A Conflict in the Radio Frequency Spectrum of LEO-HTS and HEO-HTS Systems

Valentin R. Anpilogov[1,2], Andrey A. Gritsenko[1,3], Yury N. Chekushkin[1], Igor V. Zimin[1]
[1]PhysTech-School of Radio Engineering and Computer Technologies
Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia
[2]JSC “VSAT-TEL”, Moscow, Russia
[3] JSC Information Space Center “Severnaya Corona”, Saint Petersburg, Russia
avr@cts.ru, org@spacecenter.ru, yury_check@yahoo.com, iv.zimin@mail.ru

Many analytical companies associate the development of the satellite communications market with new LEO/MEO/HEO-HTS systems with the target function of broadband access. The basis of these systems is the use of multisatellite constellations. Their practical realization requires solving numerous scientific and technical problems. One of the most painful problems is the problem of electromagnetic compatibility (EMC) between projected systems as well as between projected and operating satellite networks. The article shows that the realization of any of LEO-HTS systems results in a conflict situation in the radio frequency spectrum of the fixed-satellite and broadcasting-satellite services (Ku, Ka, Q/V bands). It is shown by the example of the analysis of EMC of LEO-HTS OneWeb and HEO-HTS Express-RV systems, the latter being oriented to servicing the Arctic regions in the Ku band, that to parry this conflict situation, a decrease in the capacity of subscriber radio links of the Express-RV system and/or an increase in the size of its subscriber antennas are required. The results of the analysis are presented for several geographical locations of subscriber terminals (from 60° N and more) and show that time intervals of interference action and C/I values depend considerably on their location in the Express-RV coverage area.

Keywords — non-geostationary systems, LEO/MEO/HEO-HTS, interference

I. Introduction

In the last few years, a considerable amount of information on the prospects for development of low-orbit broadband satellite systems has been published [1, 2], the basis of these systems being multisatellite constellations. Such constellations are projected of hundreds and even thousands of small micro class satellites in the Ku, Ka, Q/V bands of the fixed-satellite service (FSS). These systems were designated as LEO-HTS since they repeat the ideology of multibeam formation of a coverage area that is characteristic of HTS geostationary satellites. It is obvious that the development of microsatellites, the deployment and upkeep of a multisatellite constellation require solving numerous scientific and technical problems. But there are two problems that remain beyond active discussion, and their solution is not known for the present. The first problem is connected with the development of convenient and cheap subscriber terminals equipped with scanning antennas [3, 4]. The second problem consists in providing electromagnetic compatibility of projected LEO-HTS systems among themselves and with other FSS satellite systems, including already operating ones [5-8]. Its solution for prevention of interference of operating geostationary communications and broadcasting satellites to receiving stations is provided by changing the spatial orientation followed by the shutdown of LEO-HTS satellites at the instants of passing the equatorial zone [5-7]. However, the questions of EMC between projected LEO-HTS satellite systems and projected satellite systems in other orbits (MEO/HEO-HTS) have no unequivocal answer yet. Besides, there is no adequate apparatus for simulation of such situations that is approved by the ITU international organization.

As of today, the most advertized LEO-HTS system is the OneWeb system. In [5, 6] it was already noted that there is a serious problem of providing the joint operation of subscribers in the Ku band of the OneWeb system and the Express-RV system that uses orbits of the Tundra type (in simulation, the features of multibeam formation of the coverage area were not taken into account). The present paper considers the problem of action of interference produced by satellites of the LEO-HTS system on receiving subscriber terminals of the HEO-HTS satellite system in view of the features of formation of a multibeam coverage area. Simulation of a conflict situation in the radio frequency spectrum was carried out in view of assumed ballistic construction of the OneWeb (LEO-HTS) system and the Express-RV (HEO-HTS) system using orbits of the Molniya type.

