_{1ST} = \rho_{ST}\pi\left(2RdR + (dR)^2\right).$$

The probability $p(R, dR)$ that the value of the distance of some ST – a point source of EMF, arbitrarily selected from $N_{\Sigma ST}$, will fall into the interval $\{R, R+dR\}$ is equal to

$$p(R, dR) = \frac{dN}{N_{\Sigma UE}} = \frac{2RdR + (dR)^2}{L_{max}^2}, \quad H \leq R \leq R_{max} .$$

So, the probability distribution density (p.d.d.) $w(R)$ of the distance R from the OP of an arbitrarily selected ST is determined by the ratio

$$w(R) = \lim_{dR \to 0} \frac{p(R,dR)}{dR} = \frac{2R}{R_{max}^2 - H^2}, \quad H \leq R \leq R_{max} . \tag{3}$$

Thus, at the random uniform distribution of STs – EMF sources on a plane located at a certain height above the plane of the OP location, the type of the p.d.d. of the distance of EMR sources from the OP at $R_{max} \gg H$ does not depend on this height; only the region of its definition depend on it.

For subsequent determination of the p.d.d. of the EMF PFD values created by ST emissions in the OP, it is necessary to evaluate the possibility of using the dependence (1) which is typical for the RWP conditions in free space, in the considered spatial model in Fig. 1. This dependence loses its adequacy in the case of multipath RWP, which is typical when the ST is located outside the OP vicinity with a radius of the $R_{BP} \geq 4H_{OP}H_{ST}/\lambda$, corresponding to the breakpoint distance from OP [5], where λ is the EMF wavelength. For SCS using mega-constellations of LOCSs, SHF frequency bands with λ = 2...3 cm are allocated, for which $R_{BP} \geq 200$ m. In low-rise urban development, tens of individual STs fall within the OP breakpoint vicinity. In the case of terrestrially distributed EMR sources, the EMB intensity in the OP is determined by radiations of the nearest sources [6], for which the distance from the OP is significantly less than R_{BP}, and RWP conditions in the analyzed model can be considered to correspond to the free space RWP conditions (1). An additional argument in favor of using model (1) for all sources from the radio visibility region from the OP is the significant scattering of the centimeter range EMFs when they are reflected by the earth's surface, which on average significantly reduces the effect of the rays reflected from it on the EMF levels.

At a monotonic functional dependence (1) $Z = \Phi(R)$ and at equal ST EIRP (quasi-isotropic sources of EMF, $P_e = const$), the p.d.d. $w(Z)$ in the ensemble of ST EMFs in OP is determined from (1), (3) as follows [3, 7]:

$$\left.\begin{aligned} & w(Z) = w\left(R = \Phi^{-1}(Z)\right)\left|\frac{dR}{dZ}\right|, \quad Z = \Phi(R) = \frac{P_e}{4\pi R^2}; \\ & R = \Phi^{(-1)}(Z) = \left(\frac{P_e}{4\pi Z}\right)^{\frac{1}{2}}; \quad \left|\frac{dR}{dZ}\right| = \left(\frac{P_e}{16\pi}\right)^{\frac{1}{2}} Z^{-\frac{1}{2}}. \end{aligned}\right\}. \tag{4}$$

It is obvious that the domain of values of $Z \in [Z_{min}, Z_{max}]$ is uniquely related to the domain of definition of R values and the dependence $Z = \Phi(R)$:

$$\left.\begin{aligned} & Z_{min} = \frac{P_e}{4\pi R_{max}^2} \quad \rightarrow \quad R_{max} = \left(\frac{P_e}{4\pi Z_{min}}\right)^{\frac{1}{2}}, \\ & Z_{max} = \frac{P_e}{4\pi H^2} \quad \rightarrow \quad H = \left(\frac{P_e}{4\pi Z_{max}}\right)^{\frac{1}{2}}. \end{aligned}\right\} \tag{5}$$

