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CONTEMPORARY SATELLITE COMMUNICATION SYSTEMS AND INNOVATIVE METHODS FOR INCREASE OF THEIR EFFICIENCY

A U T O R E F E R A T

DISSERTATION

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1. Prof.
2. Prof.
3. Prof.
4. Prof.
5. Assoc. Prof.

Substitute Members:

6. Prof.
7. Assoc. Prof.

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Thesis*: **CONTEMPORARY SATELLITE COMMUNICATION SYSTEMS AND INNOVATIVE METHODS FOR INCREASE OF THEIR EFFICIENCY***

Aim and Tasks of the Research

Objectives of the dissertation work:

Design of a satellite communications ground subsystem for low-orbit satellites

Subject of the research: The ground part of a satellite communication system

The solved tasks and their sequence in the dissertation work are:

1. Analytical overview of the development of satellite communication systems
2. Analysis of the main technological components of satellite communication systems
3. Designing the technological infrastructure of a ground station for low-orbit satellites
4. Evaluation and comparisons of technological parameters of the designed ground station through measurements of its parameters.

Developments from the dissertation research were practically verified in a built ground station for satellite communications.

Publications of the doctoral student on the topic of the dissertation

1. D. Karastoyanov, K. Terziev and E. Blagoeva, "Use of Satellites for Observation of Objects in Agriculture," 2022 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), Maldives, Maldives, 2022, pp 1-5, DOI: 10.1109/ICECCME55909.2022.9988626, ISBN 166547095-7, Code 185686

2. Терзиев К., Карастоянов Д., СЪВРЕМЕННИ САТЕЛИТНИ КОМУНИКАЦИОННИ СИСТЕМИ. XXIX Международна научно-техническа конференция – АДП 2020, бр. 2, Publishing house of TUSofia Publisher, Department "Automation of Discrete Production Engineering", 2020, ISSN:2682- 9584, 149-154

3. Красимир Терзиев, Димитър Карастоянов, СТРУКТУРА И ОРГАНИЗАЦИЯ НА СПЪТНИКОВА КОМУНИКАЦИОННА СИСТЕМА, XXX Международна научно-техническа конференция – АДП 2021, Издателство на ТУ София, брой 3, 2021, ISSN 2682-9584, 181-184

4. Красимир Терзиев, Димитър Карастоянов, LEO СПЪТНИЦИ ЗА НАБЛЮДЕНИЕ НА ЗЕМНАТА ПОВЪРХНОСТ В СЕЛСКОТО СТОПАНСТВО, XXXI Международна научно-техническа конференция – АДП 2022, Издателство на ТУ София, брой 4, 2022, ISSN 2682-9584, 210-214

5. Krasimir Terziev, Dimitar Karastoyanov. The Impact of Innovation in the Satellite Industry on the Telecommunications Services Market., Problems of engineering cybernetics and robotics, print ISSN: 2738-7356, ONLINE ISSN: 2738-7364, 2020, Vol. 73, pp 30-38

6. - К. Терзиев., Иновативни методи за повишаването на ефективността на съвременните сателитни комуникационни системи., ROBOTICS, AUTOMATION AND MECHATRONICS' 21 RAM 2021, Prof. Marin Drinov Publishing House of Bulgarian Academy of Sciences, 2021, ISSN:1314-4634, 108-111

7. К. Терзиев., Комерсиални спътникови телекомуникационни системи. ROBOTICS, AUTOMATION AND MECHATRONICS' 20 RAM 2020, Prof. Marin Drinov Publishing House of Bulgarian Academy of Sciences, 2020, ISSN:1314-4634, 30-33

Preface

Satellite systems are a technological means of data transmission that covers large distances. This also determines their application and distribution, where the conditions for communications and access to IT infrastructure are highly limited. Satellite communications can be implemented with various telecommunication modules, systems, and subsystems. Accordingly, technological solutions lead to different properties, requirements, and communication and data transmission service parameters. As an element of satellite communication systems, the type of equipment and devices requires different technological solutions to meet the standards and ensure reliable satellite connectivity. As a technological problem, it is the choice of compatible and suitable technological modules, which together provide communication services with a corresponding transmission speed, reduced attenuation of signals, and secure access to this type of communication for end users.
The current dissertation work aims to design the ground part of a satellite communication system. It is intended to transmit data to satellite systems and constellations in low earth orbit, which satellite operators and users prefer because it provides less delay between the request and the execution of the communication.

Chapter 1: Analytical overview of satellite telecommunication systems

1.1 Historical overview of the satellite industry

Historical facts indicate that the pioneer of satellite technology was a twenty-seven-year-old Air Force officer and scientist named Arthur Clarke, who described the initial concept during a training camp. The boy wrote an article, "Extraterrestrial relays," which recreates the idea of communication satellites, and the text was published in the British publication "Wireless World." He describes that an artificial satellite at a precise distance from the Earth would remain pointed at the same point for 24 hours and with an optical radius of about half the Earth's surface. According to his theory, three ground stations would be needed to cover 360 degrees and provide global communication connectivity. The exact distance determined from the equator at which the satellite will move at the same speed as the earth is 35,786 km, and it is named after its creator, Clark's orbit. In this way, all antennas on the ground will be pointed fixedly at one position and will not need to be pointed and adjusted periodically to transmit or receive data. Scientists consider the system Arthur Clark described as a turning point in the satellite industry, which laid the foundation for commercializing satellite communication services. He is also called the father of industry.

1.2 Commercial Satellite Industry Application

In 1962, the administration of President John Kennedy proposed the creation of the development of a global communication satellite system, the document of which was signed by him on August 31 of the same year. The new private company "COMSAT" is being created, which will aim to partner with other countries to build a global commercial satellite network. On August 20, 1964, the first international satellite communications organization, “Intelsat" was established in Washington. Now comes the time for the creation and launch of the first commercial geostationary satellite being developed by Hughes Aircraft. Early Bird 1 (later renamed Intelsat 1) was launched on April 6, 1965. It could hold 240 simultaneous calls and broadcast only one black-and-white television channel. The satellite covered the region around the Atlantic Ocean, providing a communication link between North America and Western Europe. "Early Bird 1" was planned to last 18 months but remained in orbit for 3 1/2 years. In the late 1960s, Intelsat provided global coverage once Intelsat 3 was operational. In the early 1980s, the main companies operating satellites with global coverage were Intelsat and Intersputnik ". Intelsat and its more than 100 member countries transmitted two-thirds of the world's communications traffic and almost all television media content over its network. One of the pioneers of satellite cable program distribution was Sidney Topol, part of a small company called Scientific Atlanta. He developed a 10-meter antenna cable operator to receive signals from satellite platforms.

To millions of people, the satellite broadcast of pictures of the first moon landing in 1969 and the 1972 Summer Olympics in Munich, Germany, proved to the world the power and influence of technology.

1.3 Integrated cable and satellite data transmission

At that time, another visionary and entrepreneur in Europe saw the power of satellite technology and would later build such a telecommunications network. His name is Rupert Mudrock. Murdoch was born in 1931 in Melbourne, Australia. He is the son of successful newspaper publisher Sir Kate, who died unexpectedly when Murdoch was just 21 and attending Oxford University. He inherited from his father two Australian newspapers, "The Adelaide News" and "The Brisbane Courier Mail," which he turned into two powerful multimedia conglomerates. In the 1980s, he owned various newspapers worldwide, such as the New York Post and the popular London edition of the Times. In 1985, Rupert also purchased Twenty Century Fox films and TV studios for US$575 million and 6 TV channels from Metromedia and launched Fox Networks. To avoid US regulations prohibiting holding a media broadcasting license, he acquired US citizenship on 4. September 1985. DTH services in the US appeared thanks to Stanley Hubbard, who at that time was part of "USSB - US Satellite Broadcasting", which received the first license for the services in 1981. Initially, the receiving antennas intended to receive the signal were in frequency band C. Unfortunately, the price, dimensions, and limited capabilities limited the service only to people who engaged in the activity as a hobby. These shortcomings did not allow the mass and commercial penetration of the service, which also limited the revenue receipts. Towards the end of 2000, the satellite industry and business underwent major changes. On April 9, 2003, Murdoch's News Corp and General Motors agreed to a $6.6 billion deal for a 34% stake in Hughes Electronics, including DirecTV and 80% of PanAmSat and Murdoch's News Corp.” was the most powerful media empire at the time.

1.4 Competition and Market Applications

Following its market logic, the satellite industry is starting to develop headlong, given the opportunities opening up and the relaxed regulations that are happening thanks to "PanAmSat." The company's entry into the market makes it possible to break Intelsat's monopoly and create conditions for greater investor interest and higher levels of competition.

The beginning of the new wave of satellites is the company "Orion Network Systems," headed by John Puente - one of the leading engineers at "Comsat Laboratories." In the mid-1990s, satellite operators actively opposed the monopoly of "Intelsat" and demanded its privatization, leading to equality and free market competition between participants. In 1995, negotiations for the privatization of the company began. On February 10, 1997, the "Intelsat 2000 Working Party" - committee issued a report on restructuring "Intelsat" to participate in the market without discriminatory factors.

In the '90s, there was a serious boom in Internet technologies and all telecommunication services, which led to even more serious interest of investors in this market niche. Forecasts and marketing studies prove that serious satellite service growth is expected. At this time, new aggressive strategies began with the creation of new and much more technologically capable satellite networks.

In March 2000, the US Congress adopted the "Open-Market Reorganization for Betterment of International Telecommunications" (Orbital Act). This document aims to provide market participants with even greater freedom and competitive ability. This directive also states the requirement for the privatization of Intelsat and imposes certain obligations on the company. On November 17, 2000, at a general meeting of "Intelsat," with 144 participants from various governments, they accepted by anonymous voting a plan for the privatization of "Intelsat." After 37 years as a state-owned company, Intelsat officially became a private company on July 18, 2001. In the first year of the new millennium, the satellite industry marked its zenith despite the turbulent entry of Internet technologies and Telecom services. The Satellite Industry Association published a report with data on a total 80 billion-dollar turnover. The average growth on an annual basis is 15%, which is promising for new investments and the presence of a stable sector. What was started 37 years ago by Intelsat is now becoming a powerful global satellite industry.

1.5 Development of satellite technologies and penetration of low earth orbit networks

Low Earth Orbit (LEO Orbit) satellites have become increasingly popular in recent years because they provide high-speed Internet and other communications services to users on the ground with significantly better parameters than existing geostationary earth orbit technology. However, one of the main problems is that the existing ground stations cannot receive and process the traffic from them efficiently due to the lack of a sufficient number of them to work in a specific frequency spectrum and to cover the requirements of the new satellite constellations. Ground stations are essential for receiving signals from satellites and relaying them to the appropriate destination. They act as a gateway between the satellite and the end user, ensuring that data from the satellite is received and processed correctly. In addition, the shortage of ground stations may limit the potential of LEO satellites to provide new services and capabilities, including remote sensing, earth observation, and environmental monitoring. To solve this problem, there is a need to expand the telecom infrastructure, especially in areas with high population density. Using more antenna systems allows us to manage the growing satellite capacity and its precise regional distribution to hubs more efficiently to not overload the network and ensure free capacity. They can be strategically placed in areas with higher demand, increasing the overall coverage of the satellite network. One of the critical elements for satellite operators is the distribution of traffic across satellite platforms and teleport stations, which requires constant optimization of this process by satellite constellation owners. This can be achieved through advanced communication technologies, data analysis, and traffic monitoring tools that can help optimize traffic routing between different stations, ensuring that the available capacity is used to its full potential. The growing number of Teleport antennas also requires the improvement of the communication infrastructure by expanding the available terrestrial data transmission capacities to handle large volumes of data.

