Radio links from low-orbit satellites

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Abstract. In this article, methods of transmitting the information from low-orbit satellites to the Earth are considered. Transferring the information from a low-orbit satellite to geostationary spacecraft at millimeter-wave frequencies that strongly attenuate in the atmosphere is proposed. The possibility of transmitting information from a low-orbit satellite transmitter with a power no more than 1–2 W and small-sized antenna arrays on the communication line is shown.

1. Introduction
The transfer functions of radio channels of radio satellite significantly differ by their properties. For example, in the low-orbit satellite system Gonets-D1M, with spacecraft located in almost circular polar orbits with a height of 1400-1500 km, the characteristics of communication channels with terrestrial subscribers differ significantly from the characteristics of the radio channels of these satellites with spacecraft located in geostationary orbits. During radio communication with ground subscribers, the radio signals of low-orbit spacecraft moving in orbits up to 2000 km high, passing through the atmosphere, decaying in its gases and dissipating on atmospheric turbulences and various hydrometeors (rain, snow, fog). Under the influence of solar and geomagnetic activity, the ionosphere gets excited and a large number of heterogeneous formations of various sizes become in a constant motion, dissolving and reappearing, which causes scattering and chaotic rotations of the plane of polarization of radio waves. Because of all these reasons, in addition to the main signal, a lot of scattered waves come to the antenna at the receiving point, the interference of which causes fading - random changes in the amplitude and phase of the signal.

Low-orbit spacecraft, in addition to mobile personal satellite communications (low-orbit IRIDIUM and GLOBAL STAR systems, “Gonets D1M”), are used for remote sensing of the Earth, collection of meteorological data, for optical photography with meter-resolution equipment - EROS-B, Resurs-DK, Cartosat-2, Kompsat-2 and decimeter resolution - WorldView, GeoEye-2, etc. Satellite photographs are required for land surveyors, foresters, ecologists, military, cartographers, units of the Ministry of Emergencies and other services, and photos received in the spring, allow predicting the crops.

2. Materials and methods
The mass and altitude of a low-orbit satellite is directly related to its life span and the speed of its movement in orbit. Therefore, the transfer of large amounts of information to the Earth at a high satellite speed in orbit (centrifugal force is aligned with centripetal at a speed of 7.9 km/s) creates a serious problem, since a high-speed satellite cannot transmit information to a ground station in time.
The problem of transferring information from low-orbit SC to the Earth can be solved in various ways. For example, in the IRIDIUM radio communication system, a satellite transmits information along a chain to other SC of its constellation until it reaches a satellite located in the visibility range of one of the ground receiving stations. But this requires a large constellation of satellites, which is too expensive. GLOBAL STAR satellites transmit information to the Earth themselves, but this requires a large number of ground-based receiving stations, and in many areas of the Earth they are not available and this limits the capabilities of satellite constellation. Another way to transfer large amounts of information to the Earth is to transmit it to geostationary satellites, which are in constant communication with each other and with ground stations. This variant of network interactions seems more advantageous, since it does not require powerful transmitting equipment on board of a low-orbit spacecraft and allows using an existing network of ground-based receiving stations. This variant is considered in more details below.

The radio channels of low-orbit spacecraft with medium-orbit and geostationary spacecraft have a large length, which causes a strong weakness of the signal, called attenuation in free space and described by the expression [1].

\[ L = 20 \log \left( \frac{4\pi R}{\lambda} \right) , \text{dB} \]  

where: \( L \) is the loss of radio signal transmission in free space, \( R \) is the distance of the communication line, \( \lambda \) is the wavelength.

Multipath in radio channels passing only through outer space is rare. It can arise mainly due to reflections of signals from other spacecraft and numerous space debris. This determines, if not the complete absence of fading, then their shallow depth and small variance in the process of delaying information patches. However, the strong attenuation of radio signals along long paths and the difficult interference environment in conditions of near space forces us to apply the measures to increase the noise immunity (interference immunity) even for outer space communication lines.