In the case under consideration, ST antennas are quite complex systems – active phased antenna arrays (APAA) with a number of elements up to 2^8–2^{10}, therefore, it is possible to assume their implementation using known methods of attenuating the rear and side lobes [8, 9] and to accept the P_e value of the ST EIRP in the lower hemisphere using the following two-level model of the AT antenna radiation pattern (ARP) with a conical ML beam of equal width $\Delta\varphi_M$ in azimuth α and zenith angle β, used earlier in [2]:

$$\left.\begin{aligned} & G_{MLM} = \frac{C_{PM}}{(1 + C_{PM})\sin^2(\Delta\varphi_M/4)}, \ P_{eMLM} = G_{MLM} P_{TRP}; \\ & G_{SLM} = \frac{1}{(1 + C_{PM})\cos^2(\Delta\varphi_M/4)}, \ P_{eSLM} = G_{SLM} P_{TRP}; \\ & G_{SLRM} = \frac{G_{SLM}}{G_{MLM}} = \frac{tg^2(\Delta\varphi_M/4)}{C_{PM}}; \\ & C_{PM} = \frac{P_{MLM}}{P_{SLM}}, \quad P_{MLM} + P_{SLM} = P_{TRP}; \\ & g_{NM}(\alpha,\beta) = \begin{cases} 1, & \alpha,\beta \in \Delta\Omega_{MLM} = 4\pi - \Delta\Omega_{SLM}, \\ G_{SLRM} = \dfrac{tg^2(\Delta\varphi_M/4)}{C_{PM}}, & \alpha,\beta \in \Delta\Omega_{SLM}, \end{cases} \end{aligned}\right\} \tag{6}$$

where G_{MLM} is the ML gain in its “rectangular” model, G_{SLM} and G_{SLRM} are absolute and relative SL levels, C_{PM} is the ratio of powers emitted by the ML (P_{MLM}) and by the SL (P_{SLM}), respectively; $\Delta\Omega_{MLM}$ and $\Delta\Omega_{SLM}$ are solid angles corresponding to the ML and SL; $g_{NM}(\alpha, \beta)$ is the normalized ARP, P_{TRP} is the total ST radiated power (TRP) in the definition [10]; P_{eMLM} and P_{eSLM} are EIRP through ML and SLs respectively. In this model, in comparison with its traditional presentation in [2], the indices of parameters and characteristics g_{NM}, G_{MLM}, G_{SLM}, G_{SLRM}, C_{PM}, P_{MLM}, P_{SLM}, $\Delta\varphi_M$, $\Delta\Omega_{MLM}$ and $\Delta\Omega_{SLM}$ contain the symbol "*M*", indicating that they belong to the two-level ARP model, in which the ML width $\Delta\varphi_M$ is determined not by the "half power" (half power beamwidth (HPBW)), but corresponds to the first null beamwidth (FNBW).

According to [8, 9], in antennas with narrow MLs, their FNBW is 2.10–2.26 times greater than its HPBW ($\Delta\varphi_M \approx (2.1\ ...\ 2.26)\Delta\varphi$), which practically coincides with the corresponding ratio for the ML of the basic ARP $(\sin x)/x$. As a result, the ML gain G_{MLM} of model (6), in which the ML width $\Delta\varphi_M$ corresponds to FNBW, turns out to be approximately 2.2 times (3.4...3.5 dB) less compared to the ML gain G_{ML} for HPBW given for real antennas; which should be taken into account when performing calculations using (6).

Figure 2 shows the calculated dependences of G_{MLM} (solid lines), G_{SLM} (dashed lines) and G_{MLM}/G_{SLM} ratio (dotted lines) in model (6) on the C_{PM} ratio of the ST radiating power over the ML and SL for $\Delta\varphi_M = 4°$ (red lines), $\Delta\varphi_M = 8°$ (blue lines) and $\Delta\varphi_M = 16°$ (green lines). To check the correctness of the model, the specified dependences are also calculated for $\Delta\varphi_M = 180°$, which, as expected, intersect at the point $C_{PM} = 1$, at $C_{PM} >> 1$, $G_{MLM} \rightarrow 2$ and $G_{SLM} \rightarrow 0$ is observed, and symmetrically at $C_{PM} << 1$, $G_{SLM} \rightarrow 2$ and $G_{MLM} \rightarrow 0$ is observed. In the region of real values of the ST ML beam width $\Delta\varphi_M \leq 10°$, the SL levels are practically independent of the $\Delta\varphi_M$ value (the dotted lines for $\Delta\varphi_M = 4°...16°$ coincide), which is explained by the insignificance of the influence of changes in the small solid angle $\Delta\Omega_{MLM} = 4\pi - \Delta\Omega_{SLM}$ of a narrow ML on the value of the large solid angle $\Delta\Omega_{SLM}$.