1.6 Conclusion

A historical and technological analysis of the development of the technologies applied to realize services through satellite communications has been made. It is well established that the ground infrastructure of a satellite communications system is an essential component for the operation of communications, managing customer traffic, and providing reliable connectivity. This justifies the need to develop technological solutions for the ground subsystems of LEO communication satellites. By investing in infrastructure and advanced technology, we can improve the capacity and efficiency of satellite networks, ensuring that consumers have access to high-speed Internet, data and voice, and other communications services. Introducing innovative methods and designing products that would handle data transmission more efficiently would provide prerequisites for dealing with the increasing number of satellites.

The main task of this dissertation is to design and develop a project for the installation and configuration of a satellite ground antenna operating with satellites in low earth orbit, as well as to propose innovative methods for receiving, sending, processing, and accessing satellite data by users, operating the constellations and platform. With the implementation of this satellite terminal, the optimization of such systems for working with satellites in low earth orbit will be proven, thus providing prerequisites for constructing a technological ground infrastructure to cover the growing volume of Internet traffic. A quantitative assessment and system performance approach will also be applied by analyzing the data being processed by the system and comparing it qualitatively with existing systems.

Chapter 2. Analysis of the main technological components of satellite communication systems.

2.1 Main components and characteristics of the satellite link

Satellite connections and data transmission are essential in the global telecom industry. They are part of the global telecommunications network. Their essential advantage is that they communicate to the most remote and inaccessible places without available cable infrastructure. It is necessary to install a satellite transceiver antenna and a modem to communicate with a satellite and thus secure and ensure access to the Internet. Artificial satellites are located in space at a certain orbital position and are not affected by natural disasters on the earth's surface, such as earthquakes, floods, fires, and others. In addition, apart from conventional connectivity for terrestrial communication services, satellite constellations also provide Internet access to sites in seas and oceans where it is impossible to provide access through a standard cable network. Using this technology, thousands of objects from space can be simultaneously covered by using only one satellite beam from space. Satellite communications carry all services, such as data, voice services, video, and multimedia content. Their flexibility also allows the construction of different types of transmission environments and network topology, implementing different data encryption methods for higher security and possibly building virtual private networks.

Their role is key to ensuring uninterrupted connectivity and the transfer of masses of data to and from inaccessible points to ensure global telecommunications coverage. In addition to Internet traffic and data transmission, they provide access to media and television content to households in remote and inaccessible areas where cable routes and networks are not built. Rapid network deployment, wide coverage areas through a single satellite platform, and reliable and high-speed satellite connectivity make them one of the fastest-growing industries in the 21st century.

Below, I describe the main components of a satellite communication link (Figure 1).

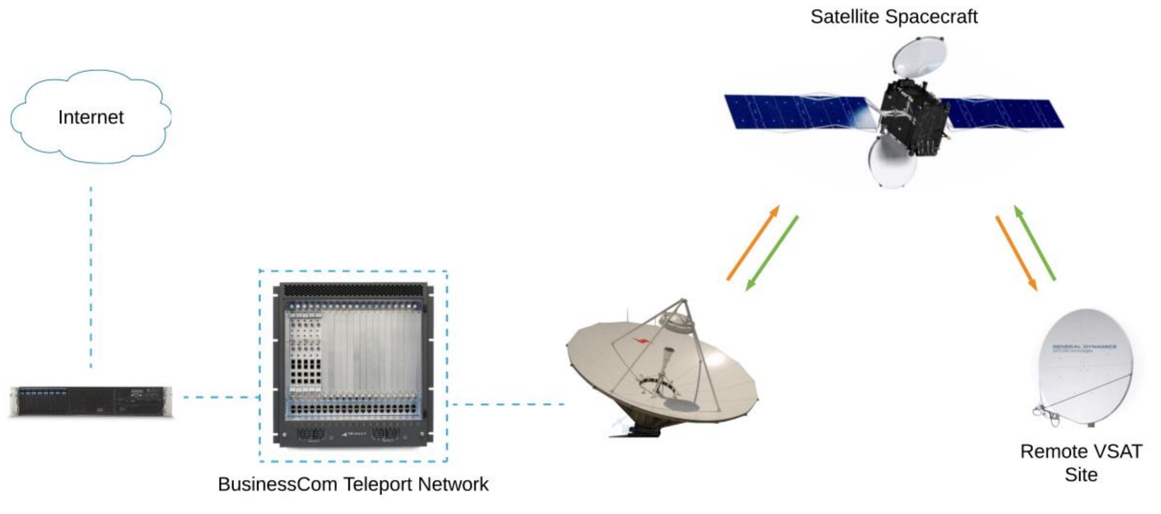

Figure 1 – Main components of the satellite link, [BusinessCom Networks]

Satellite communication includes two main segments - space and ground segment. Below, I describe these two strands and the individual sub-elements to build satellite communication.

2.1.1. Ground segment

One of the essential components for implementing data transmission through a satellite platform is the ground segment or ground station. We encounter it more often as Gateway or Teleport. It consists of a system of antennas and a wide range of hardware, most often installed in a nearby data center, that receive and transmit data to the satellites in a specific frequency and modulation scheme and thus establish communication in a specific frequency band and modulation scheme. scheme. The most often installed equipment are receivers, modulators, demodulators, modems, converters, amplifiers, matrixes, switches, hubs, etc. Satellite operators use TTC (telemetry, tracking, and control) antennas - which monitor the satellite's orbital position and other critical parameters in real-time to ensure a secure service for users. Telemetry and remote monitoring and control are implemented through this system.

End customer antennas can be divided into three main categories - fixed (stationary), mobile (on-the-move), and portable (flyaway), and they are used according to the specific application. They are characterized by frequency spectrum, size and type of reflector, polarization, automatic or manual tracking, type of orbit, and others. The larger the diameter of the reflector, as well as the output power of the amplifier, the more efficient the system we have and, accordingly, the better the communication with the satellite. The choice of individual elements is often determined by the satellite operator, who prepares a Link Budget, which provides guidance and recommendations for minimum antenna requirements.

Building the ground segment requires a proper selection of individual components that function together to ensure quality communication and data transmission (Figure 2,3). The main elements that are part of an antenna system for an end user are the following.:

- Antenna system reflector - a part of the antenna that reflects the received radio-electromagnetic rays and feeds them to the irradiator. Using a larger diameter allows a more efficient satellite link to be built. The material from which the reflector is made is key; therefore, carbon fiber, glass fiber, and aluminum are often used.
- Irradiator set (RF feed) includes the irradiator, a transducer (Orthomode Transducer), and the converters and amplifiers are often mounted to it. Depending on the satellite beam, it can operate in linear or circular polarization.
- Amplifier/Converter (Block Up Converter) – amplifiers are operated in the Teleport station as part of the transmission antennas or integrated into the final client terminal. Their function is to receive the signal from the data center (most often from the modulator or modem) and convert it from the IF or L frequency spectrum to a higher one that corresponds to the satellite system - most often C, Ku, Ka, X. It then amplifies the signal to send the received information to a satellite. It is preferable to use higher output powers to make more efficient use of the available capacity.
- Low noise amplifier - Low noise block converter (LNB) - This component receives the signal from the satellite and then amplifies it to be processed by the end device. It also converts from higher frequency (C, Ku, Ka, X) to lower IF. There are two main types

of low-noise amplifiers - "Phased Lock Loop" and "Dielectric Resonator Oscillator". Phased Lock Loop amplifiers can be with external or internal reference - "external" and "internal reference.”

- Waveguide: This part of the antenna transports the electromagnetic wave from the radiator to the LNB.
- Antenna heating – Used in locations where temperatures drop below freezing and reflector freezing and antenna failure are possible, resulting in satellite contact or signal interference loss. Different types of heating are used; most often, it is attached to the back of the antenna, but there are controllers through which the system's parameters are set.
- Mounting bracket – we often have mounting brackets with or without drilling the base for end-customer terminals, the so-called "Non-penetrating roof mounts" and "Penetrating roof mounts." A different product type is also recommended depending on the terrain on which the activity is carried out.

Figure 2 – Receive Antenna, [personal archive Krasimir Terziev]

Figure 3 – Antenna Components, [personal archive Krasimir Terziev]

As I already mentioned, in addition to the antenna system for the construction of satellite communications, we also have a different type of additional equipment used in a data center or at the place of operation of the service to establish a connection with the platform in space. I describe some of the main components:
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- Modem - this device performs modulation and demodulation - converts the digital signal sent by the computer to analog (modulation) and back analog to digital signal (demodulation). Modems process data packets and are characterized by a maximum volume of processed data (bytes) sent quickly (seconds). Modern modems offer speeds expressed in Mbps - megabit per second. Because modems perform modulation and demodulation, they are designed for two-way data exchange - reception and transmission.

- Modulator - A modulator is a device that superimposes low-frequency on high-frequency information or signals for the purpose of wireless data transmission. Modulation is necessary because it is part of establishing satellite communication. Signals can be digital or analog. The main types are divided into three main directions - amplitude, frequency, and phase.

  Amplitude - amplitude modulation (AM), analog and amplitude shift keying (ASK), digital.

  Frequency - frequency modulation (FM) - analog and frequency shift keying (FSK), digital.

  Phase–phase modulation (PM), analog and phase shift keying (PSK), digital
- Demodulator – it has the exact opposite function of a modulator. Its task is to demodulate AM, FM, and PM-modulated signals and decode and convert them into audio and video output. We can also formulate this process as extracting the original data from the satellite and separating the useful signal from the multiple radio-electromagnetic waves to be received by the end device.
- Converter is called a step-up converter, which converts a lower radio frequency to a higher one. When we observe the reverse process, converting from a higher frequency to a lower one, we use a step-down converter (down-converter). A high frequency characterizes spontaneous communications, so it is necessary to use this equipment to send the data at the specific frequency in which the satellite platform operates.
- IP network switch – IP switches transmit information to the network from the devices connected to them through physical, usually Ethernet ports (different numbers - from 4 to 96). They provide secure and reliable wired communication between devices instead of wireless Wi-Fi. They are most often used in places where there is a need to support many end devices, and most often, they handle Layer 2 or Layer 3 protocols.
- Router – Also called router. Its role is key in communication networks because it routes or distributes packets from different networks using pre-configured logic in IP addresses/tables. Without it, IP networks and communications cannot function in sync.
- Hub – This equipment is installed and integrated with the telecommunication infrastructure of the Teleport stations to ensure simultaneous communication with several satellites and provides the possibility of connecting numerous end terminals and devices for data transfer or Internet access. The hubs are characterized by the support of large satellite capacities and correspondingly fast processing of a large volume of information. They also save resources in building the telecommunications infrastructure and network because the hardware is already pre-installed and configured, and the service is provided easily and quickly.
- Matrix is a product through which remote control, monitoring, and management of received (downlink) and sent (uplink) signals from and to the satellite is carried out. Teleport stations, satellite operators, media companies, and other organizations in the industry use matrices to process traffic according to their needs.

