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HONFY JÓZSEF RADIO AMATEUR CLUB**

RADIOCOMMUNICATIONS WITH THE SZESAT-1 SATELLITE

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ABSTRACT

Human curiosity is inexhaustible, after exploring earth, space is the next big step. Without satellites these explorations wouldn't be possible without risking human life. We, the SZESAT interdisciplinary College for advanced studies, have a dream: building a satellite.

Our paper intends to study and summarize the knowledge that is necessary to establish radio transmission between our next satellite called SZESAT-1 and the Earth Station of the University of Győr. This study is important for us to know if it is possible to establish a connection through our options, with the new working satellite in process.

It is our task to define the frequency on which we are allowed to transmit and receive radio signals. We need to define the technical conditions which can guarantee the establishment of the connection with high reliability on this frequency.

To determine the technical parameters and expectations, we will have to carry out calculations and noise measurements in the given frequency.

Apart from the calculations we need to investigate the possible orbits and elevation of the satellite to choose the correct antenna for the Earth Station and for the satellite.

In the chosen frequency band, we will make noise measurements to decide which area is appropriate for the project.

After taking the calculations and measurements into consideration, we will commence the planning of the scheme of the system of the station and the satellite, including hardware and software elements. Following planning, we will commence the phase of implementation.

Based on scientific knowledge and utilization of engineering skills we would like to make our satellite's launch and operation possible.

KEYWORDS: <RADIOCOMMUNICATION>, <SATELLITE>, <SPECTRUM>, <YAGI ANTENNA>, <SATELLITE>, <REPETER>, <RADIO AMATEUR>, <NODE-RED>, <AUTOMATIZATION>.

INTRODUCTION

Wireless communication via electromagnetic waves between a cube satellite and an earth station facilitates long-distance transmission of information. [1] This mode of communication is vital for scientific research purposes. SZESAT-1 will employ a wavelength of 70 centimeters for both uplink and downlink transmissions.

To enable communication with the satellites, we utilize a hardware setup consisting of the base radiocommunication IC-9700. This equipment allows for the reception and transmission of messages, operating across both VHF and UHF bands, and incorporates D-STAR technology.

Subsequently, utilizing a Main control panel featuring a SIEMENS PLC, we can manage the antenna rotors either automatically or manually. Additionally, live camera footage from IP cameras is employed to monitor weather conditions and the positions of the antennas, as well as to assess the functionality of the rotors.

The software that was used in the automatization for sending and receiving messages and the analysis of the signals are as follows:

Initially, Gpredict software is utilized, serving as a real-time satellite tracking and orbit prediction tool. It offers predictions for future satellite passes along with detailed information for each pass. Furthermore, it facilitates the organization of satellites into visualization modules.[2]

In this program, you can view the satellite's footprint, which represents the area on Earth that the satellite can broadcast to. [3]

Next, we employ Node-RED, a visually programmable software tool written in JavaScript. It serves to process the data obtained from Gpredict. [4]

Alternatively, SatDump software can be used for processing satellite data in conjunction with an RTL-SDR.

Afterwards, the data are sent to the Programmable Logic Circuits that signals the rotors to change the azimuth and the elevation of the antenna.

The communication module of SzeSat-1 will incorporate the STM32WL55JCI7 microcontroller and the PE4245 RF switch for connectivity purposes.

CHAPTER I

1. THEORETICAL FRAMEWORK

1.1. Small Satellites

Sputnik 1 was the first artificial Earth “Small” satellite launched on 4 October 1957 with external radio antennas to broadcast radio pulses. It was a 58 cm diameter, 83 kg polished metal sphere with a 1W transmitter on 20.005 and 40.002 MHz .The analysis of the radio signals was used to gather information about the electron density of the ionosphere. [1]

In 1980s, a new modern small satellite arose and opened a new class of space applications. The major design problem and constraint is the design of small low-cost satellite bus are identified using the subsystem approach. Key design areas include the improvement of battery technology and the development of a deployable solar array, attitude control assemblies, onboard data processing and storage and ground station acquisition. [1]. A small satellite is any satellite that weighs less than 300 kg. The space industry is moving towards a future with large constellations of small satellites capable of providing all sorts of services in a big geographical area or across the globe. [1]

Within commonly agreed definition, small satellite can be distinguished by the following categories:

- Minisatellites: In the range 100-500 kg.
- Microsatellites: With a wet mass of less than 100 kg.
- Nanosatellites: This category has been originally developed and promoted through the “CubeSat” family, starting from the 1U form factor (about 1 litre for a mass of about 1 to 1.2 kg).
- Picosatellites: Very small satellites with a mass range from 0,1 to 1 kg.
- Femto-satellites: Very small-scale satellites of less than 100 grams have been design over the last fifteen years.

The small satellites are typically deployed in low Earth orbit (LEO), that is relatively close to surface of the Earth. It is at an altitude of less than 2000 km but could be as low as 160km above sea level. The orbital parameters of small satellite system aren't different of the traditional satellites.

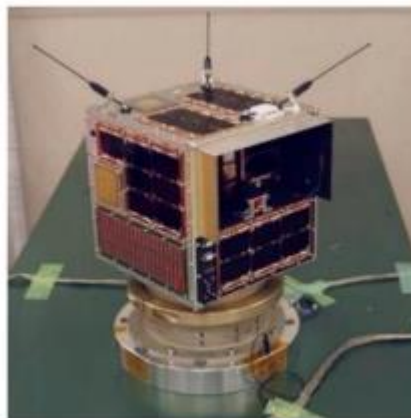


Illustration 1: HORYU-4 flight model.

Source: (ITU, 2023).

1.2. Radiocommunication planning

A communication system consists of the ground station and the space segment. The three functions of a communication system are receiving commands from Earth (uplink), transmitting data down to Earth (downlink) or receiving information from another satellite (crosslink).[5]

The type of communication system used is radio frequency (RF).

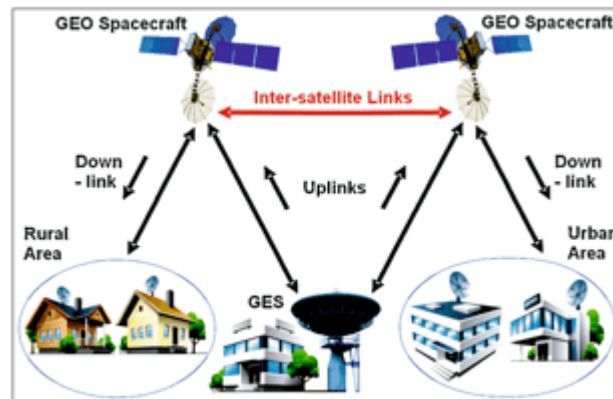


Illustration 2: Satellite uplink, downlink and crosslink.

Source: (D. Stojce, 2019).

A system of radio frequency communicates by sending data using electromagnetic waves that are transmitted and received by antennas. The information is modulated onto radio frequency electromagnetic waves and sent over a channel, through the atmosphere or space, to receiving system where it is demodulated.

A radio communication system has a radio transmitter, a free space communication system channel, and a radio receiver. A radio transmitter system includes a interface, modulator, power amplifier, and an antenna. The modulator encodes digital data onto a high frequency electromagnetic wave. The power amplifier increases the output RF power of the transmitted signal to be sent through free space to the receiver using the transmit antenna.[5]

Then, the radio receiver system uses a receiving antenna, low noise amplifier, and demodulator. The receiving antenna collects the electromagnetic waves and routes the signal to the receiver, which demodulates the wave and converts the electrical signals back to the original digital message. The low noise amplifiers are sometimes used to minimize thermal noise in specific frequency bands and increase the signal strength.[5]

In radiocommunication planning there are the following terms:

1.2.1. Frequencies

Frequency is the measure of number of times a phenomenon is repeated per unit of time.

The Frequency band allocated to a station is the range of frequencies within which the transmission of a specific station is authorized. The width of this band is equal to the necessary bandwidth plus twice the absolute value of the frequency tolerance.[6]

Radio frequencies for spacecraft are conducted between 30MHz and 60GHz. The lower frequency bands (up to S-band) are typically more mature for small satellites use. Higher frequencies offer a better ratio of gain-to-aperture-size, but this is offset by the increased atmospheric attenuation at those frequencies and the higher free space loss that is directly proportional to the square of the frequency. [5]

Satellite communications are conducted over a wide range of frequency bands, in accordance with Table 1.

Table 1: Radio Frequency Bands

Band	Frequency ranges
VHF	30 to 300 MHz
UHF	300 to 1000MHz
L	1 to 2 GHz
S	2 to 4 GHz
C	4 to 8 GHz
X	8 to 12 GHz
Ku	12 to 18 GHz
K	18 to 27 GHz
Ka	27 to 40 GHz
V	40 to 75 GHz

Table 2: Frequency and wavelength for amateur satellites.

Satellite Amateur	
Frequency	Wavelength
7000-7100 KHz	21-meter dipole antenna
14 000-14 250 KHz	10,5-meter dipole antenna
144-146 MHz	1-meter-long dipole
435-438 MHz	0,7 meter 0,35-meter-long dipole
2400-2450 MHz	0,125-meter 0,062 meter

The typical bands considered for small satellites are UHF, S, X, and Ka. The most mature bands used for CubeSat communication are VHF and UHF frequencies but in recent years the S, X, and Ka band are used for recent and future communications by small satellites.

If the frequency is small the wavelength is too long, and if the frequency is higher there are much noise from mobile service providers. So, the useful frequency for us is between 435-438MHz with a wavelength of 0,7 meters.

In this investigation the Cube satellite will use UHF frequencies with 436MHz.

The wavelength of the frequency is the distance between the peaks of electromagnetic waves whose smallest parts are photons move at the speed of the light. This length is usually specified in meters, centimeters, or millimeters [7]. The following equation to calculate the wavelength contains the speed of light ($c=300.000 \text{ km/s}$) and the frequency f :

$$\lambda = \frac{c}{f} \quad (1)$$

1.2.2. Wave Polarization

Every electromagnetic wave is characterized by its “polarization”, defined from the orientation of the electric field vector. In [6], the following cases are distinguished :

- Horizontal polarization: The electric field vector is in a horizontal plane.
- Vertical polarization: The electric field vector is located in a vertical plane.
- Oblique polarization: The electric field vector has an inclination of 45° with respect to the horizontal. It is the result of two components of equal amplitude and phase polarized horizontally and vertically, respectively.
- Circular polarization: The end of the electric field vector describes a circle. It is the result of vertically polarized components and horizontally, of equal amplitude, and combined in quadrature of phase.

In this project the antenna will have circular polarization.

1.2.3. Doppler effect

The Doppler effect involves the variation in the wavelength of any type of wave emitted or received by a moving object. Amateur radio satellites emit and receive Radio frequency waves and, in addition, move at relatively high speeds to maintain their orbits, for that reason they are subject to the influence of the doppler effect.[8]

When a satellite comes into view on our horizon, the frequency at which it transmits will be increased due to the Doppler effect. Therefore, we must tune our receiver to a higher frequency to be able to listen to the satellites' carrier. When it passes directly overhead, that is, right in the middle of the pass, the frequency will not undergo any shift and will coincide with the satellite's transmission carrier. As it starts moving away from us and disappears from our horizon, the frequency will decrease, so we must adjust our reception frequency downward to continue listening to the satellite. The following formula allows to calculate the maximum frequency shift with respect to the carrier frequency emitted or received by a satellite.

$$F_r = \frac{F_p}{V_l} * V_s \quad (2)$$

Where, F_r is the frequency at which the satellite signal is received, F_p is the carrier frequency on which the satellite broadcasts, V_l is the speed of light, and V_s is the satellite's speed.

1.2.4. Footprint

Satellite footprints correspond to the regions of the Earth's surface encompassed by the signal transmitted by a satellite. These footprints are defined by factors such as the satellite's orbital path, antenna configuration, and transmission strength. Every satellite possesses a distinct coverage area, which may vary in size from a localized area to an entire continent or even global coverage.[3]

Most cube satellites, are to be found in low Earth orbit (LEO) that is an orbit around the Earth with an altitude that lies towards the lower end of the range of possible orbits, this is around 1200 miles or less. [3].

Orbital height ranges from 350/1450 km (elliptic Orbit). From the geometry of the orbit, the longest distance that has to be communicated through is the horizon. In Hungarian relations this can be even 4500 km.

In the Illustration 3, you can see the footprint of some satellites, with the help of the GPredict software.

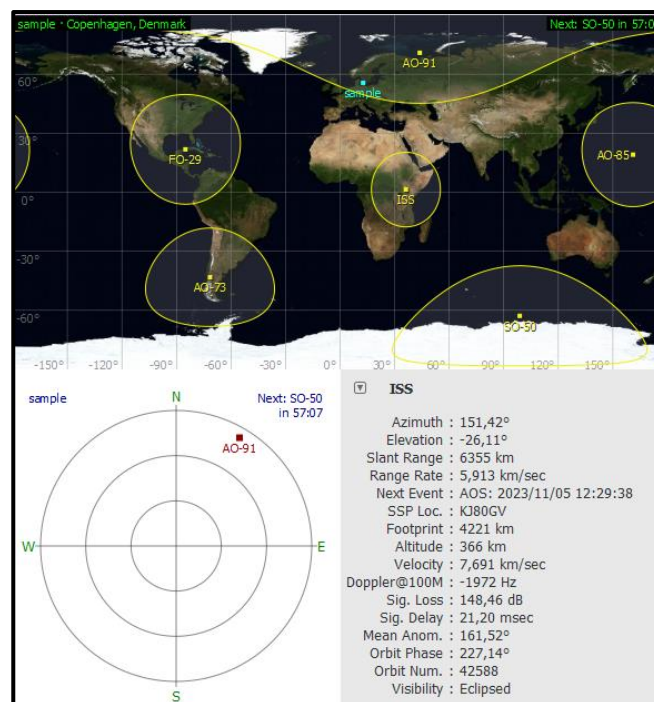


Illustration 3: Footprint of satellites.

