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SENSING SATELLITARE

**“PRELIMINARY DESIGN OF AN INTER-SATELLITE LINK FOR
COSMO AND SICRAL CONSTELLATIONS”**

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Glossary

To avoid repetitions in the text, we will use the following symbols and names.

<u>Symbol</u>	<u>Definition</u>
Ω	Right ascension of ascending node
ν	Orbit true anomaly
Υ	Vernal equinox
ω	Argumentum of perigee
λ	wavelength
m	Mass
t	Instantaneous time
a	Semi-major Axis
e	Eccentricity
h	Specific Angular Momentum
i	Inclination
r_a	Apogee Radius
r_p	Perigee Radius
b	Semi-minor Axis
n	Mean motion
C_D	Drag Coefficient
A/m	Area over Mass Ratio
ϑ_{3dB}	Antenna beam-width
R_b	Bit rate
B	Bandwidth
BPSK	Binary phase shift key modulation
BER	Bit Error Rate
η	Antenna efficiency
η_{BPSK}	Spectral efficiency of BPSK modulation
ISL	Inter-satellite link
OISL	Optical ISL
N	Ascending Node

<i>M</i>	Mean Anomaly
<i>X, Y, Z</i>	Co-ordinate Axis
<i>STK</i>	Satellite Tool Kit
<i>TLE</i>	Two Line Element
<i>ECI</i>	Earth Centered Inertial
<i>ECEF</i>	Earth Centered Earth Fixed
<i>GUI</i>	Graphical User Interface
<i>EHF</i>	Extremely high frequency
<i>SHF</i>	Super high frequency
<i>UHF</i>	Ultra-high frequency
<i>GEO</i>	Geostationary Earth Orbit
<i>MEO</i>	Medium Earth Orbit
<i>LEO</i>	Leo Earth Orbit
<i>GPS</i>	Global Positioning System
<i>ISS</i>	International Space Station
<i>SICRAL</i>	Sistema Italiano per Comunicazioni Riservate ed Allarme
<i>COSMO</i>	Constellation of small Satellites for Mediterranean basin Observation
<i>CSG</i>	COSMO Sky-Med Second Generation
<i>CSK</i>	COSMO Sky-Med (First Generation)
<i>RF</i>	Radio Frequency
<i>RX</i>	Transmitter
<i>TX</i>	Receiver
<i>RHCP</i>	Right-Hand Circular Polarization
<i>LHCP</i>	Light-Hand Circular Polarization
<i>APM</i>	Antenna Pointing Mechanism
<i>EIRP</i>	Effective Isotropic Radiated Power

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Introduction

The aim of this work is to evaluate the possibility to implement a low-cost and low-complexity ISL (inter-satellite link) between geostationary military satellites SICRAL and COSMO-Skymed. For these reasons, we have focused on RF ISL instead of OISL (optical inter-satellite link) even if OSIL is the new ISL strategy. The reasons of our choice are essentially in the opportunity to cut costs thanks to the reuse of SICRAL payload and the fact that RF technologies are more developed and diffused than optical ones. So, using RF link you can exploit a better and more mature knowledge to do the ISL link budget. Moreover, RF link establishment is easier than optical one because of the visibility requirements which for OISL are very binding and they impact on Time of Access performances and on complexity design project. So, RF ISL appear to be the best solution to respect two fundamental targets:

- Low complexity project, which we can obtain by using a well-known technology, with less complex visibility constraints (RF),
- Low cost implementation, which is possible thanks to the double use of SICRAL payload. In this way the implementation costs of ISL payload are absorbed with respect to the costs of an optical dedicated payload for ISL.

With this analysis we have finally demonstrate that communication satellites could have a dual use and their payloads could be used to implement ISL with great benefits in term of costs and complexity, but also in term of time performances. In facts, the ISL is fundamental to improve time performances and so, the amount of downloaded data of LEO (Low Earth Orbit) satellites, which without ISL have to wait for passing on the ground stations, and transition are very few in 24 hours, to have TC uplink to update the mission or to download data. The choice to make an effort to improve this technology is coherent with Defence trends: nowadays due to the improvement of new threats we have to keep

the situation awareness and to keep up with technological developments in order to react faster and faster at the problems we should face. Army, Aviation and Navy are dislocated in several countries for peace and humanitarian missions, but now, even more than in the past, they intervene also in natural disasters to help populations during critical situations, in national borders and abroad. So, the role of Earth monitoring satellites has become more and more important for this kind of missions and the parameter that influences the final results in this field is surely the ***response time***. The purpose of the ISL in this paper is to improve the ***response time*** in order to achieve a faster operative reaction.

1.ISL Overview

1.1 ISL Mission

Inter-satellite link (ISL) is a link used for communication between satellites and has a function of dual-way ranging. The aim of this technology is to improve satellites capability and coverage, especially for what concern LEO satellites which have a small visibility time with ground station. This paper is devoted to investigate the possibility to implement a data Intersatellite Link between satellites of an Earth Observation constellation and a dedicated TLC GEO satellite. An EO system is mainly composed of two segments (space and ground) connected by a complex network of communications that permits to manage the operations of the constellation. Due to the high performances in terms of imaging capabilities of the radar/optical payloads a corresponding high capacity to download data to ground is needed. Polar stations offer a service needed to provide the

requested images to the users in a near real-time manner. In this paper an alternative approach, using an Intersatellite link system (ISLs) instead of polar stations, is presented. Why is so important to implement the ISL between LEO and GEO? Because of the new strategical requirements that became more and more complex: high-resolution images taken by Earth Observation satellites (LEO) are more-and-more becoming essential in military operation and in support of civil and disaster management tasks and applications. Having the right data at the right time can be the difference between success and failure and may even be vital, for example, for coordination of rescue and aid teams following natural disasters. Earth Observation satellites mostly use direct RF links to deliver their images and recorded data to ground (Figure 1, top). For images requiring high downlink data-rates or rapid delivery, the LEO satellite capability is improved by increasing the number of global ground receiving stations. This increases the number of visibility arcs, but increases ground-segment complexity and cost, above all in terms of maintenance. It is also limited geographically to land-based locations and further restrictions such as stringent ITU interference regulations and geo-political considerations. Moreover, thanks to the ISL you can achieve also other benefits and improvements of the service, for example in term of security: in facts by the communication link between LEO and GEO you can continuously monitoring satellites behaviour in order to detect on time eventual anomalous conduct of any member of the constellation, improving *the time of alarm* which is a parameter not to be underestimate today with all the cyber-attacks by hackers, especially for military use satellites. You could receive specific telemetries by GEO satellites which inform you about the operating state of the LEOs in real-time manner, to prevent disaster isolating the satellites in fault from the constellation. You can also improve the precision of orbit determination of LEOs to schedule maneuvers for orbital corrections. In few words: ISLs improve the navigation constellations autonomy properties being less vulnerable to ground station unavailabilities.

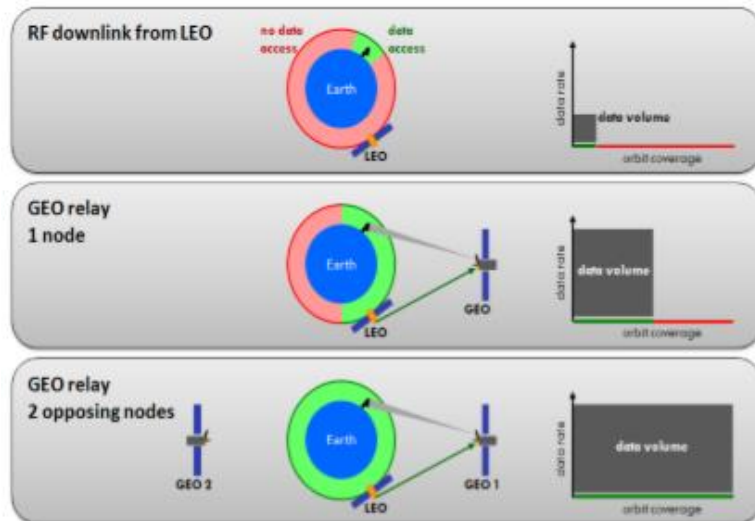


Figure 1: RF downlink from LEO compared with GEO relay: orbit coverage and data volume (schematic)

Intersatellite communications are used primarily for "networking" a constellation of satellites at data rates up to many Gbps or for data relay purposes from tens of Mbps up to Gbps. These ISLs can be between all the various orbits that one might consider: low earth orbit (LEO), medium earth orbit (MEO), highly elliptical orbit (HEO), and geosynchronous earth orbit (GEO). There are currently systems like Iridium and NASA's Tracking and Data Relay Satellite System (TDRSS) that are using RF ISLs for these purposes. The ill-fated Japanese COMETS was to use RF ISLs. There are planned systems like ESA's ARTEMIS that will use RF and optical ISLs. The technologies you can use in order to implement the ISL are essentially of two type:

- RF ISL
- OISL (Optical)

Their technical features will be analysed in the following chapters.

In our analysis we have considered a LEO satellite and a GEO satellite, so let's see some differences and typical characteristics of these orbits.

1.2 Satellite Orbit Definition

An orbit is a regular, repeating path that an object in space takes around another one. An object in an orbit is called a satellite. Orbital equations of motion are governed by Kepler and Newton's laws. Kepler's laws describe the motion of planets in the solar system and can be applied to artificial Earth satellite motion as well. Six quantities describe the orbit of a satellite, three each for position and velocity in a cartesian coordinate system or an element set, typically used with scalar magnitude and angular representation of the classical or Kepler orbital elements. A state vector is usually obtained from numerically integrating the equations of motion. The Keplerian orbital elements (Figure 1.1) are often referred to as classical or conventional elements. This set of orbital elements can be divided into two groups, namely: dimensional and orientational elements. Dimensional elements specify the size and shape of the orbit and relate the position in the orbit to time, whereas orientational elements specify the position of the orbit in inertial space.

- Semi-major Axis (a): defines the size of the orbit.
- Eccentricity (e): defines the shape of the orbit.
- Inclination (i): vertical tilt of the orbital plane with the unit vector in the Z axis with respect to the equatorial plane.
- Right Ascension of Ascending Node (Ω): angle between the vernal equinox (Y) vector and the ascending node (N). The ascending node is the point where a satellite passes through the equatorial plane moving from South to North.
- Argument of Perigee (ω): angle from the ascending node to the orbital eccentricity vector. The eccentricity vector points from the Earth's centre to perigee with a magnitude equal to the eccentricity.
- True Anomaly (γ): angle from the eccentricity vector to the satellite position vector. Mean anomaly (M) and eccentric anomaly (E) are also used in calculation of orbit parameters.

The last two elements define the position of the satellite on the orbital plane.

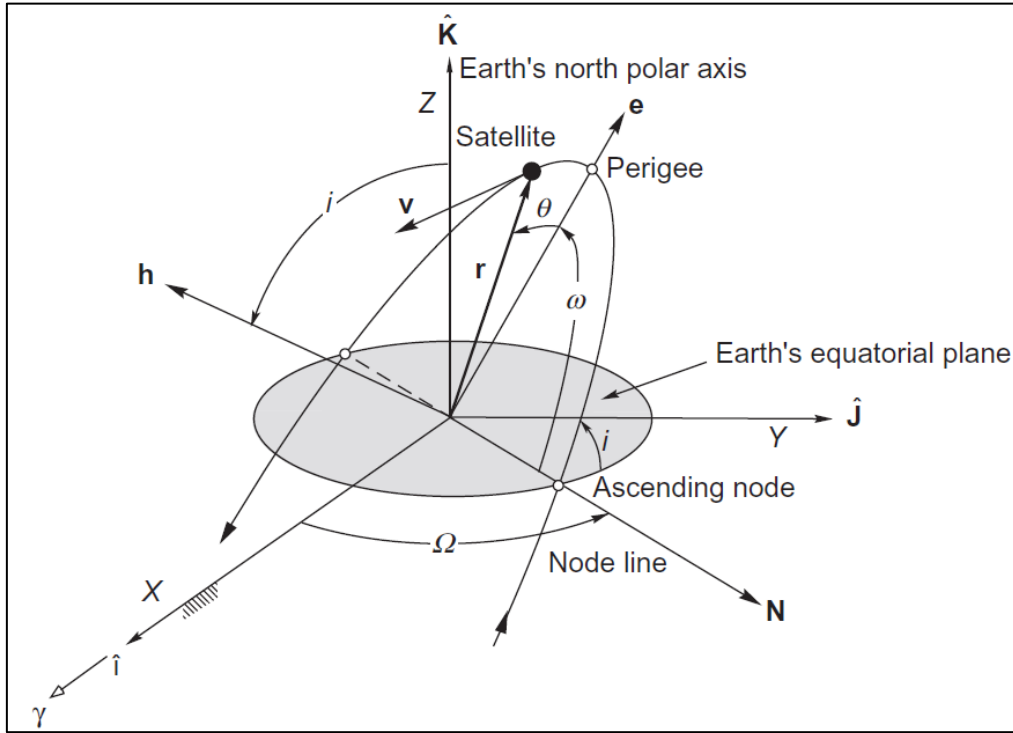


Figure2– Visualization of the Keplerian orbital elements

A summary of some parameters defining the geometry of an ellipse is given in Table 1.

Element	Symbol	Equation
Semi major axis	a	$a = \frac{r_a + r_p}{2}$
Semi minor axis	b	$b = \sqrt{a^2(1 - e^2)}$
Eccentricity	e	$e = \frac{r_a - r_p}{r_a + r_p}$
Apogee radius	r_a	$r_a = a(1 + e)$
Perigee radius	r_p	$r_p = a(1 - e)$
Semiperimeter	p	$p = a(1 - e^2)$
Mean motion	n	$n = \sqrt{\frac{\mu}{a^3}}$
Orbital period	P	$P = \frac{2\pi}{n}$

Tab. 1 Parameters defining the geometry of an ellipse

The orbital elements contain the same information as the position and velocity vectors at a specific time. Assuming R and V are known, as illustrated in Table 1, the orientation of the orbit in space can be visualized by changing from one set of coordinates to the other.

1.3 Geostationary Orbits

There are many types of satellite orbits depending on the orbit radius (or semi-axis). Changing the radius, we have different orbital periods and consequently the satellite missions change. A geostationary satellite is an earth-orbiting satellite, placed at an altitude of approximately 35,800 kilometers (22,300 miles) directly over the equator, that revolves in the same direction the earth rotates (west to east). At this altitude, one orbit takes 24 hours, the same length of time as the earth requires to rotate once on its axis. The term geostationary comes from the fact that such a satellite appears nearly stationary in the sky as seen by a ground-based observer. A single geostationary satellite is on a line of sight with about 40 percent of the earth's surface. Three such satellites, each separated by 120 degrees of longitude, can provide coverage of the entire planet, with the exception of small circular regions centred at the north and south geographic poles. A geostationary satellite can be accessed using a directional antenna, usually a small dish, aimed at the spot in the sky where the satellite appears to hover. The principal advantage of this type of satellite is the fact that an earthbound directional antenna can be aimed and then left in position without further adjustment. The exact position of a geostationary satellite, relative to the surface, varies slightly over the course of each 24-hour period because of gravitational interaction among the satellite, the earth, the sun, the moon, and the non-terrestrial planets, slight asymmetries in the Earth's gravitational field due to the fact that the Earth is not completely spherically symmetric. As observed from the surface, the satellite wanders within a rectangular region in the sky called the box. Sometimes we need to correct or change

the orbit of a satellite because these forces act on the satellite to change its orbit over time and get out from its box. These forces cause two major effects, longitude drift and orbit inclination augmentation, that need to be compensated with station-keeping maneuvers.

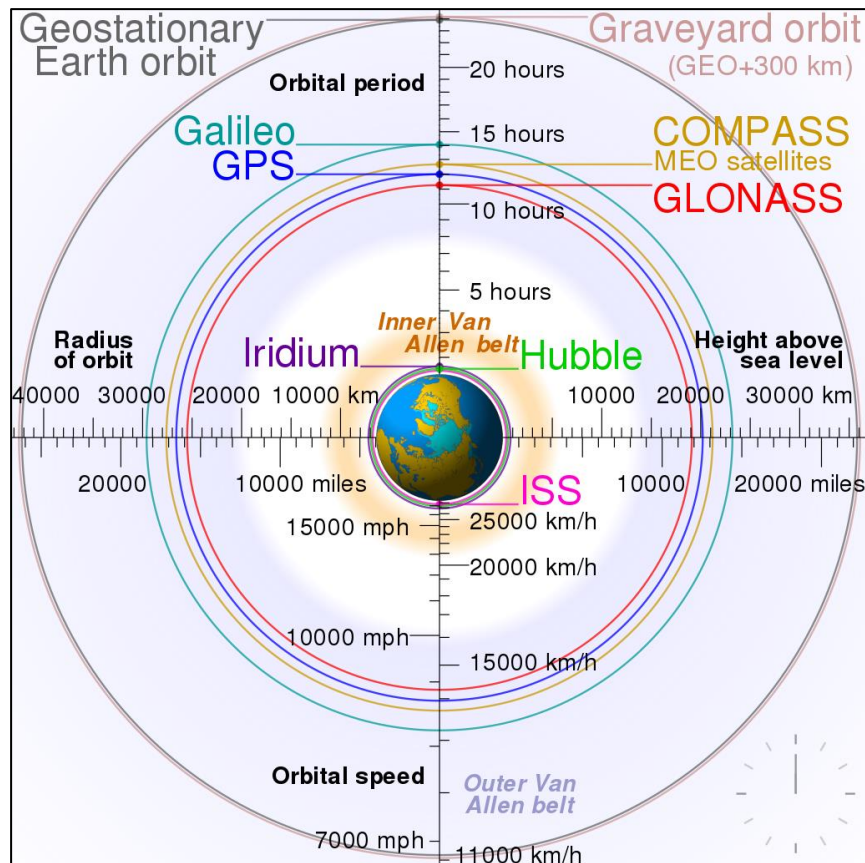


Figure 3 –Comparison of geostationary Earth orbit with GPS, GLONASS, Galileo and Compass satellite navigation system orbits, with the International Space Station, Hubble Space Telescope and Iridium constellation orbits, and the nominal size of the Earth.

1.4 LEO Orbits

A low Earth orbit (LEO) is, as the name suggests, an orbit that is relatively close to Earth's surface. A low Earth orbit (LEO) is an Earth-centred orbit with an altitude of 2000 km or less (approximately one-third of the radius of Earth), or with at least 11.25 periods per day (an orbital period of 128 minutes or less) and an eccentricity less than 0.25. Most of the manmade objects in outer space are in LEO. There is a large variety of other sources that define LEO in terms of altitude. The altitude of an object in an elliptic orbit can vary significantly along the orbit. Even for circular orbits, the altitude above ground can vary by as much as 30 km (especially for polar orbits) due to the oblateness of Earth's spheroid figure and local topography. While definitions based on altitude are inherently ambiguous, most of them fall within the range specified by an orbit period of 128 minutes because, according to Kepler's third law, this corresponds to a semi-major axis of 8,413 km. For circular orbits, this in turn corresponds to an altitude of 2,042 km above the mean radius of Earth, which is consistent with some of the upper altitude limits in some LEO definitions. The LEO region is defined by some sources as the region in space that LEO orbits occupy. Some highly elliptical orbits may pass through the LEO region near their lowest altitude (or perigee) but are not in an LEO Orbit because their highest altitude (or apogee) exceeds 2,000 km. Sub-orbital objects can also reach the LEO region but are not in an LEO orbit because they re-enter the atmosphere. The distinction between LEO orbits and the LEO region is especially important for analysis of possible collisions between objects which may not themselves be in LEO but could collide with satellites or debris in LEO orbits. The mean orbital velocity needed to maintain a stable low Earth orbit is about 7.8 km/s (28,000 km/h), but reduces with increased orbital altitude. Calculated for circular orbit of 200 km it is 7.79 km/s (28,000 km/h), and for 1,500 km it is 7.12 km/s (25,600 km/h). The delta-v needed to achieve low Earth orbit starts around 9.4 km/s. Atmospheric and gravity drag associated with launch typically adds 1.3–1.8 km/s (4,700–6,500 km/h) to the launch vehicle delta-v required to reach normal LEO orbital velocity of around 7.8 km/s (28,080 km/h; 17,448 mph). Unlike GEO satellites

that must always orbit along Earth's equator, LEO satellites do not always have to follow a particular path around Earth in the same way – their plane can be tilted. This means there are more available routes for satellites in LEO, which is one of the reasons why LEO is a very commonly used orbit. LEO's close proximity to Earth makes it useful for several reasons. It is the orbit most commonly used for satellite imaging, as being near the surface allows it to take images of higher resolution. It is also the orbit used for the International Space Station (ISS), as it is easier for astronauts to travel to and from it at a shorter distance. Satellites in this orbit travel at a speed of around 7.8 km per second; at this speed, a satellite takes approximately 90 minutes to circle the Earth, meaning the ISS travels around the Earth about 16 times a day. However, individual LEO satellites are less useful for tasks such as telecommunications, because they move so fast across the sky and therefore require a lot of effort to track from ground stations. Instead, LEO communications satellites often work as part of a large combination, or a constellation, of multiple satellites to give constant coverage. In order to increase coverage, sometimes constellations like this consisting of several of the same or similar satellites are launched together to create a “net” around the Earth. This lets them cover large areas of Earth simultaneously by working together.