2.1.2 Space Segment

It includes the artificial satellite, also called a satellite. The word comes from the English Artificial Satellite - an artificial satellite that is put into orbit for the needs of telecommunication services. Its function is to receive signals from the ground and send/reflect them to another preset point or location that is part of the beam coverage.

More than 11,000 artificial satellites are in Earth orbit and are used for various purposes and applications. Their sizes vary, ranging from so-called "Cube" satellites - just over 4 inches and can be grasped with one hand - to those weighing 10 tons and 34 meters long. The satellites are launched from a special rocket in which the satellite folds and gradually unfolds as it reaches a certain height in space. Part of the rocket burns up in the atmosphere.

There are two main elements of satellites:

1. "Bus" - a modular structure that essentially forms the basis of the satellite and supports the main systems and subsystems for normal operational work.
2. "Payload" - includes the communication part of the satellite - the transponders and communication antennas - receiving and transmitting.

Parts of the “Bus” segment

- Structural Subsystem - This provides the mechanical support for the entire satellite, including the payload and other subsystems. It is designed to withstand the stresses of launch and the harsh conditions of space.
- Power subsystem – it generates, stores, and distributes electrical energy to the various systems of the satellite. The main source of energy used by electronic equipment in space is solar cells. However, batteries are also included in such systems that offer standby power in the event of a lack of solar power. It should be noted here that the power generated by a single solar cell is quite smaller than what is required by the equipment, so instead of using one, arrays of cells are used in series and parallel configurations to achieve the desired power level.
- Attitude Control and Determination Subsystem - this system maintains the orientation and position of the satellite in space, ensuring that the antennas, sensors, and solar panels are correctly pointed. It usually consists of sensors to measure the attitude and position of the satellite and actuators, such as thrusters or jet wheels, to make corrections as needed.

  Controlling the satellite corresponds to controlling its orientation as it orbits the Earth. This is a crucial part of satellite system design and maintenance as it allows the satellite dish to be aimed precisely at the specific region of the earth.

During this process, the satellite's orientation in space is established, and then the correct controlling action must be activated in the event of an error. In general, the position of satellites changes over time, so it requires monitoring and periodic correction. Satellite platforms must also occupy a certain orbital position to comply with International Telecommunication Union requirements and not interfere with neighboring platforms in space.

- Thermal Control Subsystem - Satellites orbiting the earth are affected by large temperature fluctuations, and various reasons exist. The satellite's temperature varies due to solar radiation from the Earth. Apart from these, a satellite system also generates heat, and all these factors raise the temperature, and for proper operation, it must be kept within limits. To achieve this, one of the important factors is that the equipment operates in a suitable atmosphere. This system regulates the satellite's temperature to protect sensitive electronics and other components from extreme temperature fluctuations. It typically uses passive techniques, such as insulation, and active techniques, such as heaters and radiators, to maintain a stable environment.
- Propulsion Subsystem - This enables the satellite to change its orbit or maintain its position. Propulsion may involve chemical, electrical, or other propulsion technologies depending on mission requirements.
- Communication Subsystem - This enables communication between the satellite and ground stations, facilitating the transmission of commands, telemetry, and payload data. A communication subsystem usually consists of antennas, transmitters, and receivers. The system produces electrical signals in proportion to the quantity needed to be measured, encodes them, and transmits them to the desired ground station. The telemetry feature is all about measuring distance. Telemetry signals consist of environmental information, satellite information, power, and stored fuel pressure.

Parts of the "Payload" segment

- Transponder – this is the part of the satellite that receives and transmits data (Figure 4). It is the most important part through which a telecommunication signal is carried to and from the ground. A transponder is a channel formed by series-connected units between transmitting and receiving antennas. They are not separate equipment but a combination of elements forming a communication channel. The transponder is, therefore, an essential unit of satellite communication. The bandwidth of the transponder depends on the satellite's technology and the nature of the signal being transmitted. It is included in both the uplink and the downlink.

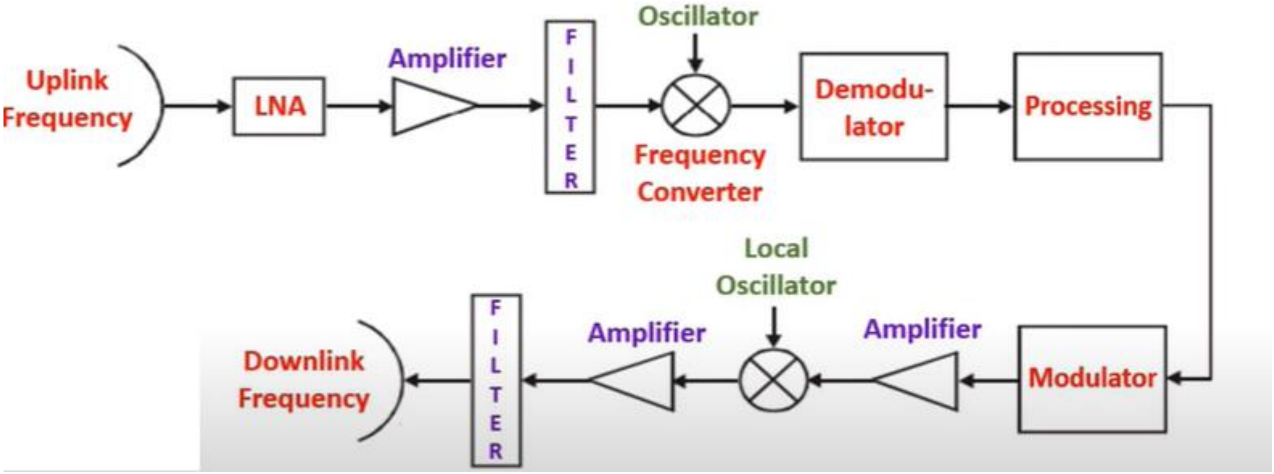


Figure 4 – Satellite Transponder and Reception/Transmission of data, [SatNow]

2.2 Basic network topologies and frequency bands applicable in satellite communications.

Star, Mesh, and single channel per carrier (SCPC) are the main network topologies used in satellite communications.

- SCPC or "single channel per carrier" is widely used. The satellite transponder has a certain frequency band and is divided into several carrier frequencies, considering the frequency band of the number. For example, a 'C' band satellite with a total bandwidth of 500MHz is split between many transponders with a bandwidth 36MHz. It is used to carry information in the form of voice or data. These voice or data lines are called a channel. "SCPC" means Satellite Transponder Single Channel. The voice or data channel is modulated over a carrier frequency and transmitted to the satellite using the ground antenna. The same modulated signal is converted/amplified and sent down to the receiving terminal on the other side via a transponder. Here, we have an analogous principle of sending, processing and receiving the information as with MCPC (multiple channels per carrier).
- Star - satellite networks with a star topology provide IP connectivity to a ground hub at the operator's Teleport station. Using network equipment that connects to a VSAT (very small aperture terminal) hub simultaneously delivers satellite capacity to multiple remote client terminals that access the Internet network.

One of the technologies used in star networks is TDMA - "time division multiplexing," which is used when sending data to multiple destinations. This makes it possible to use the same frequency, which divides the signal into several time slots. The terminals are alternated at very short intervals, using the same assigned and predefined transponder slot, thus optimizing the use of the satellite resource and capacity.

Satellite communications must respect a certain frequency spectrum allocated by the satellite operators. In addition, they must respect and work in full compliance with the international regulations that are defined and controlled by the International Telecommunication Union (ITU), Figure 5.

The frequency spectrum is the basis for establishing and maintaining a reliable communication link and also determines the necessary equipment that must be used in the execution of this process. It is important to note that frequency is an essential parameter that affects the wavelength and, consequently, many aspects of the communication system.

The most widely used frequency bands are VHF, L, S, C, X, Ku, and Ka.

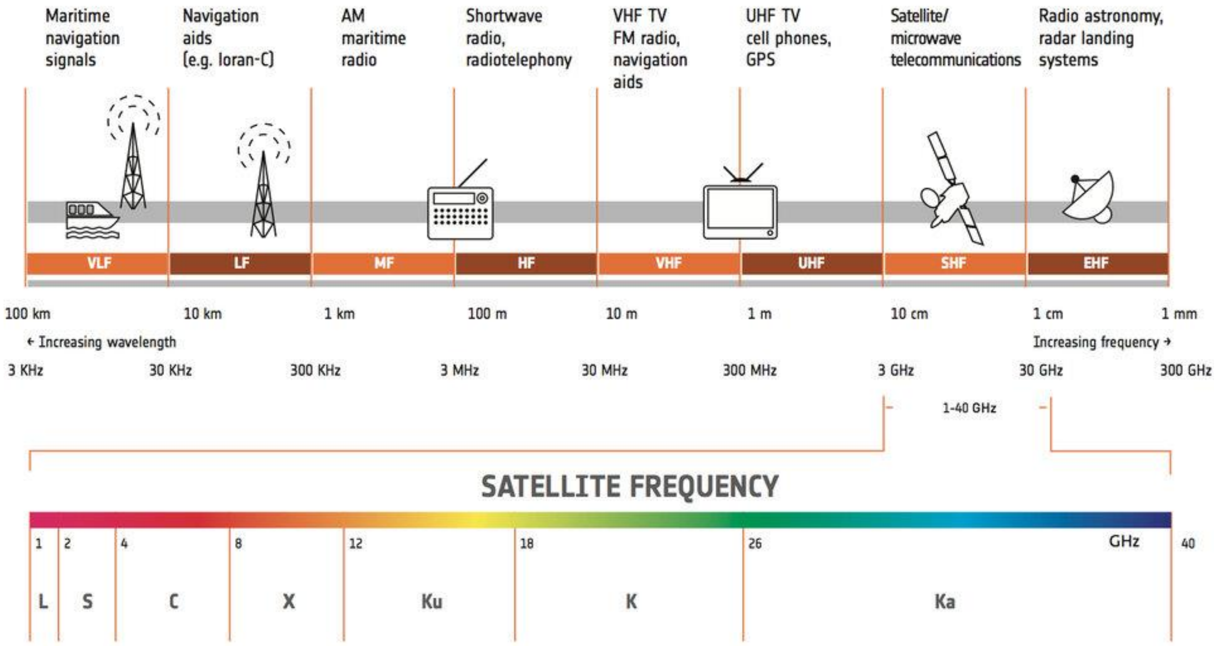


Figure 5 – Radio Frequency Spectrum, [European Space Agency]

2.3 The main types of services offered by satellite networks. Types of satellite orbits.

- Fixed Satellite Services (Fixed Satellite Services - FSS) - Connect one or more fixed terrestrial locations by relaying through one or more satellites. When we transmit through several satellites, the so-called "inter-satellite service" communication occurs. This solution is distinguished by the fact that it can easily be divided into several carriers, making it preferred in constructing satellite links. Phone voice services, data transfer, fax, video and TV content, radio, and more are supported.
- Radio and Television broadcasting (Broadcast Satellite Service - BSS) – this technology is often used to broadcast TV channels and content, for example, in "Direct to Home" services. Here, using entire transponders to carry the multiplexed TV content to the end customer antennas is typical. Cable operators use this method due to the efficiency of the frequency band and the use of all the capacity in the transponders - 36MHz, 54MHz, or 72MHz. They are divided into two basic types - multifunctional and systems for direct satellite reception, and they differ by the maximum permissible power flux density (Power Flux Density).
- Direct radio and television services (Direct broadcast system - DBS). Given their dependence on flux density and their higher frequency than standard, they offer more

limited coverage of the Earth's surface. The frequency band of the satellite is 17.3 – 18.1 GHz and 11.7 – 12.75 GHz from the satellite. Circular polarization is most often used.

