ELECTROMAGNETIC COMPATIBILITY BETWEEN 4G/5G MOBILE COMMUNICATIONS AND RAILWAY TELECOMMUNICATION EQUIPMENT

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ABSTRACT

Modern railway transport and infrastructure require modern communication systems. Railway transport control systems are complex critically important informatization objects and have several control levels: operation, centralization and element control. Today, the transport industry is gradually mastering the next generation of technological radio communications based on LTE (Long-Term Evolution) and 5G technologies. The development of telecommunication systems in railway transport allows improving the quality of services provided to passengers and ensuring a higher level of safety thanks to remote monitoring used to promptly identify and resolve emergency situations. However, it is difficult to find optimal solutions now, due to the large number of communication nodes, difficult operating conditions, electromagnetic interference and limited space. In this work a systems analysis of electromagnetic compatibility of 4G/5G mobile communication equipment and railway equipment is performed. Unified criteria for the stability of railway signaling and telecommunications equipment to radio frequency electromagnetic influence through housing ports are used. A statistical approach is applied based on the analysis of the conditionally average level of electromagnetic background generated by 4G/5G base stations. The worst estimate of the required spacing of 4G/5G equipment and railway equipment providing their EMC is also applied. The analysis results show a significant potential hazard of radiation from 4G/5G base stations and subscriber equipment, underestimation of which is fraught with catastrophic consequences. Possible ways to eliminate the risk of disruption of railway signaling and telecommunications equipment in a complex electromagnetic environment created by 4G/5G systems are discussed.

KEYWORDS: *4G/5G systems, mobile communications, railway signaling, electromagnetic exposure*

Introduction

The massive use of electronics and wireless technologies in all infrastructures of modern society without a timely solution of the emerging EMC problems of the shared equipment of various infrastructures can cause conflicts between them. Such conflicts are especially acute at the explosive nature of the expansion of the use of wireless technologies in a separate infrastructure. Today, the most rapidly expanding is information infrastructure which encompasses mobile communication (MC) systems and networks. During the 4G-5G-6G evolution of MC, the change of MC generations every 10 years is accompanied by a tenfold increase in the quantity of sources of radio-frequency electromagnetic radiation, a hundredfold increase in the area traffic capacity (mobile traffic area density) and data rates over radio channels with a corresponding increase in broadbandness and the complication of the time-frequency structure of MC radiations, as well as a significant expansion of the used frequency range [1, 2].

For example, a big plus of 5G is that passengers do not have to spend money on paid Wi-Fi. If you focus on 5G, then the carrier does not have to do anything at all - just wait until mobile operators install 5G base stations along the railway tracks. Then carry out an inexpensive upgrade of train modems that receive a signal from mobile operators, from LTE to 5G and power the on-board Wi-Fi network with this traffic. The weak point of this strategy is that 5G equipment along the railway appears only on very popular and short routes.

5G inherits the general disadvantage of cellular communications in the form of a drop in bandwidth when registering a large number of subscribers in a cell. Another disadvantage is the growing latency when registering a smartphone in the cell of the next base station as the train picks up speed. Accordingly, the speed of the Internet connection on the device will drop. Already for a speed of 100 km / h, the connection degradation will be about 30%. It is expected that for high-speed trains (250-400+ km/h), the quality of communication via a cellular channel will be even worse. It is worth noting the asymmetric nature of 5G communication, when the download speed for all operators is approximately 20 times higher than the upload speed. This drawback, especially in trains, is difficult to eliminate due to the physics of the process. The base station has a powerful transmitter, so the signal can have a complex modulation form to ensure a broadband connection. The smartphone transmitter, on the contrary, is low-power and works from inside the metal body of the car, so a simpler modulation scheme is forced to be used (usually at the level of data speed for 4G-3G), so that the base station can receive a weak signal from the subscriber. These shortcomings are not critical in themselves, but in total they give a negative synergistic effect. A modern train has a large number of digital systems, the most important of which is real-time video surveillance and online transmission of images from the driver's cabin and from cameras in the cars to the traffic control center. This allows for machine facial recognition to prevent criminal and terrorist activity on trains, as well as to quickly respond to various emergency situations (fire, derailment, etc.). Communication interruptions for remote video surveillance are unacceptable, and 5G's capabilities in terms of outgoing traffic (upload) are too weak to transmit video streams from multiple HD cameras.