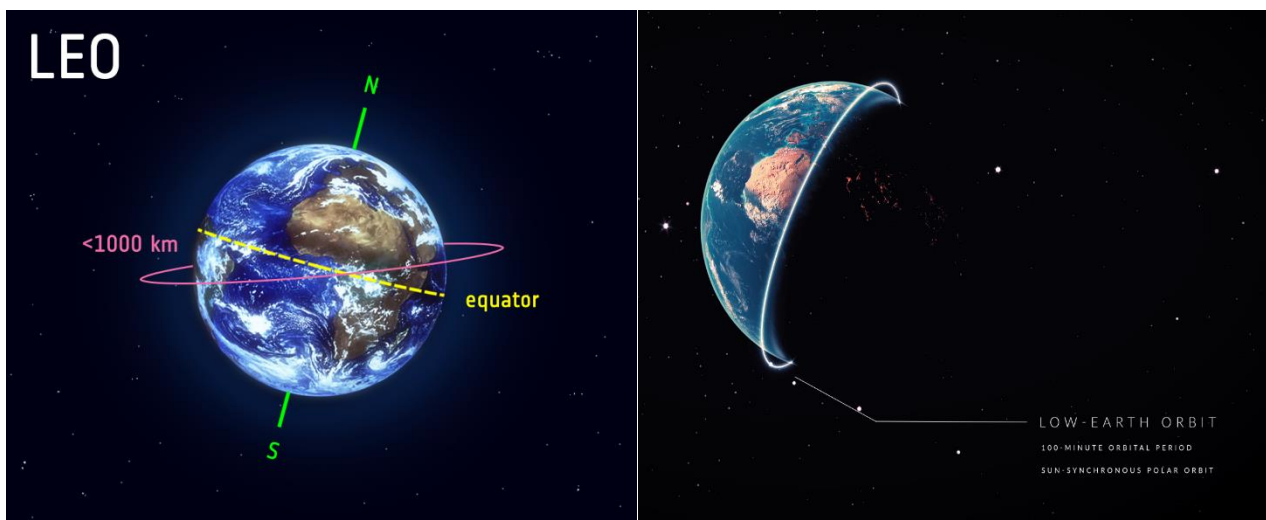


Figure4/5- Representation of LEO orbit.

1.5 Overview on SICRAL Constellation

SICRAL (Sistema Italiano per Comunicazioni Riservate ed Allarme) is a constellation of three military satellites, which guarantees the service availability for strategic communication also in case of war or disaster. SICRAL is an excellent system for its versatility and flexibility, in fact it guarantees the interoperability of all Defence network thanks to cross band frequency capability. It is made of two parts:

- Ground segment for satellites telecommand and control which is dislocated in Vigna di Valle (prime station) and back up control system in Fucino, and user terminals,
- Space segment composed by three military satellites: SICRAL1, SICRAL1B and SICRAL2

The frequency band in which the system operates are: UHF, SHF, S and EHF-Ka bands. SICRAL program started in 2001 with SICRAL1 launch, which is still operative. The second step of SICRAL program has started in 2009 with SICRAL1B launch (his operative life is 13 years), and the third phase has initiated in 2015 with SICRAL2 launch, which is born thanks to the Italian and French cooperation, in fact it presents a double payload: French dedicated payload and Italian payload. All the three satellites are provided by TT&C payload for telecommand, telemetry and ranging services, TT&C antennas use S-band frequency and EHF-band frequency. The nominal system for TM and TC is represented by EHF-band antennas (20-44 GHz) because of the use of a spread spectrum modulation (in fact EHF-band is called secure TT&C). Moreover, onboard TT&C antennas see only national terrain, so satellites could be controlled only in national borders, this allows system strength to hacker attacks. TT&C S-band is a backup station, useful in case of loss of the EHF-band link, because it is more susceptible to weather changings. From Vigna di Valle is possible also to use SHF link for TT&C services. For the design analysis we have used as input data typical values which are similar to the technical requirements from TLC GEO satellites payloads like SICRAL ones.



Fig.6 SICRAL constellation overview.

1.6 Overview on COSMO Sky-Med Constellation

COSMO Sky-Med (Constellation of Small Satellites for Mediterranean basin Observation) is a 4-spacecraft constellation (for what concern CSK that stands for COSMO Sky-Med first generation, now the launch of CSG, which are COSMO second generation new satellites, has started), conceived by ASI (Agenzia Spaziale Italiana), and funded by the Italian Ministry of Research (MUR) and the Italian Ministry of Defence (MoD). The program is managed in cooperation of ASI and MoD. The contract was assigned to an Italian industrial team, that is in charge of the project development. Thales Alenia Space Italia (TAS-I) is the prime contractor of the end-to-end system and leads an industrial

team of small and medium sized Italian companies including many from the Finmeccanica group. Telespazio is the main Ground Segment contractor responsible for the development of the control centre for the constellation, and of the user's ground segments for acquiring, processing and distributing the data gathered by the satellites for civil and defence applications. The COSMO Sky-Med program represents the largest Italian investment in space systems for Earth Observation. Each of the four satellites is equipped with a SAR (Synthetic Aperture Radar) instrument and is capable of operating in all visibility conditions at high resolution and in real time. The overall objective of this program is global Earth observation and the relevant data exploitation for the needs of the military community as well as for the civil (institutional, commercial) community. Sample applications of COSMO Sky-Med data are seen the following fields:

- Defence and security applications: Surveillance, intelligence, mapping, damage assessment, vulnerability assessment, target detection/localization
- Risk management applications: Floods, droughts, landslides, volcanic/seismic, forest fire, industrial hazards, water pollution
- Other applications: Marine and coastal environments, agriculture, forestry, cartography, environment, geology and exploration, telecommunication, utilities and planning
- Provision of commercial imaging services
- The high revisit frequency offered by the four X-band SAR spacecraft is also expected to provide a unique potential to the operational meteorological user community through provision of ancillary data and/or data on meteo-correlated phenomena, in particular as regards sea ice monitoring and study of ocean wave patterns.
- A strong emphasis is given to the dual-use (civil and military) nature of the system. The IEM (Interoperability, Expandability and Multi-sensoriality) concepts are also stressed, since

these qualities bring COSMO Sky-Med to be a versatile system able to expand its architecture toward a set of "Partner missions."

Each COSMO Sky-Med spacecraft is three-axis stabilized, consisting of the main body (bus), two deployable solar arrays, and a SAR antenna. The bus provides all support functions like: AOCS, electrical power (power generation, storage and distribution), data handling, thermal control, RF communications, and on-orbit propulsion for orbit injection and maintenance.

COSMO Sky-Med is made of two segments:

- The Spatial segment: composed of four LEO satellite equipped with high resolution SAR sensors which operate in X band with a very smart and innovative acquisition and transmission system,
- The Ground segment: made of infrastructure with the aim of commanding and controlling the entire constellation and to receive, elaborate and file data.

COSMO Sky-Med has the capability of a global coverage of the entire world and thanks to the characteristic of its payload it can operate in all weather and lightning conditions, giving geolocate images with very high spatial resolution and short response times. COSMO Sky-Med system has been designed to satisfy the needs of a large user community so it can operate in three modes:

- Routine mode: nominal operative mode in which mission planning is done every 24 hours,
- Crisis mode: operative mode in which mission planning is done every 12 hours with the possibility to give a priority for shooting specific areas,
- Emergency mode: asynchronous operative mode which is activate only in exceptional conditions in order to obtain an acquisition in the shortest possible time.

The four satellites are in sun-synchronous polar orbits with a 97.9° inclination at a nominal altitude of 619 km and an orbital period of 97.2 minutes. The local time ascending node at the equator is 06:00. The expected operating life of each satellite is estimated to be 5 years. Each satellite repeats

the same ground track every 16 days, and all of the satellites follow the same ground track. They cross the equator at 06:00 and 18:00 local time each day. The satellites are phased in the same orbital plane, with COSMO Sky-Med's 1, 2 and 4 at 90° to each other and COSMO Sky-Med 3 at 67.5° from COSMO Sky-Med 2. This results in varied intervals between the satellites along the same ground track of between 1 and 15 days. The sun-synchronous orbit is used to keep the solar cells illuminated at all times.

The satellites' main components are:

- Two solar arrays for 3.8 kW at 42 V DC
- Stabilization, navigation and GPS systems
- Synthetic aperture radar working in X band
- 300 Gbit on-board memory and 310 Mbit/s data-link with ground segments

The radar antenna is a phased array that is 1.4 m wide x 5.7 m long. The system is capable of both single- and dual-polarization collection. The centre frequency is 9.6 GHz with a maximum radar bandwidth of 400 MHz. The COSMO Sky-Med satellites have three basic types of imaging modes:

- **Spotlight**: a high-resolution mode collected over a small area by steering the radar beam slightly fore-to-aft during the collection period.
- **Stripmap**: a medium-resolution mode collected over long, continuous swaths in which the beam is pointed broadside to the satellite track.
- **Scan-SAR**: a low-resolution mode that creates extra-wide swaths by collecting short segments at different ranges and then mosaicking them together.

There are two Spotlight modes:

- **Spotlight1**, which is a military-only mode, and

- **Spotlight2**, which provides a resolution of 1 m over a 10 km x 10 km area. Spotlight polarization is limited to either HH or VV

There are two Stripmap modes:

- **Himage**, which provides a resolution of between 3 and 5 m over a swath of 40 km, and
- **Ping-pong**, which collects dual-polarization data at 15 m resolution over a swath of 30 km. The dual-polarization data can consist of any two polarizations (HH, VV, VH, HV), and it is non-coherent, as it is collected in "pulse groups" that alternate from one polarization to the other.

There are two Scan-SAR modes:

- **Wide-region**, which provides 30 m resolution data over a swath of 100 km, and
- **Huge-region**, which provides 100 m resolution data over a swath of 200 km.

The system is sized to collect up to 450 images per satellite per day thanks to the ground segment of the system which is composed of:

- Command Centre:

 Italian mission planning and control of *Fucino*

- Tracking and data stations:

 Argentine *Cordoba* station

 Sweden *Kiruna* station

- User Ground Segments:

 Italian *Matera* Civil User Ground Segment

 Italian *Pratica di Mare* Defence User Ground Segment

 France Defence User Ground Segment

The first generation of COSMO satellites has different performances compared with the last generation, we have focused on data volume and time performances, the main characteristics are reported in the following table (Table 2). Another important difference, which improves CSG (COSMO second generation) capability respect to CSK (COSMO Sky-Med, first generation), is the kind of modulator used for the X-Band transponder downlink: in CSK is used a D-QAM modulation and in CSG is used a 8-PSK modulation combined with a 4D-TCM convolutional coding plus Reed Solomon coding, so in the second generation you have a great gain in term of signal to noise ratio which improve BER performances and so data volume. Moreover, depending on the product quality required by the user, is possible to use a BAQ compression algorithm to improve the number of available images.

Orbit	Sun synchronous @ 619Km
Repeat Cycle	16 days
Accessibility	+/- 90° latitude
Access Area	20° - 60°
Daily Imaging capability per satellite	520 standard images (dual pol) <i>(CSK 450 single pol)</i>
Onboard Data Storage	1400 Gbit <i>(CSK = 320 Gbit)</i>
Downlink data rate	520 Mbps <i>(CSK = 310 Mbps)</i>
Satellite Mass	2240 Kg <i>(CSK = 1860 Kg)</i>
Peak power consumption during acquisitions	20 KW <i>(CSK = 12 KW)</i>
Projected satellite life time at full performance	7 years <i>(CSK = 5 years)</i>

Tab. 2 CSK and CSG differences.

1.7 Time Performances

In the paragraph above three different System operative modes have been defined, allowing to respond to different needs in term of required programming latency. In the first mode (routine) the requests of the users pertaining image acquisitions are planned and sent to the constellation once a day. In the second mode (crisis) this operation is done twice a day. The third mode (very urgent) is asynchronous, allowing the servicing of an image acquisition request with the minimum possible latency. The system is capable to satisfy a User Request (ability to deliver the image product required by an End User in a timely manner) which in the case of the first level of SAR standard products (not derived from spotlight mode acquisitions) is within 72 hours for the system working in routine mode (acquisition plan uploaded once a day), 36 hours for the crisis mode (acquisition plan uploaded twice a day) and 18 hours for very urgent mode (acquisition plan uploaded asynchronously). More in general, the time performances of the constellation are defined on the basis of the following four definitions:

- **reaction time:** time span from the User request acceptance and Deposit at the C-UGS to the SAR image acquisition,
- **information age:** from the SAR image acquisition to the product availability at the C-UGS (data latency),
- **response time:** is the sum of the reaction time and the information age,
- **revisit time:** time span between two consecutive acquisitions over the same target.

This last figure is directly connected to the response time, which is the time span between the delivery of the image requests by the users and the availability of the ordered data. The response time includes also the revisit time and the time required to download the data to ground and to postprocess. The delivery time is not considered in the Response Time. You can see the planning

and downlink process in the figure 7. The following table (Tab. 3) reports the values to be considered for the above times (values are referred to routine operative conditions):

	1 satellite	2 satellites	3 satellites	Full constellation
Information age	12 h	12 h	12 h	12 h
Response Time	110 h	90 h	85 h	72 h
Revisit time	65 h	40 h	40 h	12 h

Tab.3 Time performances

Please note that these values refer to routine (nominal) operational status, and that they are worst case foreseen values on the overall globe, while actual values depend upon site coordinates, active ground segment, constellation configuration, operational mode etc. Response time is also affected by access time of Satellite to the control station because it determines the gap necessary to upload the new mission plan.

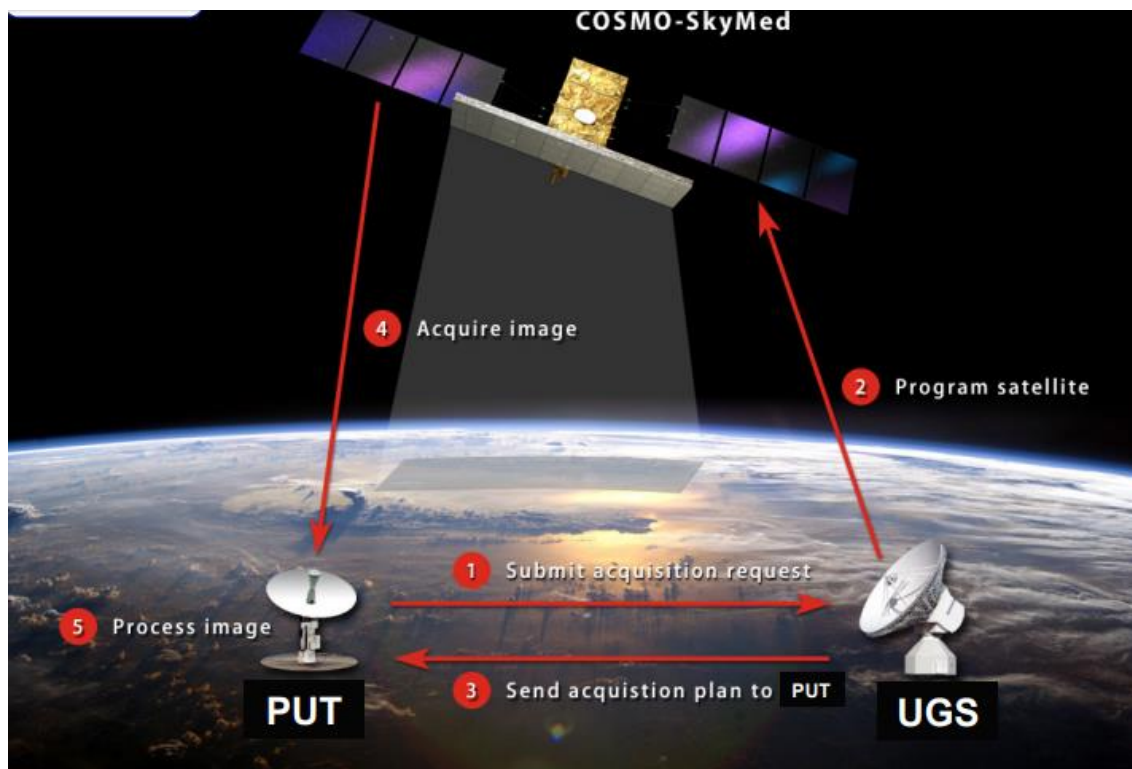


Figure 7: COSMO planning and downlink process.

Whit ISL we surely can obtain a lower **response time**, now we analyse what are the time intervals we can optimise thanks to ISL. In the previous lines we have individuated the way to calculate response time:

$$response_{time} = information_{age} + reaction_{time}$$

Where:

- $information_{age}$ is clearly dependent on data processing time, which cannot change by using of ISL strategy, the ground station visibility time window and the maximum latency necessary to have a COSMO pass on the ground station. These two last parameters could be reduced using the ISL thorough a lower time latency between two consecutive visibility intervals and a higher duration of the visibility time windows.
- $reaction_{time}$ which depends on revisit time, which is fixed both without ISL than with ISL, and visibility time constrains, because you have to wait for a COSMO passage on the ground station to uplink the new mission plan. So ISL can reduce the waiting time for the TC uplink, improving the $reaction_{time}$.

2. Feasibility and Trade-Off Analysis for Inter-Satellite Link Implementation: Design Factors and Technological Solutions

2.1 Comparison Between Optical and Radiofrequency Inter-Satellite Link Performances

For what concern OISLs, due to the shorter wavelength, a better ranging resolution can be achieved and the higher carrier frequency in the optical domain opens up a larger spectrum. Therefore, OISLs have the capability for higher data rate throughput than RF ISLs solution. As the optical beams are much narrower than RF beams, no interference with other potential optical communication systems will occur. Therefore, the optical frequency spectrum is not regulated, which makes the planning and operation of a navigation constellation much easier. Moreover, the narrower beams of the OSLs are more robust to jamming and interception compared to RF ISLs. Optical ISLs (OISLs) offer a very attractive solution for intersatellite links in terms of size, weight and power while providing multi gigabit per second data rate capabilities. In addition, optical communication links offer high operational security and immunity to interference sources while benefitting from a non-regulated optical frequency spectrum. For those reasons, optical intersatellite links for navigation constellations have been investigated in several studies supported by DLR and ESA. TESAT with partners have investigated the benefit of OISLs for navigation systems and on the Galileo OISL Terminal design. LEO-GEO connections were successfully demonstrated a decade ago by the ARTEMIS – Spot 4 mission, with data rates of 50 Mbps. Based on the successful demonstrations of optical link capabilities, the European Space Agency has decided to implement a high data rate (1.8 Gbps) laser communication system between earth observation LEO S/C that are deployed in the Copernicus

program of the European Union and dedicated GEO nodes with visibility of central Europe for minimum latency, near real-time delivery of earth observation data to the customers. Today, optical communication in space is a reality and is taken into account in current and future space programs. Starting from LEO to LEO ISLs demonstrated in 2008, TESAT has built a broad portfolio of optical communication solutions ranging from powerful GEO to GEO long distance ISLs to small, low complex DTE solutions for cube-sat missions. Since end of 2016, the European Data relay service is operational relying on optical intersatellite links from LEO to GEO orbits. This second-generation LCTv2.2 design is derived from the first generation LCT concept, which was foreseen for LEO constellation applications end of the 1990s. The first LCT of the second generation was launched in 2013 on board of Alphasat. Further LCTv2.2 terminals were installed on Sentinel-1A/-1B/-2A/-2B and on EDRS-A satellites, forming together the European Data Relay Satellite System EDRS. The LCTv2.2 is designed for a data relay scheme (Figure 8). A terminal mounted on a LEO satellite or on a UAV is transmitting the data optically to an LCT mounted on a GEO satellite. The data is then transmitted via a Ka-band downlink to a Ka-band ground station. The main advantages of the data relay scheme is its ability to bring the data directly to the processing centre in near real time. This is because for more than half of the user satellites orbit, visibility to the GEO is given. In addition, the Ka-band ground stations can be placed close to the data processing centre rather than close to the poles.