- Direct-to-home services (Direct-to-home - DTH) is the most frequently used service for broadcasting television content to end subscribers. The advantage is that the equipment is affordable and of appropriate dimensions, which facilitates end users' operation. This service is offered by cable operators who provide a set of satellite dishes and decoder through which many channels are provided.
- MSS - mobile satellite services - providing a satellite connection to mobile objects, on which portable and portable antennas and terminals are most often installed, which have automatic tracking to track the satellite to which they are directed. The industries in which they are applied are marine, aviation, and land, such as trains, buses, etc. Depending on the application, the end terminals are mounted in different locations. Inland mobile solutions, the antenna is on the vehicle; ships or luxury yachts in the marine sector are installed on board, and in the aviation industry on the plane.
- Radio amateur links - mostly carried out through amateur satellites, and communication links are built for non-commercial purposes.
- Global Positioning System (Global Positioning System - GPS) - a network of satellites located in an average earth orbit (about 20,000 km from the earth's surface), which serve to determine the position, speed, and time with an accuracy of up to 1 nanosecond at any point on globe and Earth orbit in real-time. By measuring the exact distance from the location, we are looking for a group of satellites whose coordinates are already accurate and predetermined.
- Meteorological services – meteorological satellites such as METEOSAT NOOA for observation and the study of the earth for meteorological purposes.
- Radiodetermination satellite services (Radiodetermination satellite service - RDSS) are used in aviation to accurately determine objects' location, speed, or other parameters. The "RDSS" system allows the exchange of accurate data and coordinates between different objects, not just one-way.
- Radio navigation satellite systems (Radio Navigation Satellite Services - RNSS) are used in the marine industry to determine the vessel's time, location, and speed. Voice communication services are also provided here.
- Military services – a network of satellites used for military purposes. Often, they operate in a different frequency band than the commercial one – for example, X.

Chapter 3. Designing the technological infrastructure of a ground station for low-orbit satellites

3.1 Scope of the project

"OC LEO 1 Ground Station" is a professional ground station for operation with satellites in low earth orbit, which offers the service - ground station as a service for satellite missions, "multi-mission ground station as a service" and operates in frequency band S in the range 2035MHz – 2310MHz. The antenna system works in circular polarization - with left and right orientations respectively. The size of the reflector is 3.2 meters. The data processing technology is based on the "Network Cloud Engine," which includes multiple microservers operating in the cloud, which perform the operation and monitoring of the various ground stations in a network, as well as provide access to the user interface for the work of the end user. The project involves the installation of a satellite antenna operating with low earth orbit satellites in the S-band frequency band, which operate in orbit about 120 to 2000 km above the earth's surface. By implementing this innovation, satellite operators will be able to receive data from specific platforms, and companies or users will have their resources in space, in case they have their satellite or constellation. This system is aimed at universities, research institutes, schools, and satellite operators who can operate the ground segment and process data from their networks in space. The main applications are satellite images of the earth, environmental monitoring, scientific research and analysis, military intelligence, disaster and accident prevention, agricultural and livestock development, and other telecommunication needs. Through the ground antenna, access to a cloud application with a simple and intuitive interface is provided, enabling the implementation of a satellite mission through which data from specific satellite platforms can be received and processed by end users. The satellite ground antenna I will present is part of a communications network and enables rapid access to many satellite platforms that perform a wide range of missions.

The technology we use in this case allows access to a network of terrestrial satellite dishes located in different geographical areas through a single access point, using a cloud-based platform called "Network Cloud Engine" (NCE), Figure 6, to transmit the data from the satellite mission control center to the satellite constellation. The advantage of this solution is that the service operator does not have to manage each satellite terminal individually, but by means of "NCE" orchestrates the entire process from one place. In this way, the user can simultaneously and efficiently plan and implement numerous satellite missions and receive the datasets to a central server in the cloud, after providing an individual username and password.

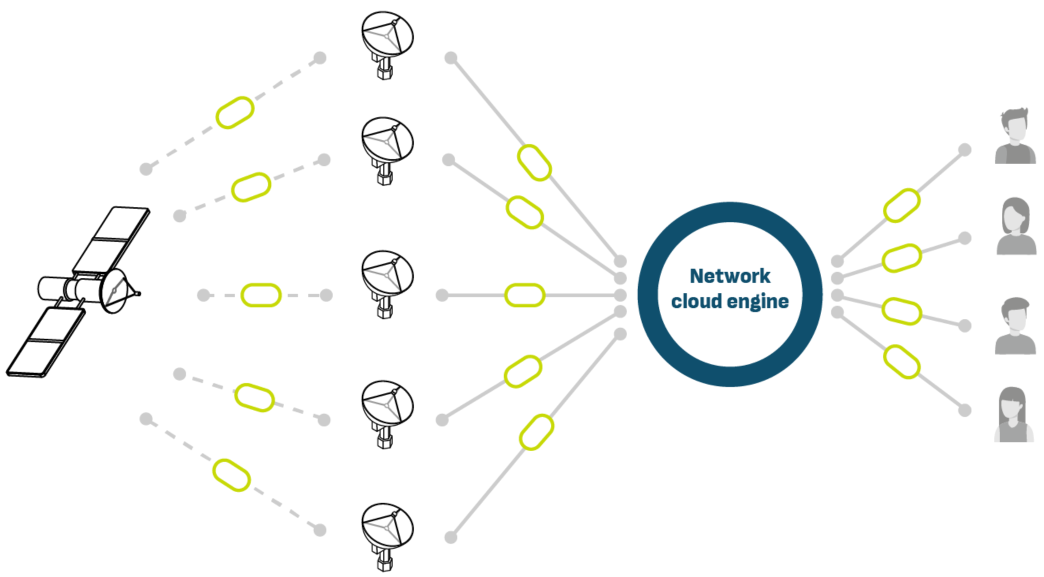


Figure 6 – data processing process – Data Flow, [Krasimir Terziev]

3.2 General plan and main components of "OC LEO 1" ground antenna, (Figure 7)

- Parabolic reflector – is a 3.2m metal disk (made of aluminum), an irradiator set in frequency band "S" (RF Feed).
- Upper Pylon – a mechanical system that houses the elevation and azimuth motors, as well as components for sending signals on the "up" line
- Lower Pylon – A main column that supports the upper pylon and connects the ground station to the ground. It also houses antenna elements, a low-noise amplifier (LNA), a high-power amplifier (HPA), a synchronizer/resolver (determines the exact position of the antenna system in azimuth and elevation in degrees), an antenna control system (antenna control unit).
- Air conditioning – provides suitable temperature and cooling of the elements in the lower pylon.
- Link arm – a fiberglass or aluminum support arm that supports the YAGI antennas
- UHF YAGI antenna – antenna operating in the UHF frequency band
- VHF YAGI antenna - antenna operating in the VHF frequency band

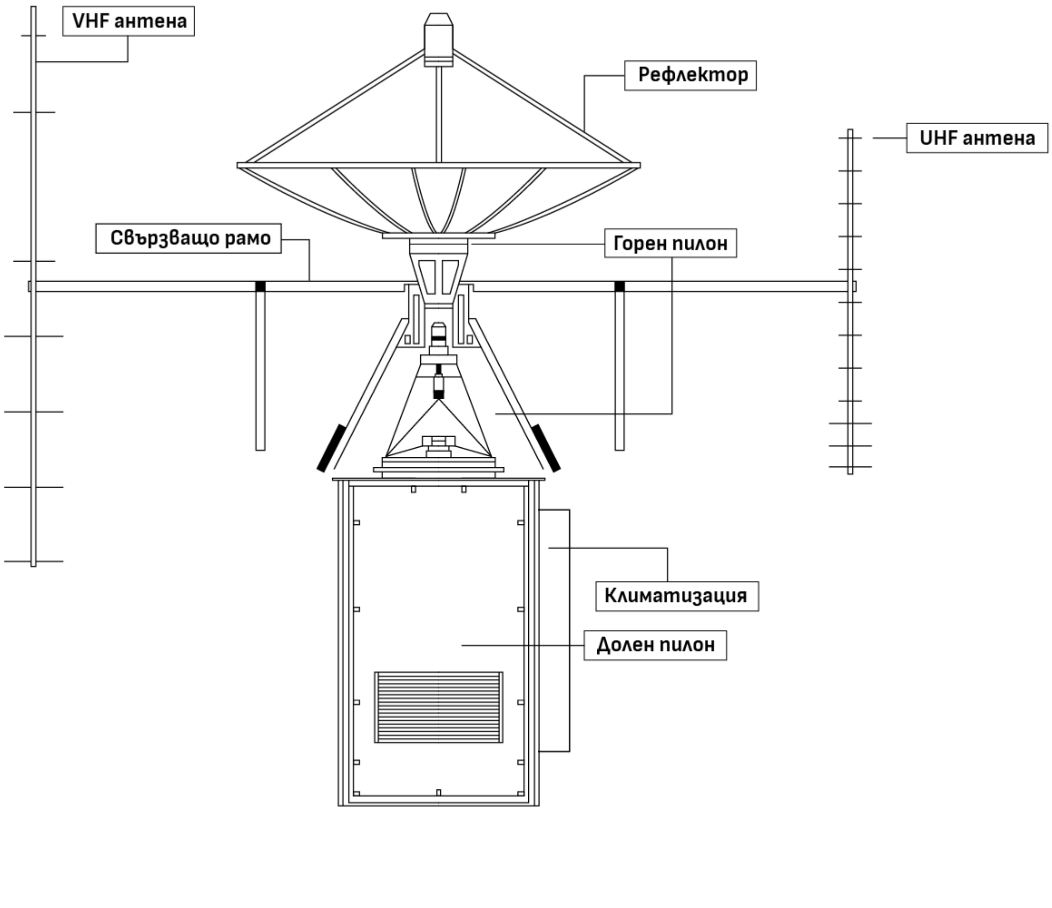


Figure 7 – Depiction of OC LEO 1 DY antenna, [Krasimir Terziev]

Technical specification S-band, antenna system "OC-LEO 1"

Specification	Receive / Rx	Transmit / Tx
Frequency spectrum	2210-2310 MHz	2035-2120 MHz
Maximum isotropic gain	34.8dBi	34.8dBi
Beam width	3.1°	3.3°
Polarization	Right/Left oriented, X-POL	Right/Left oriented, X-POL
Noise temperature of the receiver	291 K @ 5° EL	Not applicable
Equivalent Isotropic Radiated Power - EIRP	Not applicable	54 dbW
G/T	10.6dB/K	Не се прилага
Amplifier Tx		100W
Modulation	It is configured depending on the satellite system	It is configured depending on the satellite system

Scope of the project – design installation of an antenna system for satellite communication in low earth orbit.