In the Illustration 4, you can see the predictions of satellite, in this case for ISS. These predictions can be seen on the N2YO.com website.

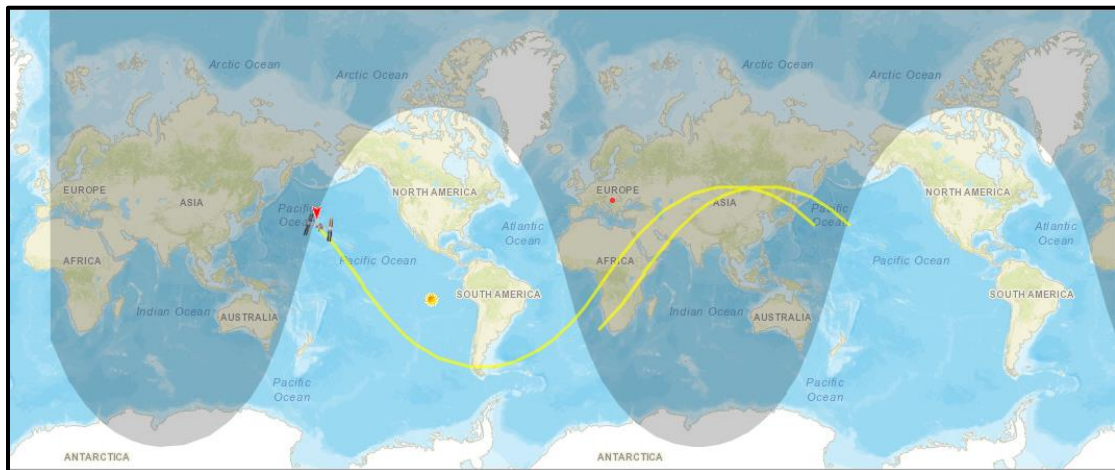


Illustration 4: Example with trajectory of ISS around the Earth in N2YO.com.

In the Illustration 5, you can see the 10 days predictions of ISS trajectory according to our location in this case in Europe. These predictions can be seen on the N2YO.com website. And it will be able seen the trajectory of the small satellite in the future.

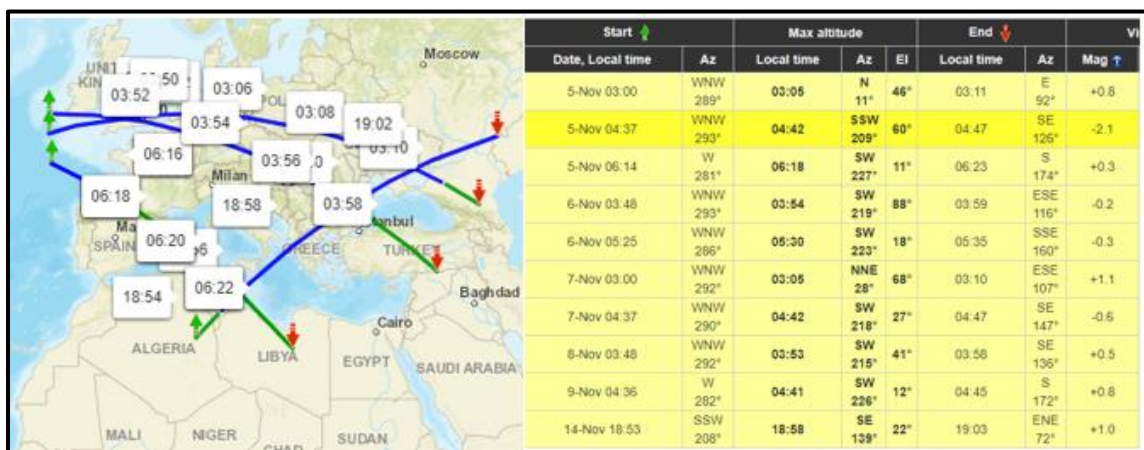


Illustration 5: Example about the trajectory ISS in 10 days

With GPredict and N2YO.com, we can see when we are within the ISS orbit and thus be able to communicate.

CHAPTER II

2. METHODOLOGICAL FRAMEWORK

2.1. System Design

The system design consists of the satellite, antenna uplink, antenna downlink and the radio equipment.

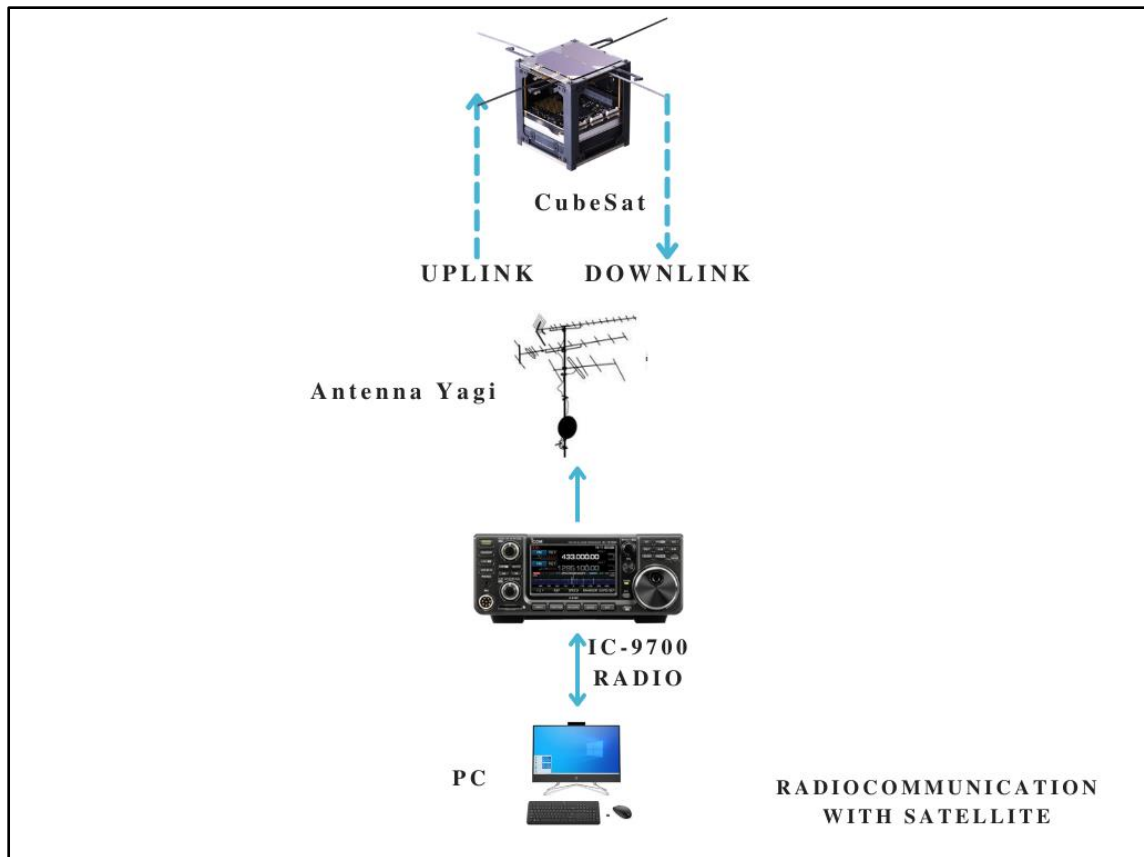


Illustration 6: System Design Satellite communication.

2.2. System Components

A small satellite RF communication setup comprise a transceiver composed of a radio, amplifier, and antenna. Radios receive a message from the command and Data Handling (CDH) subsystem, then produce and modulate an electromagnetic wave to create a signal.[5]

Radios provide a degree of power amplification, but frequently, signals from small satellites necessitate additional enhancement. The power amplifier will take the signal from the radio and increase the RF output power before sending it to the transmit antenna. And in the receive side, a low noise amplifier will take the weak signal from the receive antenna and amplify it while minimizing thermal noise. So, the radio will then be able to process the stronger signal with higher accuracy. [5]

The digital message encoded on the RF carrier signal will be sent to and from the antennas of each system.

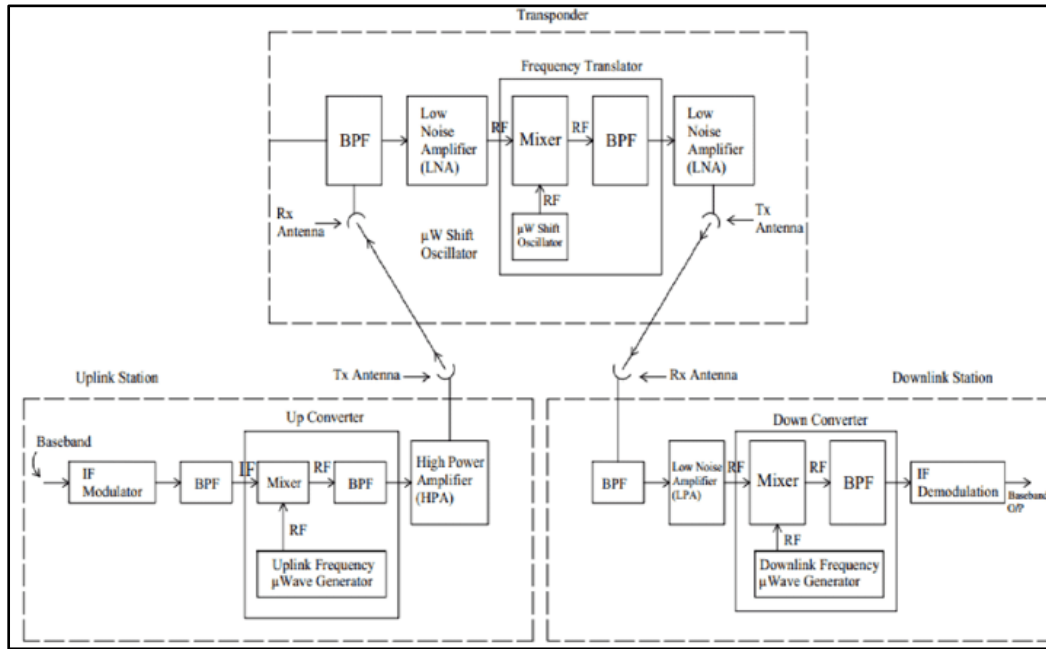


Illustration 7: Transmit and receive block diagram.

Source: (Karim et al, 2018).

The system components to establish the communication between the earth station and the satellite are the following:

2.2.1. Communication

The communication between Earth Station and SZESAT-1 satellite:

2.2.1.1. Earth Station

The Earth Station is located in the top of the dorms building in the Széchenyi Istvan University. This station has the following components.

2.2.1.1.1. Transceiver Equipment

The transceiver Equipment is the Radio IC-9700 which can be seen in the Illustration 7, this employs an RF direct sampling system. RF signals are directly converted to digital data in the ADC, and then processed in the FPGA. It has the D-STAR Repeater (DR) function. The IC-9700 has 99 satellite memory channels for both uplink and downlink frequencies and mode.[9]



Illustration 8: Radio IC-9700.

Source: (Icom Inc, 2018).

The technical parameters in [10] are shown below.

Table 3: General specifications of the IC-9700 Radio.

General	
Frequency coverage	EUR version: 144.000–146.000, 430.000– 440.000, 1240.000–1300.000 MHz
Antenna connectors	144 MHz SO-239 (50 Ω), 430/440, 1200 MHz Type-N (50 Ω)
Power supply requirement	13.8 V DC $\pm$ 15% (Negative ground)
Power consumption	TX Less than 18 A (High power) RX 1.2 A typical (Standby), Less than 1.8 A (Maximum audio)
Operation temperature range	–10 °C to + 60 °C; 14 °F to 140 °F
Frequency stability	Less than $\pm$ 0.5 ppm (–10°C to + 60°C; 14°F to 140°F)
VHF and UHF PA provides	powerful 100W (144 MHz), 75W (430/440 MHz) and 10W (1200MHz)

Source: (COM, 2018)

Table 4: Transmitter specifications of the IC-9700 Radio.

Transmitter			
Output power:		FM	AM
	144 MHz	0.5–100 W	0.125–25 W

	430/440 MHz	0.5–75 W	0.125–18.75 W
	1200 MHz	0.1–10 W	0.025–2.5 W
Modulation system	SSB, FM, AM, DV, DD		
Carrier suppression	More than 50 dB		
Unwanted sideband	More than 50 dB		
Sensitivity	FM (12 dB SINAD) Less than 0,18 μ V. Approximately 0,15 μ V		
Selectivity	FM (BW=15kHz) More than: 12 kHz/-6 dB Less than: 20 kHz/-60 dB		

Source: (ICOM, 2018)

Table 5: Receiver specifications of the IC-9700 Radio.

Receiver	
Receiver system:	144, 430/440 MHz RF Direct Sampling 1200 MHz Down Conversion IF Sampling
Intermediate frequency:	311–371 MHz (1200 MHz)
Audio output power	More than 2.0 W (1 kHz, 10% distortion) into an 8 Ω load

Source: (ICOM, 2018)

The output power of the transceiver with an amplifier will be 1000W.

2.2.1.1.2. Wave guide

The wave guide in the earth station is the coaxial cable. The coaxial cable is a type of cooper cable specially built with a metal shield and other components engineered to block interference.

In the Earth station we use an 7/8” Rf coaxial cable, this has low attenuation, low standing wave, high shielding, damp-proof gas, free maintenance, flexible, high anti tensile strength. The application range is in broadcast and television, microwave, telecommunication, aerospace, vessel, or other circumstance where RF cable is needed. This cable has a maximum frequency of 5100 MHz with 9.30dB/100m of attenuation, an impedance of 50 ohms, and a maximum power rating of 92 kW.