II. Initial Parameters Taken in Simulation

In LEO-HTS systems, multibeam coverage areas are formed, and in each beam part of the common radio frequency band allocated to the system is used, but there is identical polarization in all beams (for example, subscribers receive signals at right-hand polarization and transmit at left-hand polarization in all beams, or vice versa). In HEO-HTS systems, multibeam coverage areas are formed as well, and one usually seeks to choose the parameters of a satellite constellation such that there is the effect of quasi-geostationarity [9] that ideally makes it possible to use subscriber terminals with small antennas without beam scanning or with minimum scanning angles. In this case the polarization plan of a HEO-HTS satellite can provide for both left-hand and right-hand polarization of subscriber beams. But it is obvious that to provide the isolation of subscriber beams of LEO-HTS and HEO-HTS, they should be orthogonal (the beam isolation in this case is infinitely large). But perfect circular polarization is unattainable. Let us take the worst value of the ellipticity both of the satellite and of the earth station within 0.7-0.8. In this case the isolation of orthogonal signals with elliptical polarization [10] will be A_{pol} = 12.3-16.2 dB (the orientation of polarization ellipses changes in satellite

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motion in the orbit and depends on the beam frequency, so the most disadvantageous case (coincidence of major axes of polarization ellipses) is taken). It should be noted that the ellipticity coefficient is maintained within the main lobe of the antenna pattern, but beyond this range its values can be significantly worse. In addition, its value changes when exposed to hydrometeors in the atmosphere.

To exclude the ambiguity of ratios of a useful signal to interference (C/I) obtained in simulation because of a change in polarization parameters, we will assume that there is no polarization isolation of beams, but then we will take it into consideration in the final budget. Presented in Table 1 are the taken radio engineering parameters of subscriber beams, and in Table 2 the ballistic parameters of satellite constellations are given.

The frequency bands of beams of the OneWeb satellite alternate in such a manner that frequencies are repeated twice. Accordingly, two beams of the OneWeb satellite will act on the receiving terminal of the Express-RV satellite. These beams are separated in space. Each such pair of beams has its own spatial location that will change specularly for ascending and descending OneWeb satellites. The parameter under study is the ratio of the useful signal (C) received by the Express-RV subscriber station to interference (I) produced by two beams of the OneWeb satellites, with beams coinciding in frequency, but without considering polarization isolation.

As a model of the directivity diagram of antennas of subscriber stations, the model presented in the Recommendation ITU-R S.1428 was used.

TABLE I. RADIO ENGINEERING PARAMETERS OF SUBSCRIBER TX BEAMS

Parameter	OneWeb	Express-RV
Radio frequency band of subscriber beams in the Space-Earth link, GHz	10.7 - 12.7	10.97 - 11.7
Frequency band of a subscriber beam, MHz	250	54
Subscriber beams of the satellite	16 beams, 48°x3° each	12 beams, 2.75°x2.75° each
EIRP in the direction of the beam boundary, dBW	34.6	54
Spectral density of EIRP in the direction of the beam boundary, dBW/4 kHz	-13.4	-12.7
Polarization in subscriber beams	right-hand	left-hand

TABLE II. BALLISTIC PARAMETERS OF SATELLITE CONSTELLATIONS

Parameter	OneWeb	Express-RV
spacecraft in a satellite constellation	648	4
Orbits	Polar: Inclination 87.9° 18 orbit planes with 36 satellites in each 10° between orbit planes	Molniya: Inclination 62.8° Eccentricity 0.722 Longitude of apogee 75° E Argument of perigee (270±1)º Orbits are separated by 90º
Operating of orbit altitudes	1200 km	max 39,500 km min 30,000 km

III. RESULTS OF SIMULATION

Simulation of the Express-RV ballistic constellation (Table 2) shows that the boundaries of scanning of a beam of antennas of subscriber terminals, depending on their geographical location, vary within small limits and are limited to 12°x2°. However, the major axis of this angular ellipse has a considerable change in inclination. Thus a receiving subscriber antenna without scanning cannot have a gain more than about 30 dB, and the size of its aperture is about 70x14 cm. Scanning in one plane of +/-6° is permissible for antennas with an aperture diameter up to 0.9-1.0 m, that is, the maximum gain is up to about 38 dB.

OneWeb beams produce interference zones. Illustrated in Fig. 1 by the example of six OneWeb satellites is a change in these zones for two beams received in simulation. The interference level depends considerably on the geographical location of an Express-RV subscriber station and the strategy of shutdown of neighboring OneWeb satellites, so it is problematic to reveal general regularities. The C / I level also depends on the location of the receiving subscriber terminal (Table 3) and the size of its antenna.