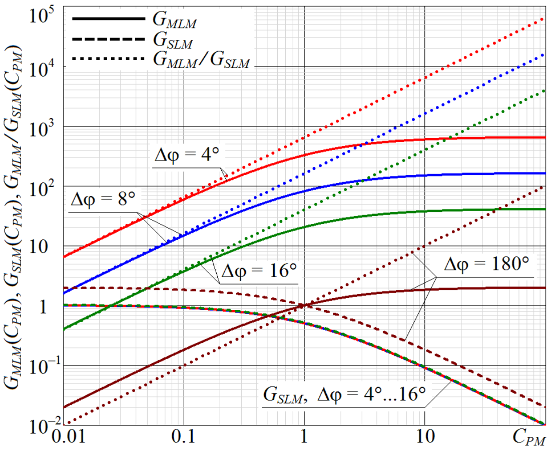

Fig. 2. Dependences of the ML and SL gain factors and their ratio G_{MLM}/G_{SLM} in the ST ARP model on the ratio C_{PM} of the radiating power by ML and SL.

From the curves shown in Fig. 2 it is evident that, taking into account the difference in the ML gain of real antennas and the two-level model (6) by approximately 2.2 times, the ratio of the gain factors by ML and SL of 35…50 dB, inherent in the most advanced APAA with optimized current distribution over the aperture [9], corresponds to the SL level of –10…–20 dB compared to isotropic radiation and SL EIRP of approximately (0.01–0.1)P_{TRP} at a C_{PM} value of 10…20 dB.

If all radiating ST are identical, and their SL EIRP are equal to $P_{eSL} = G_{SLM}P_{TRP} = P_e$, then, using (4), (5), we can obtain expressions for the p.d.d. $w(Z)$ and mathematical expectation $m_1(Z)$ of the PFD Z of ST EMFs in the OP:

$$\left.\begin{aligned} w(Z) &= \frac{Z_{min}Z_{max}}{(Z_{max}-Z_{min})Z^2}, \quad Z_{min} < Z < Z_{max}; \\ m_1(Z) &= \frac{Z_{min}Z_{max}}{(Z_{max}-Z_{min})} ln \frac{Z_{max}}{Z_{min}}. \end{aligned}\right\}. \tag{7}$$

For the considered model of spatial ST distribution

$$m_1(Z) = \frac{P_{TRP}G_{SLM}}{2\pi(R_{max}^2 - H^2)} ln \frac{R_{max}}{H}. \tag{8}$$

Thus, the relationship for the average intensity $Z_{\Sigma ST}$ of the EMB created in the OP by a set of SN from the radio visibility region takes the following form:

$$Z_{\Sigma ST} = N_{\Sigma ST} m_1(Z) \approx \frac{B_{STSL}}{2} ln \frac{R_{max}}{H}, \tag{9}$$

$$B_{STSL} = \rho_{ST} P_{eSL} \approx \frac{\rho_{ST} P_{TRP}}{(1 + C_P) cos^2(\Delta\varphi/4)}, \tag{10}$$

where B_{STSL} is the average electromagnetic loading on area created by EMR SLs of STs.

Relations (9), (10) allow us to estimate the average EMB intensity $Z_{\Sigma ST}$ created by radiations of ST distributed on a conditional plane above the OP at a height of H. As an illustration, Fig. 3 shows the calculated dependences of the average EMB levels generated in the OP by the ST radiations on the C_{PM} ratio of the ST radiation powers by the ML and SLs with different area densities ρ_{ST} of the emitting STs and with typical parameters of the STs EMR close to those used in the Starlink network: the STs ML half-power width (HPBW) $\Delta\varphi = 4°$ ($\Delta\varphi_M = 9°$) and $P_{TRP} = 4$ W.