Illustration 9: 7/8" Feeder Cable.

Source: (LIANSTAR, 2019)

2.2.1.1.3. *Helical Antenna*

In RF communications the role of the antenna is to increase and focus the strength of the signal in a specific direction.

For communication with the small satellite, the helical antenna is a type of antenna has a very distinctive shape, as can be seen in the Illustration 10.



Illustration 10: Helical Antenna.

Source: (Tutorialspoint, 2024)

The helical antenna is a wire antenna and itself forms the shape of a helix. This antenna works in VHF and UHF bands in the frequency range of operation of 30MHz to 3GHz.

The antenna provides circularity polarized waves, and it is used in extra-terrestrial communications in which satellite relays are involved. Also, it is used to establish communications between the moon and the Earth. But it requires wider outdoor shape. [11]

2.2.1.1.4. *Yagi Antenna*

The Yagi-Uda antenna was invented in 1926 by Dr. H. Yagi and Shintaro Uda, its structure normally consists of a number of directors and reflectors that enhance radiation in one direction when properly arranged on a supporting structure.[12]

The earth station will be using one antenna for uplink and downlink, this will be 32JXX70 Cross Yagi antenna 432MHz with 2x16 elements. A cross Yagi has two normal yagi antennas mounted on the same boom, rotated 90 degrees in position. This is used to satellite communications. Besides, the signal has to cross the ionosphere, which can cause unpredictable polarization rotations. And the circular polarization is used to reduce losses. This polarization is produced by two linearly polarized orthogonal signals of equal amplitude which are 90 degrees out of phase.

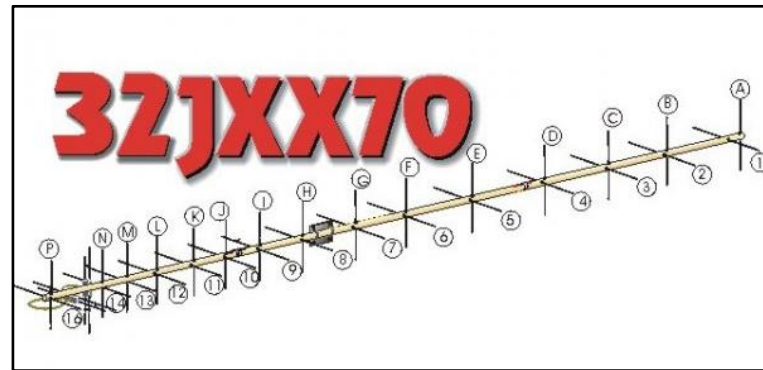


Illustration 11: 32JXX70 Cross Yagi Antenna.

The technical parameters of the antennas are:

Table 6: Technical parameters Yagi Antenna.

32JXX70 Yagi Antenna	
Gain	14,39 dBd /16,53dBi
Frequency	432 MHz-440Mhz
Angle -3dB e/h	28,8°-30,4°
SWR	1:1,2
Boom length	3,15m
Boom diameter	25-30-25
Element diameter	5mm
Dipole	T-match
Connector	N precision
Power max	1000 W
Pole diameter	75 mm Ø Max
Weight	3,2 kg
Wind area	0,14 m ²
Polarization	Circular

Source: (I ØJXX, 2024)

It was decided to use this 32JXX70 cross Yagi antenna for radio communication, because the rotation of the antenna is easier as it is less heavy and requires less space, unlike the helical antenna. In addition, this antenna also has circular polarization and good gain.

2.2.1.2. *Cube Satellite*

Cube satellites began as a collaborative effort in 1999 between Jordi Puig-Suari, a professor at California Polytechnic State University and Bob Twiggs, a professor at Stanford University's Space System Development Laboratory. Thanks to cubeSats, many major universities now have a space program. [13]

CubeSat must conform to specific criteria that control factors such as its shape, size, and weight.

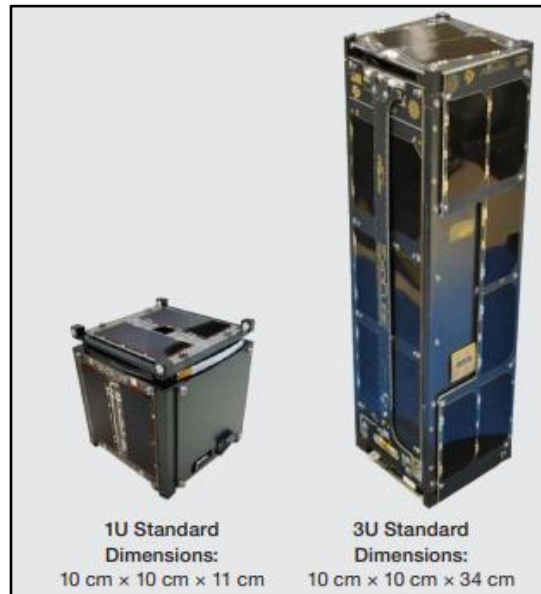


Illustration 12: Cube satellites.

Source: (NASA, 2017)

The SZESAT-1 satellite uses the UHF frequencies with 436MHz.

The system of communications is made up of the following:

2.2.1.2.1. *Communications module system on the cube satellite*

Radios for small satellite downlink are transceivers, it means transmitter and receiver in one. Transceivers convert digital information into an analog RF signal using a variety of modulation and coding schemes. Radios from TT&C are designed for low data rate, with high reliability and only need to transmit health data and receive commands.[5]



Illustration 13: Example of software defined radio.

Source: (GomSpace, 2024)

Some main functions of the module system are:

- Telemetry over Lora (TinyGS Network).
- High-Rate data downlink in 435-438MHz HAM band (GMSK 9600/19200 bits/s).
- RF switch between two independent channels.
- Cold redundant system.

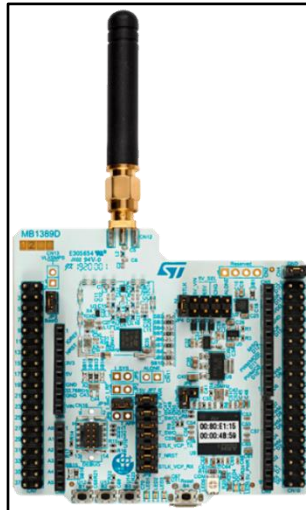


Illustration 14: Nucleo-WL55JC1 Development board.

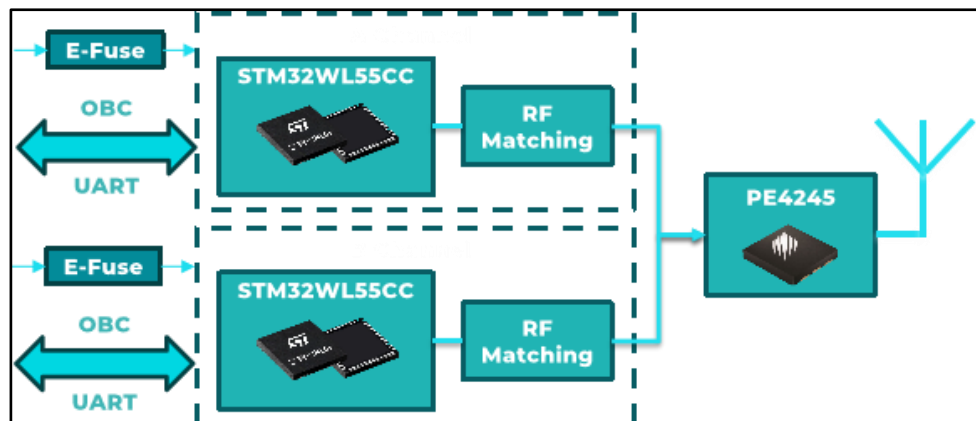


Illustration 15: Block diagram of the COM Module.

The COM module will have two parts. First part handles Telemetry data transmission. Second part handles picture transmission and communication.

The orbit of the satellite will be on LEO (Low Earth orbit). One rotation around Earth takes 90 to 100 minutes. Over the development of the last TDK project, it is known for us, that one pass ranges from 6-12 minutes through our orbit, for the remaining time, the telemetry of the satellite cannot be received with our ground station. This causes challenges in the meaning of receiving telemetry data from the satellite.

Therefore, the solution is that the telemetry data will be sent with Lora, a long range, low power consumption technique, this way radio amateurs can also receive telemetry data with self-made and cheap ground stations. Over the TinyGS network this telemetry data will be sent to us.

TinyGS is an open network of Ground stations distributed around the world to receive and operate LoRa satellites, weather probes and other flying objects, using cheap and versatile modules. [14]

The COM Module STM32WL55JCI7 microcontroller be used, since it can handle LoRa radiocommunications and GSMK modulation.

The technical parameters of the microcontroller are:

Table 7: Technical parameters of STM32WL55JCI7 microcontroller.

General Specifications	
Power Satellite	20 dBm
Receiver sensitivity	-148dBm
Transmission over LoRa (bandwidth)	20 dBm (125KHz)
Range of frequencies	435-438MHz

Switching between the two parts is carried out by the PE4245 RF switch. The PE4245 is manufactured on pSemi's Ultra CMOS process, a patented variation of silicon-on-insulator (SOI) technology on a sapphire substrate, offering the performance of GaAs with the economy and integration of conventional CMOS.

2.2.1.2.2. *Antenna*

COTS antennas are available for small satellites and can be built to order. For missions don't have high data rate requirements, a simple patch or monopole antenna with low gain and efficiency will be enough. Due to the low directionality, these antennas can generally maintain a communication link even when the spacecraft is tumbling, which is benefit for CubeSats that lacking good attitude and accurate pointing control.[5]

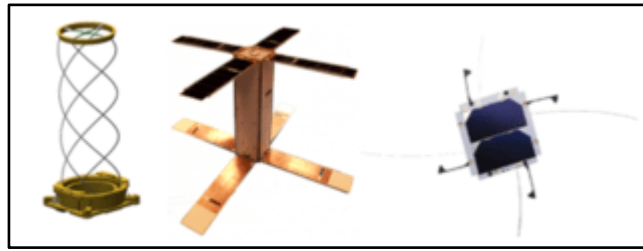


Illustration 16: Example of deployable quadrifilar helical antenna, UHF crossed dipole antenna and UHF antenna with solar panels.

Source: (S. Caldwell, 2024)

The cube satellite will be using a V shape dipole antenna.

The known technical parameters of the antenna of the satellite for now, will be the following:

Table 8: Technical parameters of V shape dipole antenna.

General Specifications	
Antenna Gain	0 dB

2.2.2. Tracking System Earth Station

Tracking System Earth Station is made up of:

2.2.2.1. Rotator

The two-antenna group (4*12 Yagi @144MHz) and (4*19 Yagi @436MHz) have rotors that can move on 2 axels, elevation, and azimuth. This, it is possible to automate the tracking of a satellite's orbit with the antennas.

Antenna rotation is done automatically using Gpredict. But it can also be rotated manually using two Elevation-Azimuth Dual Controllers G-5500 seen in the Illustration 11, one for each antenna.

Azimuth allows you to move the antenna from right to left. It varies from 0° to 360°.It starts with North at 0° and rises clock wisely.

Elevation allows the antenna to be moved up to down. It is measured in degrees, starting at 0° and ending at 90°. 0° is the surface level, 90° is the point where an object can rise above the surface, also called "Zenith".



Illustration 17: Elevation-Azimuth Dual Controller G-5500.

Source: (Unicom Radio, 2023)

2.2.2.2. Controller Software

Gpredict is a real-time satellite tracking and orbit prediction application. It can track a large number of satellites and display their position and other data in lists, tables, maps, and polar plots (radar view). Gpredict can also predict the time of future passes for a satellite and provide you with detailed information about each pass. [2]

This software has a Rotator Control that you can see in the Illustration 17, it shows us the predicted course of the satellite and the current stance of our antenna. The Azimuth and elevation values that the antenna needs to direct itself towards the chosen satellite are observed.

The targeted satellites name can be seen on the box. The satellites current Azimuth is after de (Az), while the current elevation of the satellite is after the (EL), and (ΔT) means that how many time is left before the satellite comes above the horizon. That is, if the satellite is already up, then how many minutes left before the satellite goes below the horizon.

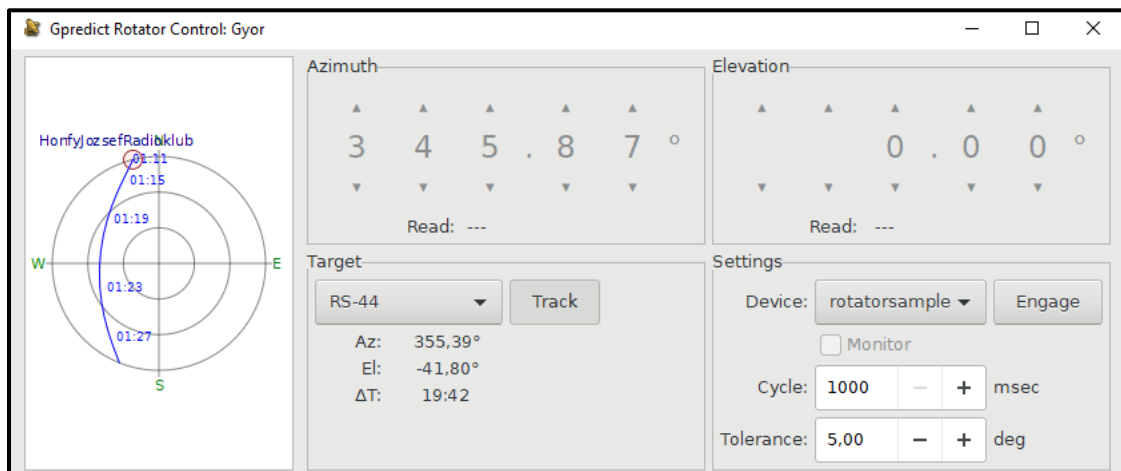


Illustration 18: Gpredict Rotator Control.