Frequency restrictions and increasing requirements to increase the speed of information transmission and reduce the time delays of signals during propagation stimulate the use of frequencies of millimeter range (MMR). Let us consider the possibility of using MMR frequencies on the radio links of low-orbit spacecraft with mid-orbit and geostationary spacecraft. The main disadvantage of MMR is that, in atmospheric conditions, the MMR signals decay intensively. This is caused both by scattering of millimeter waves in inhomogeneous atmosphere, and by resonant absorption of wave energy by oxygen and water molecules [2]. Molecules of water and oxygen possess electric and magnetic moments that resonate at certain frequencies of MMR, which causes intense absorption of radio wave energy, as shown in figure 1.

But MMR has a number of advantages compared to other range frequencies [3]. The main advantages of MMR are as follows:

- possibility of high-speed data transmission, which ensures compliance with the requirements of the 5G communication generation;
- small dimensions of the antenna devices, which allow building an effectively amplifying antenna array with ultra-narrow radiation patterns and high signal concealment;
- multipath and fading of the signal with sharp antenna patterns are weakly expressed [4];
- small dimensions and mass of antenna devices, which is important for low-orbit spacecraft;
- the possibility of applying space-time coding technology - MIMO, which significantly improves the quality of information transfer;
- high immunity to industrial interference.

At frequencies of 22.2 GHz and 180 GHz, a significant attenuation of signals occurs due to absorption in water, and at frequencies of 60 GHz and 118.8 GHz due to absorption by oxygen molecules [2]. But there is no water vapor between the low-orbit and geostationary spacecraft, and oxygen molecules are
rare in an over-rarefied atmosphere. Therefore, the MMR frequencies with extreme attenuation in the atmosphere can be used to transmit information from low-orbit spacecraft to geostationary ones. At the same time, ground-based sources will not be able to create tangible interference with low-orbit spacecraft due to the absorption of MMR frequencies in the atmosphere. In turn, the spacecraft signals at these MMR frequencies will not interfere with ground-based radio equipment. From geostationary spacecraft information is not difficult to transmit to subscribers on Earth using regular transponders.

\[ P_{th} = kT\Delta f, \]  

where \( k = 1.23 \cdot 10^{-23} \) is the Boltzmann constant, \( T \) is the effective noise temperature of the antenna, and \( \Delta f \) is the receiver passband at the output of the intermediate frequency amplifier.

The effective noise temperature of communication line antennas from a low-orbit spacecraft to a geostationary satellite at a frequency of 60 GHz when shielded from terrestrial radio stations by the atmosphere (figure 1) practically coincides with the noise temperature of space and does not exceed 100

Figure 1. The linear attenuation of MMR frequencies in the atmosphere [2].

3. Results

Let’s consider the energy potential of a radio link from a low-orbit spacecraft to a geostationary satellite. Since the micro strip rectangular printing antenna of the PATCH type at a frequency of 60 GHz has a size of 2.5x1.96 mm and provides amplification up to 9 dB, it is not difficult to organize an antenna array of 120x120 mm in size to obtain a gain of up to 40 dB [5]. The threshold sensitivity of the receiving device is defined by the expression.
Using expressions (1) and (2), we calculate the energy potential of a communication line with a length of 34 thousand km, from a low-orbit spacecraft to a geostationary spacecraft.

The calculation results are shown in figure 2.

**Figure 2.** The energy potential of the radio link between low-orbit and geostationary satellites.

In figure 2, the straight line OA shows the power of the radio transmitting device, the straight lines AB and CD show the amplification of the transmitting and receiving antenna arrays, the line BC characterizes the total losses during propagation over a distance of 34 thousand km and losses in antenna-feeder devices on the transmitting and receiving sides of the communication line. The line O-A-B-C₁-D₁ shows the energy potential for the systems with noise-resistant coding.

4. Conclusions

According to the results of the calculations, it is clear that the transfer of large amounts of information from low-orbit spacecraft to the earth station is possible through geostationary spacecraft. In this case, on the radio link from the low-orbit spacecraft to the geostationary spacecraft, it is advantageous to use the MMR frequency, which is most strongly attenuated in the Earth’s atmosphere. The use of MMR frequencies will reduce the weight and dimensions of the antenna devices, and at the same time improve the noise immunity of the radio link. When using on such radio links small-sized antenna arrays of 512 or 1024 micro strip antennas of the PATCH type, the transmitter power on the board of low-orbit spacecraft will not exceed 1-2 W.

Reference

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