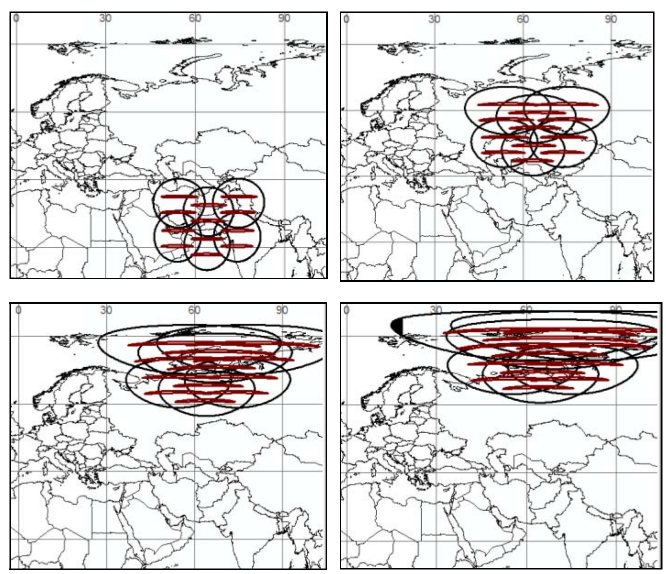

Fig. 1. The transformation of coverage areas of two subscriber beams of six OneWeb satellites producing interference to Express-RV subscriber terminals at coincident frequencies.

The interference level decreases with increasing size of a receiving subscriber antenna. Of special interest are the results for the maximum size of the antenna, the use of which does not require beam scanning. The beamwidth of such an antenna is 12°x2° (the size of an artificial antenna is about 0.35 m according to S.741). Presented in Table 3 are the values of C/I for three points: Northern (80° N, 75° E), Central (60° N, 75° E), and Western (60° N, 30° E).

TABLE III. ESTIMATION OF INTERFERENCE IN THE USE OF THE 0.35 M RECEIVING ANTENNA

Control point	C/I, dB	Upstream of OneWeb satellites		Downstream of OneWeb satellites	
		Single continuous interference, min	*P[a] of interference, %*	*Single continuous interference, min*	*P[a] of interference, %*
Northern	10	0.43	5.61	0	0
	15	0.5	9.77	0	0
	20	0.6	18.52	0	0
	25	360	100	1.22	29.64
	30	360	100	360	100
Central	10	0.37	3.05	0.38	3.15
	15	0.43	4.75	0.45	4.56
	20	0.5	7.19	0.5	7.04
	25	1.48	20.36	1.03	21.03
	30	360	100	360	100
Western	10	0.58	6.24	0.57	5.55
	15	0.68	8.70	0.68	8.20
	20	0.82	13.21	0.88	12.64
	25	2.42	60.23	3.1	59.85
	30	360	100	360	100

[a] P is the share of time (%) in the 6-hour interval during which the value of C/I is below a specified level.

The qualitative aspect of interference acting on receiving subscriber terminals with the 0.35 m antenna of the Express-RV system in the 6-hour interval is illustrated in Fig. 2 for the Northern control point. Each of the plots in Fig. 2 shows the character of interference at different frequencies corresponding to specific pairs of beams of the OneWeb satellite. Of eight pairs of beams of the OneWeb satellite that use the same frequencies, presented in Fig. 2 are the results of simulation only for four pairs. Figs. 2a and 2b correspond to the action of the beam pairs (1 and 9) and (8 and 16). In this configuration, the beams 1 and 16 deviate from the local vertical through an angle about 22.5° northward and southward respectively, and the beams 8 and 9 deviate from the local vertical through an angle about 1.5°. Figs. 2c and 2d correspond to the action of the beam pairs (4 and 12) and (5 and 13). In this configuration, the beams 4 and 13 deviate from the local vertical through an angle about 13.5° northward and southward respectively, and the beams 5 and 12 deviate from the local vertical through an angle about 10.5°.

If it is assumed that the said configuration of beams corresponds to satellite motion in the downstream, after a while the situation will be reversed since at the control point satellite motion will already be in the upstream. In this case the satellite will as though make a 180° turn relative to the axis of the local vertical. Accordingly, the picture of interference will change.

The C/I values presented in Table 3 and Fig. 2 do not take into account the additional polarization isolation A_{pol}. As a result, to estimate a permissible threshold C/N (it limits the choice of signal-code sequences), it is possible to use the relation $C/N < C/I+A_{pol}$ -12.2 dB that follows from the recommendation S.741.