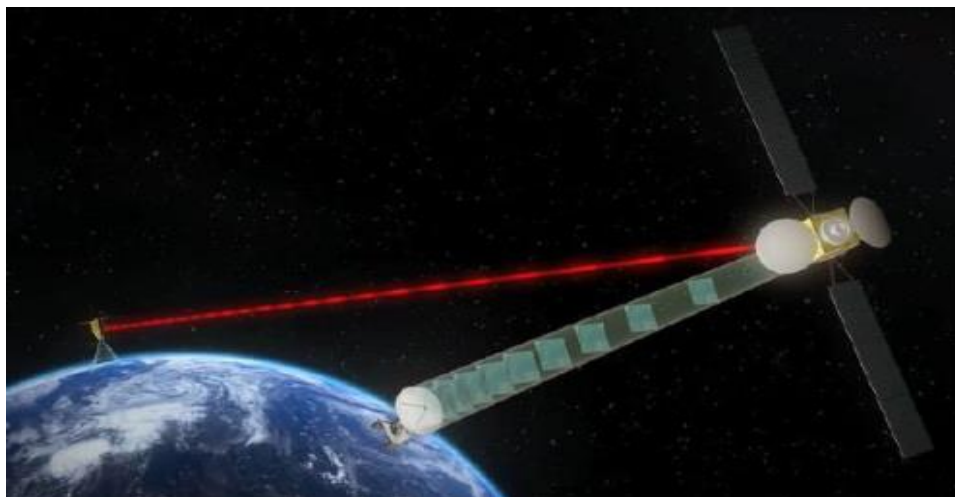


Figure 8: OISL GEO-LEO and downlink GEO-ground in ka-band.

The Alphasat LCT was the first build of the second generation LCTv2.2. Figure 9 shows the LCT shortly before integration into the Spacecraft.



Figure 9: Alphasat LCT before integration into the Spacecraft.

Even if, for what mentioned above, OISL appear to be the best technological solution for ISL to improve response time and data rate in a space mission, there are many disadvantages to consider: due to the narrower beams of the optical domain, tracking mechanisms are necessary in order to establish a communication link between satellites, and geometrical visibility must be very precise, so the optical link have to reposition the beam pointing mechanisms very often and fast to reach an extremely accurate tracking; RF links can be established faster than optical links. Visibility constraints and distance limitations are more binding for OSLs than RF ISLs. RF ISLs can easily improve the time of access useful for communication ISLs, exploiting the total amount of time in which satellites are in visibility, even if the pointing is not perfectly aligned. Furthermore, RF technologies are more matures and you can take advantages from a profound knowledge. Radio Frequency (RF) technology is the more consolidate technology usable for inter-satellite

communication links. An RF link could reach high data rate only using the very large bandwidth available in the millimetre wave region. In particular Q/V-band or W-band frequency range, but also the Ka-band are extensively used; this permits also to avoid interference with other systems. The upcoming “beyond Ka-band” RF links can be a good competitor for the optical systems, due to the possibility to use a very large uncrowded spectrum (some GHz) to reach a very high throughput, to reduce the antenna size or beam-width (with regard to lower frequency RF systems) and to reduce the strict pointing requirements of the optical link systems. RF links can provide omni-directional coverage when considering multi-antenna combination. Although RF equipment is subject to co-channel interference, multipath, atmospheric and man-made noise, a careful system design and use of technologies (such as spread spectrum modulation) can significantly reduce interference effects in most cases. Furthermore, long term experience with radio transmission for space-to-ground links makes RF-based inter-satellite communication more reliable and easier to be implemented in space. RF ISL is preferred to OISL also because we have evaluated the possibility to use TLC GEO satellites payloads for ISL establishment with LEO satellites, in this way we can cut costs and achieve important results and gain through a double use payload, without increasing mass and volume of the satellites, and using the same ground stations to monitor e control GEO and LEO satellites and to downlink data. So, our choice is motivated by cost amount and complexity reductions. The project, in spite of the simplicity and the inexpensiveness, shows very good performances and gains, comparable with the ones reached through an OISL technology.

3. Radiofrequency Inter-Satellite Link Preliminary Design and Simulation

3.1. Preliminary Design and Simulation Process

In this study RF ISL has been designed and tested. We have considered two kind of missions:

- Tasking mission: so, the ability to plan the LEO mission through SICRAL ground station telecontrol plus ISL SICRAL-COSMO,
- Data relay mission: that is the capability to receive on SICRAL ground station the data from the LEO satellite.

For the analysis, we have chosen two specific satellites: a GEO satellite from SICRAL Constellation and a LEO satellite from COSMO Constellation. For what concern the GEO satellite we have considered technical data and link requirements typical of TLC GEO satellite payloads similar to the SICRAL ones. So, the GEO link performances and payload antennas parameters are fixed and we have focused on the design of a LEO ideal payload to have the best performances. We have designed COSMO ideal antennas taking into account the compatibility constraints with the SICRAL ground station downlink capacity, so the amount of downloaded data is realistic. At the end of the analysis we have also compared the most important performances parameters: Time of response, Time of Access and Downloaded images of our designed system provided by ISL with the a capacity comparable to the COSMO one. The simulation process has been iterative because we have started from SICRAL examples to get link budget initial parameters, which were dimensioned for a space to ground communication links, so it is a sizing optimal for TT&C ground antennas which are bigger

and more powerful than the ones you can have on a LEO satellite. After a first STK (Satellite Tool Kit) simulation we refined our sizing by updating the initial parameters with the ones shown in the simulations, in particular for $\frac{G}{T}$ constrains of the RF ISL implemented with antennas provided by a tracking system, in fact in this case minimum $\frac{G}{T}$ values are very different than the ones exhibited in a GEO-ground link. Obviously, the link budget and the simulations have been done in the worst cases conditions for every frequency band analyzed. To create the scenarios on STK software we have used two satellites, one LEO and one GEO, whose orbits are similar to respectively COSMO Sky-Med 1 and SICRAL2 ones.

3.2. *Input Parameters and Constrains definition*

The initial parameters to start the preliminary design have been chosen from near-SICRAL payload specifications, in particular:

- GEO antennas design and performances;
- Bandwidth and payload channel capacity:
 - 8192 Hz for S-band,
 - 25 kHz for single channel in UHF band (x 15 channels),
 - 40 MHz for SHF band,
 - 50 MHz for Ka band;
- Up/Down link Frequency:
 - $f_{UHF} = 310 \text{ MHz}$,
 - $f_S = 2 \text{ GHz}$,
 - $f_{SHF} = 8 \text{ GHz}$,
 - $f_{Ka} = 20 \text{ GHz}$;

- $\frac{G}{T_{min}}$ is the antenna gain-to-noise-temperature, it is a figure of merit in the characterization of antenna performances, where G is the antenna gain in decibels at the received frequency, and T is the equivalent noise temperature of the receiving system in kelvins. For every different frequency-band we have considered the minimum value of this parameter, to size the system in a way to guarantee the possibility of link establishment even in the worst cases conditions. There are reported the considered values:

- $\frac{G}{T_{miUHF}} = -14 \text{ dB/K},$
- $\frac{G}{T_{min_S}} = -20 \text{ dB/K},$
- $\frac{G}{T_{min_SHF}} = -12.7 \text{ dB/K},$
- $\frac{G}{T_{min_Ka}} = 1.5 \text{ dB/K}.$

After a preliminary STK simulation done with the above mentioned requirements, we obtained the $\frac{G}{T_{min}}$ for SICRAL-COSMO RF ISL from an STK link budget report, so the values of $\frac{G}{T_{min}}$ used for the design of the system are reported below:

- $\frac{G}{T_{miUHF}} = -14 \text{ dB/K},$
- $\frac{G}{T_{min_S}} = -20 \text{ dB/K},$
- $\frac{G}{T_{min_SHF_fixed}} = -12.7 \text{ dB/K},$
- $\frac{G}{T_{min_SHF_with TRK}} = 1.69 \text{ dB/K}$
- $\frac{G}{T_{min_Ka}} = 11 \text{ dB/K}.$

Please, notice that $\frac{G}{T}$ is a fundamental parameter in the design analysis because it impacts on received power, and so on $\frac{C}{N_0}$, which influences the data rate (R_b). If we did not change the initial $\frac{G}{T}$ values, we should have underestimated the R_b .

- Modulation: we have chosen an un-coded BPSK modulation with unitary spectral efficiency ($\eta_{BPSK}=1$), as used for S-band telemetry data. It is the simplest modulation used for satellite communications, and we have selected this one in order to underline the real minimum system performances which are due only to the antenna design. Moreover, to analyse the worst case ever, we have assumed a Viterbi coding soft decision with the halving of the amount of useful downloaded bits respect to the total downloaded data. So, our performances do not benefit from Viterbi's convolutional coding, (we have simulated a simple un-coded BPSK modulator), but we have taken into account the informative bit reduction which is typical of this algorithm which is commonly used for satellites S-Band telemetry data.
- $BER \leq 10^{-5}$ (Bit Error Rate) which is a very important link budget parameter. All the STK report simulations have been filtered by this BER threshold in order to eliminate from the time of access all the time windows in which this requirement is not respected. The value has been chosen by considering a typical performance for a TT&C satellite link. BER cannot be bigger than this threshold to guarantee right data.
- $\frac{E_b}{N_0} = 9.6 \text{ dB}$ which represent the power efficiency in a white Gaussian noise channel it depends on modulation and BER, so as we have fixed modulation and BER also this parameter is determinate (Figure 10).
- COSMO bandwidth. CSG (Cosmo Second Generation satellite) is supposed to have a data-rate of 520 Mb/s thanks to an 8-PSK modulation with convolutional coding, we have calculate the real downlink bandwidth which COSMO should have for a BPSK modulation with unitary spectral efficiency instead of $\eta_{8-PSK}=3$ as is in 8-PSK.

$$B_{COSMO} = \frac{R_{b-8PSK}}{\eta_{8PSK}} = \frac{520.000.000}{3} [Hz] = 173 \text{ MHz}$$

- D_{COSMO} which is the max diameter which COSMO payload antenna could have
 - $D_{COSMO} \leq 0.7 \text{ m}$ for UHF and SHF band antennas,
 - $D_{COSMO} \leq 0.5 \text{ m}$ for ka band antenna,
 - $D_{COSMO} \leq 0.25 \text{ m}$ for S band antenna.
- Maximum output power:
 - $P_{OUT} \leq 20 \text{ dBW}$ for UHF and S bands,
 - $P_{OUT} \leq 26 \text{ dBW}$ for SHF and Ka bands.

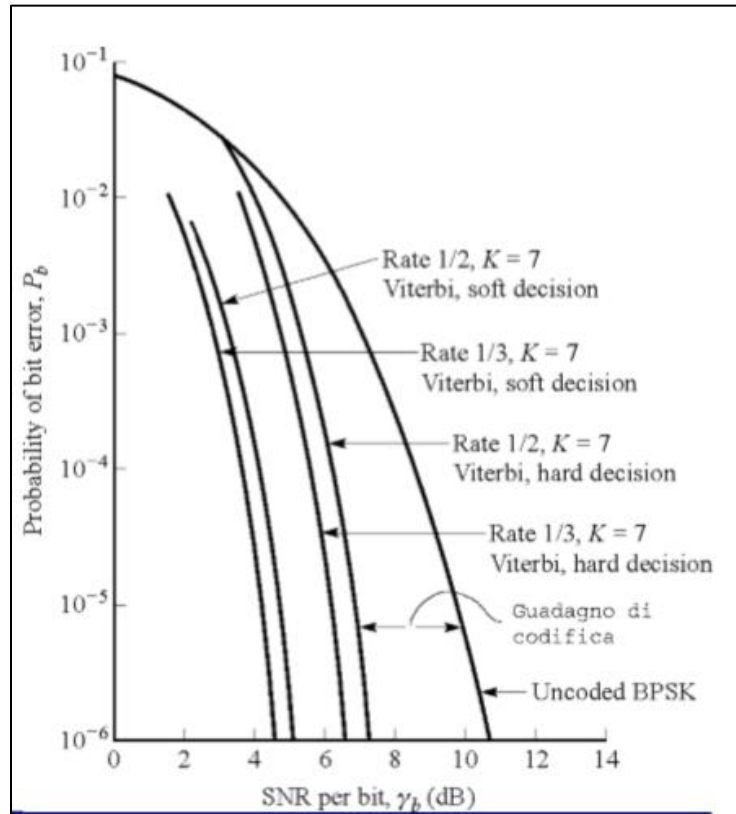


Figure 10 BER - SNR graph.

3.3. Matlab Link Budget

Before starting simulations on STK, we have studied with Matlab software the best design for COSMO antennas. We have generated a Matlab code in which we have put in relationship all these fundamental parameters (Figure 11):

- $\vartheta_{3dB} \simeq \frac{\lambda}{(D \times \sqrt{\eta})}$ which represents the beam width in which gain is maximum, (η is antenna efficiency and is fixed at 0.67 and D is antenna diameter).
- $G = \eta \times \left(\frac{\pi \times D}{\lambda}\right)^2 \times e^{-2.76 \times \left(\frac{\vartheta}{\vartheta_{3dB}}\right)^2}$ which is the antenna gain, assumed a Gaussian antenna of STK model.
- $\frac{C}{N} = \frac{E_b}{N_0} \times \frac{R_b}{B} = \frac{E_b}{N_0} = 9.6 \text{ dB}$, in our case, when we are able to reach the maximum possible data rate, $\frac{C}{N}$ is equal to 9.6 dB because of the BPSK modulation with unitary spectral efficiency, so the bit rate to bandwidth ratio $\left(\frac{R_b}{B}\right)$ is equal to one in the best cases. The bandwidths values are chosen for every frequency band similar to the ones of SICRAL payloads, as reported in the paragraph above.
- $\frac{C}{N_0} = EIRP - L + \frac{G}{T} - K = \frac{C}{N} \times B = \frac{E_b}{N_0} \times R_b$, where:
 - $EIRP = G_{TX} \times P_{TX}$ gain multiplied by output Power,
 - $L = \left(\frac{4\pi R}{\lambda}\right)^2$ where R is the maximum distance between LEO and GEO satellites and from STK simulation we have estimated its value which is 44638460 m,
 - $\frac{G}{T}$ which is chosen equal to the minimum possible $\frac{G}{T}$ in order to evaluate the worst case, the different values, depending on the frequency band considered, are reported in the previous paragraph.
 - K is Boltzmann's constant which is equal to $1.380649 \times 10^{-23} \text{ JK}^{-1}$.

This formula shows that $\frac{C}{N_0}$ is linked to data rate (R_b) and power and losses performances, so it is a crucial value for the link budget analysis.

```
% INPUT
f=[310 2000 8000 8000 21000];% [f_UHF_LEO2GEO f_S_LEO2GEO f_SHF_LEO2GEO f_SHF_LEO2GEO f_Ka_LEO2GEO] MHz
BW=[0.375 0.008192 40 40 50];% [BW_UHF BW_S BW_SHF BW_SHF+TRK BW_Ka] MHz
G_T=[-14 -20 -12.7 1.69 10];% [G_T_UHF G_T_S G_T_SHF G_T_SHF+TRK G_T_Ka] dB/K
Pmax=[20 20 26 26 26];% [Pmax_UHF Pmax_S Pmax_SHF Pmax_SHF+TRK Pmax_Ka] dBW
Dmax=[0.7 0.25 0.70 0.7 0.5];% [Dmax_UHF Dmax_S Dmax_SHF Dmax_SHF+TRK Dmax_Ka] m
Rmax_LEO2GEO=46500000; % m
BER_tgt=10^(-5);
n_Rb=100; % number of data rate values
eta=0.67; % antenna efficiency for Gaussian model

% LINK BUDGET
Eb_NO_tgt=(erfcinv(2*BER_tgt))^2; % linear, BPSK only
lambda=physconst('LightSpeed')./(f*10^6); % m
k=10*log10(physconst('Boltzmann')); % dB/J/K
L=10*log10((4*pi*Rmax_LEO2GEO./lambda).^2);
d_BW=BW*10^6/n_Rb; % frequency step for data rate calculation
Gmax=10*log10((pi./lambda.*Dmax).^2*eta); % gain obtained for fixed Dmax
Rb=zeros(n_Rb,length(BW)); % data rate matrix preallocation
C_NO=zeros(n_Rb,length(BW)); % C/N0 matrix preallocation
EIRP=zeros(n_Rb,length(BW)); % EIRP matrix preallocation
Greq=zeros(n_Rb,length(BW)); % Greq matrix preallocation
Preq=zeros(n_Rb,length(BW)); % Preq matrix preallocation
Dreq=zeros(n_Rb,length(BW)); % Dreq matrix preallocation
theta3dB=zeros(n_Rb,length(BW)); % theta3dB matrix preallocation
for i=1:length(BW)
    for j=1:n_Rb
        Rb(j,i)=d_BW(i)*j; % bit/s
        C_NO(j,i)=10*log10(Eb_NO_tgt*Rb(j,i)); % dBHz
        EIRP(j,i)=C_NO(j,i)+L(i)-G_T(i)+k; % dBW
        Greq(j,i)=EIRP(j,i)-Pmax(i); % dB
        Preq(j,i)=EIRP(j,i)-Gmax(i); % dBW
        Dreq(j,i)=sqrt((10^(Greq(j,i)/10))/eta)*lambda(i)/pi; % m
        theta3dB(j,i)=lambda(i)/Dreq(j,i)/sqrt(eta)*180/pi; % deg
    end
end

% MAX DATA RATE ALGORITHM
% For each Band (UHF, S, SHF,SHF+TRK, Ka) searches the minimum difference
% Dmin (CALCULATED FROM LINK BUDGET) - Dmax (INPUT)
diff=zeros(n_Rb,length(BW)); % Dmin matrix preallocation
diffmin=zeros(1,length(BW));
Rb_max=zeros(1,length(BW)); % data rate maximum for each Band
a=zeros(1,length(Dmax));
for l=1:length(Dmax)
    diff(:,l)=abs(Dreq(:,l)-Dmax(l));
    diffmin(l)=min(diff(:,l));
    mask=diff(:,l)<=diffmin(l);
    [a(l),b]=find(mask);
    Rb_max(l)=Rb(a(l),l);
end
```

Figure 11: Matlab link budget code.

Please, notice that R_b is proportional to $\frac{c}{N_0}$ and it is the only parameter we can change to make easier the link establishment (because we have fixed the maximum P_{out}), so, it is not always possible to reach the target of having a maximum data rate with $R_b = B$. For this reason, we have firstly calculated the best data rate we could obtain respecting the imposed limits in term of: output powers, BERs and LEO antennas diameters sizes. Now you can see the results of these preliminary analysis looking at the following graphs. See that in some cases (UHF-case and SHF-fixed antenna-case) we could have reached the equality between bandwidth and bitrate, but it couldn't have been the best solution in term of downloaded data volume because of the restriction of ϑ_{3dB} (for increasing antenna gain and so EIRP, that are necessary if you want a maximum data rate, you have to reduce antenna beam-width), which has the consequence of reducing visibility time. So, our choices have been made in order to optimize the amount of downloaded bit, and it depends on both time visibility and data rate.

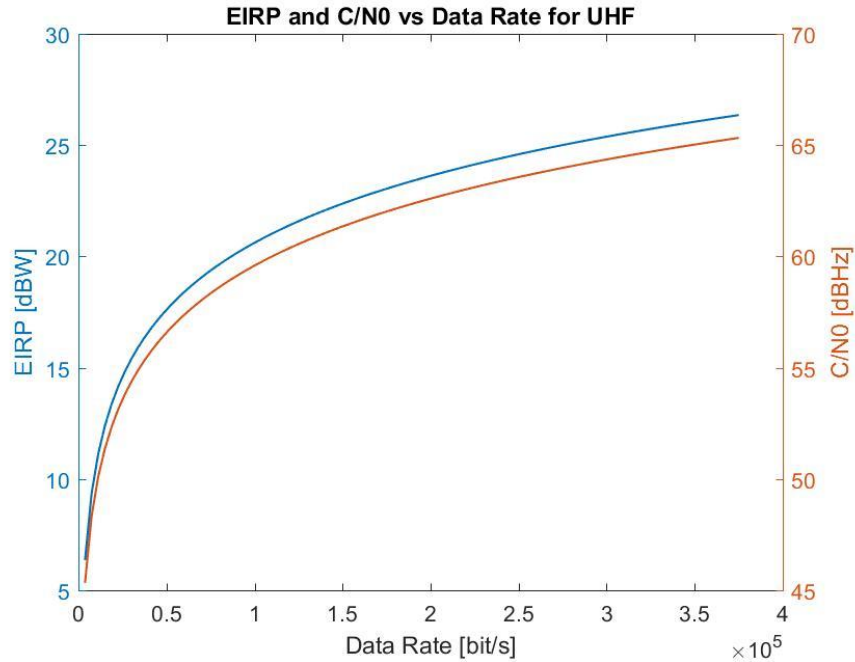


Figure 12 EIRP and C/N0 vs Data Rate for UHF-band case.