The wanted Device can be selected, then by pressing the engage button, the antenna will start to face the designed location. It is also possible to set the period of the cycles in msec and the Tolerance in degrees.

With Gpredict we control the antennas according to the satellites current position over Node-Red.

Node-red translates the signals Gpredict sends us for the PLC. Then the PLC sends voltage to the rotors according to the signals. The rotors have built in resistors both in azimuth and elevation to send data to the PLC about the antennas pointing direction.

2.2.2.3. *SatDump Software*

This software is a satellite processing software of general purpose. It is a one stop shop that provides all necessary stages to get from the satellite transmission to actual products.[15]

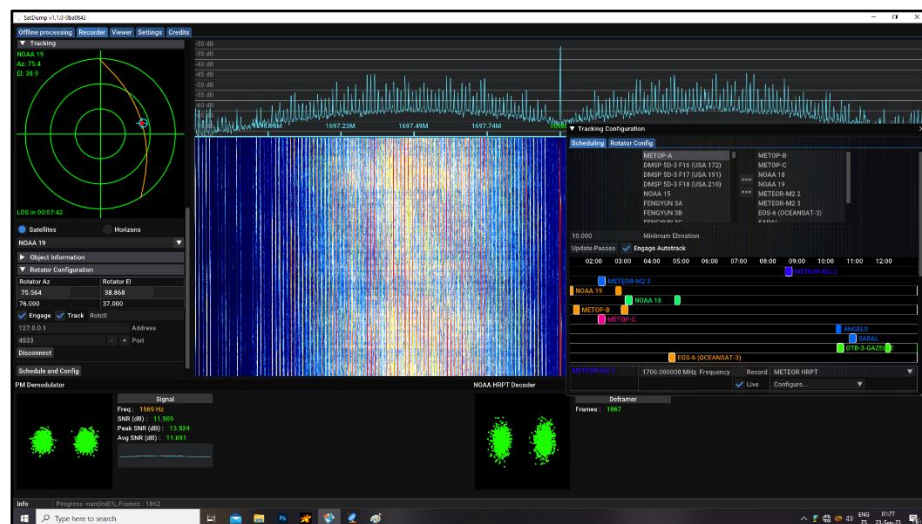


Illustration 19: SatDump software.

Characteristics from [15]:

- Support of many SDRs such as RTL-SDR, Airspy, HackRF, BladeRF, LimeSDR, PlutoSDR, etc.
- Recording of radio basebands from SDR.
- Decoding and processing the data from over 90 different satellites and even space probes.
- Real-time interpretation of compatible satellite connections like ATP, LRPT, HRPT, LRIT, HRIT and many more.
- Deciphering images and data received from satellites like NOAA 15-18-19, Meteor-M, etc.

- Calibrated and georeferenced L1b products output on selected satellites, such as Sea Surface Temperature, Microphysics, etc. ready to use for specific applications such as numerical weather forecasts.
- Assistance in overlaying satellite imagery onto a map, which includes the capability to layer it with other instruments or satellite data.
- Scheduler and rotator control for automated satellite stations.
- Ingestor for automated geostationary weather satellites reception.

2.2.2.4. RTL-SDR device

It will be used SatDump software with RTL-SDR to receive the data from the satellite.

The RTL-SDR is a small device with an USB output and Coaxial input for easy use RTL-SDR is capable of functioning as a computer-based radio scanner, enabling the reception of live radio signals in your vicinity without the need for internet connectivity. Depending on the specific model, it can receive frequencies ranging from 500 kHz to 1.75 GHz.

Traditional radio components like modulators, demodulators, and tuners have typically been realized using analog hardware components. However, with the emergence of modern computing and analog-to-digital converters, many of these traditionally hardware-based components can now be implemented using software. This has given rise to the term "software-defined radio" (SDR). SDR facilitates convenient signal processing, paving the way for the production of inexpensive wideband scanner radios.

2.3. GMSK Modulation

The Gateway Minimum Shift Keying (GMSK) modulation means a continuous phase change, the phase changes linearly at breakpoints, without breaks. This modulation limits the bandwidth of the modulated signal by filtering the modulation signal. The binary NRZ modulating signal containing the information, goes through a Gaussian filter to the modulator, therefore there is no sudden phase change, but the phase change is rounded, as determined by the filter. [16]

GMSK is very attractive for its excellent efficiency power spectral, and it is used in satellite data communication systems and high-speed wireless communication systems.

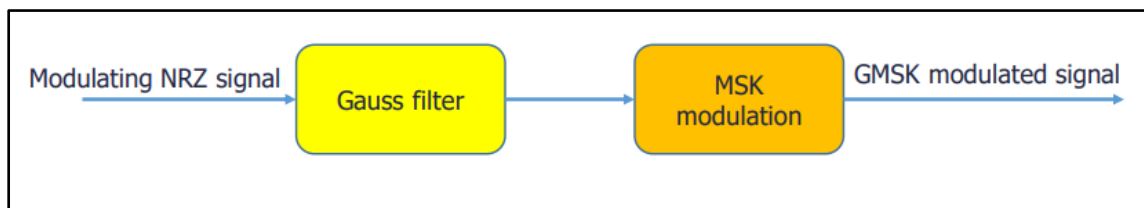


Illustration 20: Block diagram GMSK.

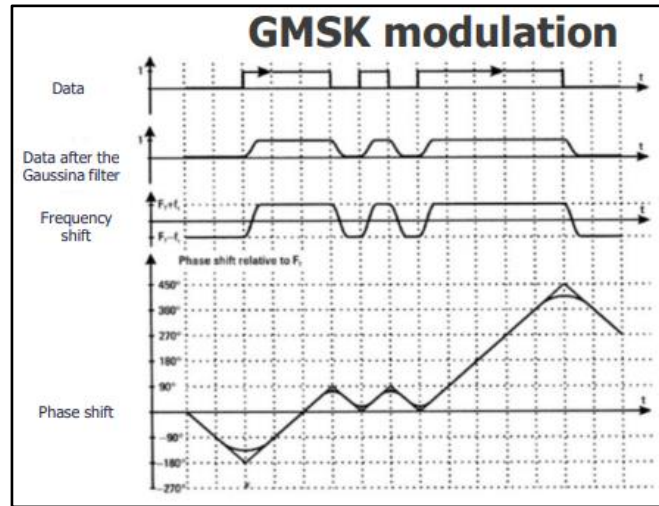


Illustration 21: GMSK Modulation.

2.4. Doppler effect calculation

The calculation according to equation (2), for the maximum frequency shift due to the doppler effect at the downlink frequency of the ISS on the UHF band, it emits 436MHz to a speed of 8000 m/s, and the speed of light is 300.000km/s is as follows:

$$F_r = \frac{436.000.000Hz}{300.000.000m/s} * \frac{8000m}{s} = 11.626Hz \quad (3)$$

This value of (11.349 Hz), will be above when the SZESAT-1 satellite approaches and bellow when it moves away.

$436.000.000 \text{ Hz} + 11.626Hz = 436.011.626 \text{ Hz}$, when it appears on the horizon.

$436.000.000 \text{ Hz} - 11.626Hz = 435.988.374 \text{ Hz}$, when it disappears on the horizon.

Generally, to work on amateur radio satellites in VHF the Doppler effect is around +-3kHz, while in the UHF band this will vary around +-10kHz.

In Table 11, you can see how the frequency shift varies due to the Doppler effect in the two bands (VHF and UHF) for the adjustment of the ISS and our transmitter.

Table 9: Doppler Effect.

Uplink and Downlink TX and RX (MHz)
435,980
435,990
436,000
436,010
436,020

2.5. Noise Level Measurement

The monitoring equipment that we used is Rohde & Schwarz UMS. This system is the ideal for the effective and budget-priced monitoring of electromagnetic emission. Used in conjunction with ARGUS control, measurement and analysis software, the UMS becomes highly versatile and flexible monitoring system capable of handling wide variety of task.

The Rohde & Schwarz Argus UMS equipment in the Illustration 13, combines ITU-compliant monitoring, direction finding with conventional angle of arrival and emitter location based on measuring the time difference of arrival in a compact outdoor solution. This equipment is installed in the Room D 800 and the antenna is installed in the roof of building C.

We measured the noise level with the software Rohde & Schwarz Argus-UMS remotely from the labor D-800.



Illustration 22: Rohde & Schwarz Argus UMS equipment.

The noise levels in the roof of room D-800 and in the roof of the Radio Amateur Club, can be seen in the Table 10.

Table 10: Noise level.

Roof of building D-800		Radio Amateur Club roof	
Uplink 145 Mhz	Downlink 436 Mhz	Uplink 145 Mhz	Downlink 436 Mhz
-69,78dBm	-69,61dBm	-157dBm	-154dBm

Theoretical analysis of power noise from the cube satellite, it was used the Boltzmann's constant (K), the absolute temperature of device (T) and the circuit bandwidth (B), with the following equation:

$$N_p = K.T.B \quad (4)$$

$$N_p = \left(1,380 * \frac{10^{-23} J}{K} \right) * (1,5^\circ K) * (125 KHz) = 2,59 * 10^{-18} W$$

$$10 \log_{10} 2,59 * 10^{-18} = -175,88 \text{ dBW} \quad (5)$$

At the weather station we did able to see the forecast for Győr, and the wind speed values during March 1,2023 - March 31,2023 in the top of the Room D of the university, can be seen in Illustration 14.

Summary March 1, 2023 - March 31, 2023							
	High	Low	Average		High	Low	Average
Temperature	18.8 °C	-1.2 °C	7.0 °C	Wind Speed	57.0 km/h	0.0 km/h	12.9 km/h
Dew Point	7.4 °C	-8.1 °C	-0.4 °C	Wind Gust	90.0 km/h	--	14.2 km/h
Humidity	100 %	32 %	62 %	Wind Direction	--	--	South
Precipitation	0.00 mm	--	--	Pressure	1,012.53 hPa	978.67 hPa	--

Illustration 23: Wind speed summary March 1,2023-March 31, 2023.

2.6. Free Space Attenuation

The Free Space Attenuation is the loss on signal strength of a signal as it travels through free space. This value is usually calculated by discounting any obstacles or reflections that might occur in its path. Enter the Frequency and distance to calculate the Free space Attenuation and it is expressed in dB.

For calculations we use the following equation from ITU.

$$FSPL: 32,4 + 20 \log_{10}(d) + 20 \log_{10}(f) \quad (6)$$

Distance: d (Km)

Frequency: f (MHz)

Speed of light in vacuum: c (m/s)

Transmitting Antenna Gain: G_{Tx}

Receiving Antenna Gain: G_{Rx}

Polarisation attenuation + humidity attenuation + atmospheric attenuation = +3 dB.

For uplink and Downlink:

Distance: 4500 km

$$FSPL: 32,4 + 20 \log_{10}(4500km) + 20 \log_{10}(436 M Hz) + 3dB = 161,25 dB \quad (7)$$

Distance: 412 km

$$FSPL: 32,4 + 20 \log_{10}(412km) + 20 \log_{10}(436 M Hz) + 3dB = 140,49 dB \quad (8)$$

2.7. Link Budget Calculation

The link budget plays a crucial role in the engineering planning of satellite communication systems. It is the accounting of signal gains and losses travelling through a medium from transmitter to receiver. This link budget calculates and provides information of losses and gains, available power at transmitter, antenna gain, propagation losses and performance losses due to noise and natural interference.

This analysis helps continuously optimize equipment resource allocation and device parameters to meet user communication capacity and quality requirements while ensuring suitable safety margins. [17]

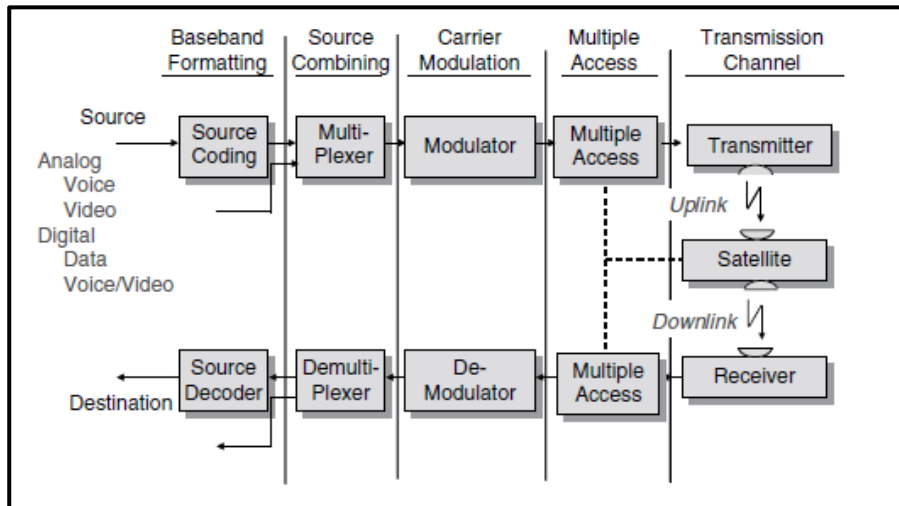


Illustration 24: Satellite (ISS) communications

According to equation (1), we can start calculating the wavelength.

For uplink and downlink:

$$\lambda = \frac{c}{f} = \frac{300\,000\,000\text{m/s}}{436\,000\,000\text{ Hz}} = 0,70\text{ m} \quad (9)$$

UHF frequencies have smaller waves that produce broader reception, and VHF has longer wavelengths for uplink.