Phase 1 - Site selection for "OC LEO 1" antenna system

- Choosing a physical location to mount an antenna
- Choosing a suitable place for the electrical panel and the additional external elements
- Determining the length of cable routes and pipes for connection to the electrical network and Internet cables

Phase 2 – Site Preparation

- Design and construction of foundations as well as support points
- Design and preparation of grounding equipment
- Design and preparation of electrical connections and Internet cables
- Design and preparation of the necessary pipes for laying cables
- Design and construction of lightning arresters
- Site/Site Safety – The Teleport Operator observes and follows safety instructions for all employees and personnel performing project activities.

3.3. Technical requirements of the antenna system

- Electrical requirements

The antenna requires single-phase AC power, 110 – 240VAC, 50 – 60Hz. The connection should be protected and secured with automatic fuses. The maximum power for the ground station is 6Kw, 32Amp.

- Grounding of the facility

For the project, all the necessary electrical components are provided to ensure the grounding of the antenna. In addition, regulatory requirements and standards are also observed when performing this activity.

- Lightning protection

The project also includes the necessary equipment and provides lightning protection for the antenna system. All elements are professionally installed to secure the equipment. The lightning protection that is part of this project is not limited to the antenna system but also extends to other equipment and components connected to the ground station. The approach involves the professional design and installation of electrical discharge systems specifically designed for this system. They must be integrated into the facilities and be capable of dissipating the potentially destructive electrostatic discharge that can cause malfunctions in operation and communication with the satellite. All methods used are by safety and quality standards, considering local weather conditions and the likelihood of lightning.

- Requirements for Internet connectivity.

Internet connectivity is planned to provide the necessary ground capacities to serve the satellite missions without service interruption. For this purpose, the antenna system, particularly the modem, is connected to the MAN (Metropolitan Area Network) of an Internet service provider, through a LAN interface and a port that supports speeds up to 1Gbps. Redundant connectivity through another provider is also provided to avoid loss of satellite communication. This provides basic Internet connectivity and redundancy, as well as enabling high-speed transfer between the satellite platform and the ground station. Capacity is a key factor considering the increasing data processed by low-Earth orbit systems.

Description of the activities to be performed by the system integrator

In order to guarantee the correct installation of the "OC LEO 1" antenna (Figure 8), as well as its functioning, the system integrator must prepare the precisely intended installation site by carrying out, according to the preliminary requirements, the following activities:

Choosing a suitable installation location that has a good view of the horizon for the antenna.

- Choosing a place to install an electrical panel
- Choosing a location for mounting a webcam stand
- Preparing the foundation for the installation
- Laying cable routes for Internet connectivity
- Wiring to connect the electrical cables
- Preparation of electrical connections for grounding
- Preparation of lightning protection equipment
- Preparation of the installation site, provision of necessary machinery/cranes and personnel for the day of installation of the equipment
- The system integrator must provide a lifting machine so that the antenna can be lifted and placed in the exact location provided in the design. The use of an assembly crane is necessary to assemble all parts of the antenna before installation.

Choosing a suitable collocation location for the “OC LEO 1” Antenna system

The system integrator should consider the following requirements and details before making a final choice for the "LEO OC 1" antenna location:

- Good visibility to the horizon and sufficient elevation angle of the antenna to the satellite platform
- Absence in the vicinity of objects that would cause interference
- Absence in the vicinity of objects that would prevent the smooth rotational movement of the antenna, which would limit its range and, accordingly, prevent communication with the satellite.
- Absence of transmitters or other antennas that could cause frequency interference and degrade the signal

Preliminary analysis on building a solid antenna base

- Preliminary analysis regarding the provision of the antenna system with sufficient capacities for electricity and Internet connectivity.
- Preliminary analysis of how to co-locate and protect adjacent equipment
- Systems for prevention and protection against unauthorized access.
- Ensuring access for the lifting machines and cranes provided for the installation
- Providing access to perform the installation activities
- Provide access to perform scheduled antenna maintenance as well as field equipment.

Summary of installation prerequisites – Figure 8

- Ensuring good visibility to the horizon - before the installation of the antenna, we carefully check that the nearby objects and obstacles are compatible with the visibility requirements of the project and do not hinder the movement of the antenna to track the satellite in low earth orbit.
- Ensuring access – the technological object must provide normal access to the existing infrastructure, such as electricity, sewer network, equipment, communications, and others. In addition, the hardware and location should be safe to operate and maintain.
- Wind strength - performing a field test of the antenna at maximum wind strength values to determine that the reflector is stable and does not change its acceptable parameters for communication with satellites.
- Frequency interferences – before putting the antenna into operation, we must make sure that there is no other radio equipment in the vicinity that could interfere and create interference with the "OC LEO 1" antenna system.
- Meteorological conditions and environment – analyzing climatic conditions within the year to ensure that they would not interfere with the functioning of the “OC - LEO 1” antenna
- Site access and security – integration of a control system through personalized cards to prevent unauthorized access by persons to endanger or disrupt the operation of the antenna system.
- Site Permits – to secure the necessary building permits for the construction and installation of the antenna.
- Radio-frequency licenses – to obtain the necessary radio licenses that are necessary for the operation of the antenna. These licenses are issued by the Communications Regulatory Commission.

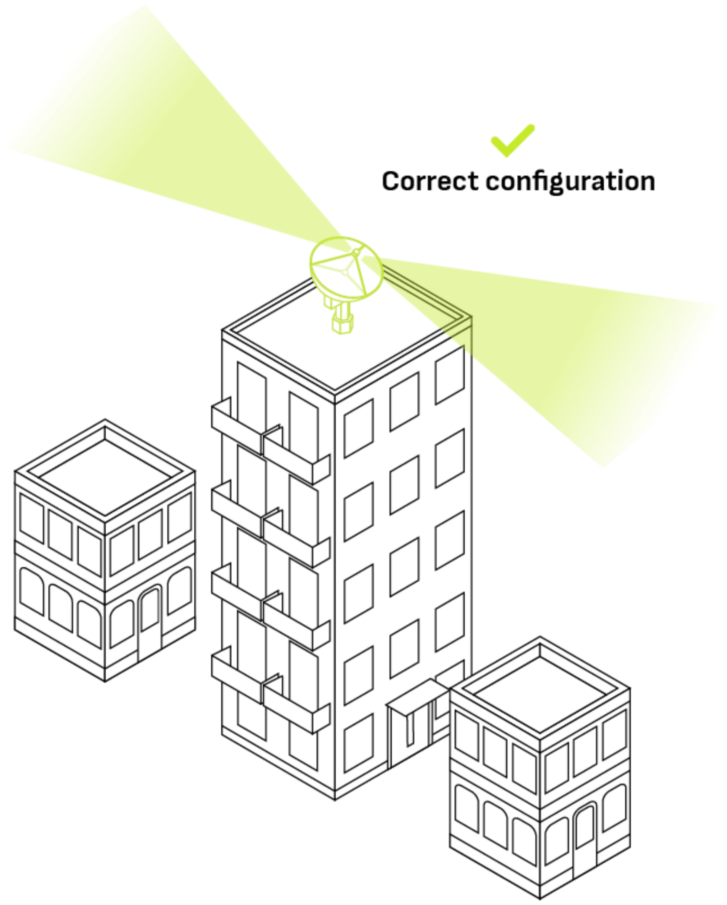


Figure 8 – Correct configuration, [Krasimir Terziev]

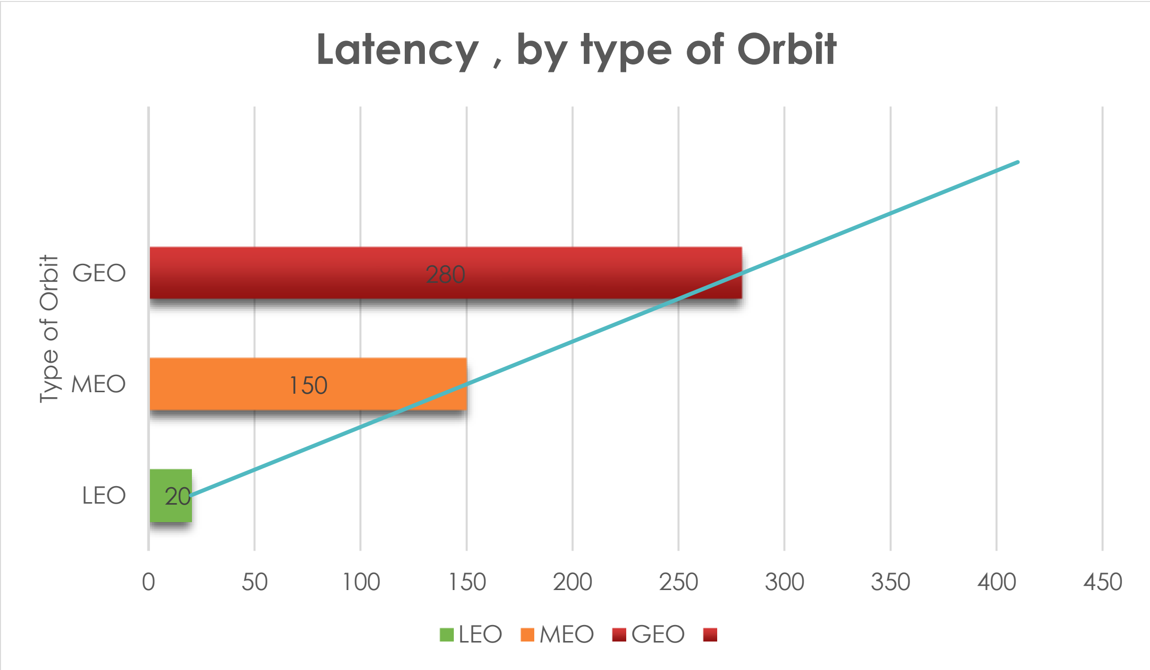
Chapter 4. Evaluation and comparisons of technological parameters of the designed ground station through measurements of its parameters.

4.1 Research and determination of the technical characteristics of the designed ground station for space communications

In this chapter, an analysis of the technological parameters of the designed low earth orbit satellite communication system is made. Measurements and evaluation of the designed antenna part of a satellite communication system were performed. Improving the parameters of the antenna system allows increasing the functionality of the entire satellite communication. The main technological values that determine the functionality and quality of the satellite connection have been determined. The results of the experimental application of the satellite antenna are presented and a quantitative evaluation and analysis of the quality and efficiency of the system is performed. The results of the empirical studies are analyzed and described, entered in tables and visualized through diagrams.