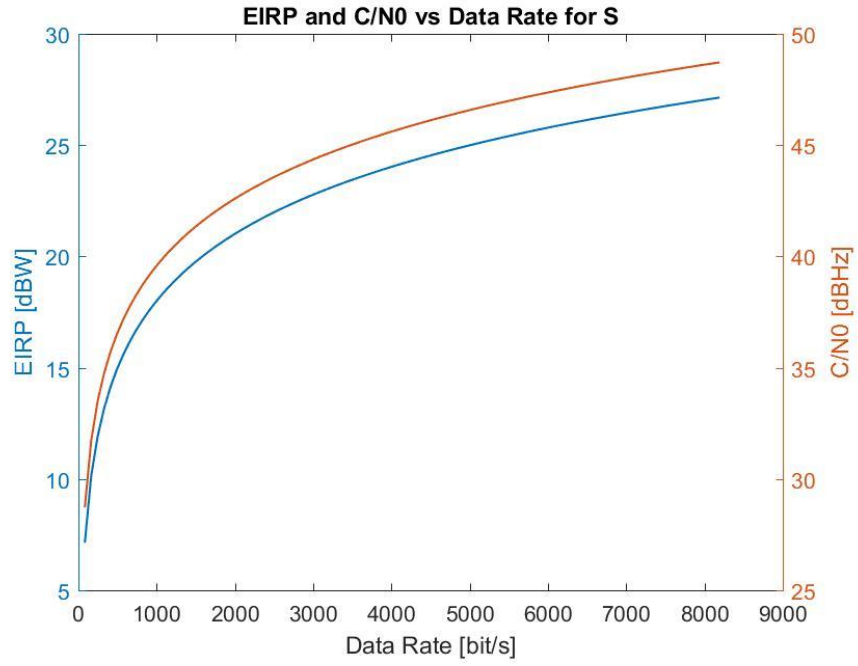


Figure 13 EIRP and C/N0 vs Data Rate for S-band case.

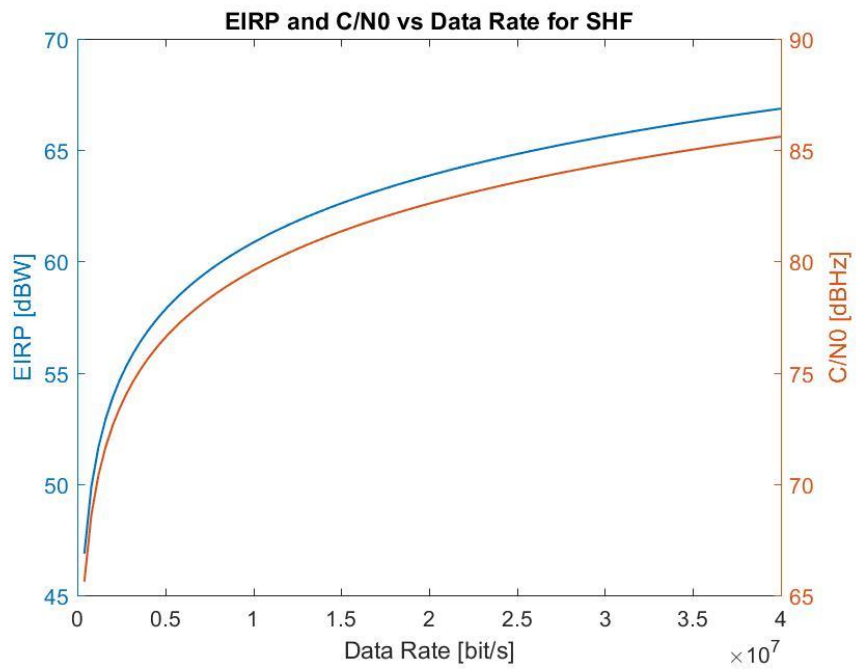


Figure 14 EIRP and C/N0 vs Data Rate for SHF-band case.

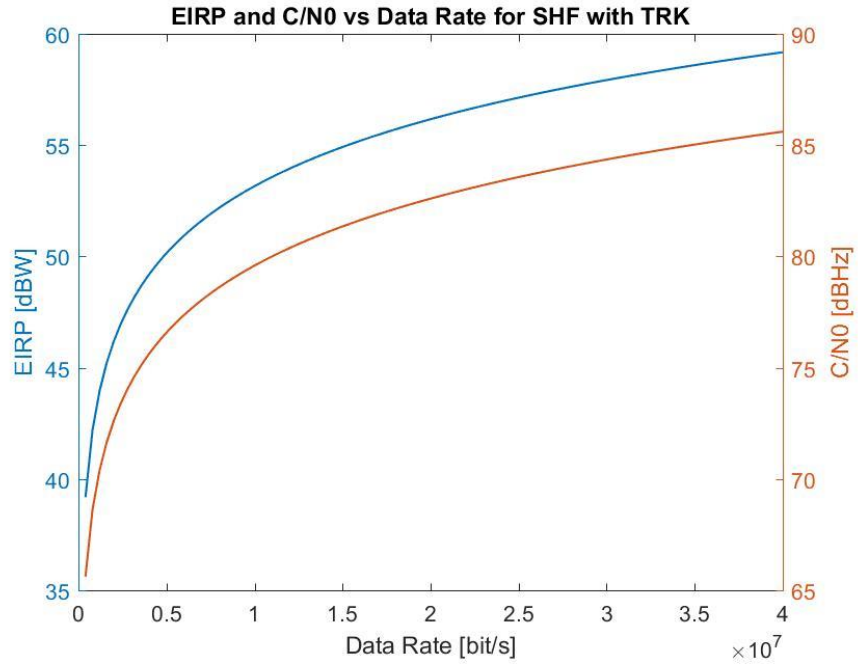


Figure 15 EIRP and C/N0 vs Data Rate for SHF-band antenna with tracking system.

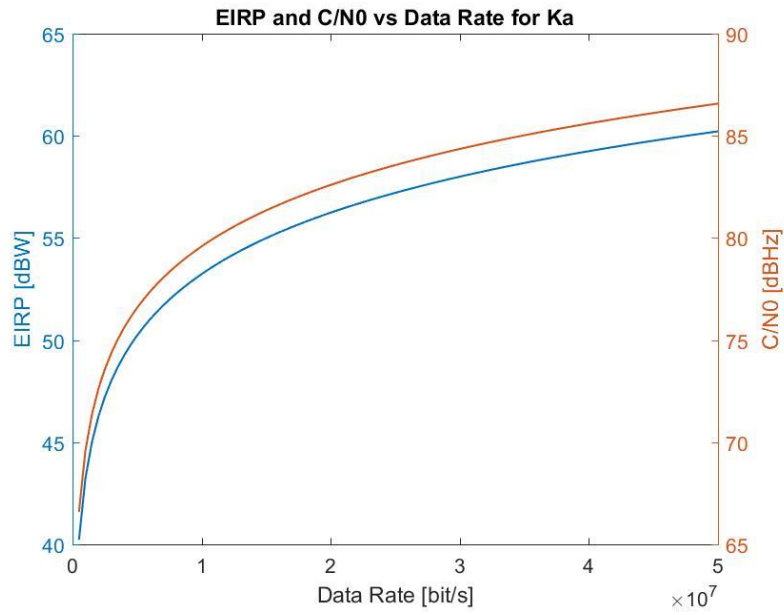


Figure 16 EIRP and C/N0 vs Data Rate for Ka-band antenna with tracking system.

These plots show the relation between $\text{EIRP}, \frac{C}{N_0}$ and Data rate, to have a greater Data rate you might have a bigger $\frac{C}{N_0}$ and consequently a bigger EIRP and so you need an higher gain. In the following lines we analyze the best sizing for COSMO antennas, which maximizes data download performances.

3.4. STK Analysis and Simulations

After a preliminary study with Matlab software, to find the best dimensioning trade-off between the various design parameters, we have created in STK different scenarios to simulate real ISL situations. In the following paragraphs are reported the results of the various STK analysis:

- UHF-band fixed antenna with large beam coverage,
- S-band fixed antenna with large beam coverage,
- Three SHF-band horn antennas with 30° beam-width for a total beam coverage of 90°,
- SHF- band antenna with tracking system,
- Ka-band antenna with tracking system.

3.4.1 UHF-Band Case

SICRAL UHF payload antenna has the following characteristics:

- $f=310$ MHz,
- Channel bandwidth=25 kHz,

- Number of channels = 15,
- Total useful bandwidth= $25 \times 15\text{kHz} = 375\text{ kHz}$,

The other design constrains which we have considered in our analysis are:

- $D_{COSMO} \leq 0.7\text{ m}$,
- $P_{out} \leq 20\text{ dBW}$,
- Modulation: BPSK,
- $BER \leq 10^{-5}$,
- $\frac{G}{T_{min}} = -14\text{ dB/K}$

So, the maximum data rate which we can obtain, for not coded BPSK modulation ($\eta = 1$), is 375 kHz for the UHF-band. BER is set to be less or at most equal to 10^{-5} and Time of Access STK report is filtered by this link margin threshold, so all the time windows in which BER does not respect the technical requirement are eliminated. Starting from these constrains we have proceeded at the design through the use of the formulas we have described in the previous paragraph. In the following screen (Figure 17) you can see UHF-band constrains and mathematical results of the Matlab analysis.

```

CASE 1: UHF Band
frequency = 310.000000 MHz
Channel BW = 0.375000 MHz
LEO TX Power max = 20.000000 dBW
LEO Antenna max diameter = 0.700000 m
GEO Antenna G/T = -14.000000 dB/K
Max Data Rate = 300000.000000 bit/s
C/N0 required = 64.359071 dBHz
EIRP required = 25.383984 dBW
Diamater required = 0.698990 m
Gain required = 5.383984 dB
Theta 3dB required = 96.844128 deg
Power required (for fixed D) = 19.987458 dBW

```

Figure 17 UHF Matlab analysis results.

Max allowable data rate, in this case, is less than bandwidth because we have limited the LEO antenna diameter. To have $R_b = B$ we should have had $D=0.75$ m (Figure 18). The necessary output power to obtain an $R_b = 300$ kb/s with $D=0.7$ m is 20 dBW (Figure 19), which is the maximum allowable P_{OUT} .

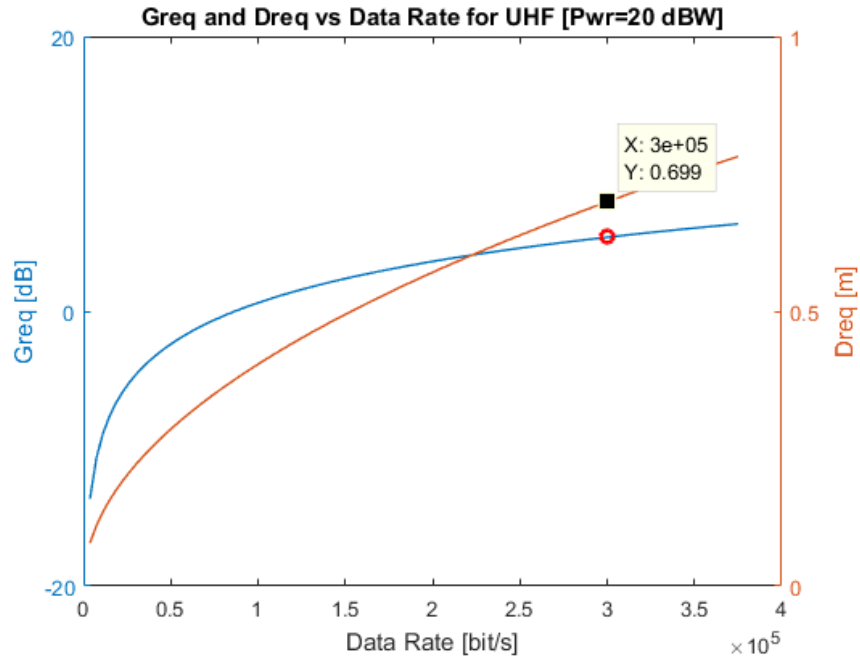


Figure 18 Greq and Dreq vs Data Rate for UHF-band with Pmax.

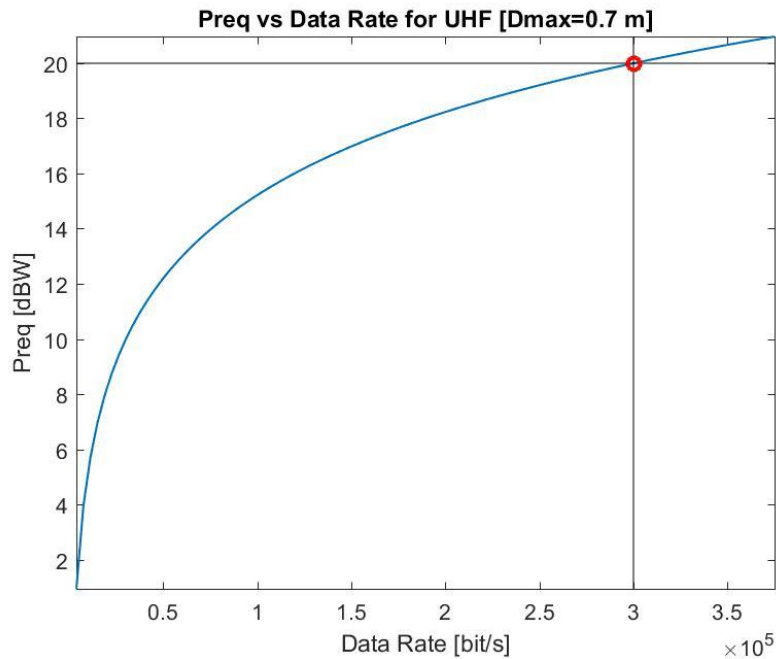


Figure 19 Preq vs Data Rate with for UHF-band with Dmax.

In this case we have not provided the antenna of a tracking mechanism, because thanks to 96.8 degrees beam-width a nearly omnidirectional coverage is guaranteed. The best position for UHF-band fixed antenna, to maximize the visibility time between LEO and GEO satellites, is on the upper face of the satellite, looking towards geostationary orbit as you see in Figure 20 and Figure 21. What you see in yellow colour is COSMO Sky-Med orbit and beam-width, SICRAL is represented with pink colour.

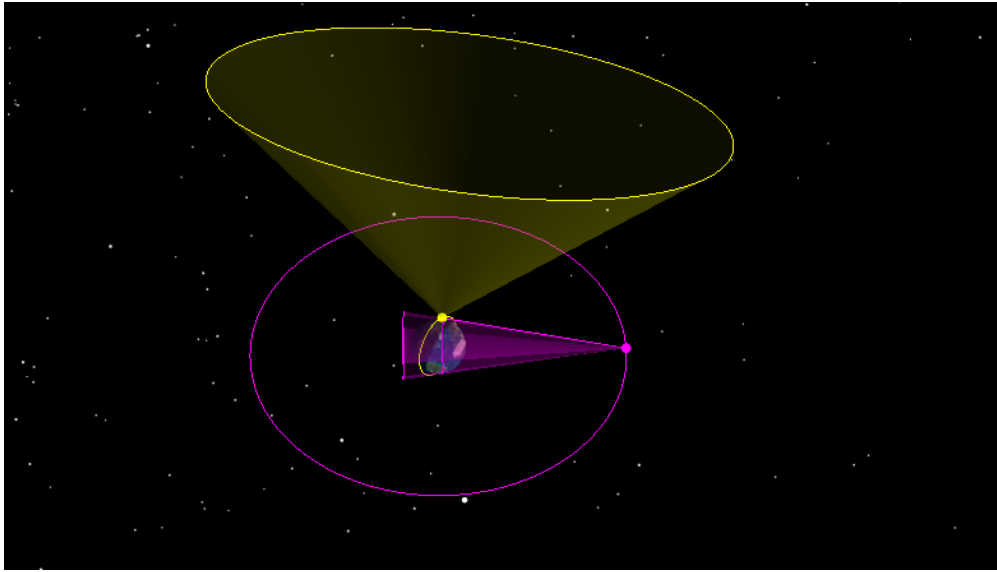


Figure 20 STK scenario for UHF band simulation.

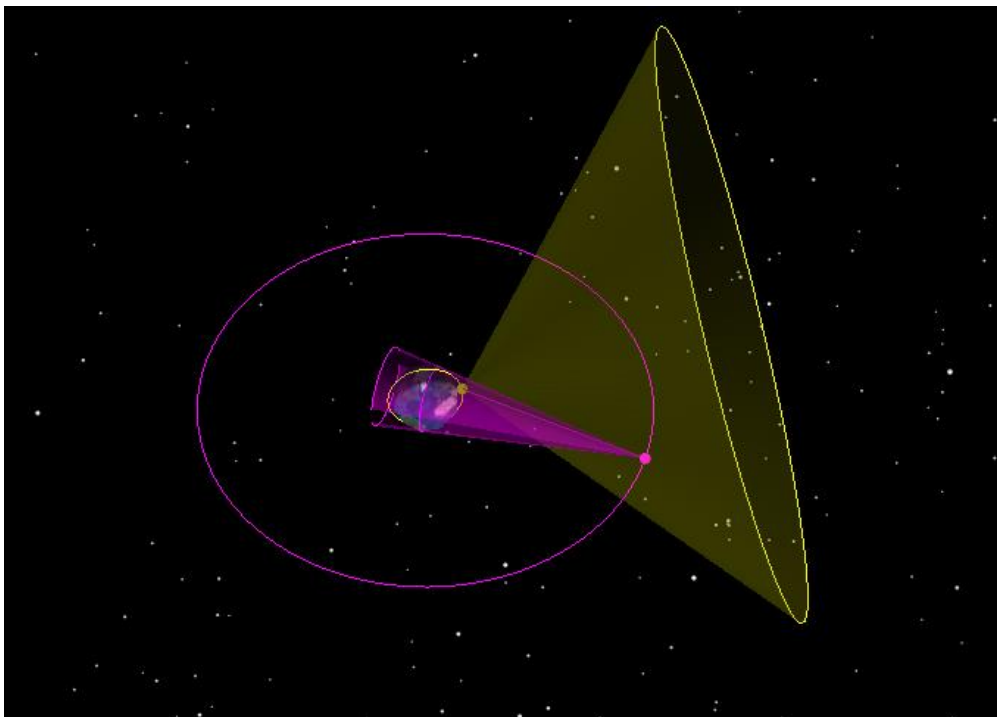


Figure 21 STK scenario for UHF band simulation.

In the following screen (Figure 23) you can see STK Access report in which there are all the time windows in which satellites are in visibility and BER link threshold is respected. The simulation duration is 24 h in order to evaluate daily performances.

UHF_TX-To-UHF_RX_S2				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	13:30:52.588	25 Feb 2020 13:43:48.923	776.334
2	25 Feb 2020	15:04:02.635	25 Feb 2020 15:22:19.089	1096.454
3	25 Feb 2020	16:42:00.559	25 Feb 2020 16:56:04.490	843.931
4	26 Feb 2020	01:39:20.660	26 Feb 2020 01:53:22.886	842.226
5	26 Feb 2020	03:13:04.893	26 Feb 2020 03:31:21.807	1096.914
6	26 Feb 2020	04:51:33.903	26 Feb 2020 05:04:33.086	779.183
Global Statistics				
Min Duration	1	25 Feb 2020 13:30:52.588	25 Feb 2020 13:43:48.923	776.334
Max Duration	5	26 Feb 2020 03:13:04.893	26 Feb 2020 03:31:21.807	1096.914
Mean Duration				905.840
Total Duration				5435.042

Figure 22 STK Access Report screen for UHF band simulation.

UHF-BAND PERFORMANCES IN 24 H						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED BITS	NUMBER OF IMAGES	NUMBER OF TC
1	776,334	300000	232900200	116450100	0,014556263	465,8004
2	1096,454	300000	328936200	164468100	0,020558513	657,8724
3	843,931	300000	253179300	126589650	0,015823706	506,3586
4	842,226	300000	252667800	126333900	0,015791738	505,3356
5	1096,914	300000	329074200	164537100	0,020567138	658,1484
6	779,183	300000	233754900	116877450	0,014609681	467,5098
TOT	5435,042	300000	1630512600	815256300	0,0101907038	3261,0252

Tab. 4 UHF band ISL performances.