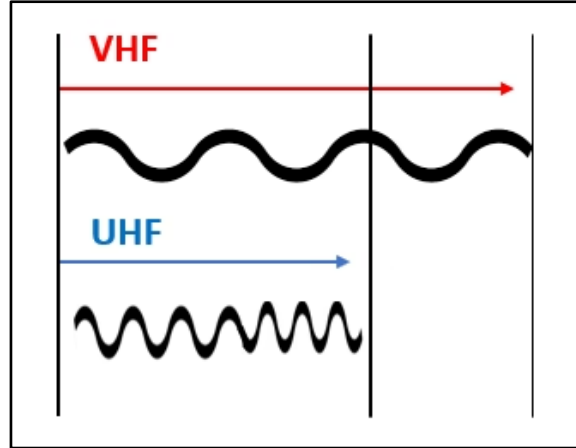


Illustration 25: Wavelength of VHF and UHF

Source: (Thomas Taylor,2019)

2.7.1. Yagi Antenna

According to the technical parameters of the radios in Table 3 and Table 6, and the technical parameters of the antennas in Tables 5 and Table 7, and the measurement of the noise level, the following data are available:

Gain of the Transmitter antenna: G_t

Gain of the Receiver antenna: G_r

Transmitter power: P_t

Receiver power: P_r

Wavelength: λ

To calculate the link budget in Yagi antennas, the following equation is used.

$$P_s = G_t + G_r + P_t + 20 \log_{10} \frac{\lambda}{4\pi R} \quad (10)$$

Data:

With 436 MHz with $\lambda = 0,70\text{m}$

Antenna Gain SZESAT-1: 0 dB.

Antenna Gain 32JXX70 antenna: 15,53 dB.

Power transceiver earth station $P_t = 1000 W = 30dB$

Sensitivity transceiver earth station: $S = 0,15\mu V = -123,47dBm = -153,47 dBW$

Power transceiver satellite $P_t = 100 mW = 20dBm = -10dBW$

Sensitivity transceiver Satellite: $S = -148dBm = -178dBW$

Noise measurement downlink earth station= $N = -124dBm = -154dBW$

Noise measurement from lora in the satellite: $N_p = -175,88 dBW$

With maximum Satellite distance: 4500 Km

Uplink:

$$\begin{aligned} P_s &= 16,53dB + 0dB + 30dBW + 20 \log_{10} \frac{0,70m}{4\pi(4500000m)} \\ &= -111,62 dBW \quad (11) \end{aligned}$$

Link Budget

$$\begin{aligned} \left(\frac{C}{N}\right)^{dB} &= P_s - \text{Noise from satellite} \\ \left(\frac{C}{N}\right)^{dB} &= -111,62 dBW - (-175,88 dBW) = 64,26 dB \quad (12) \end{aligned}$$

Downlink:

$$\begin{aligned} P_s &= 0dB + 16,53dB - 10dBW + 20 \log_{10} \frac{0,70m}{4\pi(4500000m)} \\ &= -151,62 dBW \quad (13) \end{aligned}$$

Link Budget

$$\begin{aligned} \left(\frac{C}{N}\right)^{dB} &= P_s - \text{Noise from earth station} \\ \left(\frac{C}{N}\right)^{dB} &= -151,62 dBW - (-154 dBW) = 2,38 dB \quad (14) \end{aligned}$$

With maximum Satellite distance: 412 Km

Uplink:

$$P_s = 16,53dB + 0dB + 30dBW + 20 \log_{10} \frac{0,70m}{4\pi(412000m)} = -90,85 dBW \quad (15)$$

Link Budget

$$\left(\frac{C}{N}\right)^{dB} = P_s - \text{Noise from satellite}$$

$$\left(\frac{C}{N}\right)^{dB} = -90,85 \text{ dBW} - (-175,88 \text{ dBW}) = 85,03 \text{ dB} \quad (16)$$

Downlink:

Data

$$P_s = 0 \text{ dB} + 16,53 \text{ dB} - 10 \text{ dBW} + 20 \log_{10} \frac{0,70 \text{ m}}{4\pi(412000 \text{ m})}$$

$$= -130,85 \text{ dBW} \quad (17)$$

Link Budget

$$\left(\frac{C}{N}\right)^{dB} = P_s - \text{Noise from earth station}$$

$$\left(\frac{C}{N}\right)^{dB} = -130,85 \text{ dBW} - (-154 \text{ dBW}) = 23,15 \text{ dB} \quad (18)$$

Table 11: Comparison power signal with sensitivity with the distance 4500 km.

Sensitivity	Power Signal
Sensitivity receiver earth station: -153,47 dB	Downlink Ps= -111,62 dBW
Sensitivity receiver satellite: -178dB	Uplink Ps=-151,62 dBW

Table 12: Comparison power signal with sensitivity with the distance 412 km.

Sensitivity	Power Signal
Sensitivity receiver earth station: -153,47 dBW	Downlink Ps= -130,85 dBW
Sensitivity receiver satellite: -178dBW	Uplink Ps=-90,85 dBW

2.8. Earth Station location aspects

The Earth Station is located on the top k3 building into the Széchenyi Istvan University.

2.8.1. Visibility

We examined the top of D building to see if it is suitable for the location of the Yagi antennas, but in this place, there are a 3-meter grid antenna that made visibility difficult, as seen In Illustration 26.



Illustration 26: Roof of Room D in the University

We have chosen to locate the earth station on the top between the building K3 and building K4, since this place has good visibility, as seen in Illustration 18.

2.8.2. Antenna

On the flat roof of this university building there was already an antenna mast that can be seen in Illustration 27. It was then possible to install the antenna supports with the appropriate weight on this mast.

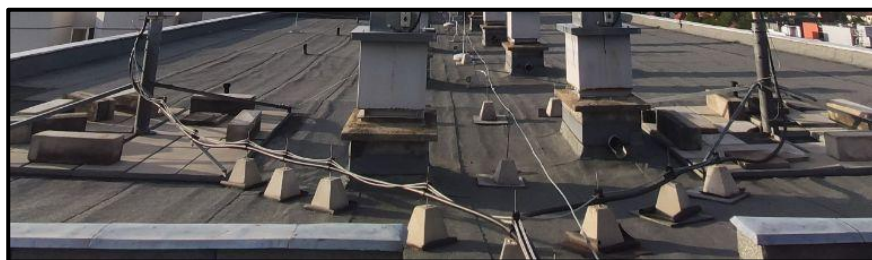


Illustration 27: Antenna mast on the top of the building.

2.8.3. Power Supply

The power supply was resolved by the university.

2.8.4. *Lightning protection*

The lightning protection was resolved by the university.

2.8.5. *Waveguide routing*

The University's existing conduits and cable guides can be used.

2.8.6. *Indoor Equipment placement*

University can be solved in the D800. The conditions are given, as shown in Illustration 28.



Illustration 28: Antenna for measure noise level.

In the case of a college, in the amateur radio club can be solved. The conditions are given, as shown in Illustration 29.



Illustration 29: Amateur Radio Club

2.9. The Implemented station structure on top of the college

The Earth station was implemented on top of the college. In the Illustration 30, you can see the J32XX70 cross Yagi antenna that will be installed.



Illustration 30: J32XX70 Antenna in the amateur radio club.

In the Illustration 31, we can see the movement of the antennas through a camera.



Illustration 31: Video of visualization antennas in the top of dormitory.

In the Illustration 32, you can see the radio IC-9700 that we use to communicate with satellites.



Illustration 32: Radio IC-9700 implemented in the station.

On a computer seen in the Illustration 33, we can control the use of the Gpredict software for the movement of the antennas. And we can also monitor the use of other applications such as RS-BA1 to see the electromagnetic spectrum, view node-red programming and SIMATIC use for the PLC.

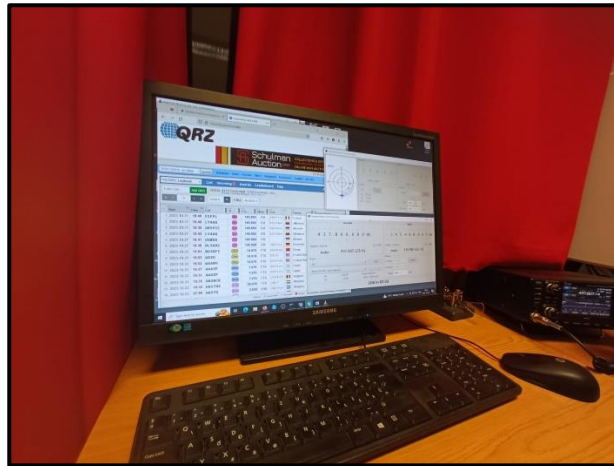


Illustration 33: Radiocommunication monitoring.

In the illustration 34, you can see the control system with a PLC for process automation with the movement of antennas with GPredict.



Illustration 34: PLC for automation in radio club.

In the illustration 35, you can see the elevation-azimuth G5500 controller in the radio station, for control manually the movement of antennas.



Illustration 35: Elevation-azimuth G5500 controller in the station.

CHAPTER III

3. ANALYSIS FRAMEWORK AND INTERPRETATION OF RESULTS

Different tests were carried out to interpret the results, which are detailed below:

3.1. Tests with WRAP simulator

WRAP is an Altair Feco component, that maximizes the benefits of emerging communication technologies for individuals, business, and society. WRAP simplifies the technical and administrative task required for radio and radar coverage planning over large regions, spectrum management, interference analysis, frequency administration and network monitoring. Besides, WRAP has optimization tools help users achieve desired network performance goals without the hassle and cost of large planning teams.[18]

3.1.1. Simulation 1

The simulation is used to predict, analyse, optimize, and plan the coverage given by radio and radar systems.

It was considered two points, the communication between one station in Debrecen and the station of radio amateur club in the dormitory in Győr, when the satellite is just above coordinates of Budapest.

For the configurations in WRAP, it was necessary to specify the DMS coordinates:

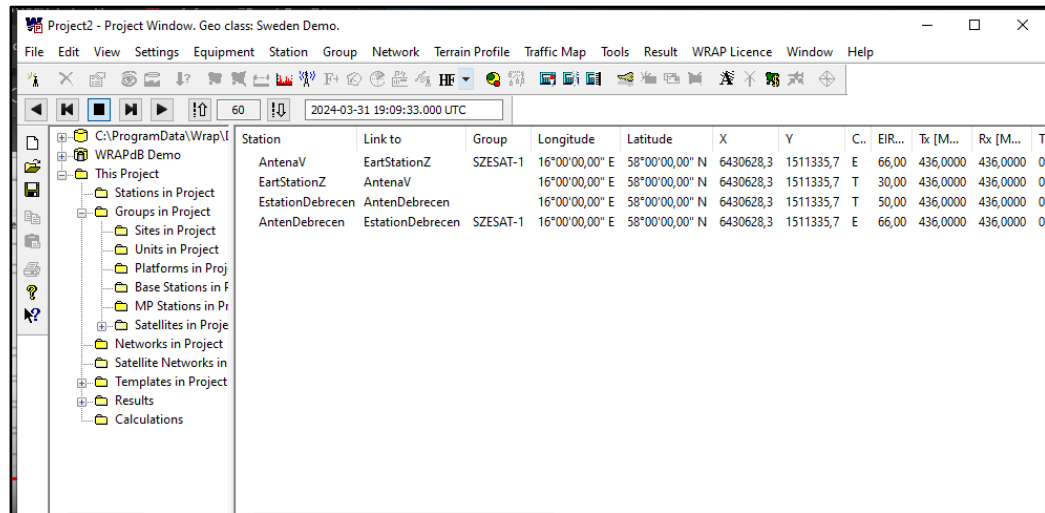
- Radio amateur club Győr: 47° 40' 59.988" North, 17° 38' 6.432" East

- Some station in Debrecen: 47° 31' 48" North, 21° 38' 21" East
- Budapest: 47° 29' 00" North, 19° 02' 00" East

Other parameters were also specified such as frequency, maximum distance between the earth station and the satellite, antenna gains, etc.

This satellite does not apply any gain to the signal it receives, it only retransmits it as it arrived, which is why the gain is zero. A temperature of 150 degrees kelvin is considered.

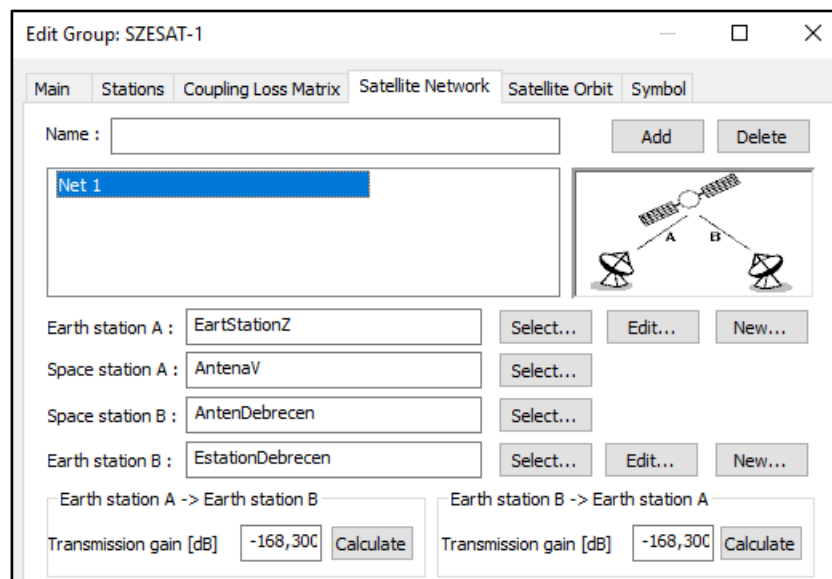
In the Illustration 36, the satellite antennas and earth stations created in the program are displayed.