After performing a thorough analysis of the data received from the system, we can evaluate which indicators we observe improved functional and operational characteristics.
The designed and developed antenna system has been experimentally evaluated, which shows superior results compared to the current technological level of the antenna part of a satellite communication system.

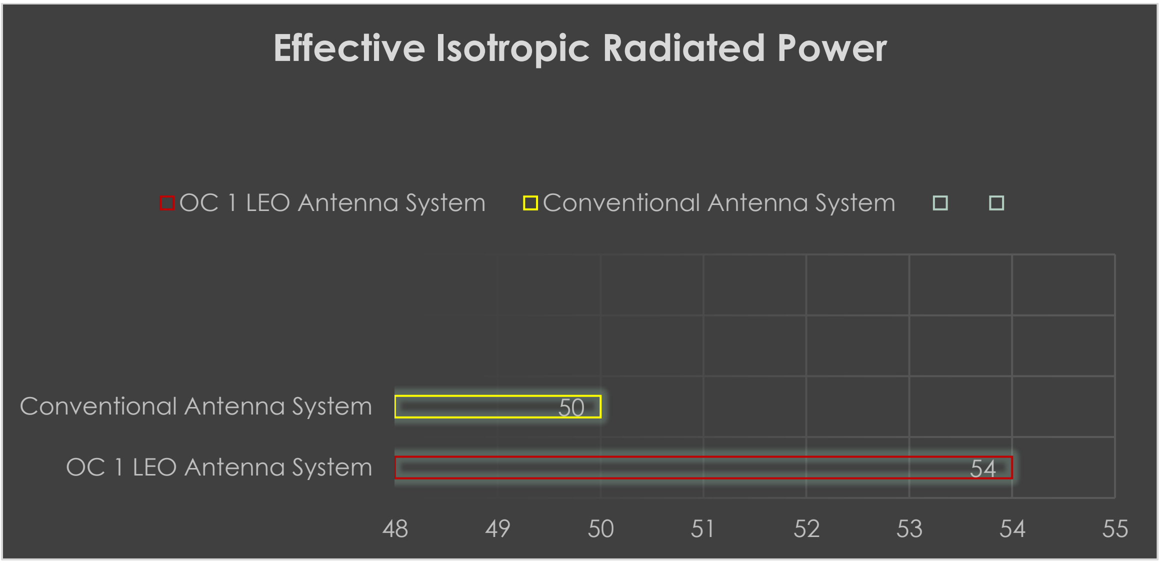
Graph 1



Type of Orbit	LEO	MEO	GEO
Latency m/s	20	150	280

Conclusion: This graph presents a comparison of the use of antenna systems in low earth orbit, versus medium orbit and geostationary orbit platforms.

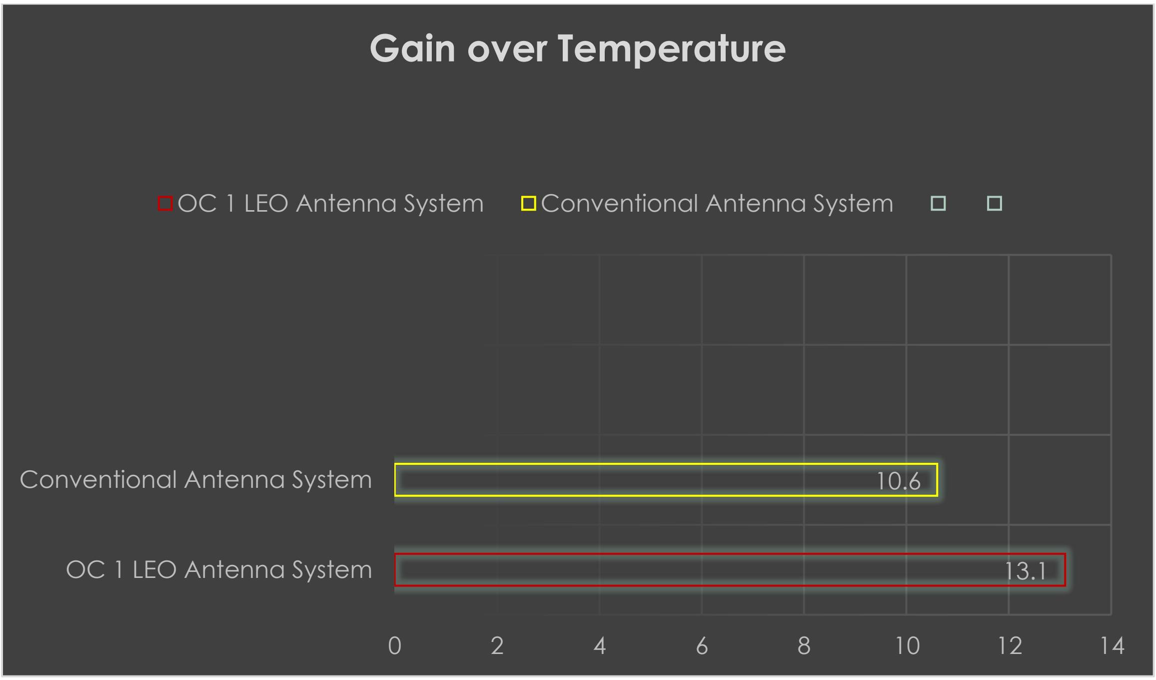
Graph 2



Parameters	OC LEO 1 Antenna	Conventional Antenna System	Difference
EIRP	54dBW	50dBW	4dBW

Conclusion: The graph presents a comparison and analysis of the effective isotropic radiated power values for the "OC LEO 1" antenna system, compared to conventional antennas.

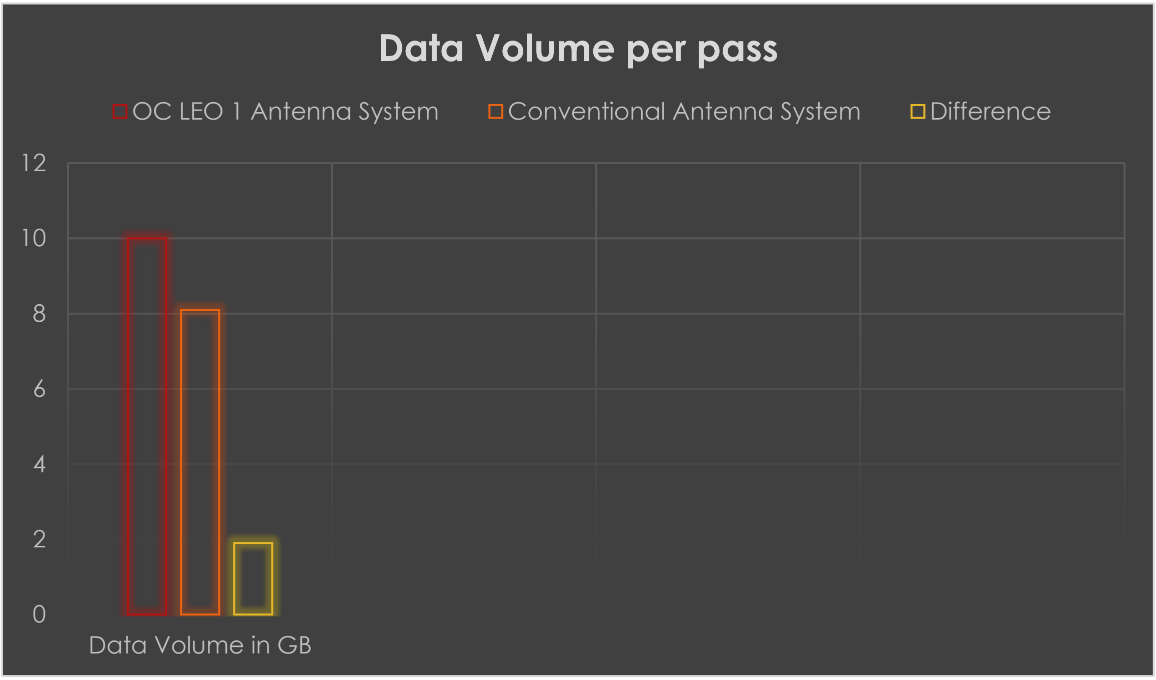
Graph 3



Parameters	OC LEO 1 Antenna System	Conventional Antenna System	Difference
G/T	13.1dB/K	10.6dB/K	2.5dB/K

Conclusion: In the graph, we have examined one of the critical parameters of the antenna system on which the reception of a satellite signal from space depends, namely "Gain vs. Temperature" - G/T. A comparison was made between the designed antenna system "OC LEO 1" and conventional antennas. Estimating this value gives us information about the antenna's ability to receive weak signals from space and at the same time maintain low noise levels that negatively affect and reduce the useful signal received by the receiver. Higher G/T levels enable the system to work better near other telecommunications equipment, preventing interference that leads to degradation of the radio signal. Antennas with low G/T levels often cannot receive a satellite signal that is attenuated in the atmosphere. In the designed low earth orbit antenna "OC LEO 1" we have an advantageous value of 13.1dB/K, which is 2.5dB/K higher than the conventional equipment. Operating our antenna allows us to communicate more efficiently with the satellite, resulting in a greater volume of data being received during the satellite's over-the-horizon crossing.

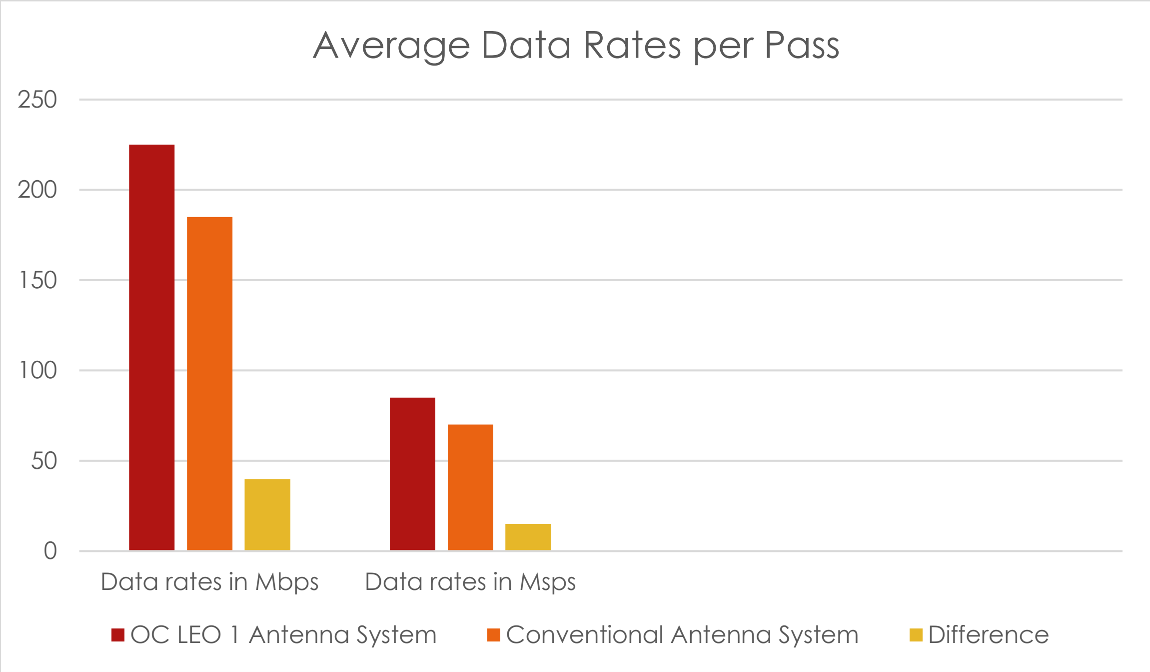
Graph 4



Parameters	OC LEO 1 Antenna System	Conventional Antenna System	Difference
Data Volume	10 GB	8.1GB	1.9GB

Conclusion: This graph presents an analysis and evaluation of the performance of the antenna system when the satellite passes over the horizon. A comparison was made between the designed antenna system and conventional antennas. It visualizes the data we expect to be received by the satellite platform with an average communication time with the antenna (satellite pass) of 5-7 minutes. As a result of the lower values of time delay, optimized G/T and EIRP parameters, we also achieve faster data exchange rates and the possibility of obtaining a larger volume of information. Advantageous results of the designed low earth orbit system are presented with values of 10GB, which are 1.9GB more than the current antennas on the market.