An analysis of the dependencies in Fig. 3 allows us to conclude that the average intensity of this EMB component is determined by the radiating STs closest to the OP (which also corresponds to the results of [6]), and therefore depends weakly on the height $H_{ST} > H_{OP}$ determining the RWP breakpoint distance R_{BP} from OP, as well as on the radius R_{max} of the radio visibility zone: its increase by 10 times from 1 to 10 km (which corresponds to an increase by 2 orders of magnitude of the number of components taken into account in (2) when determining the total average EMB level) led to an increase in the calculated value of the EMB intensity $Z_{\Sigma BS}$ by only 1.6 dB; the curvature of the earth's surface, which reduces the hypothetical radio visibility zone to the zone of real direct visibility, will make this difference insignificant.

B. EMB Component Created by Satellites

A technique of estimation of EMB levels created by EMFs of LOCS constellations near the earth's surface was presented in [2]. Dependences of average levels of this component of SHF EMB on the total number N_Σ of satellites in LOCS mega-constellations for the typical orbital altitude $H_S = 550$ km and different levels of the LOCS total radiated power $P_{S\,TRP}$ almost completely radiated by narrow beams towards the earth's surface ($C_{PM} > 10$) is given on Fig. 4.

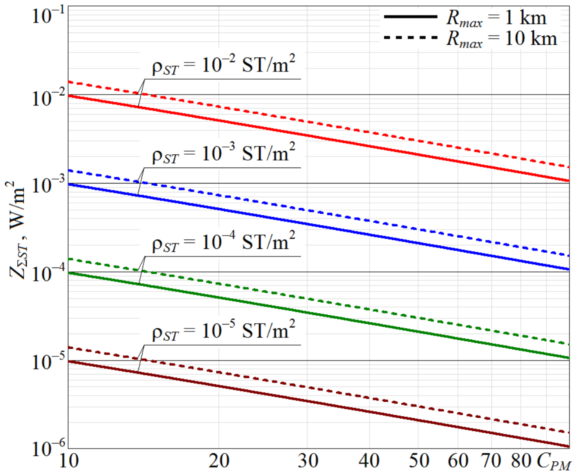

Fig.3. Dependences of average levels of EMB, created by ST, for typical parameters of ST EMR on the C_{PM} ratio of ST radiation power by ML and SL for different ST area density.

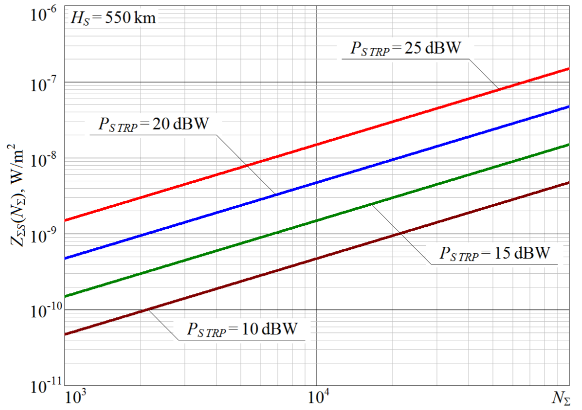

Fig.4. Dependences of average levels of EMB, created by LOCS, on their total number N_Σ in LOCS mega-constellations for typical orbital altitude $H_S = 550$ km and different levels of LOCS total radiated power $P_{S\,TRP}$.

A comparison of the dependencies in Fig. 3 and Fig. 4 indicates that the average intensity of the anthropogenic EMB created at the earth's surface by the SCS based on the LOCS megaconstellations is determined by the radiations of the ground segment of this SCS, since the contribution to the average EMB intensity of the component created by ST radiations exceeds the contribution of LOCS radiations by at least 2–3 orders of magnitude.