Station	Link to	Group	Longitude	Latitude	X	Y	C..	EIR...	Tx [M...	Rx [M...	T
AntenaV	EartStationZ	SZESAT-1	16°00'00,00" E	58°00'00,00" N	6430628,3	1511335,7	E	66,00	436,0000	436,0000	0
EartStationZ	AntenaV		16°00'00,00" E	58°00'00,00" N	6430628,3	1511335,7	T	30,00	436,0000	436,0000	0
EstationDebrecen	AntenDebrecen		16°00'00,00" E	58°00'00,00" N	6430628,3	1511335,7	T	50,00	436,0000	436,0000	0
AntenDebrecen	EstationDebrecen	SZESAT-1	16°00'00,00" E	58°00'00,00" N	6430628,3	1511335,7	E	66,00	436,0000	436,0000	0

Illustration 36: Stations in project.

In the Illustration 37, the transmission gain of each station is displayed.



Edit Group: SZESAT-1

Main Stations Coupling Loss Matrix **Satellite Network** Satellite Orbit Symbol

Name : Add Delete

Net 1

Earth station A : Select... Edit... New...

Space station A : Select...

Space station B : Select...

Earth station B : Select... Edit... New...

Earth station A -> Earth station B
Transmission gain [dB] Calculate

Earth station B -> Earth station A
Transmission gain [dB] Calculate

Illustration 37: Satellite network.

In the illustration 38, the entire area covered by the satellite for communication between the two points is observed, considering a radius of 200 km.

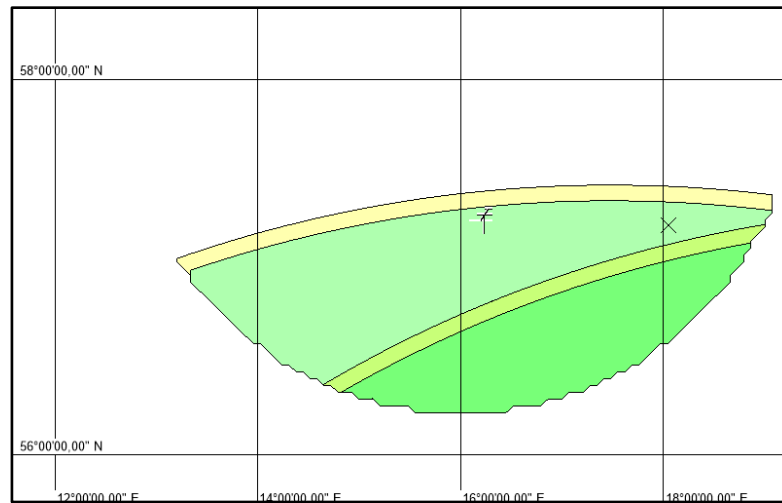


Illustration 38: Coverage of satellite in two points for downlink.

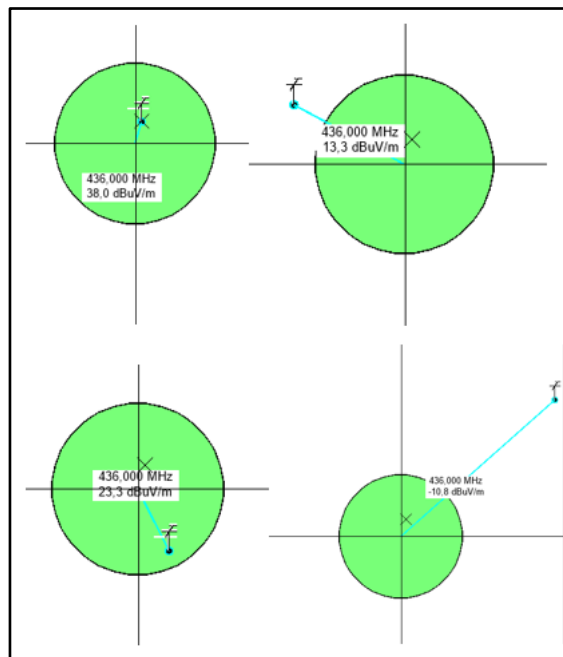


Illustration 39: Coverage of satellite in two points for uplink.

The Illustration 40 and Illustration 41, show the frequency spectrums for downlink and uplink.

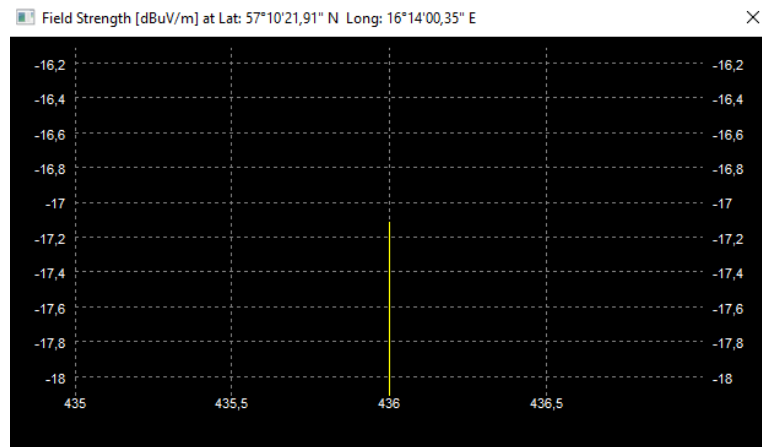


Illustration 40: Frequency Spectrum for downlink from satellite.

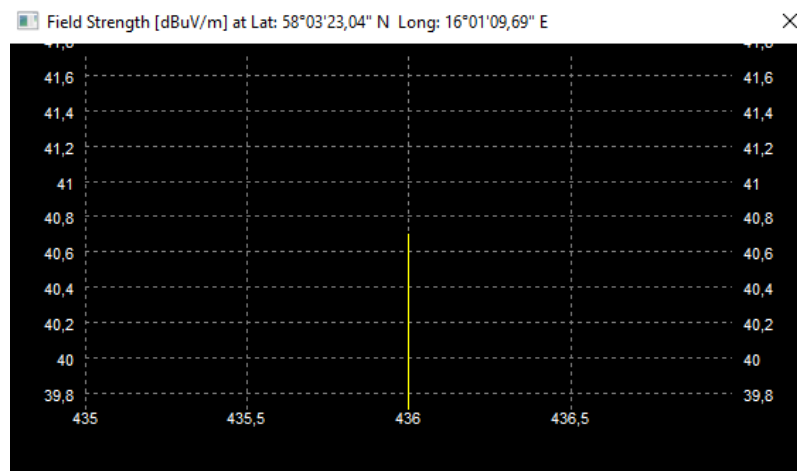


Illustration 41: Frequency Spectrum for uplink from satellite.

In Illustration 42, the total area and the percentage of covered areas in Debrecen are observed.

Value	Area [km2]	Covered Area [km2]	Covered Area [%]	Sum	Covered sum	Covered sum [%]
-124	125795,7	33148,9	26,4	0	0	0,0
-124	125795,7	33148,9	26,4	0	0	0,0
-123,9	125795,7	29782,3	23,7	0	0	0,0

☒ Total Area
☒ Result Calculation Area
☐ From Map Viewer
☐ Raster data

☒ Print Population Statistics

Illustration 42: Area of coverage area from the satellite.

In Annex A show the information obtained in the simulations. We found with a radio of satellite of 200 km, it can cover the area between Gyor and Debrecen, and this satellite cover a total area of $125663,7 \text{ km}^2$. The satellite has a covered area in Gyor of $3398,5 \text{ km}^2$, and in Debrecen is a covered area of $13332,7 \text{ km}^2$.

3.1.2. Simulation 2

It was considered the coverage area in two points, one point in an Earth station in the radio amateur club in Győr, Hungary, and other point with coordinates in Vienna-Austria, when the satellite is above Bratislava-Slovakia.

For the configurations in WRAP, it was necessary to specify the DMS coordinates:

- Radio amateur club Győr: $47^\circ 40' 59.988''$ North, $17^\circ 38' 6.432''$ East
- Some station in Vienna: $48^\circ 12' 30''$ North, $16^\circ 22' 19''$ East
- Bratislava: $48^\circ 08' 53.50''$ North, $17^\circ 24' 00''$ East

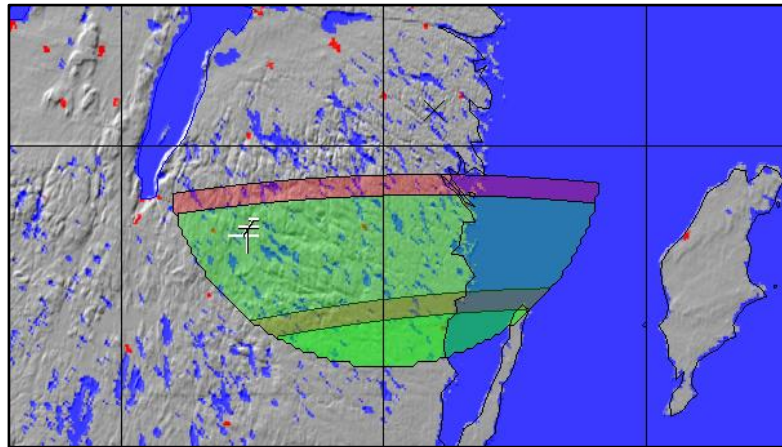


Illustration 43: Coverage Area of SZESAT-1 satellite in WRAP simulator.

When the satellite antenna moves to different positions, the amplitude of the spectrum frequency changes.

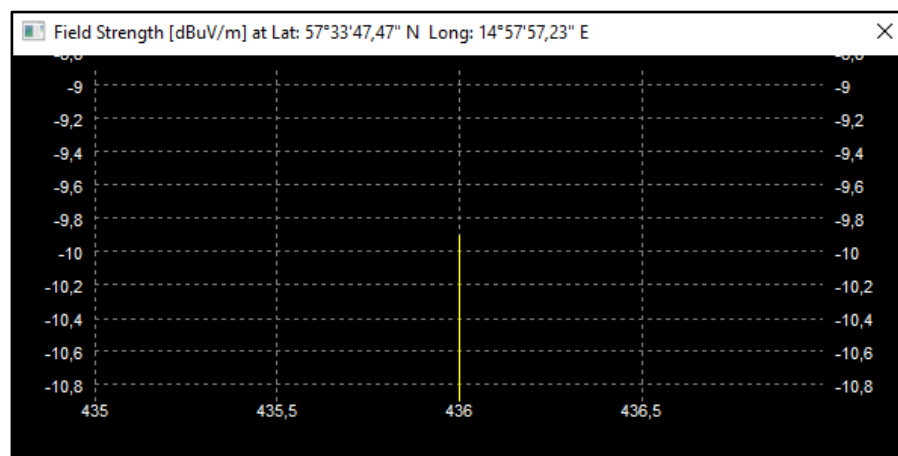


Illustration 44: Frequency spectrum for downlink from satellite, when the antenna moves to the coordinates: $57^\circ 33' 47.47''$ N, $14^\circ 57' 57.23''$ E.

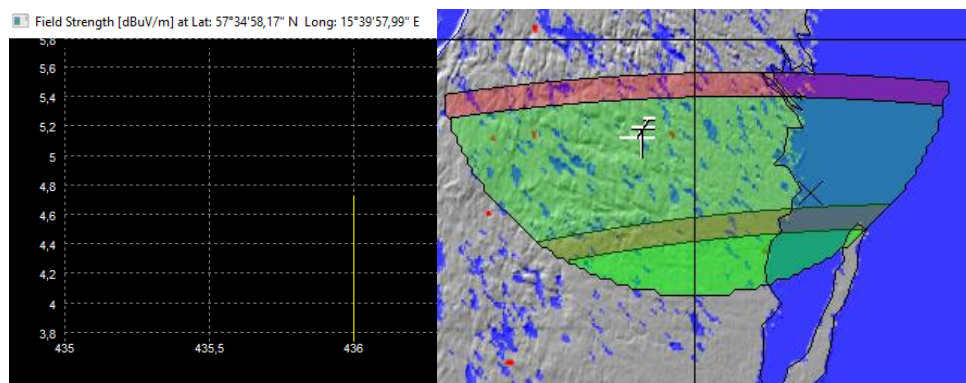


Illustration 45: Frequency spectrum for downlink from satellite, when the antenna moves to the coordinates: 57° 34' 58.17" N, 15° 39' 57.99" E.

In the Illustration 46, some parameters of the satellite's orbit are observed.

Edit Group: SZESAT-1			
Main		Satellite Orbit	
Epoch	2015-03-16 17:34:58.689 UTC		
Inclination, i [deg]	51,6453	Ascending node, Omega [deg]	185,6477
Eccentricity, e	0,0008937	Ascending node, GMT [deg]	107,9134251714
B* [1/earth radii]	0,00025665	Argument of Perigee, w [deg]	109,2385
True Anomaly, Sigma [deg]	350,6002852673		
Eccentric Anomaly, E [deg]	350,6086444770	Toggle	
Mean Anomaly, M [deg]	350,6169999999		
Semi-major axis, a [km]	6779,539576		
Mean motion, n [rev/day]	15,55209613168		

Illustration 46: Satellite orbit.

In the illustration 47 and illustration 48, the calculation of the area covered by the satellite in Vienna and Gyor.

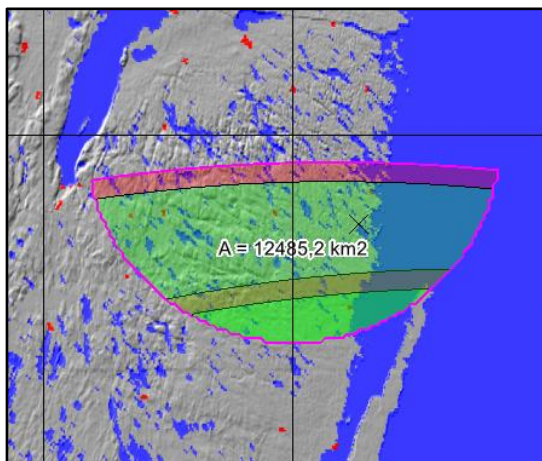


Illustration 47: Result covered area in Vienna.