All this causes a very significant complication of the electromagnetic environment (EME), especially in places with a high population density and economic activity, which can cause disruption of the operation of the technical systems of other infrastructures. This is confirmed in works [3-5], which proved the potential danger of interference from base stations (BS) and user equipment (UE) of 4G/5G MC for healthcare infrastructure equipment. Therefore, an important task is to analyze the EMC of 4G/5G MC equipment and technical systems of other infrastructures of modern society.

Modern railway control systems are among the critically important objects of informatization; they are complex and have several control levels: the operation control level, the interlocking (centralization) level, and the element control level. The widespread use of wired and wireless communication, microprocessor interlocking, signaling, and auto-blocking in these systems, which unlike electromechanical equipment has a significantly higher susceptibility to radio-frequency electromagnetic fields (EMF), causes the need to analyze and ensure the reliability of operation of modern railway signaling systems, railway communication & data transmission systems and microelectronic systems for ensuring the safety of train traffic in the context of the rapid EME complication due to the extremely intensive development of wireless technologies and 4G/5G MC.

The objective of this paper is to perform a system-level analysis of EMC between the 4G/5G MC equipment and the railway equipment, namely to estimate a danger of interference from BS and UE of 4G/5G MC to the railway signaling and telecommunication equipment.

EMC analysis of railway and 4G/5G equipment

1) The EMC analysis for railway equipment and MC 4G/5G radio equipment have been performed using exposure limits – maximum permissible levels (MPL) of EMFs in various frequency bands specified by current standards [6-8] and typical data [9-16] for parameters of 4G/5G BS and UE radiations.

2) The alysis of the EMC conditions of the specified equipment was carried out by calculating the required spatial separation between them for the case of free-space radio wave propagation – the minimum distance at which the EMF level of the MC equipment affecting the railway equipment is equal to MPL.

3) Integral assessments of the danger created in the places of operation of railway equipment by MC radiations were made by system analysis technique [17, 18] of the conditional average intensity of the electromagnetic background (EMB) created by the set of BS radiations near the earth's surface during the implementation of separate 5G scenarios.

Immunity of railway equipment to electromagnetic field

Table 1 lists the requirements [6-8] for the immunity of railway signaling and telecommunication equipment (critical railway equipment, the requirements for the immunity of which to the EMF exposure are standardized for EMFs penetrating into this equipment through the enclosure ports).

Table 1

Requirements for the Immunity of Railway Signaling and Telecommunication Equipment to EMF

Frequency band, MHz	MPL, V/m	Ref.
80–800 (Environmental phenomena is radiofrequency EMF, amplitude modulated [7])	10	[6], [7]
800–1000 1400–2000 2000–2700 5100–6000 (Environmental phenomena is radiofrequency EMF, from digital communication devices [7])	20 10 5 3	[6], [7]
2700–6000	3	[8]

It should be noted that the requirements [6-8] for the MPLs of EMFs affecting this railway equipment are defined only for a few sections of the FR1 5G frequency range, and are completely absent for the FR2 5G range. The question of the susceptibility of this railway equipment to EMFs at all frequencies of FR1 & FR2 ranges remains open, as well as the question of the influence on this susceptibility of the complication of the frequency-time structure of 4G/5G MC radiations; this may pose a great potential danger to railway transport in the future.

Required spacing of railway and 4G/5G equipment

The required distance between the railway and MC equipment for the case of free-space radio wave propagation is calculated by using the following expression:

$$d = \sqrt{30 P_{EIRP}} / E_{MPL} \text{ , m} \quad (1)$$

where E_{MPL} is the EMF MPL, [V/m]; P_{EIRP} is the equivalent isotropic radiated power (EIRP) of the MC equipment, [W].