In the table above (Table 4) are reported the performances of this solution in term of time and data volume. The amount of downloaded images is obtained by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb (8000000000 bits) which is the number of bits which composes an image. The amount of uplinked TCs, assuming for the Tasking Mission the same data rate and performances

of the Data Relay Mission, is obtained by dividing the useful downloaded bits for 250 Kb, which is the number of bits which composes a TC message(without coding). UHF-band performances are not good because of the scarce results that this strategy has exhibited in Data Relay Mission.

3.4.2 S- BAND Case

SICRAL UHF payload antenna has the following characteristics:

- $f=2$ GHz,
- Bandwidth= 8192 Hz,

other additional constrains are:

- $D_{COSMO} \leq 0.25m$,
- $P_{OUT} \leq 20$ dBW,
- *Modulation = uncoded BPSK*,
- $BER \leq 10^{-5}$,
- $\frac{G}{T_{min}} = -20$ dB/K.

So, the maximum data rate which we can obtain, for not coded BPSK modulation ($\eta = 1$), is 8192 b/s for the S-band. We have firstly fixed the maximum allowable diameter of COSMO antenna at 0.25 m and the maximum output power at 20 dBW. BER margin link threshold for STK simulation access report is set to be less or at most equal to 10^{-5} . Starting from these constrains we have proceeded at the design through the use of the Matlab code presented in the previous lines. In the following screen (Figure 23) you can see S-band constrains and mathematical results of the Matlab analysis.

```

CASE 2: S Band
frequency = 2000.000000 MHz
Channel BW = 0.008192 MHz
LEO TX Power max = 20.000000 dBW
LEO Antenna max diameter = 0.250000 m
GEO Antenna G/T = -20.000000 dB/K
Max Data Rate = 8192.000000 bit/s
C/N0 required = 48.721758 dBHz
EIRP required = 31.940037 dBW
Diameter required = 0.230465 m
Gain required = 11.940037 dB
Theta 3dB required = 45.527169 deg
Power required (for fixed D) = 19.293306 dBW

```

Figure 23 S band case Matlab analysis results.

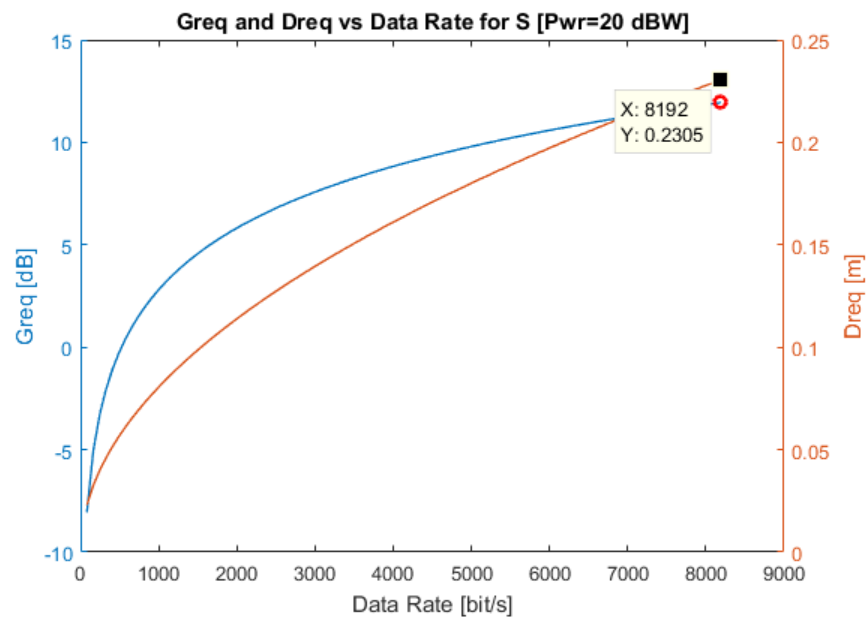


Figure 24 Greq and Dreq vs Data Rate for S band case with Pmax.

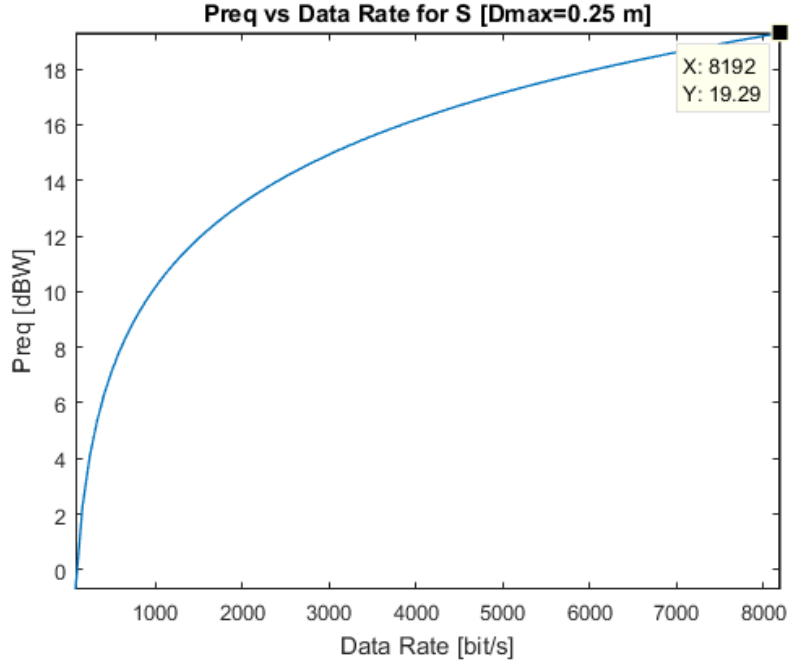


Figure 25 Preq vs Data rate for S band case with Dmax.

As you can see from the Figure 24 and 25, using the maximum output power we can obtain the equality of data rate and bandwidth with an antenna diameter of 0.23 m. From Matlab mathematical analysis you can see that the same performances are possible with $D = D_{max} = 0.25 \text{ m}$ and a $P_{OUT} = 19.29 \text{ dBW}$. To enhance link budget and to facilitate ISL establishment we have chosen the solution with the maximum P_{OUT} and $D = 0.23 \text{ m}$, because, even if in term of data rate the two solutions expressed above appear to give the same performances, with an higher output power BER threshold is respected easier and with a smaller antenna diameter the visibility time improves thanks to the resulting beam-width growth. In this case we have not provided the COSMO Sky-Med antenna of a tracking system, because we have chosen a large beam-width (79 degrees) which guarantees a good time coverage, we have also tried to optimize the antenna pointing putting the antenna in an optimal position as you can see in yellow colour form the simulation shot in Figure 26 and 27 (the pink one is SICRAL antenna).

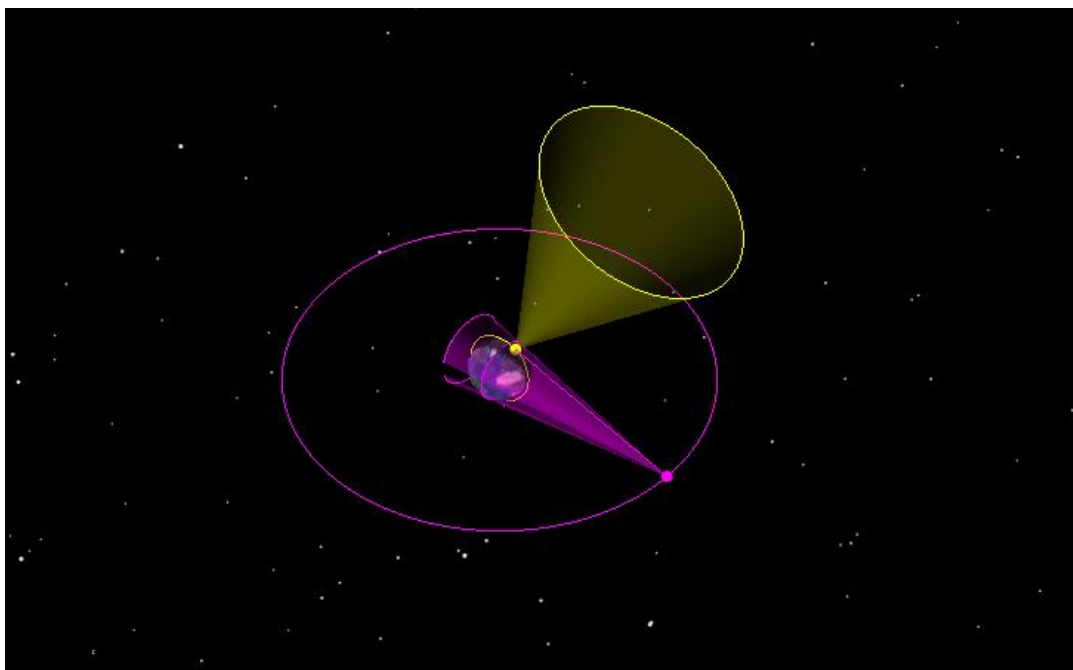


Figure 26 STK scenario for S band simulation.

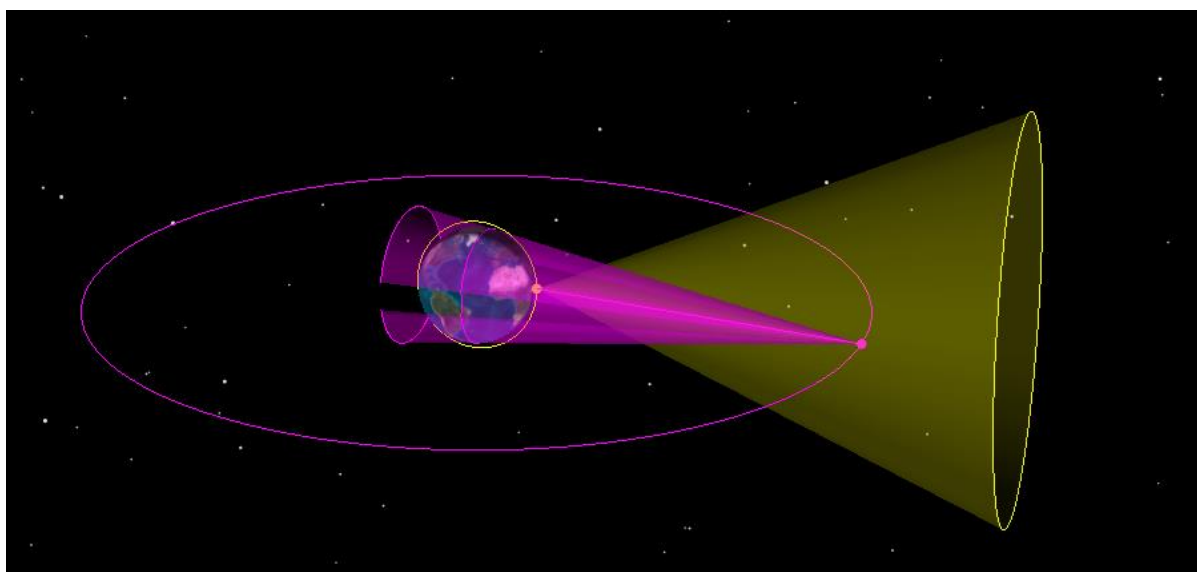


Figure 27 STK scenario for S band simulation.

We put the antenna on the upper face of the satellite looking toward GEO orbit because this was the solution with the higher visibility time amount, in fact GEO orbit is up to LEO orbit and the best way to improve the visibility time with a fixed antenna is this (Figure 26 and 27). You can see time performances and the satellites access from the report generated by STK simulation (Figure 28).

S_TX-To-S_RX				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	13:33:02.452	25 Feb 2020 13:41:40.563	518.111
2	25 Feb 2020	15:05:19.582	25 Feb 2020 15:21:01.942	942.360
3	25 Feb 2020	16:43:52.394	25 Feb 2020 16:54:10.746	618.352
4	26 Feb 2020	01:41:14.786	26 Feb 2020 01:51:30.665	615.879
5	26 Feb 2020	03:14:21.999	26 Feb 2020 03:30:04.897	942.898
6	26 Feb 2020	04:53:41.523	26 Feb 2020 05:02:23.943	522.420
Global Statistics				
Min Duration	1	25 Feb 2020 13:33:02.452	25 Feb 2020 13:41:40.563	518.111
Max Duration	5	26 Feb 2020 03:14:21.999	26 Feb 2020 03:30:04.897	942.898
Mean Duration				693.337
Total Duration				4160.022

Figure 28 STK Access report for S band simulation.

In the table below (Table 5) are reported the performances of this solution in term of time and data volume. The amount of downloaded images is obtained by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb (8000000000 bits) which is the number of bits which composes an image. The amount of uplinked TCs, assuming for the Tasking Mission the same data rate and performances of the Data Relay Mission, is obtained by dividing the useful downloaded bits for 250 Kb, which is the number of bits which composes a TC message (without coding). S-band strategy is not good because of the low available data rate, so it is better to search for another strategy.

S-BAND PERFORMANCES IN 24 H						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED BITS	NUMBER OF IMAGES	NUMBER OF TC
1	518,111	8192	4244365,312	2122182,656	0,000265273	8,488730624
2	942,36	8192	7719813,12	3859906,56	0,000482488	15,43962624
3	618,352	8192	5065539,584	2532769,792	0,000316596	10,13107917
4	615,879	8192	5045280,768	2522640,384	0,00031533	10,09056154
5	942,898	8192	7724220,416	3862110,208	0,000482764	15,44844083
6	522,42	8192	4279664,64	2139832,32	0,000267479	8,55932928
TOT	4160,020	8192	34078883,84	17039441,92	0,00212993	68,15776768

Tab. 5 S band ISL performances.

3.4.3 SHF CASE

For what concern SHF-band, we tried two different strategies:

- three shifted SHF fixed antennas,
- an SHF- band antenna with tracking mechanism.

3.4.3.1 Three SHF-band Horn Antennas

First of all, we have studied the best design to optimize the performances of a single SHF fixed antenna, assuming to have only one fixed SHF-band antenna. Our constrains in this analysis are:

- $f = 8 \text{ GHz}$,
- Bandwidth = 40 MHz,
- $D_{COSMO} \leq 0.7 \text{ m}$,
- $P_{OUT} \leq 26 \text{ dBW}$,
- *Modulation* = BPSK,
- $BER \leq 10^{-5}$,
- $\frac{G}{T_{min}} = -12.7 \text{ dB/K}$,

So, the maximum data rate which we can obtain, for not coded BPSK modulation ($\eta = 1$), is 40 Mb/s for the SHF-band. We have firstly fixed the maximum allowable diameter of COSMO antenna at 0.7 m and the maximum output power at 26 dBW. BER margin link threshold for STK simulation is set to be less or at most equal to 10^{-5} . Starting from these constrains we have proceeded at the design through the use of the Matlab. In the following screen (Figure 29) you can the mathematical results of the Matlab analysis for SHF band.

```

CASE 3: SHF Band
frequency = 8000.000000 MHz
Channel BW = 40.000000 MHz
LEO TX Power max = 26.000000 dBW
LEO Antenna max diameter = 0.700000 m
GEO Antenna G/T = -12.700000 dB/K
Max Data Rate = 1600000.000000 bit/s
C/N0 required = 71.629058 dBHz
EIRP required = 59.588537 dBW
Diamater required = 0.696579 m
Gain required = 33.588537 dB
Theta 3dB required = 3.765699 deg
Power required (for fixed D) = 25.957445 dBW

```

Figure 29 SHF band fixed antenna Matlab analysis results.

As you can see from the figure above, we can't obtain the maximum data rate because of diameter limited dimension. From a previous analysis appears that we can chose an $R_b = 1.6 \text{ Mb/s}$, but in Matlab analytical results you can see that for a such high R_b we should have a very small ϑ_{3dB} and this condition is not compatible with the fact that we do not have a tracking mechanism. So, by increasing the beam-width from a minimum value of 0° to a maximum value of 60° we have evaluated the best trade-off between data rate and ϑ_{3dB} amplitude.

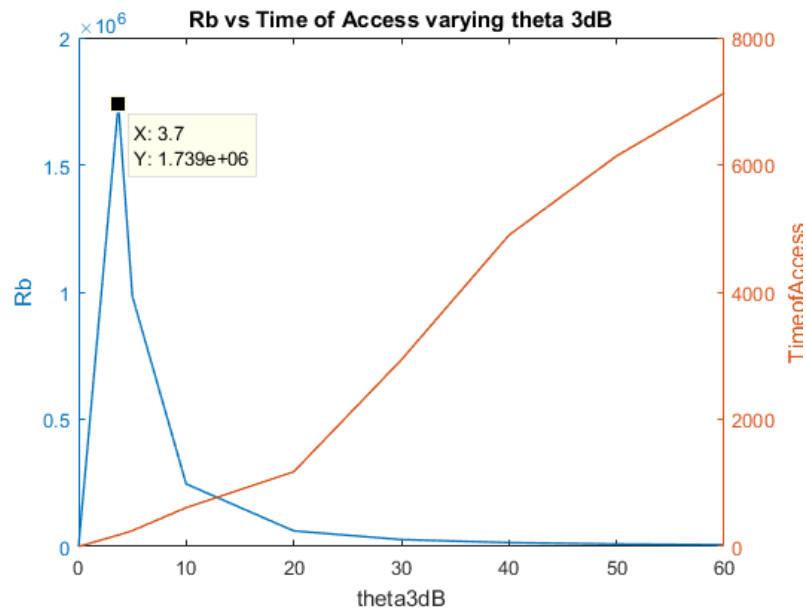


Figure 30 Data rate and Time of Access vs beam-width SHF fixed antenna.

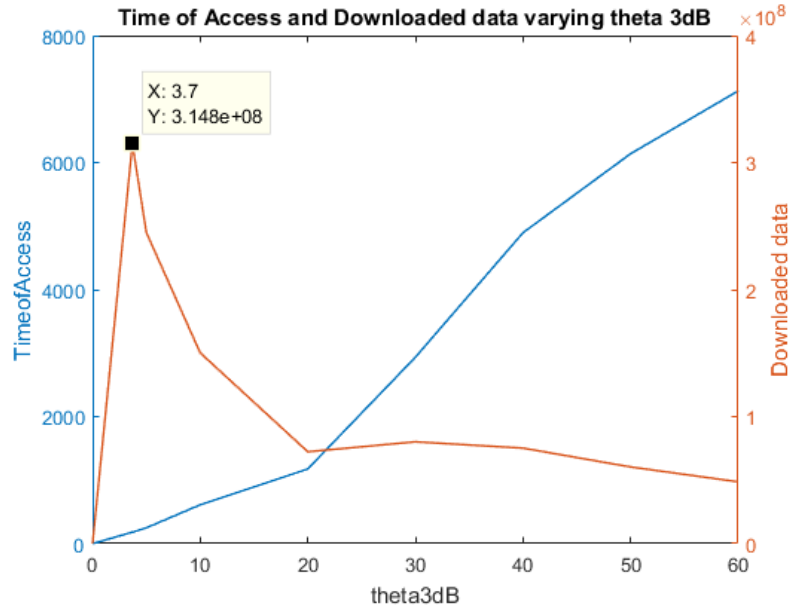


Figure 31 Time of Access and Downloaded data vs beam-width SHF fixed antenna.

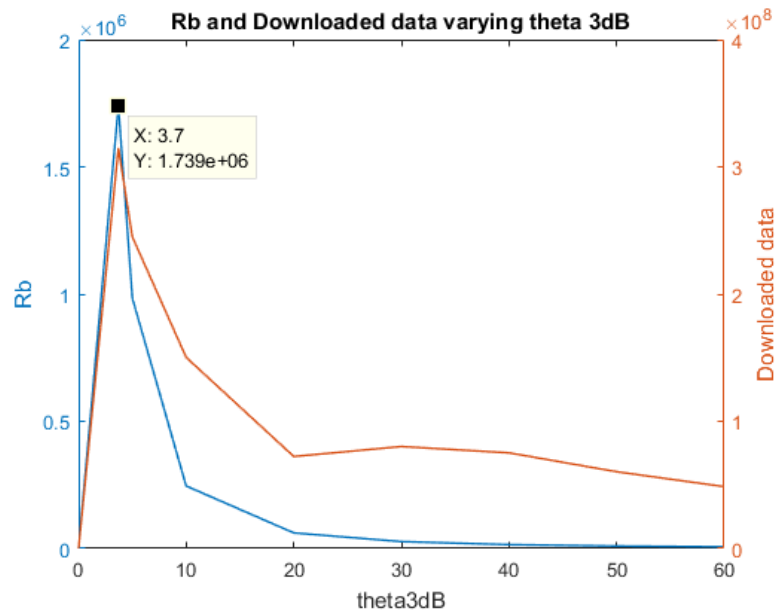


Figure 32 Data Rate and Downloaded data vs beam-width SHF fixed antenna.