C. EMB Component Created by Natural Radio Noise

When analyzing the average level of natural radio-frequency EMB at the Earth's surface, we will take into account only the following components determined by EMR sources of extraterrestrial nature [4] (atmospheric effects are not considered):

- Solar radiation. The contribution of this component to the total EMB intensity is taken into account only during daytime hours. When determining the average levels of natural EMB, only the "quiet Sun" is considered; strong bursts of radio-frequency noise intensity that occur during periods of solar activity are not considered.
- Lunar radiation. The contribution of this component to the total EMB intensity is taken into account only when the Moon is above the horizon and depends on the Moon's phase.
- Galactic noise. The average value of its intensity is defined as averaged over the entire sky. Local maxima of this radiation are not considered.
- Relic radiation (space background). It is considered as isotropic radiation of an absolutely black body with a temperature of 2.7 K.

The combination of the last two components forms the deep space radio noise (DSN).

Dependences of the EMB spectral density S_{EMB} at the Earth's surface, created by the main sources of extraterrestrial radio noise (DSN; aggregate EMB created by New Moon noise and DSN; total EMB level "Sun noise + Full Moon Noise + DSN"), on the frequency, obtained using data [4], are presented in Fig. 5; the predominant contribution to the natural EMB near the Earth surface in frequency range 10-100 GHz is made by the galactic and relic radiations.

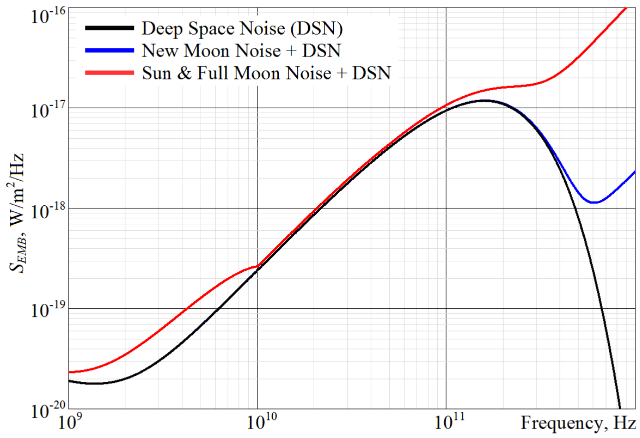

Fig. 5. Spectral density of space EMB near the Earth's surface, created by the sources of radio noise of extraterrestrial nature according to [4]).

Integrating dependencies on Fig. 5 over a given frequency band allows us to determine the averaged value of the natural radio frequency EMB intensity in this band. In particular, preliminary estimates of the intensity of this EMB component in the frequency band of 10-30 GHz, in which the downlink and uplink operation of main SCSs using the LOCS megaconstellations is carried out, allow us to conclude that this intensity is comparable to the intensity of the EMB component formed by the radiations of the SCS space segment, and is several orders of magnitude lower than the intensity of the EMB component formed by the ground ST radiations of these SCSs.

D. EMB Component Created by Gateway Stations

Gateway stations (GS) are powerful local EMR sources. They can contain from several to one and a half dozen gateway terminals (GT) located in a limited area. The parameters of Starlink GT given in [11] ($G_{ML} = 49.5$ dBi, $G_{SL} = -3$ dBi, $P_{TRP} = 17$ dBW) allow us to estimate the total averaged EMB levels created in the vicinity of the GS by radiations of its GT. Fig. 6 shows the calculated dependences of the EMB intensity Z_{GW} in definition (2), created by GT radiations, on the distance R_{GW} from the GS for a different number N_{GT} of GT and for free space RWP (under the assumption that all GTs form a local object, which, can be considered as a point source with a radiation power of $P_{TRP\Sigma} = N_{GT}P_{TRP}$). These estimates for distances from the GS more than several kilometers are pessimistic, since they do not take into account the influence of terrain irregularities, vegetation, buildings and other obstacles on the RRW conditions.