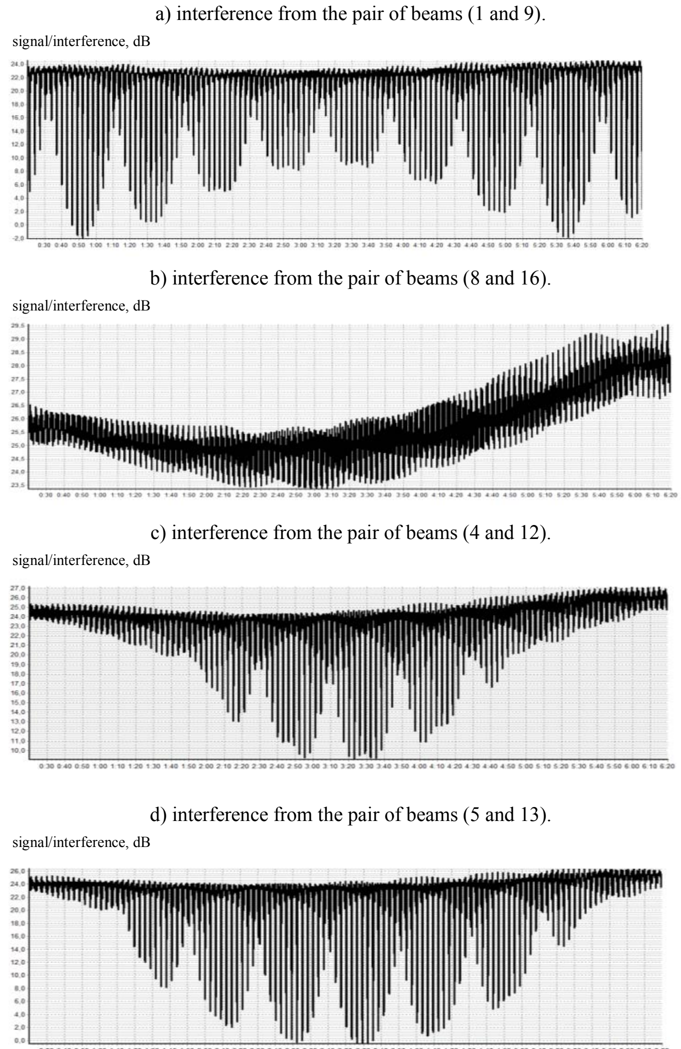

Fig. 2. The Ratios of a useful signal to interference C/I at the input of the receiving subscriber terminal with the antenna of 0.35 m of the "Express-RV" system at a 6-hour interval at the frequencies of different beams of Oneweb satellites

IV. CONCLUSION

The developed ballistic model of LEO-HTS and HEO-HTS systems makes it possible to estimate the requirements to subscriber terminals and to providing electromagnetic compatibility of LEO-HTS and HEO-HTS systems.

By the example of the design parameters of an Express-RV system (orbits of the Molniya type) it was shown that subscriber terminals can have antennas without scanning if their beamwidth is no less than 12°x2°, which corresponds to a maximum size of an antenna about 70x14 cm (equivalent circular antenna of 0.35 m) at a frequency of 11 GHz.

The presented estimations show that the value of C/I depends essentially on the geographical location of a receiving antenna and its size. The more is the size of an antenna, the less is the time interval of interference action.

The estimations of C/I for an Express-RV receiving subscriber terminal located in the Arctic region illustrate the significant action of interference from OneWeb satellites, even in view of the polarization isolation lowering the interference level by the value A_{pol} (minimum 12 dB).

The degree of interference effect will depend on the frequency and territorial plans of allocation of beams in an Express-RV system and on the geographical location of subscriber stations.

It is obvious that the Express RV satellites will also create radio interference to OneWeb subscriber terminals with scanning antennas, which requires additional research.

The use of the developed models of a conflict situation in the radio frequency spectrum for LEO-HTS and HEO-HTS systems makes it possible to minimize risks associated with estimation of interference environment in designing ground satellite networks, including those in the Arctic regions of Russia.

The results of investigations will be used in development of equipment for symmetric jam-resistant satellite communications for high-speed Internet access at remote places difficult of access.

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