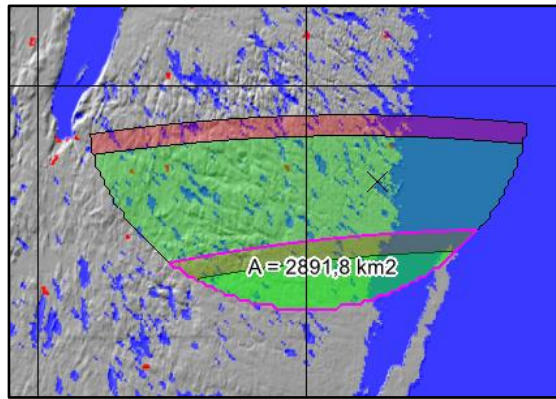


Illustration 48: Result covered area in the coordinates of the earth station in Győr.

Edit Result

Information Presentation Coverage Information

Value	Area [km2]	Covered Area [km2]	Covered Area [%]	Sum	Covered sum	Covered sum [%]
-124	31415,9	2981,9	9,5	0	0	0,0
-124	31415,9	2981,9	9,5	0	0	0,0
-123,9	31415,9	1782,5	5,7	0	0	0,0

Total Area

☒ Result Calculation Area
☐ From Map Viewer
☐ Raster data

☒ Print Population Statistics

Aceptar Cancelar Aplicar Ayuda

Illustration 49: Percentages of areas covered in Győr.

Edit Result

Information Presentation Coverage Information

Value	Area [km2]	Covered Area [km2]	Covered Area [%]	Sum	Covered sum	Covered sum [%]
-124	31415,9	12594,0	40,1	0	0	0,0
-124	31415,9	12594,0	40,1	0	0	0,0
-123,9	31415,9	10790,6	34,3	0	0	0,0

Total Area

☒ Result Calculation Area
☐ From Map Viewer
☐ Raster data

☒ Print Population Statistics

Aceptar Cancelar Aplicar Ayuda

Illustration 50: Percentages of areas covered in Vienna.

It is observed that the satellite can cover a total area of $31,415.9 \text{ km}^2$. The area covered in Gyor-Hungary is $2981,9 \text{ km}^2$ with percentages of 9,5% and 5,7%, and the area covered in Vienna-Austria is 12594 km^2 , with percentages of 40,1% and 34,3 %. In the Annex C, Annex D, Annex E, show the information collected from Wrap Software.

3.2. Matlab satellite communications toolbox

Satellite communications Toolbox provides standard-based tools for designing simulating and verifying satellite communications systems and links. This toolbox supports scenarios modeling for time-varying visibility and link budget analyses with satellites, aircraft, and other mobile platforms in a single scenario.

Simulations were conducted using data that closely resembled both our antenna and the forthcoming satellite.

In the Illustration 51, can be observed the link budget and free space for the communication between Earth station and satellite.

The altitude of Satellite is 1450 km, the distance between earth and satellite.

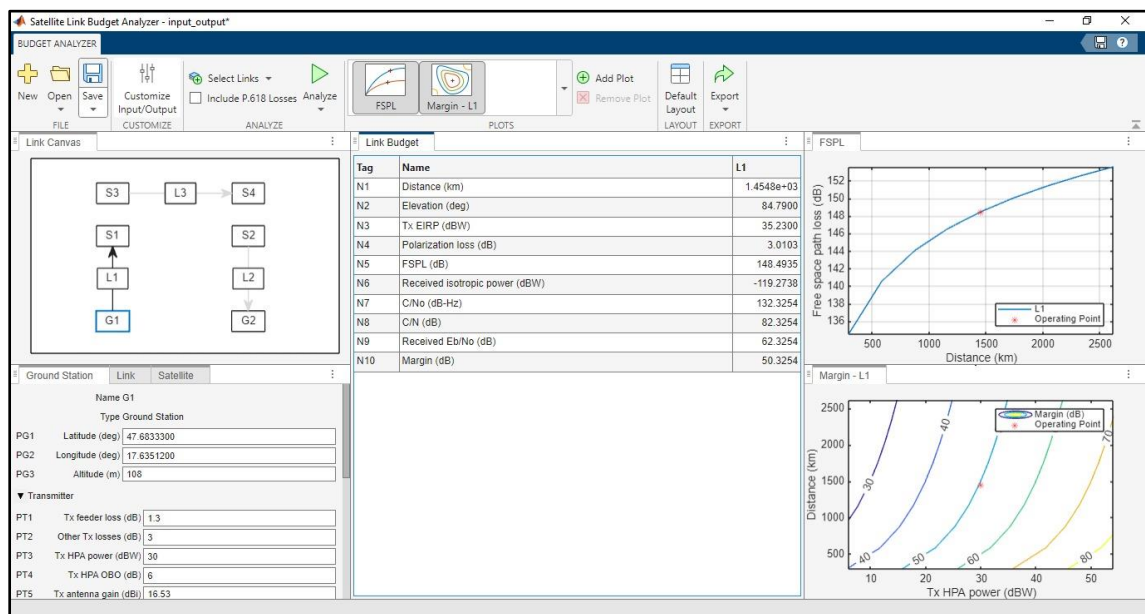


Illustration 51: Satellite link budget analyzer.

The following configurations were made with the required parameters.

Ground Station		Link	Satellite
Name G1			
Type Ground Station			
PG1	Latitude (deg)	47.6833300	
PG2	Longitude (deg)	17.6351200	
PG3	Altitude (m)	108	
▼ Transmitter			
PT1	Tx feeder loss (dB)	1.3	
PT2	Other Tx losses (dB)	3	
PT3	Tx HPA power (dBW)	30	
PT4	Tx HPA OBO (dB)	6	
PT5	Tx antenna gain (dBi)	16.53	

Illustration 52: Configuration of ground Station.

Ground Station		Link	Satellite
Name L1			
Type Link			
From G1			
To S1			
PL1	Frequency (GHz)	0.436	
PL2	Bandwidth (MHz)	0.1	
PL3	Bit rate (Mbps)	10	
PL4	Required Eb/No (dB)	10	
PL5	Polarization mismatch (deg)	45	
PL6	Implementation loss (dB)	2	
PL7	Antenna mispointing loss (dB)	1	
PL8	Radome loss (dB)	1	

Illustration 53: Configuration of Link.

Ground Station		Link	Satellite
Name S1			
Type Satellite			
PS1	Latitude (deg)	47.497913	
PS2	Longitude (deg)	19.040236	
PS3	Altitude (km)	1450	
Transmitter		None	
▼ Receiver			
PR1	Interference loss (dB)	2	
PR2	Rx G/T (dB/K)	25	
PR3	Rx feeder loss (dB)	1	
PR4	Other Rx losses (dB)	1	

Illustration 54: Configuration of satellite parameters with an altitude of 1450 km.

In the Illustration 55, can be observed the free space path loss according to the distance. The distance parameters are according to the distance in kilometers between the amateur radio club in Gyor when the satellite is over Budapest.

With an altitude of satellite of 1450 km.

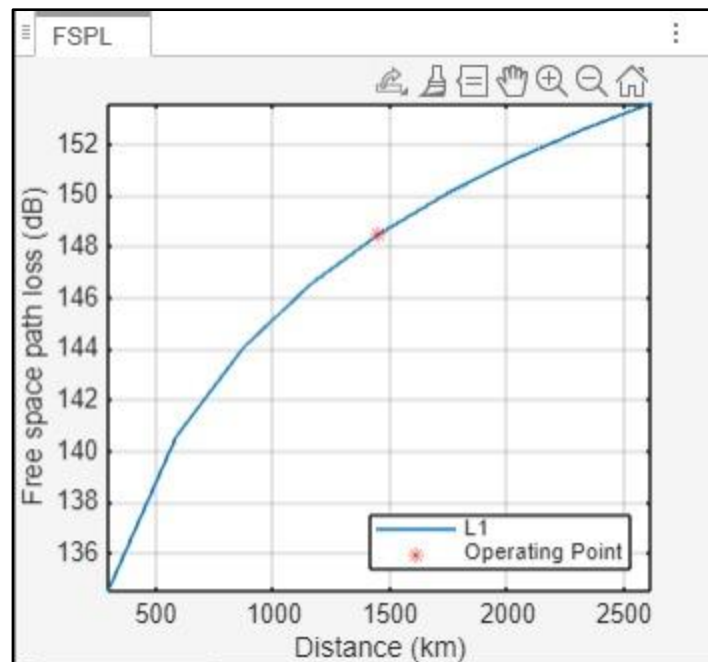


Illustration 55: Free space path loss vs distance.

In the Illustration 56, can be observed the link margin, according to the distance with the power and sensitivity of the transmitter.

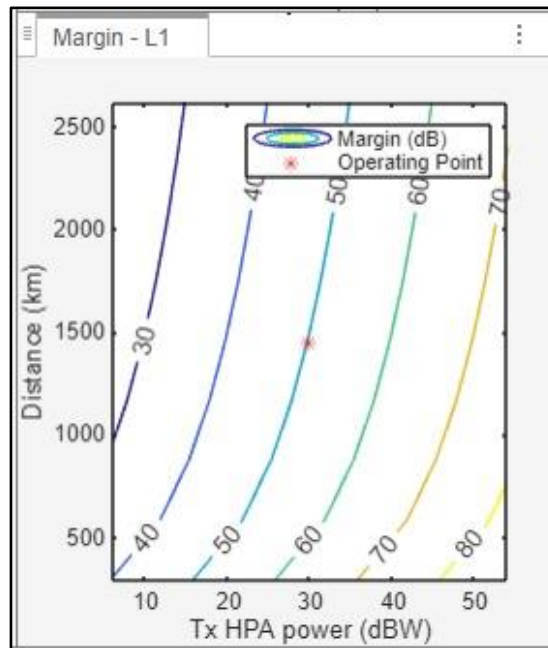


Illustration 56: Margin vs Tx HPA power (dBW)

With the maximum distance of 4500 km, it was obtained the following results:

Ground Station		Link	Satellite
Name S1			
Type Satellite			
PS1	Latitude (deg)	47.6833300	
PS2	Longitude (deg)	17.6351200	
PS3	Altitude (km)	4500	
Transmitter		None	
▼ Receiver			
PR1	Interference loss (dB)	2	
PR2	Rx G/T (dB/K)	25	
PR3	Rx feeder loss (dB)	1	
PR4	Other Rx losses (dB)	1	

Illustration 57: Configuration of satellite parameters with an altitude of 4500 km.

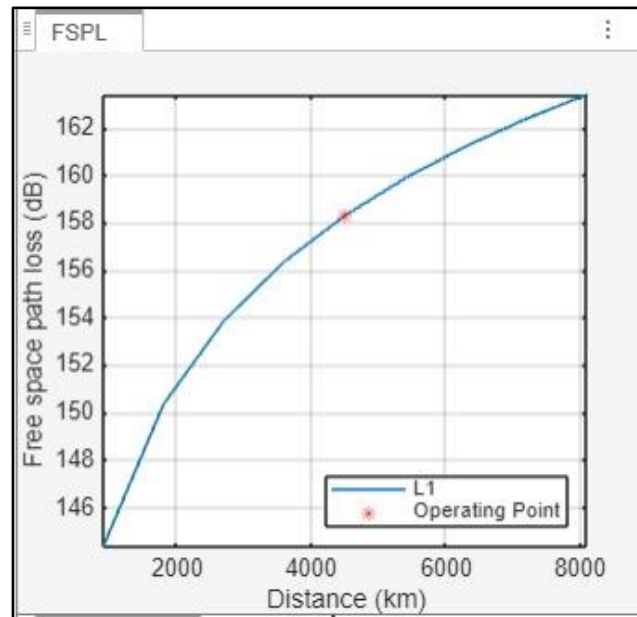


Illustration 58: Free space path loss vs distance, with altitude of 4500 km.

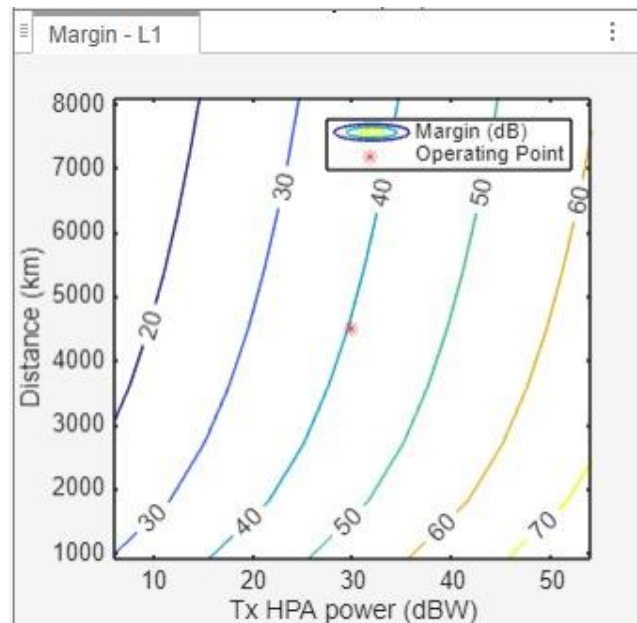


Illustration 59: Margin vs Tx HPA power (dBW) with an altitude of 4500 km.

The free space coincides with our calculation and is possible compare the values of the link budget with our calculations.

SUMMARY

The Doppler Effect in Gpredict for communication with SZESAT-1 coincides with the values found in the calculations for VHF band the Doppler effect is around $\pm 3\text{kHz}$, while in the UHF band this will vary around $\pm 10\text{kHz}$.