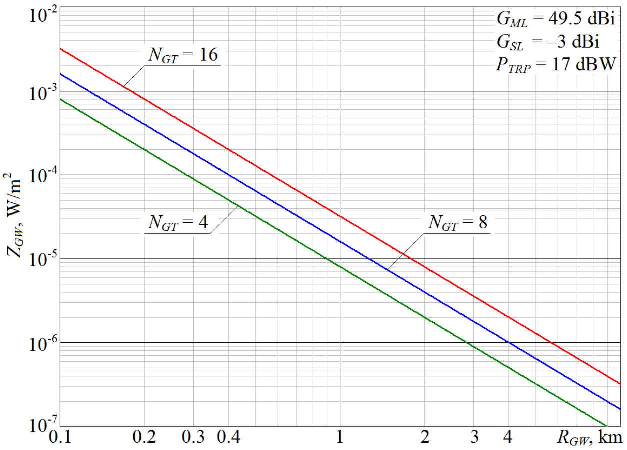

Fig.6. Dependences of average levels of EMB, created in GS vicinity, on the distance R_{GW} from the GS for a different number N_{GT} of GT, free space RWP and typical parameters of GT EMR.

A comparison of the graphs in Fig. 3 and Fig. 6 allows us to make a preliminary conclusion that the radius of GS vicinity, in which GS EMR makes the main contribution to the level of the anthropogenic EMB created by the SCS radiations, is 200-500 m, depending on the area density ρ_{ST} of radiating ST of SCS and the number of GTs in the GS.

III. THE TOTAL EMB INTENSITY CREATED BY ANTHROPOGENIC AND NATURAL COMPONENTS

At the initial stages of the SCS implementation, when there is a "spotted" area coverage by the beams LOCS radiations, the comparison of all components of the total EMB at the earth's surface makes sense in places where they are present simultaneously, i.e. in the spot of the LOCS EMR ML. At subsequent stages of the SCS implementation, when the LOCS constellation is formed, and the system provides complete area coverage, the primary interest is in the comparison of the averaged levels of anthropogenic and natural EMB components and their total level.

Table 1. Results of comparing the calculated PFD values at an earth's observation point located in the LOCS beam "spot" of the Starlink Gen1 space segment, in frequency bands D_{F1}, D_{F2}, D_{F3} & D_{F4} allocated to this segment, with the natural EMB intensity in each of these frequency bands, as well as with the integral levels of natural noise in the frequency band of 10-30 GHz used by various SCS, and in the entire SHF range.

Frequency, GHz	PFD in the beam spot center Z_{ML}, W/m^2	PFD of natural EMB sources ×10^{-11} W/m^2			PFD of natural noise $Z_{\Sigma N}=Z_{NS}+Z_{NM}+Z_{DS}$, ×$10^{-11}$ W/m^2	$Z_{ML}/Z_{\Sigma NDF}$, dB	$Z_{ML}/Z_{\Sigma N1}$, dB	$Z_{ML}/Z_{\Sigma N2}$, dB
		Quiet Sun, Z_{NS}	Full Moon, Z_{NM}	DSN, Z_{DS}				
D_{F1}: 10.7-10.94	$1.55\cdot10^{-10}$–$2.0\cdot10^{-9}$	0.58	0.02	6.7	$Z_{\Sigma NDF} = 7.3$	3.3 … 14.4	-11.2 … -0.1	-11.4 …-0.3
D_{F2}: 12.46-12.7	$1.55\cdot10^{-10}$–$2.0\cdot10^{-9}$	0.77	0.02	8.9	$Z_{\Sigma NDF} = 9.7$	2.0 … 13.1	-11.2 … -0.1	-11.4 …-0.3
D_{F3}: 17.8-18.6	$1.80\cdot10^{-9}$–$6.3\cdot10^{-9}$	5.04	0.15	58.5	$Z_{\Sigma NDF} = 63.7$	4.5 … 10.0	-0.5 … 4.9	-0.8 … 4.7
D_{F4}: 18.7-19.3	$1.20\cdot10^{-9}$–$3.9\cdot10^{-9}$	4.09	0.12	47.5	$Z_{\Sigma NDF} = 51.7$	3.7 … 8.8	-2.3 … 2.8	-2.5 … 2.6
10.0 – 30.0 (SCS main frequency range)		15.6	4.77	182.7	$Z_{\Sigma N1} = 203.1$			
3.0 – 30.0 (SHF frequency range)		19.6	4.95	190.8	$Z_{\Sigma N2} = 215.4$			

Table 2. Results of comparing of calculated values of average intensity of anthropogenic EMB components created by radiations of Starlink Gen1 LOCSs and STs at the different number of LOCS quantity and different radiating ST area density, with natural EMB intensity.