As you can see from the plots above, the maximum amount of downloaded data is obtained thanks to $\vartheta_{3dB} = 3.7^\circ$, as suggested in Matlab simulation, even if time visibility is of a few seconds (181s). In

this way you optimize the data rate and so the downloaded data volume for every pass, but a such low visibility time could not improve response time performances. So, to size the three fixed SHF antennas we have chosen a $\vartheta_{3dB} = 30^\circ$. In this way you have the best trade-off between time of access, which grows for the larger cone coverage, and data rate, improving both response time and data rate than the case without ISL. So, we have chosen for COSMO SHF-band antenna the values of the data rate equal to 27317 b/s. We have applied the same design to three SHF-band antennas arranged as in the figures below. See that Az and El pointing coordinates chosen for the three antennas (figure 36) have been set in order to optimize time coverage and to avoid the overlap of the different coverage time windows of the three antennas. This pointing design is necessary to optimize the coverage because of the impossibility of having a larger beam-width for the link budget reasons explained above.

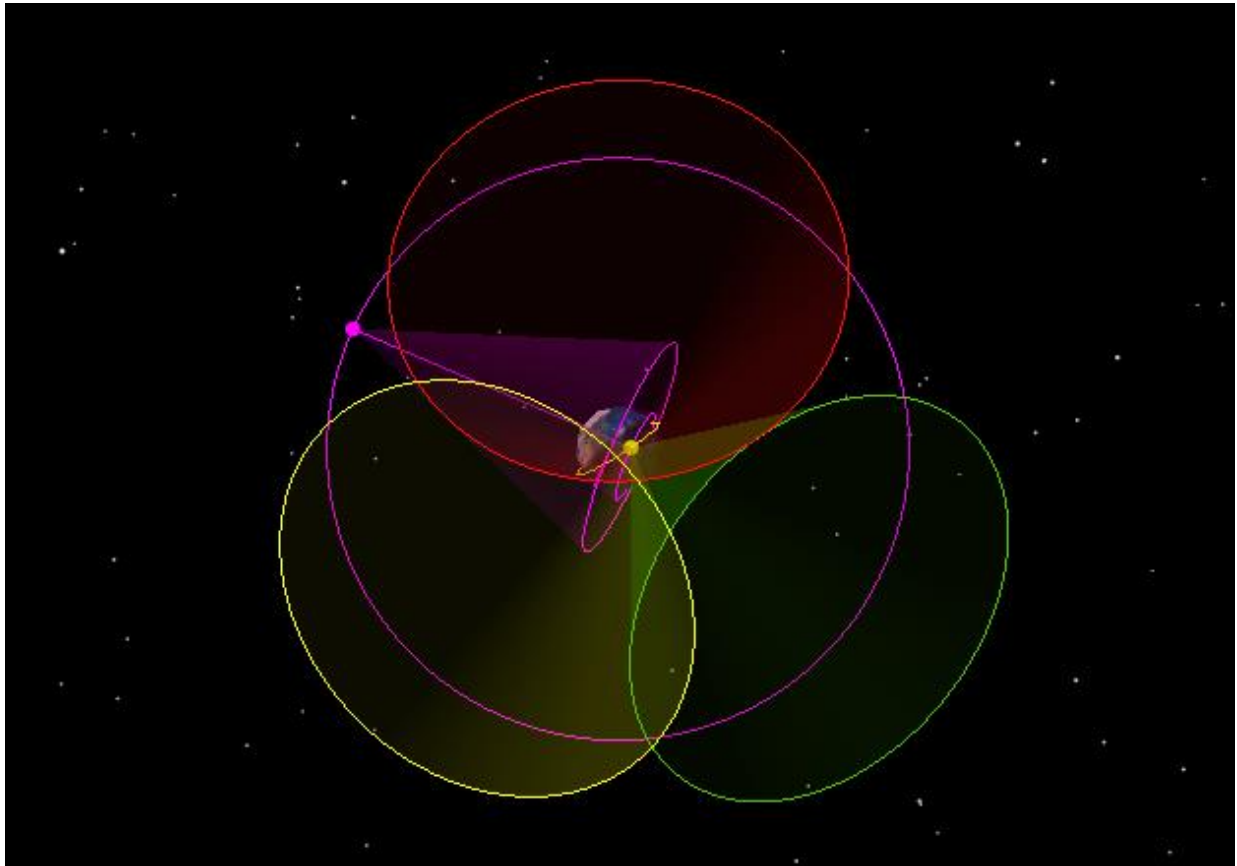


Figure 33 STK scenario for fixed SHF band antenna simulation.

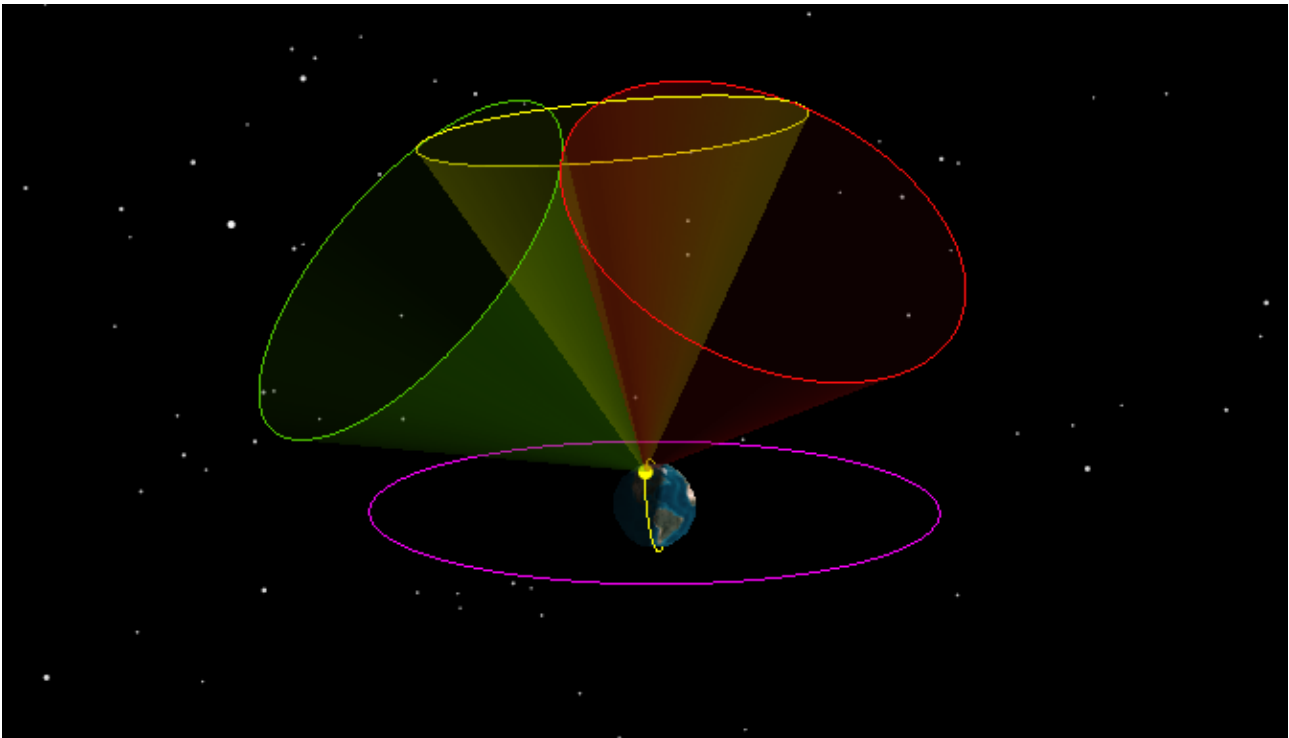


Figure 34 STK scenario for fixed SHF band antenna simulation.

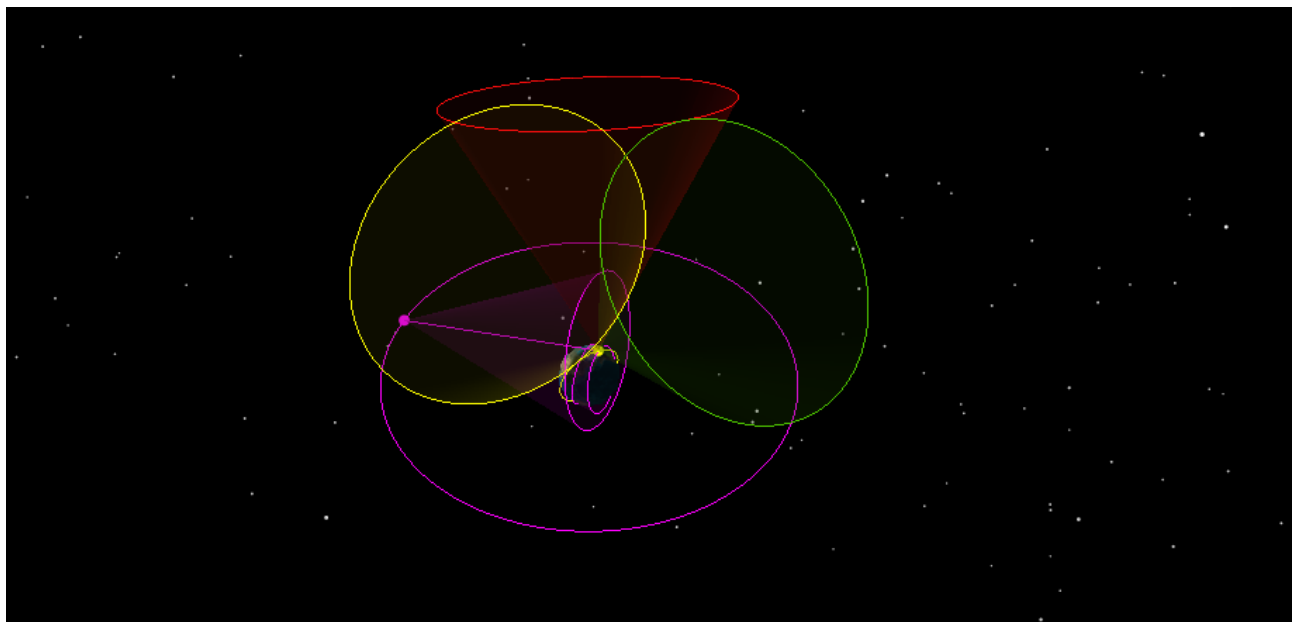


Figure 35 STK scenario for fixed SHF band antenna simulation.

SHF_2-To-SHF_RX_S2				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	16:42:56.209	25 Feb 2020 16:56:02.685	786.477
2	25 Feb 2020	18:23:35.825	25 Feb 2020 18:25:48.546	132.721
3	26 Feb 2020	00:09:45.447	26 Feb 2020 00:11:39.321	113.873
4	26 Feb 2020	01:39:21.243	26 Feb 2020 01:52:28.391	787.148
Global Statistics				
Min Duration	3	26 Feb 2020 00:09:45.447	26 Feb 2020 00:11:39.321	113.873
Max Duration	4	26 Feb 2020 01:39:21.243	26 Feb 2020 01:52:28.391	787.148
Mean Duration				455.055
Total Duration				1820.219

Figure 38 STK Access report screen of the second SHF fixed antenna.

SHF_3-To-SHF_RX_S2				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	14:57:39.508	25 Feb 2020 15:09:28.015	708.507
2	25 Feb 2020	16:37:05.286	25 Feb 2020 16:41:42.326	277.040
3	26 Feb 2020	03:06:36.827	26 Feb 2020 03:18:34.593	717.766
Global Statistics				
Min Duration	2	25 Feb 2020 16:37:05.286	25 Feb 2020 16:41:42.326	277.040
Max Duration	3	26 Feb 2020 03:06:36.827	26 Feb 2020 03:18:34.593	717.766
Mean Duration				567.771
Total Duration				1703.313

Figure 39 STK Access report screen of the third SHF fixed antenna.

In the table below (Table 6) are reported the performances of this solution in term of time and data volume. The amount of downloaded images is obtained by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb (8000000000 bits) which is the number of bits which composes an image. The amount of uplinked TCs, assuming for the Tasking Mission the same data rate and performances of the Data Relay Mission, is obtained by dividing the useful downloaded bits for 250 Kb, which is the number of bits which composes a TC message (without coding). Even if we have used three antennas simultaneously, the performances are too scares. So, we have finally decided to introduce a tracking mechanism.

SHF-BAND PERFORMANCES IN 24 H						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED	NUMBER OF IMAGES	NUMBER OF TC
1	792,679	27317	21653612,24	10826806,12	0,001353351	43,30722449
2	708,507	27317	19354285,72	9677142,86	0,001209643	38,70857144
3	151,612	27317	4141585,004	2070792,502	0,000258849	8,283170008
4	277,04	27317	7567901,68	3783950,84	0,000472994	15,13580336
5	786,477	27317	21484192,21	10742096,1	0,001342762	42,96838442
6	132,721	27317	3625539,557	1812769,779	0,000226596	7,251079114
7	113,873	27317	3110668,741	1555334,371	0,000194417	6,221337482
8	787,148	27317	21502521,92	10751260,96	0,001343908	43,00504383
9	717,766	37317	26784873,82	13392436,91	0,001674055	53,56974764
10	138,985	27317	3796653,245	1898326,623	0,000237291	7,59330649
11	792,967	27317	21661479,54	10830739,77	0,001353842	43,32295908
TOT	5399,775	27317	147505653,7	73752826,84	0,009219103	295,0113074

Table 6 SHF three fixed antennas ISL performances.

3.4.3.2 SHF Band Antenna with Tracking System

In this case we can use a narrower beam because thanks to tracking mechanism we are able to point SICRAL transponder even in not ideal visibility situations. The $\frac{G}{T}$ parameter has a great improvement, so we can proceed at the dimensioning with the following new constrains:

- $f = 8 \text{ GHz}$,
- Bandwidth = 40 MHz,
- $D_{COSMO} \leq 0.7 \text{ m}$,
- $P_{OUT} \leq 26 \text{ dBW}$,

- *Modulation = uncoded BPSK,*
- $BER \leq 10^{-5},$
- $\frac{G}{T_{min}} = 1.69 \text{ dB/K},$ which is derived from a preliminary STK simulation. Thanks to the tracking system this parameter, which with a fixed antenna reached the minimum value at -12.7 dB/k, is higher and it let us to have better design and performances than the previous strategy.

In fact, instead of the maximum R_b calculated in the last simulation, we can obtain the maximum data rate equal to 40 MHz which is exactly the SHF bandwidth, so $R_b = B$.

```

CASE 3: SHF Band
frequency = 8000.000000 MHz
Channel BW = 40.000000 MHz
LEO TX Power max = 26.000000 dBW
LEO Antenna max diameter = 0.700000 m
GEO Antenna G/T = 1.690000 dB/K
Max Data Rate = 40000000.000000 bit/s
C/N0 required = 85.608458 dBHz|
EIRP required = 59.177938 dBW
Diamater required = 0.664416 m
Gain required = 33.177938 dB
Theta 3dB required = 3.947986 deg
Power required (for fixed D) = 25.546846 dBW

```

Figure 40 SHF antenna with tracking system Matlab analysis results.

As you can see from Figure 40, Figure 41 and Figure 42, you may obtain the maximum data rate by using the maximum allowed output power (26 dBW) and a diameter smaller than the maximum permitted one (0.67 m), or by using a maximum diameter to size the antenna and a $P_{OUT} = 25.55 \text{ dBW}$.

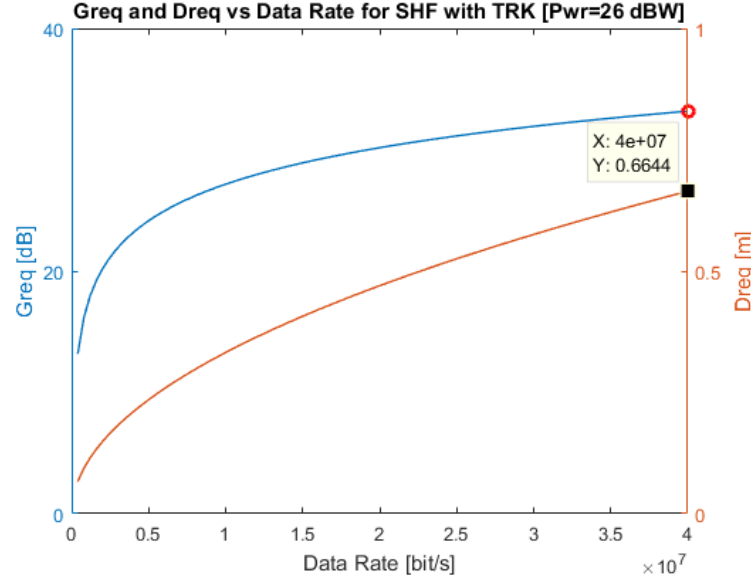


Figure 41 Greq and Dreq vs Data Rate for SHF antenna with tracking system with Pmax.

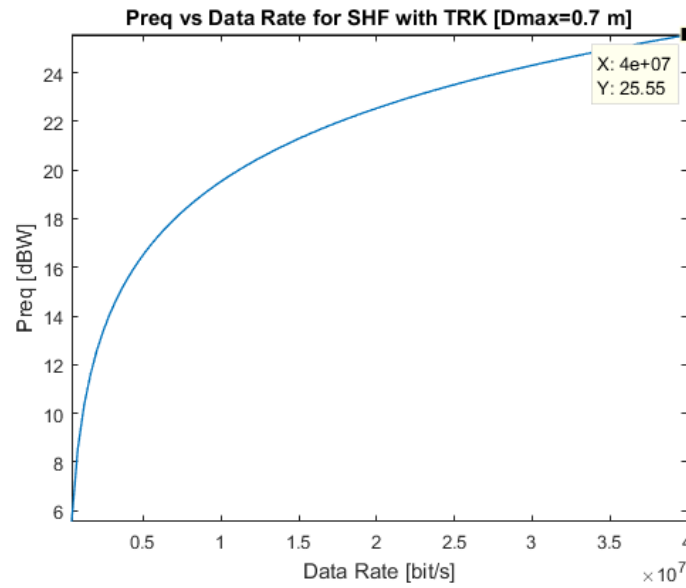


Figure 42 Preq vs Data Rate for SHF antenna with tracking system with Dmax.

To facilitate ISL establishment we have chosen the solution with the maximum P_{OUT} and $D = D_{min} = 0.67 \text{ m}$, because, even if in term of data rate the two solutions expressed above appear to give the same performances, with an higher output power BER threshold is respected easier and a smaller antenna is better for a LEO satellite payload especially for weight reasons which influences propellant consumption, and for the speed performances of the antenna motor and the mechanical usury of the tracking system. Now we analyze the time performances and the downloaded data

volume. In the following STK report you can see the time windows in which satellites could establish a link which respects BER threshold.

SHF_TX_LEO-To-SH_RX_S2				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	11:00:00.000	25 Feb 2020 11:00:19.099	19.099
2	25 Feb 2020	11:29:40.023	25 Feb 2020 12:30:47.293	3667.270
3	25 Feb 2020	13:07:52.471	25 Feb 2020 14:05:32.308	3459.837
4	25 Feb 2020	14:44:48.438	25 Feb 2020 15:41:38.000	3409.563
5	25 Feb 2020	16:20:59.372	25 Feb 2020 17:18:30.225	3450.853
6	25 Feb 2020	17:55:56.885	25 Feb 2020 18:56:33.063	3636.178
7	25 Feb 2020	19:27:11.656	25 Feb 2020 23:08:13.332	13261.676
8	25 Feb 2020	23:38:50.319	26 Feb 2020 00:39:27.781	3637.461
9	26 Feb 2020	01:16:53.343	26 Feb 2020 02:14:25.196	3451.854
10	26 Feb 2020	02:53:45.702	26 Feb 2020 03:50:36.042	3410.341
11	26 Feb 2020	04:29:51.647	26 Feb 2020 05:27:31.834	3460.187
12	26 Feb 2020	06:04:37.329	26 Feb 2020 07:05:43.543	3666.214
13	26 Feb 2020	07:35:08.288	26 Feb 2020 11:00:00.000	12291.712
Global Statistics				
Min Duration	1	25 Feb 2020 11:00:00.000	25 Feb 2020 11:00:19.099	19.099
Max Duration	7	25 Feb 2020 19:27:11.656	25 Feb 2020 23:08:13.332	13261.676
Mean Duration				4678.634
Total Duration				60822.245

Figure 43 STK access report of SHF antenna with tracking system simulation.