Tables 2 and 3 show the results of calculating the required spatial separation between the 4G/5G MC and the considered railway equipment.

In these calculations, the following data for the BS and UE characteristics of 4G/5G MC that determine their EIRP were used:

a) The adjustable output power of an outdoor BS transmitter can reach 43–53 dBm [9, 10], the BS antenna gain is 12–40 dB [11–14]. Thus, the range of EIRP values in the main lobes of BS antenna patterns from 0.1 to 100 kW is of interest for analysis.

b) UE maximum output power is 25 dBm for LTE FDD UE, 28 dBm for LTE TDD UE, and 29 dBm for 5G UE taking into account the requirement to the tolerance; UE antenna gain is 0 dBi [15, 16].

Table 2

Required spatial separation between BS with different EIRP and railway equipment

EIRP, kW	**E_{MPL}, V/m**			
	3	**5**	**10**	**20**
	Required separation, m			
0.1	18.3	11	5.5	2.7
0.5	40.8	24.5	12.3	6.1
1	57.7	34.6	17.3	8.7
5	129	77.5	38.7	19.4
10	183	110	54.8	27.4
20	258	155	77.5	38.7
40	365	219	110	54.8
60	447	268	134	67.1
80	516	310	155	77.5
100	577	346	173	86.6

Table 3

Required spatial separation between UE and railway equipment

EIRP, dBm	**E_{MPL}, V/m**			
	3	**5**	**10**	**20**
	Required separation, m			
25	1.03	0.62	0.31	0.15
28	1.45	0.87	0.44	0.22
29	1.63	0.98	0.49	0.24

Intensity of electromagnetic background created by base-station radiations

Estimates of the conditional average intensity of EMB created by MC radio networks according to the technique [17, 18] are based on determining the average electromagnetic loading on area (EMLA) created by the radiations of BS and UE located in the considered territory, which is proportional to the average AREA TRAFFIC CAPACITY , reaching 10^5 bit/s /m^2 in 4G networks and 10^7 bit/s/m^2 in 5G networks [1]. Since a data transmission mode with a significant asymmetry of uplink and downlink traffic is dominated in 4G/5G networks, the contribution of radiations of many UEs to the total EMB intensity created by 4G/5G MC systems turns out to be insignificant. This allows us to limit to considering only the EMB component near the earth's surface generated by BS radiations.

The EMB intensity Z_Σ [W/m^2] in a certain observation point is determined as a scalar sum of power flux densities Z_n of EMFs generated by a set of N sources located in the area S of their radio visibility from the observation point:

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

where Z_0 is the threshold of EMF sources radio visibility from the observation point. Due to the known properties of EME created by spatially distributed EMF sources, the value of $Z_.$ is determined by a predominant components in (2).

Estimations of the total averaged intensity $Z_{\Sigma BS}$ of EMB in the corresponding frequency band, created in the observation point by radiations of the set of BS, located uniformly randomly with respect to the observation point in all area of BS radio visibility from the observation point, can be made using the following expression:

$$Z_\Sigma \approx \frac{B_{TBS}}{2} ln\left(\frac{4\sqrt{e}H_{OP}}{\lambda}\right), \quad H_{OP} \geq \frac{\lambda}{4}. \tag{3}$$

In this expression, λ [m] is the wavelength; H_{OP} [m] is the height of the observation point over the earth's surface, note that H_{OP} is much less then the heights of BS antennas; B_{TBS} [W/m^2] is the EMLA created by BS radiations and has the meaning of the average area density of the total power of their EMFs reaching the earth's surface.