The orbit of the satellite will be on LEO (Low Earth orbit). One rotation around Earth takes 90 to 100 minutes. Over the development of our last TDK project, it is known for us, that one pass ranges from 6-12 minutes through our orbit, for the remaining time, the telemetry of the satellite cannot be received with our ground station. This causes challenges in the meaning of receiving telemetry data from the satellite. The distance between the earth station and the cube satellite will be around 412 km.

If the frequency is small the wavelength is too long, and if the frequency is 2400 Mhz – 2450 MHz, there are much noise from mobile service providers. So, the useful frequency for us is between 435-438MHz with a wavelength of 0,7 meters. In this investigation Cube satellite will use UHF frequencies with 436MHz.

Given the limited power available on the satellite, modulation of transmissions is necessary. We opt for GMSK modulation due to its power efficiency and spectral efficiency, simplifying frequency spectrum allocation. Moreover, GMSK modulation demonstrates resilience against multipath fading and Doppler effects.

Two methods are available for receiving satellite signals. The first method involves using the IC 9700, while the alternative method employs SatDump with an RTL-SDR to record data for demodulation at a later time.

The value of the free space attenuation with a maximum distance of 4500 km in a frequency of 436 MHz is 161,25 dB for uplink and downlink. The value of the free space attenuation with a distance of 412 km is 140,49dBfor uplink and downlink. The connection can only be made if we have a better signal level according to our measurements, and the signal is stronger than the free space loss itself.

The link budget of cross Yagi Antenna is 64,26 dB for uplink and 2,38 dB for downlink in a maximum distance of 4500 km. The link budget of cross Yagi Antenna is 85,03 dB for uplink and 23,15 dB for downlink in 412 km of distance. With a noise level of -175,88 dBW for uplink and -154 dBW for downlink. The values of sensitivity of the transceiver equipment's are less than the signal powers, therefore the communication is possible.

It was decided to use this 32JXX70 cross Yagi antenna for radio communication, because the rotation of the antenna is easier as it is less heavy and requires less space, unlike the helical antenna. I addition, this antenna also has circular polarization that is used to reduce losses and it has a good gain.

Gpredict contains a function called HamLib, where it is recommended to control the PLC through TCP protocol to get better remote access services instead of Node-Red. Without Node-Red it is possible to control the antennas without a local computer. This way there is less chance of malfunction. The location of the antennas should be in a clearer position and with less noise.

The SzeSat team is working on developing a COM module, that enables other radio amateurs to receive telemetry data over LoRa™ and transmit the received data over the TinyGS network for public access.

The total area covered by the satellite depends on the radius of the satellite. When the radius of the satellite is 200 km for the first simulation with wrap considering two points within Hungary, we obtain that the total area is $125663,7 \text{ km}^2$. The satellite has a covered area in Gyor of $3398,5 \text{ km}^2$, and in Debrecen is a covered area of $13332,7 \text{ km}^2$. And when the radius of the satellite is 100 km for the second simulation with Wrap considering two points in different countries, we obtain that the total area is $31,415.9 \text{ km}^2$. The area covered in Gyor-Hungary is $2981,9 \text{ km}^2$ with percentages of 9,5% and 5,7%, and the area covered in Vienna-Austria is 12594 km^2 , with percentages of 40,1% and 34,3 %.

Multiple simulations were conducted using both WRAP and MATLAB Satellite Communications Toolbox. These simulations demonstrate the accuracy of our calculations. However, simulations alone are insufficient for the success of our project; thus, we will proceed to perform measurements using our equipment in the future.

We persist in our dedicated efforts to establish communication with the Szesat-1 satellite, driven by our unwavering determination to fulfill our dream.

ACKNOWLEDGEMENTS

We extend our heartfelt thanks to our contributors, whose contributions made our work possible:

Many thanks to Dr. Vári Péter for making the start of this research possible.

Our gratitude goes to Péter Pataky for helping us conduct noise measurements.

We extend our thanks to Zoltán Nagy for his contribution to the satellite COM module.

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We are thankful to Lajos Kéri for guiding us in utilizing Gpredict effectively.

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BIBLIOGRAPHY

- [1] R. Union International Telecommunication Sector, "Handbook on Small Satellites," 2023.
- [2] Alexandru Csete, *Gpredict User Manual*. 2017.
- [3] I. Nowacki, "What are satellite footprints?," *TS2*, 2023. <https://ts2.space/en/what-are-satellite-footprints/> (accessed Nov. 05, 2023).
- [4] M. Angel Alvarez, A. Morales Gamez, and J. MirCha, *Introducción: Manual de NodeJS*. 2017. [Online]. Available: <http://desarrolloweb.com/manuales/manual-nodejs.html><http://desarrolloweb.com/manuales/manual-nodejs.html>
- [5] National Aeronautics, "State-of-the-Art of Small Spacecraft Technology," *9.0 Communications*, 2024. <https://www.nasa.gov/smallsat-institute/sst-soa/soa-communications/>
- [6] J. M. Hernando Rabanos, *Transmision por Radio*, 6th ed. Madrid, 2008.
- [7] R. Vukovic, "Wavelength," 2020.
- [8] C. Cao and S. Zhai, "The influence of LEO satellite Doppler effect on LoRa modulation and its solutio," *J. Phys. Conf. Ser.*, vol. 1883, no. 1, pp. 1–6, 2021, doi: 10.1088/1742-6596/1883/1/012071.
- [9] ICOM, "Basic manual IC-9700," vol. 200, no. 1, pp. 1–68, 2019.
- [10] ICOM, "IC-9700 Mode Transceiver," 2018.
- [11] Tutorials Point, "Antenna Theory - Helical," 2024. https://www.tutorialspoint.com/antenna_theory/antenna_theory_helical.htm
- [12] P. Vieszicke, "Yagi Antenna Design," *U.S. Dep. Commer.*, pp. 1–22, 1976.
- [13] San Luis Obispo (Cal Poly) CubeSat Systems Engineer Lab, "Basic Concepts and Processes for First-Time CubeSat Developers," *NASA CubeSat Launch Initiat.*, no. October, p. 86, 2017, [Online]. Available: https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf
- [14] TINYGS, "Open Source Global Satellite Network," 2024. <https://tinygs.com/>
- [15] Jekyll, "SatDump," 2024. <https://www.satdump.org/about/>
- [16] J. Mario Torres Nova and H. Paz Penagos, "Studying and comparing spectrum efficiency and error probability in GMSK and DBPSK modulation schemes," *Rev. Ing. E Investig.*, vol. 28, no. 3, pp. 75–80, 2008, [Online]. Available: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-56092008000300010&lng=en&nrm=iso&tlng=es%0Ahttp://www.scielo.org.co/scielo.php?script=sci_abstract&pid=S0120-56092008000300010&lng=en&nrm=iso&tlng=es%0Ahttp://www.scielo.org.co/pdf/iei/v23n3
- [17] N. Ya'acob, J. Johari, M. Zolkapli, A. L. Yusof, S. S. Sarnin, and N. F. Naim, "Link budget calculator system for satellite communication," *2017 Int. Conf.*

Electr. Electron. Syst. Eng. ICEESE 2017, vol. 2018-Janua, pp. 115–119, 2018, doi: 10.1109/ICEESE.2017.8298397.

- [18] Altair Feko, “WRAP simulator,” 2024. <https://altair.com/wrap-applications>

ANNEXES

ANNEXE A: STATISTICS OF SATELLITE COVERAGE IN GYOR AND DEBRECEN.



Coverage Result

Station : AntenaV
Position : 16,000000° E 58,000000° N
EIRP : 66,0 dBW

Calculation : Power Flux Density, dBW/m²
Direction : Downlink

Description : AntenaV, 1/4/2024, 0:42 / Resolution reduced.

Propagation model : ITU-R P.619
Temperature: 25,0 C
Humidity: 25,0 %
Time availability [%]: 50,0
Atmospheric attenuation: Terrestrial paths
Temperature: 15,0 C
Water vapour density: 7,5 g/m³
No cross polarisation in propagation media
No fixed standard deviation

Statistics :					
Min	-124,1 dBW/m²	5%	-124,1 dBW/m²	90%	-123,3 dBW/m²
Max	-122,7 dBW/m²	10%	-124,1 dBW/m²	95%	-123,1 dBW/m²
Mean	-123,9 dBW/m²	50%	-124,1 dBW/m²		

Calculation area information:
-123,9 dBW/m²

Total Area:	125663,7km2	Covered Area:	29841,5km2	Covered Area Percent:	23,7%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

-124,0 dBW/m²					
Total Area:	125663,7km2	Covered Area:	33207,2km2	Covered Area Percent:	26,4%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

-124,0 dBW/m²					
Total Area:	125663,7km2	Covered Area:	33207,2km2	Covered Area Percent:	26,4%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

**ANNEX B: STATISTICS OF COVERAGE AREA WITH COORDINATES OF
RADIO AMATEUR CLUB IN GYOR.**



Coverage Result

Station : AntennaSatelliteGyor
Position : 16,000000° E 58,000000° N
EIRP : 66,0 dBW

Calculation : Power Flux Density, dBW/m²
Direction : Downlink

Description : AntennaSatelliteGyor, 2/4/2024, 14:36

Propagation model : ITU-R P.619
Temperature: 25,0 C
Humidity: 25,0 %
Time availability [%]: 50,0
Atmospheric attenuation: Terrestrial paths
 Temperature: 15,0 C
 Water vapour density: 7,5 g/m3
No cross polarisation in propagation media
No fixed standard deviation

Statistics :					
Min	-124,1 dBW/m²	5%	-124,1 dBW/m²	90%	-124,0 dBW/m²
Max	-123,7 dBW/m²	10%	-124,1 dBW/m²	95%	-123,9 dBW/m²
Mean	-124,1 dBW/m²	50%	-124,1 dBW/m²		

Calculation area information:					
-123,9 dBW/m²					
Total Area:	31415,9km2	Covered Area:	1782,5km2	Covered Area Percent:	5,7%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%
-124,0 dBW/m²					
Total Area:	31415,9km2	Covered Area:	2981,9km2	Covered Area Percent:	9,5%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%
-124,0 dBW/m²					
Total Area:	31415,9km2	Covered Area:	2981,9km2	Covered Area Percent:	9,5%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

The result contains a raster and will not be printed.

**ANNEX C: STATISTICS OF COVERAGE AREA WITH COORDINATES IN
VIENNA.**

Station : AntennaSatVien
Position : 16,000000° E 58,000000° N
EIRP : 66,0 dBW

Calculation : Power Flux Density, dBW/m²
Direction : Downlink

Description : AntennaSatVien, 2/4/2024, 14:38

Propagation model : ITU-R P.619
 Temperature: 25,0 C
 Humidity: 25,0 %
 Time availability [%]: 50,0
 Atmospheric attenuation: Terrestrial paths
 Temperature: 15,0 C
 Water vapour density: 7,5 g/m³
 No cross polarisation in propagation media
 No fixed standard deviation

Statistics :					
Min	-124,1 dBW/m²	5%	-124,1 dBW/m²	90%	-123,4 dBW/m²
Max	-123,1 dBW/m²	10%	-124,1 dBW/m²	95%	-123,3 dBW/m²
Mean	-123,9 dBW/m²	50%	-124,1 dBW/m²		

Calculation area information:
-123,9 dBW/m²

Total Area:	31415,9km²	Covered Area:	10790,6km²	Covered Area Percent:	34,3%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

-124,0 dBW/m²

Total Area:	31415,9km²	Covered Area:	12594,0km²	Covered Area Percent:	40,1%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

-124,0 dBW/m²

Total Area:	31415,9km²	Covered Area:	12594,0km²	Covered Area Percent:	40,1%
Total Sum:	0	Covered Sum:	0	Covered Sum Percent:	0,0%

The result contains a raster and will not be printed.

ANNEX D: LINK PERFORMANCE.

Link path too long to produce profile.

Swedish geographical data submitted by Satellus and SWEDESURVEY

Data for path between EarthStationGyor and AntennaSatelliteGyor :

Position: 16°00'00,00" E 58°00'00,00" N 16°00'00,00" E 58°00'00,00" N

Azimuth: 0,0 deg	0,0 deg	
Ant Height: 0 m	0 m	
Ant Tilt: 0,0 deg	-14,0 deg	
Tx Equipment: Wrap Earth station 72 M		Wrap Satellite 72 M
Rx Equipment: Wrap Earth station 72 M		Wrap Satellite 72 M
Tx Antenna: Earth APS7/8/30B, 50 dBi		Satellite APS30B, 46 dBi
Rx Antenna: Earth APS7/8/30B, 50 dBi		Satellite APS30B, 46 dBi

Frequency: 436,0000 MHz

Warning: The path distance is out of range. Valid range is 2 - 60 km.

Distance: 4499,889 km

EER: 1,33

Capacity: 2000,00 MBit/s

Propagation:

Detvag-90/FOI : 30,0 dB

Atmospheric: 0,0 dB

Power Budget:

EIRP: 26,23 dBm

Propagation: 30,0 dB

Antenna gain: 16,5 dBi

Cable loss: 0,0 dB

Additional attenuation: 0,0 dB

Received power: -47,2 dBm

Propagation Model: Detvag-90/FOI

Quick

Automatic - Method 2

Effective antenna height: Transmitter only

Building Height Distance: 100 m

Vegetation Height Distance: 200 m

Min distance Tx effective antenna height: 0 m

Max distance Tx effective antenna height: 5000 m

Min distance Rx effective antenna height: 0 m

Max distance Rx effective antenna height: 5000 m

Atmospheric attenuation: Terrestrial paths

Temperature: 15,0 C

Water vapour density: 7,5 g/m³

No cross polarisation in propagation media

No fixed standard deviation

Effective earth radius factor: 1,33333

Settings

ITU-R 338-6, Method II

Open Terrain

Rain Intensity: 40,0 mm/h, Worst month

Layer presence: 2,0 %