SHF-BAND with TRK PERFORMANCES IN 24 H						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED	NUMBER OF IMAGES	NUMBER OF TC
1	19,099	40000000	763960000	381980000	0,0477475	1527,92
2	3667,27	40000000	1,46691E+11	73345400000	9,168175	293381,6
3	3459,837	40000000	1,38393E+11	69196740000	8,6495925	276786,96
4	3409,563	40000000	1,36383E+11	68191260000	8,5239075	272765,04
5	3450,853	40000000	1,38034E+11	69017060000	8,6271325	276068,24
6	3636,178	40000000	1,45447E+11	72723560000	9,090445	290894,24
7	13261,676	40000000	5,30467E+11	2,65234E+11	33,15419	1060934,08
8	3637,461	40000000	1,45498E+11	72749220000	9,0936525	290996,88
9	3451,854	40000000	1,38074E+11	69037080000	8,629635	276148,32
10	3410,341	40000000	1,36414E+11	68206820000	8,5258525	272827,28
11	3460,187	40000000	1,38407E+11	69203740000	8,6504675	276814,96
12	3666,214	40000000	1,46649E+11	73324280000	9,165535	293297,12
13	12291,712	40000000	4,91668E+11	2,45834E+11	30,72928	983336,96
TOT	60822,245	40000000	2,43289E+12	1,21644E+12	152,0556125	4865779,6

Tab. 7 SHF antenna with tracking system ISL performances.

The amount of downloaded images is obtained by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb which is the number of bits which composes an image. The amount of uplinked telecommand (TC) is calculated assuming for the uplink the same performances of the downlink, so by dividing the amount of useful downloaded bit by 250 kb which is the amount of bit (without coding) which composes a TC message. This solution appears to be excellent both for images download and TC uplink performances.

3.4.4 Ka-Band Case with Tracking System

The design of a Ka-band antenna with tracking system has been done starting from design constrains:

- $f = 20 \text{ GHz}$,
- bandwidth = 50 MHz,
- $D_{COSMO} \leq 0.5 \text{ m}$,
- $P_{OUT} = 26 \text{ dBW}$,
- *Modulation: uncoded BPSK*,
- $BER \leq 10^{-5}$,
- $\frac{G}{T_{min}} = 10 \text{ dB/K}$, this parameter has been calculated from a preliminary STK simulation.

From figure 44, which shows Matlab sizing analysis results, you can see that it is possible to obtain the maximum data rate $R_b = B = 50 \text{ MHz}$, whit the design constrains respect.

```

CASE 5:Ka Band
frequency = 21000.000000 MHz
Channel BW = 50.000000 MHz
LEO TX Power max = 26.000000 dBW
LEO Antenna max diameter = 0.500000 m
GEO Antenna G/T = 10.000000 dB/K
Max Data Rate = 50000000.000000 bit/s
C/N0 required = 86.577558 dBHz
EIRP required = 60.219624 dBW
Diameter required = 0.285361 m
Gain required = 34.219624 dB
Theta 3dB required = 3.501800 deg
Power required (for fixed D) = 21.128506 dBW

```

Figure 44 Ka band antenna with tracking system Matlab analysis results.

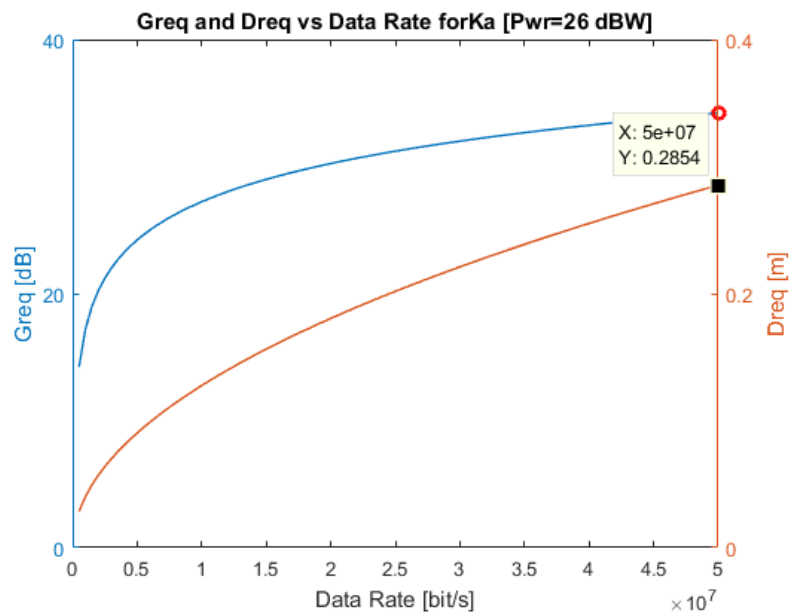


Figure 45 Greq and Dreq vs Data Rate for Ka band antenna with tracking system and Pmax.

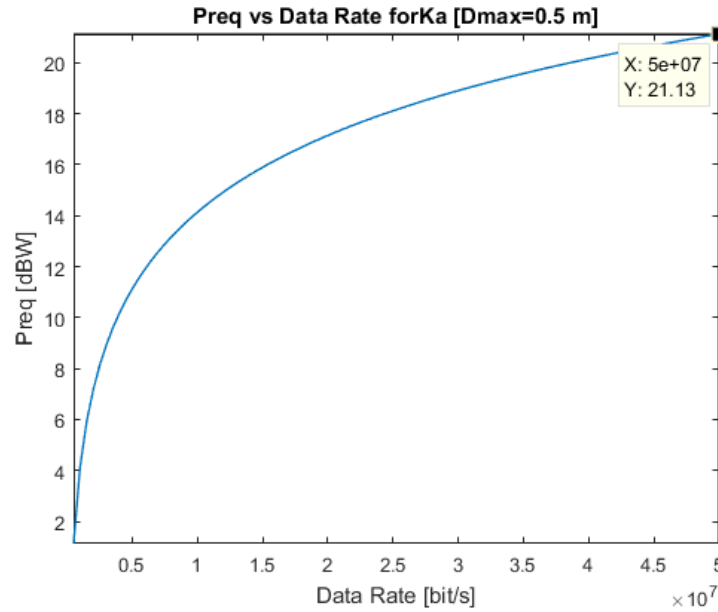


Figure 46 Preq vs Data Rate for Ka band antenna with tracking system and Dmax.

The best performances could be obtained both with the maximum output power (26 dBW) and a smaller diameter (0.29 m) than with the maximum diameter (0.5 m) and $P_{OUT} = 21.13 \text{ dBW}$. In this case we have a tracking mechanism so the consideration about the inversely proportional relation between antenna diameter dimension and antenna beam-width are not useful for the access performances improvement, but, we have chosen the solution which use the minimum diameter because it could be useful on a LEO satellite to relieve payload weight for propellant consumption and also for the speed performances of the mechanic part of the tracking system and its usury. In Figure 47 are reported STK simulation access data.

ka_TX-To-Ka_RX_S2				
Access	Start Time (UTCG)		Stop Time (UTCG)	Duration (sec)
1	25 Feb 2020	11:00:00.000	25 Feb 2020 11:00:19.099	19.099
2	25 Feb 2020	11:29:40.023	25 Feb 2020 12:30:47.293	3667.270
3	25 Feb 2020	13:07:52.471	25 Feb 2020 14:05:32.308	3459.837
4	25 Feb 2020	14:44:48.438	25 Feb 2020 15:41:38.000	3409.563
5	25 Feb 2020	16:20:59.372	25 Feb 2020 17:18:30.225	3450.853
6	25 Feb 2020	17:55:56.885	25 Feb 2020 18:56:33.063	3636.178
7	25 Feb 2020	19:27:11.656	25 Feb 2020 23:08:13.332	13261.676
8	25 Feb 2020	23:38:50.319	26 Feb 2020 00:39:27.781	3637.461
9	26 Feb 2020	01:16:53.343	26 Feb 2020 02:14:25.196	3451.854
10	26 Feb 2020	02:53:45.702	26 Feb 2020 03:50:36.042	3410.341
11	26 Feb 2020	04:29:51.647	26 Feb 2020 05:27:31.834	3460.187
12	26 Feb 2020	06:04:37.329	26 Feb 2020 07:05:43.543	3666.214
13	26 Feb 2020	07:35:08.288	26 Feb 2020 11:00:00.000	12291.712
Global Statistics				
Min Duration	1	25 Feb 2020 11:00:00.000	25 Feb 2020 11:00:19.099	19.099
Max Duration	7	25 Feb 2020 19:27:11.656	25 Feb 2020 23:08:13.332	13261.676
Mean Duration				4678.634
Total Duration				60822.245

Figure 47 STK Access Report for Ka antenna with tracking system.

The amount of downloaded images is calculated by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb which is the number of bits which composes an image. The amount of uplinked telecommand (TC) is calculated assuming for the uplink the same performances of the downlink, so by dividing the amount of useful downloaded bit by 250 kb which is the amount of bit (without coding) which composes a TC message. This solution appears to be excellent both for images download and TC uplink performances. Please, notice that time performances are the same of SHF-band antenna with tracking system, the only difference which impacts on downloaded data volume is on maximum data rate which in SHF-band is limited by SICRAL payload bandwidth.

Ka-BAND with TRK PERFORMANCES IN 24 H						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED	NUMBER OF IMAGES	NUMBER OF TC
1	19,099	50000000	954950000	477475000	0,059684375	1909,9
2	3667,27	50000000	1,83364E+11	91681750000	11,46021875	366727
3	3459,837	50000000	1,72992E+11	86495925000	10,81199063	345983,7
4	3409,563	50000000	1,70478E+11	85239075000	10,65488438	340956,3
5	3450,853	50000000	1,72543E+11	86271325000	10,78391563	345085,3
6	3636,178	50000000	1,81809E+11	90904450000	11,36305625	363617,8
7	13261,676	50000000	6,63084E+11	3,31542E+11	41,4427375	1326167,6
8	3637,461	50000000	1,81873E+11	90936525000	11,36706563	363746,1
9	3451,854	50000000	1,72593E+11	86296350000	10,78704375	345185,4
10	3410,341	50000000	1,70517E+11	85258525000	10,65731563	341034,1
11	3460,187	50000000	1,73009E+11	86504675000	10,81308438	346018,7
12	3666,214	50000000	1,83311E+11	91655350000	11,45691875	366621,4
13	12291,712	50000000	6,14586E+11	3,07293E+11	38,4116	1229171,2
TOT	60822,245	50000000	3,04111E+12	1,52056E+12	190,0695156	6082224,5

Tab. 8 Ka band antenna with tracking system ISL performances.

3.4.5 COSMO Sky-Med Access and Performances

To evaluate COSMO Sky-Med performances in absence of ISL, with a simple uncoded BPSK modulation, we have calculated COSMO access time considering the real three Ground Station used for the TC uplink and the data download:

- Cordoba station,
- Kiruna station,
- Pratica di Mare station.

CSG (Cosmo Second Generation satellite) is supposed to have a data-rate of 520 Mb/s thanks to an 8-PSK modulation with convolutional coding, we have calculate the real downlink bandwidth which COSMO should have for a BPSK modulation with unitary spectral efficiency instead of $\eta_{8-PSK}=3$ as is in 8-PSK.

$$B_{COSMO} = \frac{R_{b-8PSK}}{\eta_{8PSK}} = \frac{520.000.000}{3} [Hz] = 173 MHz$$

So, 173 Mb/s is the best data rate which COSMO can afford with BPSK modulation. We have done this calculation in order to compare the performances of COSMO Sky-Med system with the RF ISL technology and the actual performances of the System which is not provided by the ISL, with the same modulation and coding. In the Figure 48,49 and 50 you can see real COSMO Sky-Med visible passes on the three ground stations mentioned above. Thank to heavens-above.com website we have chosen the three stations locations and have obtained COSMO visible passes.

Data	Magnitudine (mag.)	Inizio			Altezza massima			Fine			Tipo di passaggio
		ora	Alt.	Azim.	ora	Alt.	Azim.	ora	Alt.	Azim.	
19 feb	5,7	04:02:14	10°	E	04:04:01	12°	ENE	04:05:50	10°	NE	visibile
19 feb	2,5	05:35:19	10°	S	05:39:38	67°	O	05:43:58	10°	NNO	visibile
19 feb	4,3	18:58:53	10°	N	19:02:49	34°	ONO	19:06:43	10°	SO	visibile
20 feb	5,2	04:18:53	10°	ESE	04:21:53	19°	ENE	04:24:53	10°	NNE	visibile
20 feb	2,9	05:53:37	10°	S	05:57:43	41°	O	06:01:52	10°	NNO	visibile
20 feb	5,1	19:17:20	10°	NNO	19:20:45	23°	ONO	19:24:07	10°	OSO	visibile
21 feb	4,6	04:36:06	10°	SE	04:39:46	27°	ENE	04:43:28	10°	N	visibile
21 feb	3,5	06:12:11	10°	SSO	06:15:52	27°	O	06:19:34	10°	NO	visibile
21 feb	5,6	19:36:05	10°	NNO	19:38:36	15°	ONO	19:41:07	10°	O	visibile
22 feb	3,8	04:53:38	10°	SE	04:57:43	42°	ENE	05:01:50	10°	N	visibile
22 feb	2,6	18:16:35	10°	NNE	18:20:58	83°	ESE	18:25:18	10°	SSO	visibile
23 feb	2,9	05:11:24	10°	SSE	05:15:42	67°	ENE	05:20:01	10°	N	visibile
23 feb	3,2	18:34:41	10°	N	18:38:59	62°	ONO	18:43:15	10°	SSO	visibile
24 feb	5,9	03:57:11	10°	ENE	03:58:14	11°	ENE	03:59:16	10°	NE	visibile
24 feb	2,5	05:29:24	10°	S	05:33:44	78°	OSO	05:38:07	10°	NNO	visibile
24 feb	4,1	18:52:55	10°	N	18:56:58	39°	ONO	19:01:00	10°	SO	visibile
25 feb	5,5	04:13:22	10°	ESE	04:16:03	16°	ENE	04:18:45	10°	NNE	visibile
25 feb	2,8	05:47:37	10°	S	05:51:49	48°	O	05:56:03	10°	NNO	visibile
25 feb	4,9	19:11:18	10°	NNO	19:14:54	26°	ONO	19:18:29	10°	SO	visibile
26 feb	4,9	04:30:27	10°	ESE	04:33:56	24°	ENE	04:37:26	10°	NNE	visibile
26 feb	3,3	06:06:06	10°	SSO	06:09:56	31°	O	06:13:49	10°	NNO	visibile
26 feb	5,5	19:29:55	10°	NNO	19:32:47	17°	ONO	19:35:38	10°	OSO	visibile
27 feb	4,1	04:47:52	10°	SE	04:51:51	36°	ENE	04:55:51	10°	N	visibile
27 feb	5,8	19:49:08	10°	NO	19:50:37	12°	ONO	19:52:05	10°	O	visibile
28 feb	3,2	05:05:34	10°	SSE	05:09:49	57°	ENE	05:14:06	10°	N	visibile
28 feb	2,9	18:28:45	10°	N	18:33:05	72°	ONO	18:37:25	10°	SSO	visibile

Figure 48 COSMO Sky-Med visible passages on Pratica di Mare ground station.

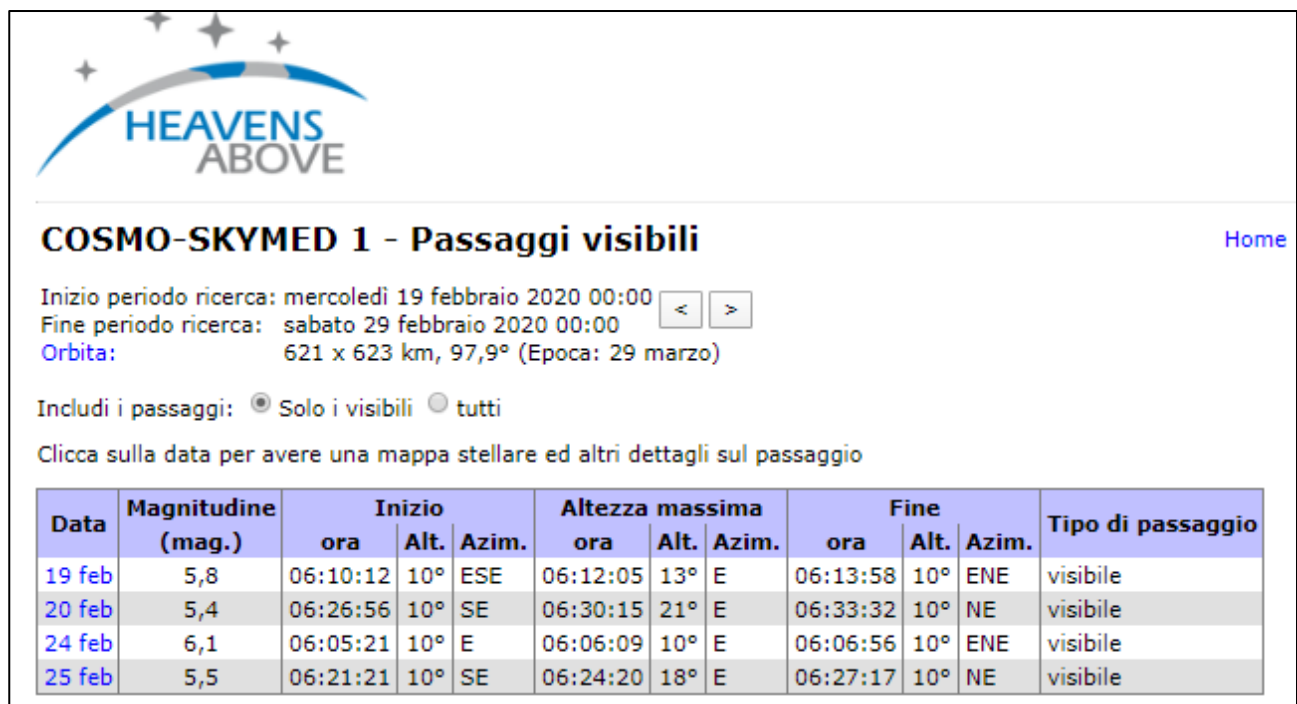


Figure 49 COSMO Sky-Med passages on Cordoba ground station.

25 feb	3,2	17:27:32	10°	NNE	17:31:36	36°	E	17:35:38	10°	SSE	visibile
25 feb	2,9	19:03:45	10°	NNE	19:08:06	68°	ONO	19:12:27	10°	SO	visibile
25 feb	4,8	20:40:09	10°	NNE	20:43:47	26°	NO	20:47:24	10°	O	visibile
25 feb	5,6	22:16:19	10°	NNE	22:18:51	15°	NNO	22:21:22	10°	NO	visibile
25 feb	5,7	23:51:25	10°	NE	23:53:38	14°	N	23:55:52	10°	NNO	visibile
26 feb	5,2	01:25:22	10°	ENE	01:28:34	20°	NNE	01:31:45	10°	NNO	visibile
26 feb	3,7	02:59:49	10°	SE	03:03:58	44°	NE	03:08:08	10°	NNO	visibile
26 feb	2,6	04:35:48	10°	S	04:40:08	59°	OSO	04:44:28	10°	NNO	visibile
26 feb	4,0	06:14:12	10°	SO	06:17:11	18°	O	06:20:12	10°	NO	visibile

Figure 50 COSMO Sky-Med passages on kiruna ground station.

The data passages of interests are between 25.02.2020, 11:00:00 h and 26.02.2020, 11:00:00 h because these are the 24 hours which we have used for STK analysis and simulations. Notice that Kiruna station has more visibility time windows because of its privileged further north position. In the followings figure are reported orbit passages details.