The technique developed in [17, 18] for estimating the average EMLA B_{TBS} is based on the analysis of the level S_{tr} [bit/s/m^2] of area traffic capacity near the earth's surface created by BS radiations. Great growth of area traffic capacity is declared in [1, 2]. In this case, the expression for estimating the average EMLA has the following form:

$$\left.\begin{aligned} B_{TBS} &\approx \frac{8\pi^2 kT_0 mK_N K_S L_P SNIR(K_{CC}+1)R_{max}^2 S_{tr}}{\lambda^2 G_0 \, log_2(1+SNIR)}, \\ SNIR &= \left(2^{mS_{ER}} - 1\right) \end{aligned}\right\} \tag{4}$$

In this expression G_0 is the BS antenna gain, R_{max} is the radius of the BS service area, k is the Boltzmann's constant, 1.38×10^{-23} J/C; K_N is the UE receivers noise factor; T_0 is the ambient temperature; K_S is a coefficient characterizing the necessary margin in the level of the signal received by UE, for the implementation of system-forming functions (handover, etc.); L_P is the necessary margin for BS radiation power to overcome the additional radio wave propagation losses in relation to the free space, caused by the attenuation of radio waves at the entrance to buildings, their fading in the "canyons" of urban development and other factors; K_{CC} characterizes the excess by the intra-network interference of the UE receiver's internal noise; S_{ER} [bit/s/Hz] is the real spectral efficiency of data transfer through BS radio channels, $m \geq 1$ is a coefficient characterizing how many times the radio channel real spectral efficiency is lower than the potential one (or higher when using MIMO technology, in this case may be $m<1$); *SNIR* – the ratio of UE input signal power to the total power of intrasystem interference and UE receiver's internal noise on its input.

Intensity of electromagnetic background for basic 5G EMBB scenarios

The figures given below show the calculated dependences of the average EMB intensity generated by the BS radiations on the area traffic capacity level, for typical radio reception parameters $K_N=5$, $T_0=290K$. Since in MC radio channels without MIMO $m \approx 2...10$, and the planned increase in the spectral efficiency of 4G/5G radio channels due to MIMO technology is 2-8 times [19], it is actually only compensates for the imperfection of the modulation/demodulation and encoding-decoding processes; therefore, it is advisable to perform estimations of the intensity of EMB created by 4G/5G MC, using (3),(4) for $m=1$, assuming that the data transfer rate in radio channels of these systems is close to the potential).

We restrict to the analysis of three basic 5G eMBB scenarios recommended by [20] that create the highest EMB levels. The calculated data presented below in graphical form were obtained for typical values of the parameters included in (4). In the figures below, four lower dotted horizontal lines (green) indicate the EMF MPL values for railway equipment that comply with the standards [6–8] (see Table 1), the upper dotted line (red) indicates the MPL 1000 μW/cm^2 recommended by [21] for people electromagnetic protection, taking into account the danger of the thermal damage of biological tissues when exposed to radio frequency EMFs.

Figure 1 corresponds to the "Dense Urban eMBB" 5G scenario, the intersite distance in which is 200 m (R_{max} = 100 m), the dependences $Z_\Sigma(S_{TR})$ of the conditional average EMB intensity on the area traffic capacity level were obtained for various frequencies of the 5G FR1 range (0.41–7.125 GHz). Their analysis allows us to conclude that already at S_{TR} = 10^5 bit/s/m^2, corresponding to the 4G limit, the generation of this traffic at frequencies above 2 GHz makes the EME created in this case potentially dangerous for railway equipment, and the increase of the area traffic capacity to the level of 10^6–10^7 bit/s/m^2 declared for 5G MC increases the intensity of created EMB by 1-2 orders of magnitude – to levels 2-3 orders of magnitude higher than EMF MPLs for railway equipment.