Graph 5



Parameters	OC LEO 1 Antenna System	Conventional Antenna System	Difference
Mbps	225Mbps	185Mbps	40Mbps
Msps	85Msps	70Msps	15Msps

Conclusion: An analysis, evaluation and comparison of the reception rates of the designed low earth orbit antenna system compared to similar products on the market is graphically presented. The differences in speeds measured in Mbps (Mega bit per second) and Msps (Mega Symbols per second) are visualized, proving optimization when operating an "OC LEO-1" antenna. Advantageous reception values of 225Mbps and 85sps are expected, which is 40Mbps and 15Msps higher speed than equivalent platforms. This allows integration with software and hardware applications requiring faster data transmission. The overall improvement of the antenna system parameters provides more secure, reliable and persistent communication with the satellite platforms in low earth orbit, with high levels of service availability.

4.2 Application of proposed methods for quantitative assessment of the quality and effectiveness of the system

Based on the comparative analyzes carried out in this chapter of the dissertation, a quantitative assessment of the quality and efficiency of the designed system "OC LEO 1" in low earth orbit was carried out. The values of the presented indicators (indicated by C1, C2, C3, C4, C5) are presented and in percentage ratio superior results compared to the current antenna systems are proven. The quality assessment was carried out according to five key criteria, and each of them is presented graphically.

The formula that is applied is:
C1 Indicator - (C1 OC LEO 1 Antenna System/C1 Conventional Antenna System) x 100%
C2 Indicator - (C2 OC LEO 1 Antenna System/C2 Conventional Antenna System) x 100%
C3 Indicator - (C3 OC LEO 1 Antenna System/C3 Conventional Antenna System) x 100%
C4 Indicator - (C4 OC LEO 1 Antenna System/C4 Conventional Antenna System) x 100%
C5 Indicator - (C5 OC LEO 1 Antenna System/C5 Conventional Antenna System) x 100%
From the obtained result, we subtract 100% to get by what percentage we have increased the efficiency of the system according to the given criterion. The difference is presented in the "Antenna System Efficiency Increase" column as a percentage.

For clarity of the results of the evaluation and analysis, radar diagrams have been prepared for the individual indicators.

Table with summary results of values for antenna system “OC LEO 1” and conventional antenna system.

Parameters:

Indicators	**OC LEO 1 Antenna System**	**Conventional Antenna System**	**Increase of the antenna system efficiency in %**
C1. Effective Isotropic Radiated Power EIRP in dBW	54	50	8%
C2. Efficiency coefficient of the antenna when receiving a signal G/T in dB/K	13.1	10.6	23.6%
C3. Data Volume per satellite pass in GB	10	8.1	23.5%
C4. Download data rates in Mbps	225	185	21.6%
C5. Download data rates в Msps	85	70	21.4%

Diagram 1:

The radar diagram illustrates a comparison of the results obtained from the graphs in this chapter for the main parameters of the designed antenna system versus conventional antennas. The difference expressed spatially in area is presented. In orange, the values of the conventional antenna systems are visualized, and in dark red, those of the designed LEO antenna system. From the results, it follows that according to data exchange speed criteria in Msbs and Mbps there is a serious optimization and improvement of efficiency, as well as in terms of data volume (Data Volume) and the reception coefficient expressed in G/T. At these parameters, we have over a 20% increase over analogous satellite systems, which is illustrated by the larger area figure represented in the diagram. The obtained results provide a quantitative assessment of which criteria are improved upon implementation of the designed system. Optimization has been demonstrated in all critical elements that are analyzed in the operation of low earth orbit antenna systems.

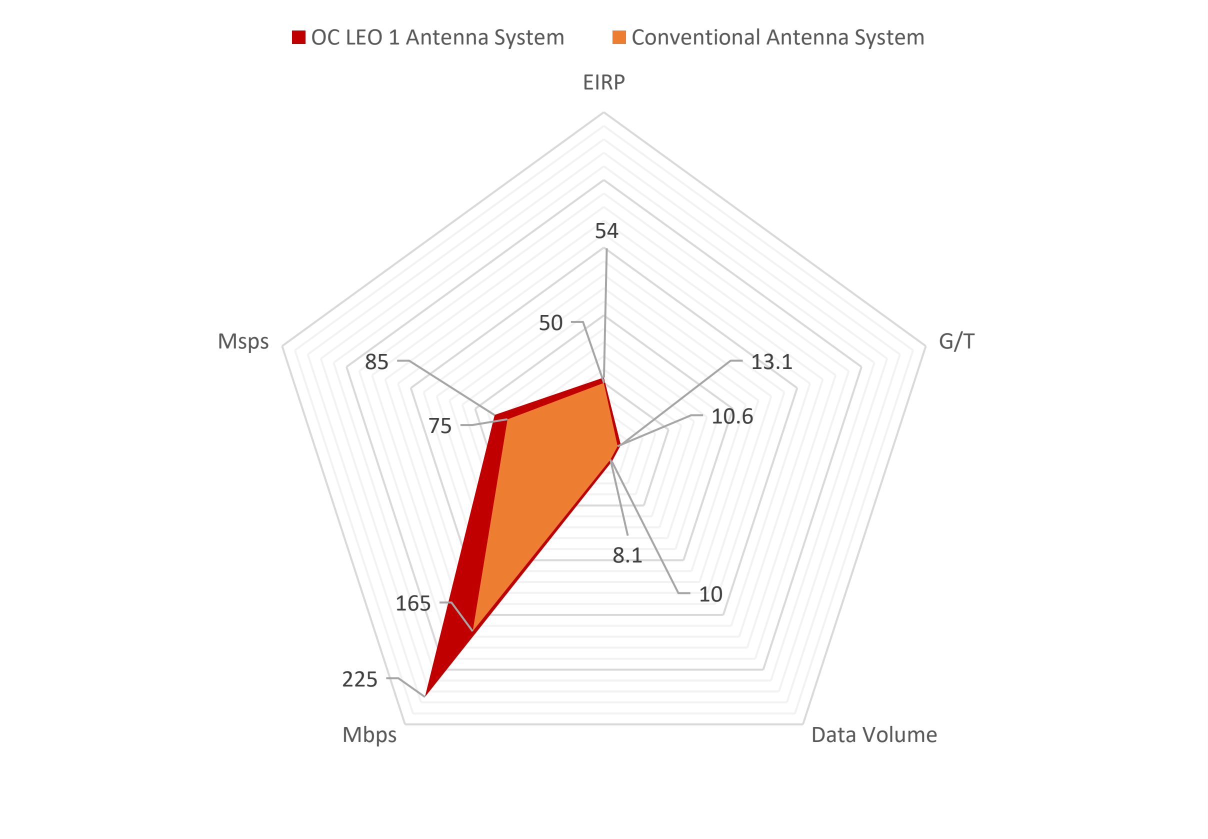
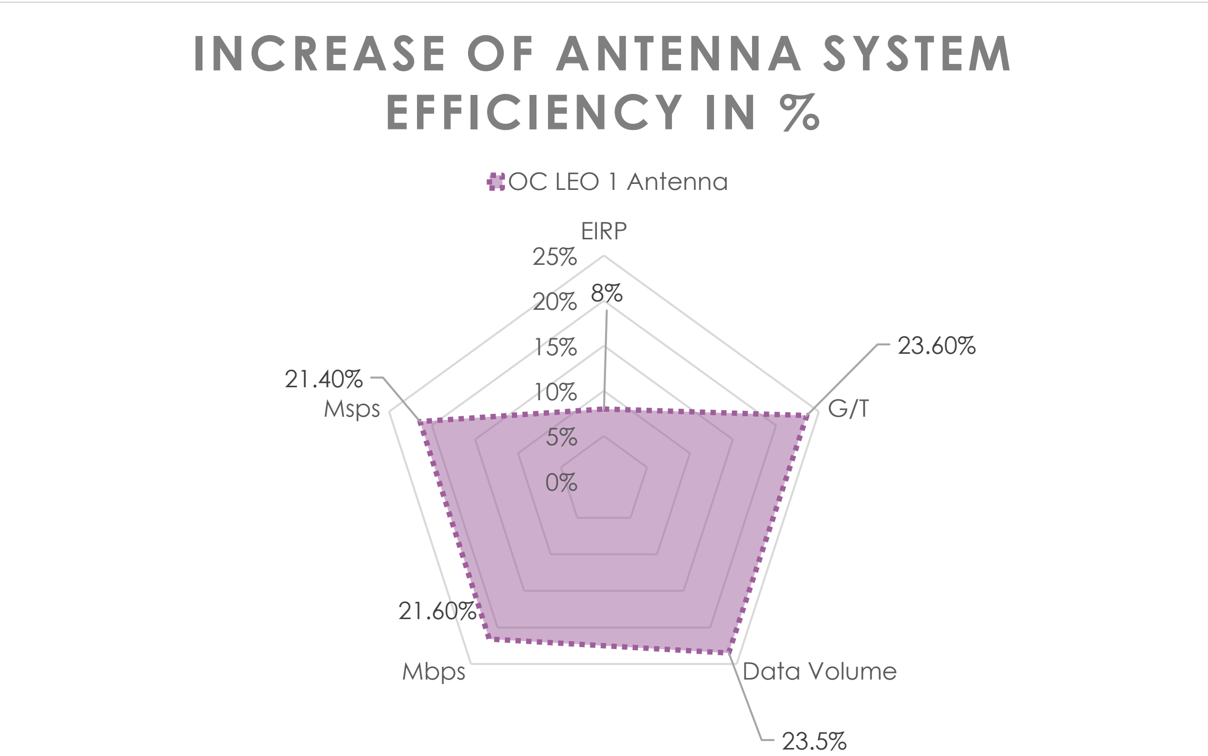
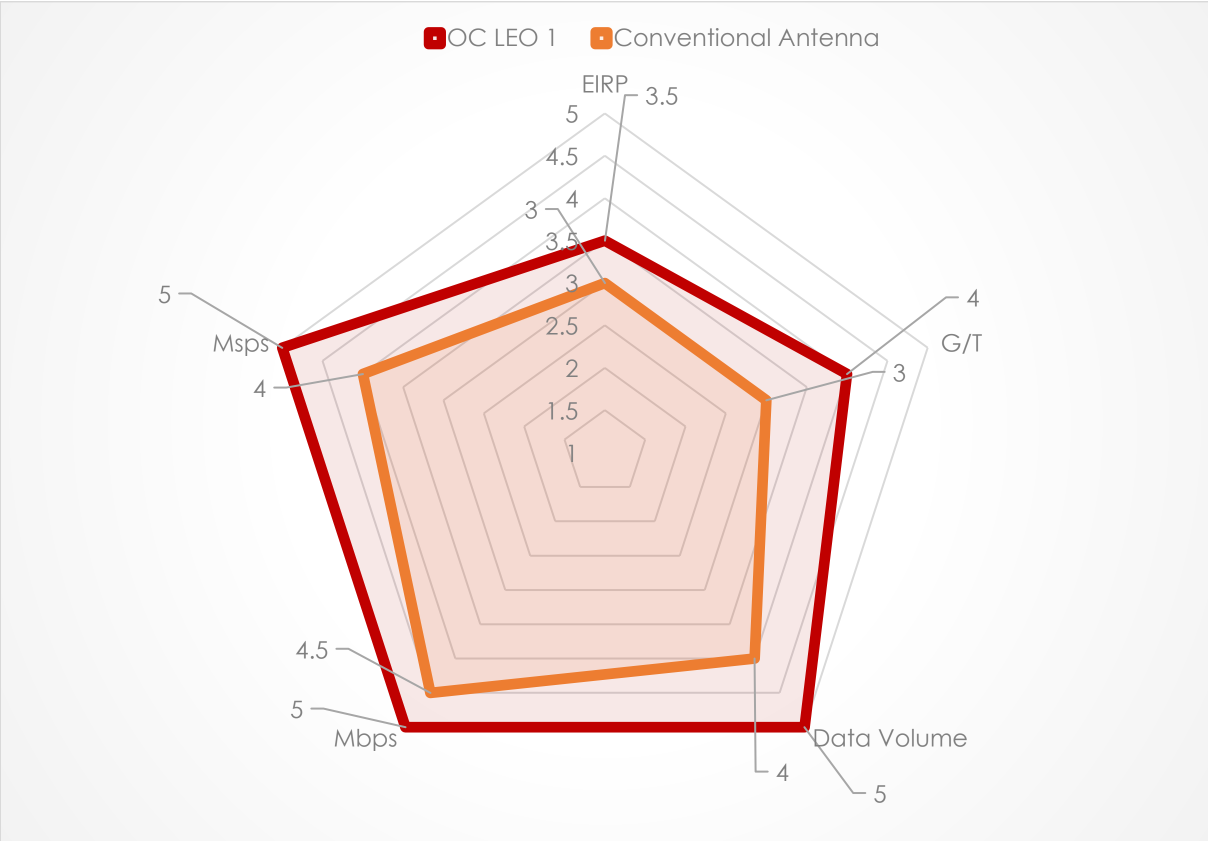