Stage of the SCS implementation	Averaged EMB levels created by LOCS EMRs, $Z_{\Sigma S}$, W/m^2		Averaged EMB levels created by ST EMRs (frequency band 14.0-14.5 GHz, R_{max} = 1 km), $Z_{\Sigma ST}$, W/m^2		$Z_{\Sigma A}=Z_{\Sigma S}+Z_{\Sigma ST}$, W/m^2	$Z_{\Sigma S}/Z_{\Sigma N1}$ $Z_{\Sigma S}/Z_{\Sigma N2}$ dB	$Z_{\Sigma A}/Z_{\Sigma N1}$ $Z_{\Sigma A}/Z_{\Sigma N2}$ dB
	P_{TRP}==20 dBW	P_{TRP}==25 dBW	C_P=20	C_P=50			
$N_\Sigma = 10^3$, $\rho_{ST} = 10^{-6}$ST/m^2	$4.7\cdot10^{-10}$	$1.5\cdot10^{-9}$	$5.1\cdot10^{-7}$	$2.1\cdot10^{-7}$	$2.1...5.1\cdot10^{-7}$	-6.4 … -1.3 -6.6 ... -1.5	20.1 ... 24.0 19.9 ... 23.7
$N_\Sigma = 10^4$, $\rho_{ST} = 10^{-5}$ST/m^2	$4.7\cdot10^{-9}$	$1.5\cdot10^{-8}$	$5.1\cdot10^{-6}$	$2.1\cdot10^{-6}$	$2.1...5.1\cdot10^{-6}$	3.6 ... 8.7 3.4 ... 8.5	30.1 ... 34.0 29.9 ... 33.7
$N_\Sigma = 10^5$, $\rho_{ST} = 10^{-4}$ST/m^2	$4.7\cdot10^{-8}$	$1.5\cdot10^{-7}$	$5.1\cdot10^{-5}$	$2.1\cdot10^{-5}$	$2.1...5.1\cdot10^{-5}$	13.6 ... 18.7 13.4 ... 18.5	40.1 ... 44.0 39.9 ... 43.7

In Table. 1 the results of comparison of the calculated PFD values at the ground observation point located in the LOCS beam "spot" of the Starlink Gen1 space segment, in frequency bands D_{F1}, D_{F2}, D_{F3} & D_{F4} allocated to this segment, with the natural EMB intensity in each of these frequency bands, as well as with the integral levels of natural noise in the frequency band of 10-30 GHz used by various SCS, and in the entire SHF range, are given. The results of comparison of the calculated values of the averaged intensity of components of the anthropogenic EMB created radiations of the Starlink Gen1 LOCS and ST multitude at different LOCS number and different ST area density, with the natural EMB intensity are shown in Table 2.

IV. CONCLUSION

1. In the LOCS beam spot, the PFD of the LOCS EMR only 3-14 dB exceed the level of natural EMB. At the gain of the ST antenna ML of 35-45 dB, this is sufficient to ensure the required SNR in the downlink radio channel. The EMF of a separate LOCS does not have a noticeable effect on the electromagnetic pollution of the habitat, since its PFD no more than 3-5 dB exceed the PFD $Z_{\Sigma N2}$ of natural microwave EMB.

2. In the frequency band of 10-30 GHz, in which the SCS operation is planned using LOCS constellations, the level of natural EMB is determined by the DSN, which at $N_\Sigma = 10^3$ is comparable with the average EMB level created by LOCS radiations, but with an increase in N_Σ to $10^4 – 10^5$, the relative contribution of the EMB space anthropogenic component increases by 10-100 (10-20 dB) times compared to the DSN.

3. The EMB created by ST radiations makes a decisive contribution to the total EMB intensity, exceeding by several orders of magnitude the levels of EMB components created by natural radio noise and radiation of LOCS multitude.

4. At full-scale implementation of SCS services using LOCS constellations, the average level of anthropogenic EMB can exceed 10^{-5} W/m^2, which not only corresponds to the "Severe Concern" category of [12], but can escalate EMC problems for the considered SCS and systems of other SHF radio services.

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