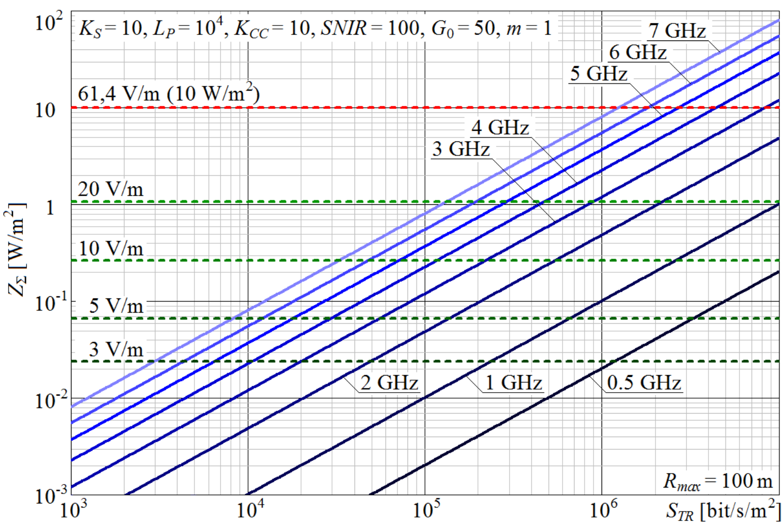

Fig. 1. Dependences of conditional average intensity of electromagnetic background created in 5G scenario "Dense Urban eMBB" on area traffic capacity for various frequencies in FR1 range

Figure 2 corresponds to the "Rural eMBB" 5G scenario, corresponding to the implementation of eMBB services in rural areas with a terrestrial density of UE that is 2 orders of magnitude lower than in the previous scenario; the intersite distance in this case was 2000 m (R_{max} = 1000 m). $Z_\Sigma(S_{TR})$ dependences were obtained for the same frequencies of the 5G FR1 range. Analysis of these dependences shows that already at an average area traffic capacity of 10^3 bit/s/m^2, which is 2 orders of magnitude lower than the limit declared for 4G systems, the EMB levels created by MC systems turn out to be comparable to EMF MPLs for the considered railway equipment, and with an increase in area traffic capacity to levels of $10^4 – 10^5$ bit/s/m^2, expected during the full-scale implementation of eMBB services in rural areas, the conditional average intensity of the created EMB is also capable of exceeding these EMF MPLs by 2-3 orders of magnitude.

Figure 3 corresponds to the "Hotspot eMBB" 5G scenario using frequencies of the 5G FR2 range (24.25–52.6 GHz with extension up to 70-100 GHz). Calculations were performed as for the basic “budget” version [20] using BS (access points) with weakly directional radiation (4 upper graphs), and for a promising version with multi-element active phased array antennas (APAA) with directional radiation in the "Beamforming" mode (4 lower graphs). This scenario is focused on implementation in areas of intensive use of MC wireless services both indoors (Indoor Hotspot) and in places where UEs are locally concentrated outdoors (Outdoor Hotspot), in particular, in places where passengers are concentrated (railway platforms, etc.).

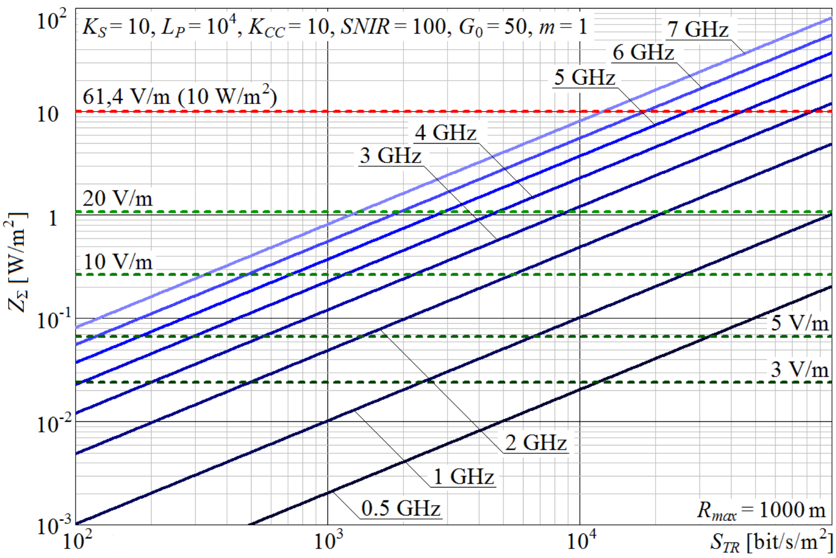

Fig. 2. Dependences of conditional average intensity of electromagnetic background created in 5G scenario "Rural eMBB" on area traffic capacity for various frequencies in FR1 range