Diagram 2:



On the radar diagram, the optimization according to the individual criteria is presented in percentage ratio, when operating the designed antenna system. Illustrated in purple is the figure that represents optimization of the five main criteria, as well as an overall increase in system efficiency. As an initial value, 0% is taken, which represents a conventional antenna system criterion (in which we have no optimization) and their improvement in terms of the main parameters such as the speed of data exchange in Msps and Mbps, as well as the volume of data received from the satellite mission, is set as a percentage , the acceptance ratio G/T and the effective isotropic radiated power.

Diagram 3:



For the purposes of evaluating the functionality of the system, a radar diagram was used, on which figures are presented, the area of which expresses the opinion and assessment of the surveyed and tested engineers. The area of a conventional antenna system is illustrated in orange, and that of the designed OC LEO 1 antenna in red. As can be seen, the area of the integrated OC LEO 1 system is larger, which proves superior results compared to the technologies currently in use. Based on the obtained results, we can conclude that we have achieved optimization of the satellite antenna, as well as better results on the main parameters, which also leads to a high level of satisfaction of the end users.

In order to calculate the increase in the efficiency of the system functionality, a test system of the designed antenna in low earth orbit, as well as a conventional antenna, installed in the technology center of the company “Orbital Connect” (supplier of satellite communication services and products) was prepared. Test satellite missions with satellites were performed on both antenna platforms, with an average duration of between 5 and 7 minutes per satellite pass. Access to the “Network Cloud Engine” software is also provided, through which a target satellite is selected, as well as the ground antenna that will receive the data from the platform. The users who test the system are 5 satellite engineers (indicated in the tables with E1, E2, E3, E4, E5) who are certified to work with Teleport stations and equipment. They get full access to the resources in the operation of the “OC-LEO 1” antenna as well as the conventional one, setting the criteria, configuring the equipment and entering the parameters in the Network Cloud Engine to get the final information in the cloud system of Amzon - “AWS Cloud” . For the conducted experiment, each engineer was given full access to the evaluated system, as well as the corresponding survey cards, through which each one of them could give their selected connection, evaluation and opinion about the system.

Objectives of the study

Conducting the research in the dissertation work has several objectives. The first objective is to obtain opinions from engineers developing antenna systems, which would have an important role in further technological and structural improvement and development of satellite systems and communication products that are part of the entire eco-system.
The second objective is to obtain empirical data, results, and analysis of low-orbit ground antennas that would have an important role in determining system performance.
The third objective is to determine whether the system is sufficiently versatile, affordable and easy to integrate to be able to be used by more business organizations, universities, as well as government and scientific institutions.

Results and evaluation methodology

To calculate the increase in system functionality, we apply a five-point rating system on a scale of 1-5 (1 - "Weak", 2 - "Average", 3 - "Good", 4 - "Very good" and 5 " Excellent' level of functionality). Non-whole, decimal numbers are also accepted for scoring (for example, 2.5 or 3.5, etc.). The values are also expressed as a percentage, with 20% considered "Poor" and 100% considered "Excellent". The criteria analyzed are P1. EIRP, P2. G/T, P3. Data Volume, P4. Mbps and P5. Msps. Each user who tests the antennas fills in his opinion and rating in the system. The total number of engineers conducting the empirical analyses and tests is E=5. After the survey is completed, the ratings are presented in tabular form and are summed and divided by the total number of users, taking the average value of the population of numerical data (arithmetic mean approach). Two tables are presented that include a five-point rating for the designed OC LEO-1 Low Earth Orbit System and conventional antenna systems. In the end, the average score of the system and the overall improvement, as a value and in percentages, are also calculated.
Considering the values from the assessments made, the results are plotted in a diagram.
The formula used to calculate the arithmetic mean of the ratings from users who tested the system is:
The formula for OC LEO 1 antenna:
Indicator P1 - $\Sigma(E1+E2+E3+E4+E5)/5 = P1Ec$
Indicator P2 - $\Sigma(E1+E2+E3+E4+E5)/5 = P2Ec$
Indicator P3 - $\Sigma(E1+E2+E3+E4+E5)/5 = P3Ec$
Indicator P4 - $\Sigma(E1+E2+E3+E4+E5)/5 = P4Ec$
Indicator P5 - $\Sigma(E1+E2+E3+E4+E5)/5 = P5Ec$

The formula for calculating an average score for system functionality:

$EcP = \Sigma(P1_{Ec}+P2_{Ec}+P3_{Ec}+P4_{Ec}+P5_{Ec})/5$

Conventional antenna formula:

Indicator S1 - $\Sigma(S1+S2+S3+S4+S5)/5 = S1Ec$

Indicator S2 - $\Sigma(S1+S2+S3+S4+S5)/5 = S2Ec$

Indicator S3 - $\Sigma(S1+S2+S3+S4+S5)/5 = S3Ec$

Indicator S4 - $\Sigma(S1+S2+S3+S4+S5)/5 = S4Ec$

Indicator S5 - $\Sigma(S1+S2+S3+S4+S5)/5 = S5Ec$

The formula for calculating the average score for the system functionality:

$EcS = \Sigma(S1Ec + S2Ec + S3Ec + S4Ec + S5Ec)/5$

System Functionality Rating Scale

Rating/Value	Result/Level of functionality
1	Weak
2	Average
3	Good
4	Very Good
5	Excellent

"OC LEO 1" antenna system rating table

Indicators	E1	E2	E3	E4	E5	Ec	Rating в % based on a five-point system
P1. EIRP	3.5	3.5	3.5	3.5	3.5	3.5	70%
P2. G/T	4.5	4	4.5	4	3	4	80%
P3. Data Volume	5	5	5	5	5	5	100%
P4. Mbps	5	5	5	5	5	5	100%
P5. Msps	5	5	5	5	5	5	100%
EcP. Average rating						**4.5**	**90%**

Table of ratings of a conventional antenna system

Indicators	E1	E2	E3	E4	E5	Ec	Rating в % based on a five-point system
S1. EIRP	3	3	4	3	2	3	60%
S2. G/T	2.5	3.5	2	4	3	3	60%
S3. Data Volume	4	5	4.5	3.5	3	4	80%
S4. Mbps	5	4	4	5	4.5	4.5	90%
S5. Msps	4	5	4.5	4.5	4.5	4.5	90%
EcS. Average rating						**3.8**	**76%**

In view of the above results, the overall functionality of the designed system is scored 0.7 points higher than the current antennas on the five-point system, or an average of 14% efficiency improvement.

4.3 Conclusion

This chapter presents the results of measurements made on the designed antenna system for satellite communications. Essential technological parameters such as time delay, satellite signal reception sensitivity, amplifier power and signal strength sent to the satellite, data transmission rate, temperature resistance, orbital specifics, as well as the overall efficiency of the designed low earth orbit system are determined. The obtained results are compared with results of currently operated technological solutions for satellite communication systems. Evaluations were made according to a set of criteria such as transmission power, reception efficiency factor, volume, and speed of transmitted data during a satellite pass and analysis of time delays by orbital position. This multi-criteria selection is graphically interpreted, allowing to make evaluations of the designed antenna system and to compare it with existing solutions. The measurements made show an increase in the required parameters of the antenna system, which favors the increase in the functionality of the ground part of satellite communication systems.

Dissertation Contributions

1. An analytical overview of satellite communications was made, through which the usefulness of using low-orbit satellites was determined and the technological functions that must be performed by ground stations were determined
2. A satellite communications ground station for low-orbit satellites is designed to support information services via low-orbit satellites
3. An antenna system has been developed for the ground station, which allows to achieve a higher communication speed, greater signal gain for reception and transmission, greater overall functionality.
4. The antenna part is evaluated through experiments, achieving higher technological parameters than an existing prototype and the use in a real satellite communications system.

Results of the dissertation work have been applied in the implementation and development of a project for an antenna system "OC-LEO 1" in frequency band S, intended for communication with satellite platforms in low earth orbit.

Acknowledgments

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