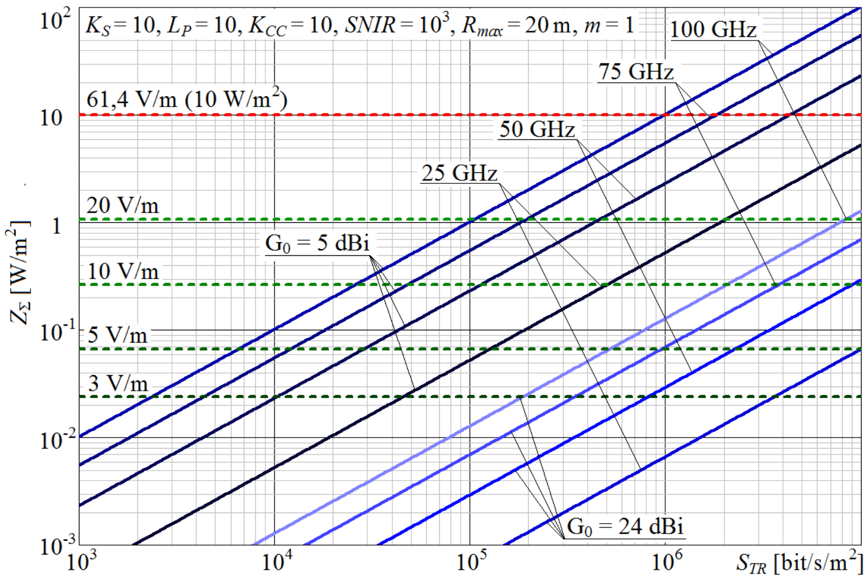

Fig. 3. Dependences of conditional average intensity of electromagnetic background created in 5G scenario "Indoor/Outdoor Hotspot eMBB" on area traffic capacity for various frequencies in FR2 range and different gain of 5G base station antennas

Analysis of dependences given in Figure 3 allows us to conclude that when using low-directional antennas in this scenario, already at average area traffic capacity level 10^5 bit/s/m^2, corresponding to the 4G limit, the location of railway equipment at distances up to 10-20 m from the BS can be dangerous, but since EMF MPLs for the FR2 range is not defined, the issue requires further study. The use of APAA with directional radiation makes it possible to reduce the average intensity of the created EMB by almost 2 orders of magnitude, making it potentially dangerous only with an average area traffic capacity reaching the upper limit for 5G 10^7 bit/s/m^2. However, it should be taken into account that the use of APAA as BS antenna systems is accompanied by an increase of 1-2 orders of magnitude in their EIRP in main lobe of BS radiation, which significantly increases the spatial separation requirements between APAA and railway equipment falling into the main lobe of APAA radiation.

Discussion

An analysis of the calculated values of the required separation of MC BS and considered railway equipment, which ensures compliance with the requirements of [6-8], indicates the following:

1. I 4G/5G frequency bands of the range 0.8-1 GHz (GSM-900, E-GSM, NR bands 81-83; E_{MPL} = 20 V/m) used mostly for long-distance narrowband low-rate MC services, EIRP value in the main lobe of BS typically does not exceed a few kW and the separation required does not exceed the height of the BS antenna.

2. I 4G/5G frequency bands of the range 1.4-2.7 GHz (GSM-1800, UMTS, LTE, NR bands 1-3, 7, 25, 34, 38, 39-41, 50, 65, 74-76, 84, 86; E_{MPL} = 5–10 V/m), EIRP values in the main lobe of BS can reach 10-20 kW, the necessary spatial separation of railway equipment and BS can reach 100-150 m, but there are no requirements for its mandatory compliance.

3. M frequency bands in the range of 2.7-6.0 GHz (NR bands 1-3, 7, 25, 34, 38, 39-41, 50, 65, 74-78, 84, 86) are increasingly used by 5G systems, including systems which use BS with APAA capable to reach up to 50-100 kW of main-lobe EIRP in the "Beamforming" mode [11, 14], and, at the same time, the susceptibility of the considered railway equipment to EMF exposure in this range is maximum (E_{MPL} = 3 V/m). The necessary spatial separation of BS with this equipment can reach up to half a kilometer, but there are no any requirements for its observance.

4. Fo the railway equipment of the element control level (for example, axle count controllers, controllers for outdoor devices – traffic lights, arrows, means of controlling the free of the path, crossings, etc.), it is impossible to provide protective space zones free from the presence of radiating UE of MC and ensuring the necessary attenuation of UE EM fields.

In particular, if at E_{MPL} = 20 V/m the required spatial separation of railway equipment of the considered type with UE even at the maximum UE EIRP does not exceed 15-24 cm, and the danger of interference to ground-based railway equipment from the UE of 0.8-1.0 GHz range is practically absent, then at E_{MPL} = 5–10 V/m in the range of 1.4–2.7 GHz, the required separation from the UE increases to 0.5–1.0 m, and at E_{MPL} = 3 V/m in the range of 2.7–6.0 GHz it reaches 1.5 m, which today requires the adoption of special restrictions on the use of UEs of the 1.4-6.0 GHz range near railway equipment complying with the requirements of [7, 8], as well as tightening these requirements for equipment of the 1.4-6.0 GHz range at least to the level of requirements adopted for the 0.8-1.0 GHz range.

5. I the near future, it is planned to use widely frequency bands of the FR2 5G range, however, there are no any requirements for the immunity of railway equipment to radio frequency EMFs of this range. Electromagnetic exposures of this range on railway equipment can be the cause of many unpleasant surprises associated with their free penetration inside equipment enclosures through the shield’s inhomogeneities and parasitic capacitances of protective filters. The lack of requirements for EMF MPL in this range for railway equipment may cause unacceptable interference for its operation.

Attention should be paid to the coincidence of the EMF MPL range of 3-20 V/m for railway equipment regulated by [6-8] and the MPL EMF range of 2.5-90 μW/cm^2 (3-18.4 V/m), accepted as hygienic standards of many countries, taking into account the danger of non-thermal effects of radio frequency EMF exposure on the human body [22]. This means, in particular, that numerous publications indicating the potential danger of electromagnetic radiation of 4G/5G MC for the population can be considered as the indirect confirmation of their danger to the operation of the corresponding railway equipment. In general, it is possible to comprehensively analyze and solve EMC problems of 4G/5G MC both with equipment of all elements of the infrastructure of a human society and with the population that forms this society.

6. Th above hygienic standards (EMF MPL for population) are limiting average EMF levels affecting the human body, and failures of electronic equipment in many cases are determined by their peak values (pulse amplitudes). In these cases, under pulsed operating modes of MC equipment (TDD modes) and with signal fluctuations in MC radio channels, these peak emissions are 1–2 orders of magnitude higher than the average EMF levels. This circumstance, as well as, in general, a significant complication of the spectral-temporal structure of the MC signals of new generations, can represent an additional danger. For pulsed RF EMFs of other systems, in particular radars, the hygienic MPLs, recalculated to determine the average values (averaging over the period of circular surveillance), are usually 20-100 times lower than for quasi-continuous MC EMFs [23]. With the expected extension of these standards to pulsed EMFs of MC in the future, their requirements will be close to the lowest MPL values for railway equipment adopted in [7, 8].

Considering the relatively low EMF MPL values for the considered railway equipment in UHF and lower part of SHF ranges, it should be recognized that it is relevant to analyze its susceptibility to the exposure of ultra wideband electromagnetic pulses and its protection against such intentional impacts, including tightening the requirements of the relevant standards, since compact generators of such exposures (capable of generating pulses with an amplitude of 10-50 kV/m at a distance of 1-2 m from this sources [24-26]) are capable potentially to disrupt the operation of the considered railway equipment from a distance of hundreds of meters.

7. D endencies in Figure 1-3 indicate that EMB created by radiations of 4G/5G equipment in places with high activity and area density of the population, the wireless information servicing of which by MC systems provides high levels of average area traffic

capacity (up to $10^5 – 10^7$ bit/s/m^2), represents a significant danger to the considered railway equipment.

The average EMB levels, determined by the average levels of EMLA (4), can be significantly reduced by taking measures of a system nature, in particular, by the reduction up to the complete elimination of the influence of intra-network interference (due to the use TDD modes and APAA in beamforming mode with high gains in narrow beams, as well as a significant increase in the amount of radio frequency resource used by MC systems); by the development of infrastructure of MC networks (increase in BS spatial density with a decrease in the communication ranges, rejection of the cellular network structure in favor of an adaptive network structure with the spatial distribution of access points, the use of reconfigurable and absorbing intelligent surfaces, etc.) with a corresponding reduction in the risk of interference to railway signaling and telecommunication equipment, and the corresponding forced risks to public health.

These measures have relatively little effect on the EIRP of BS and UE and on the necessary spatial separation of the MC radiating equipment and the considered railway equipment (calculated values of which are given in Tables 2, 3), and in some cases even increase it (in particular, at a significant increase of EIRP in the main lobe of APAA in Beamforming mode).

Conclusion

The above results indicate a serious potential danger of interference to railway signaling and telecommunication equipment in a complex EME created by a multitude of radiations of 4G/5G MC equipment during the full-scale development and implementation of 4G/5G systems and services. This danger is caused by a huge increase (by several orders of magnitude) in the spatial density of radiation sources, in area traffic capacity and data transmission rates of MC radio channels, provided by high EIRP values of the BS APAA in directions to the served UE.

These results, as well as data [3-5], indicate that the rapid MC evolution 4G□5G□6G, accompanied by a significant complication of EME, violates the previously established balance between the degree of EME complexity and the degree of electromagnetic protection of all types of the infrastructure of modern society. They are intensively saturating with a variety of radio-electronic equipment of limited immunity from unintended and intentional electromagnetic exposures. And since the electromagnetic protection of railway equipment has traditionally been given quite serious attention, it should be expected that technical systems of other types of infrastructure are affected by MC radiations no less than the equipment of railway transport and medical institutions. In this regard, the following should be recognized as relevant:

a) realization of all possible ways to exclude risks of complex EME affect created by 4G/5G systems on the operation of railway signaling and telecommunication equipment. These ways are associated with the tightening of the current standard limits for the immunity of this railway equipment to electromagnetic field in 4G/5G frequency bands, with the limitation of radiation power of 4G/5G base stations located near railway infrastructure facilities, with introducing the requirement of spatial separation between the 4G/5G base stations and the railway infrastructure facilities, and with the imposition of restrictions on the use of 5G mobile stations near railway signaling and telecommunication equipment;

b) performing a similar system EMC analysis for the 4G/5G/6G MC infrastructure and other types of infrastructure of society – economy, defense, public, market, etc., as well as other elements of social and transport infrastructures (in particular, taking into account the development of unmanned vehicles of all types), which allows specifying EMC problems for each of types of infrastructure;

c) substantiation and adoption of adequate requirements of standards for the susceptibility and EMC characteristics of equipment of various types and purposes in all MC frequency bands (in the UHF, SHF & EHF ranges), as well as effective technical, system and managerial measures to ensure the EMC of this equipment, which must be accepted to ensure its reliable functioning in technical systems of all types and elements of public infrastructure during the full-scale implementation of MC 4G/5G/6G systems and services;

d) before the completion of work on items a, b, acceptance, if necessary, of temporary restrictions on the conditions for the joint operation of the 4G/5G MC equipment and critical equipment of other infrastructures – transport, healthcare, economics, etc., ensuring the protection of equipment and systems of these infrastructures from the impact of MC EMFs (in particular, similar to restrictions adopted to protect the population from MC EMFs, taking into account the closeness of the MPL values of radiofrequency EMFs for technical equipment and for the population).

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