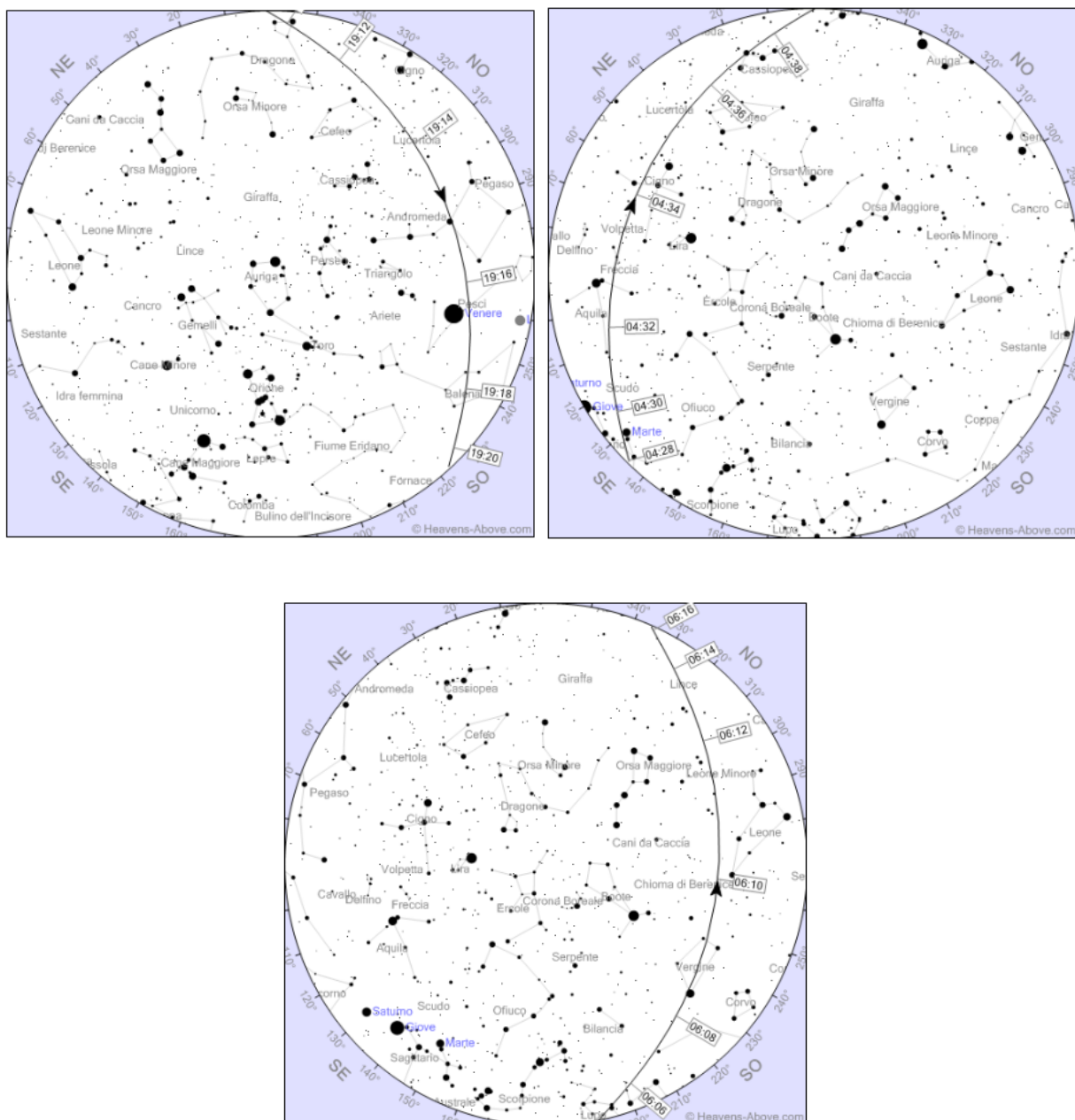


Figure 51 COSMO Sky-Med first Pratica di Mare passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	19:08:50	0°	360° (N)	2.913	6,0	-14,5°
raggiunge l'altezza di 10°	19:11:18	10°	348° (NNO)	2.001	5,3	-15,0°
Culmina	19:14:54	26°	292° (ONO)	1.241	4,9	-15,7°
Cala sotto l'altezza di 10°	19:18:28	10°	236° (SO)	1.988	6,0	-16,3°
Tramonta	19:20:55	0°	224° (SO)	2.889	6,6	-16,8°

Tab. 9 COSMO Sky-Med first Pratica di Mare passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	04:27:57	0°	134° (SE)	2.894	6,4	-27,3°
raggiunge l'altezza di 10°	04:30:27	10°	121° (ESE)	1.992	5,7	-26,9°
Culmina	04:33:56	24°	67° (ENE)	1.297	4,9	-26,2°
Cala sotto l'altezza di 10°	04:37:25	10°	14° (NNE)	2.003	5,4	-25,6°
Tramonta	04:39:56	0°	1° (N)	2.914	6,2	-25,1°

Tab. 10 COSMO Sky-Med second Pratica di Mare passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	06:03:43	0°	190° (S)	2.890	5,9	-9,5°
raggiunge l'altezza di 10°	06:06:06	10°	201° (SSO)	1.989	5,0	-9,1°
Culmina	06:09:56	31°	264° (O)	1.109	3,3	-8,4°
Cala sotto l'altezza di 10°	06:13:48	10°	326° (NO)	2.002	4,8	-7,6°
Tramonta	06:16:13	0°	337° (NNO)	2.914	5,7	-7,2°

Tab. 11 COSMO Sky-Med third Pratica di Mare passage details.

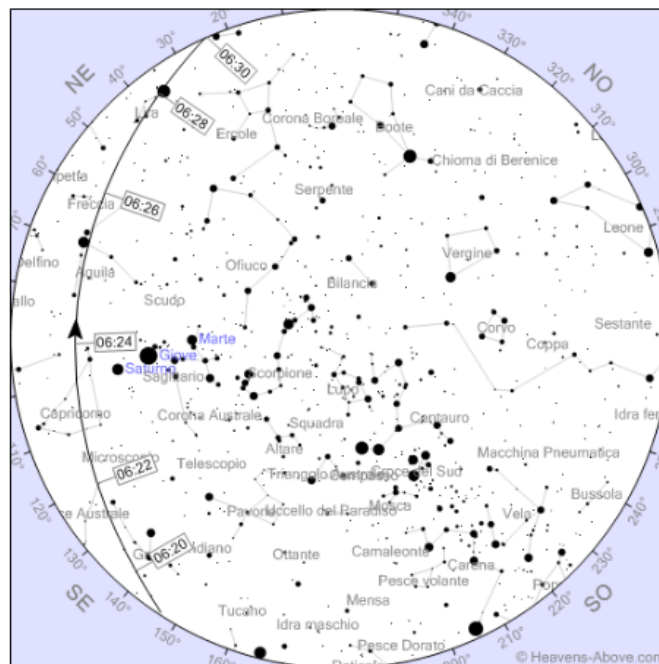
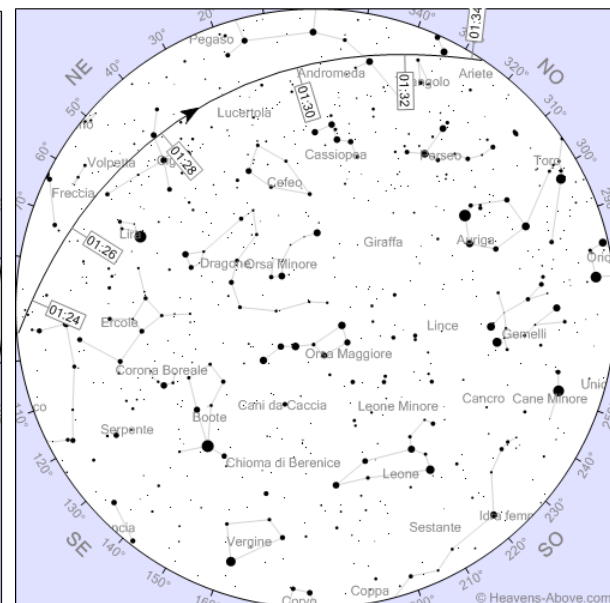
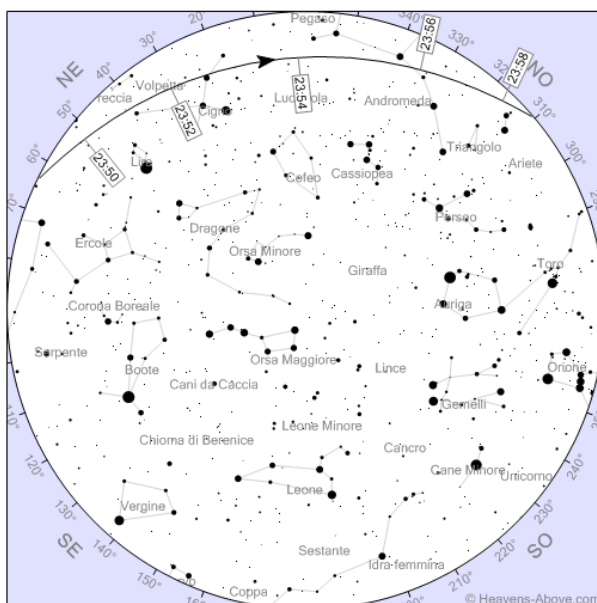
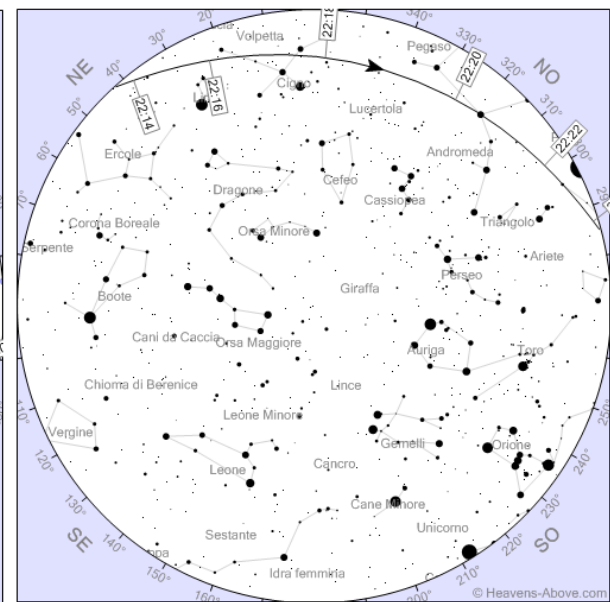
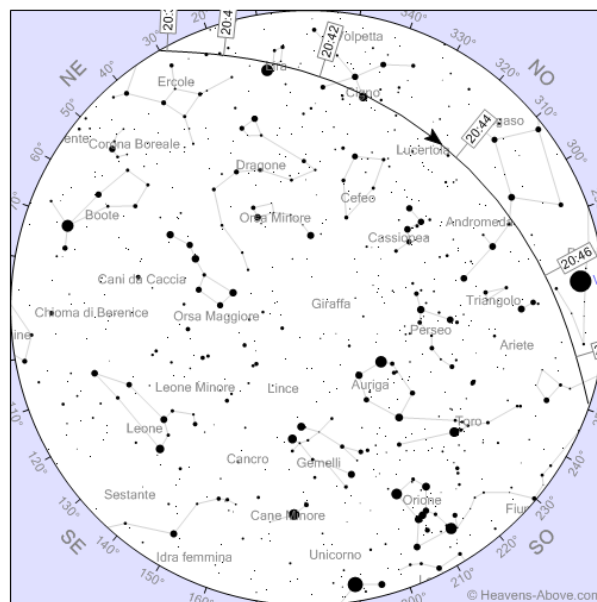
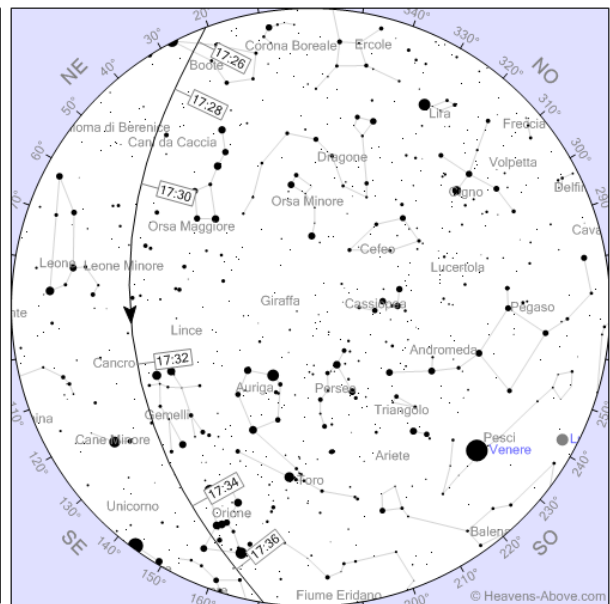
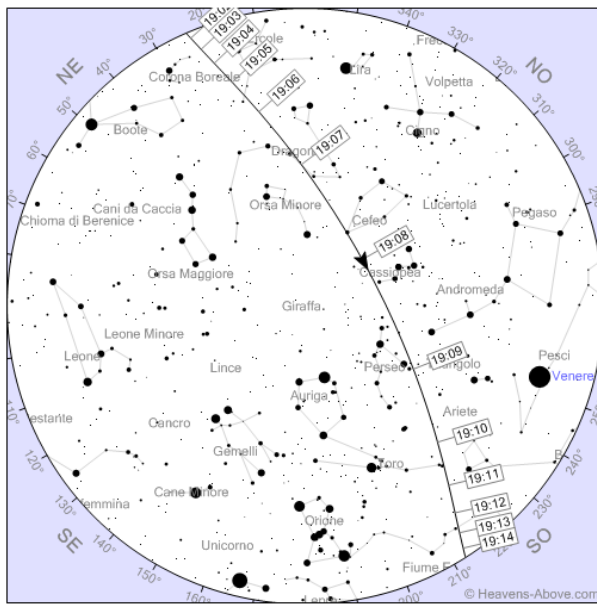


Figure 52 COSMO Sky-Med Cordoba passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	06:18:31	0°	147° (SSE)	2.932	6,9	-10,1°
raggiunge l'altezza di 10°	06:21:22	10°	128° (SE)	2.016	6,5	-9,5°
Culmina	06:24:20	18°	85° (E)	1.562	5,7	-8,9°
Cala sotto l'altezza di 10°	06:27:16	10°	42° (NE)	1.997	5,5	-8,3°
Tramonta	06:30:04	0°	23° (NNE)	2.893	6,1	-7,7°

Tab. 12 COSMO Sky-Med Cordoba passage details.



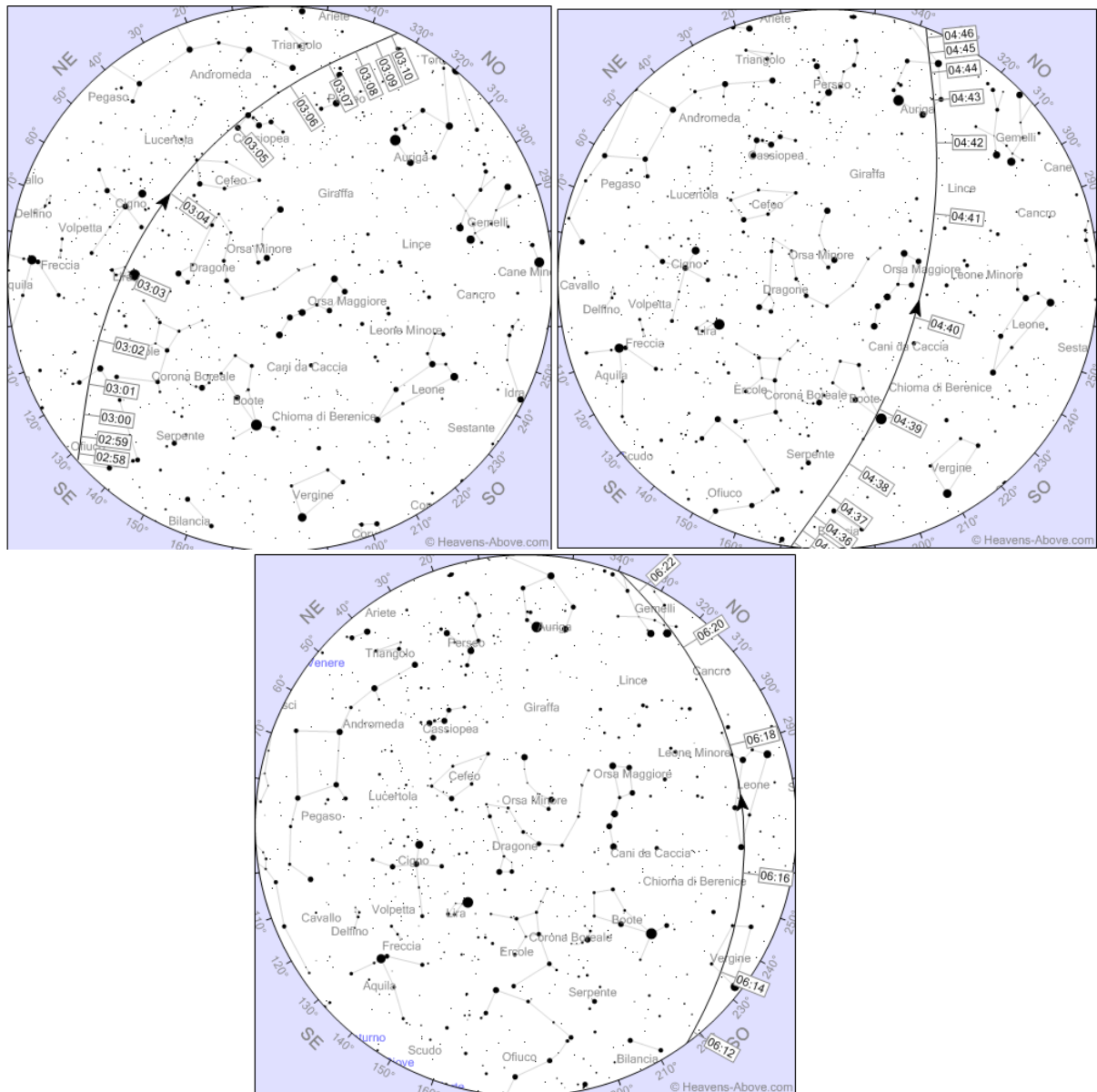


Figure 53 COSMO Sky-Med Kiruna passages details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	17:25:11	0°	19° (NNE)	2.924	5,7	-5,9°
raggiunge l'altezza di 10°	17:27:33	10°	28° (NNE)	2.012	4,8	-6,1°
Culmina	17:31:36	36°	96° (E)	1.003	3,2	-6,5°
Cala sotto l'altezza di 10°	17:35:38	10°	163° (SSE)	1.999	5,1	-6,9°
Tramonta	17:37:58	0°	172° (S)	2.902	6,0	-7,1°

Tab 13 COSMO Sky-Med Kiruna first passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	19:01:33	0°	22° (NNE)	2.923	5,9	-14,9°
raggiunge l'altezza di 10°	19:03:45	10°	20° (NNE)	2.013	5,1	-15,1°
Culmina	19:08:06	68°	298° (ONO)	679	2,9	-15,5°
Cala sotto l'altezza di 10°	19:12:26	10°	216° (SO)	2.000	5,4	-15,9°
Tramonta	19:14:37	0°	214° (SO)	2.904	6,2	-16,1°

Tab. 14 COSMO Sky-Med Kiruna second passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	20:37:42	0°	28° (NNE)	2.923	6,1	-23,1°
raggiunge l'altezza di 10°	20:40:09	10°	17° (NNE)	2.013	5,4	-23,3°
Culmina	20:43:47	26°	321° (NO)	1.240	4,8	-23,5°
Cala sotto l'altezza di 10°	20:47:24	10°	265° (O)	2.005	5,7	-23,8°
Tramonta	20:49:50	0°	253° (OSO)	2.909	6,5	-24,0°

Tab. 15 COSMO Sky-Med Kiruna third passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	22:13:22	0°	41° (NE)	2.922	6,3	-28,9°
raggiunge l'altezza di 10°	22:16:20	10°	19° (NNE)	2.013	5,7	-29,1°
Culmina	22:18:51	15°	344° (NNO)	1.688	5,6	-29,2°
Cala sotto l'altezza di 10°	22:21:22	10°	308° (NO)	2.010	5,9	-29,3°
Tramonta	22:24:20	0°	286° (ONO)	2.916	6,6	-29,4°

Tab. 16 COSMO Sky-Med Kiruna fourth passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	23:48:17	0°	62° (ENE)	2.920	6,3	-31,2°
raggiunge l'altezza di 10°	23:51:26	10°	38° (NE)	2.012	5,8	-31,2°
Culmina	23:53:39	14°	7° (N)	1.768	5,7	-31,2°
Cala sotto l'altezza di 10°	23:55:51	10°	337° (NNO)	2.012	5,9	-31,2°
Tramonta	23:59:00	0°	312° (NO)	2.920	6,5	-31,1°

Tab. 17 COSMO Sky-Med Kiruna fifth passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	01:22:44	0°	93° (E)	2.915	6,3	-29,2°
raggiunge l'altezza di 10°	01:25:23	10°	77° (ENE)	2.009	5,6	-29,1°
Culmina	01:28:34	20°	30° (NNE)	1.454	5,2	-29,0°
Cala sotto l'altezza di 10°	01:31:45	10°	344° (NNO)	2.013	5,7	-28,8°
Tramonta	01:34:23	0°	328° (NNO)	2.922	6,4	-28,7°

Tab. 18 COSMO Sky-Med Kiruna sixth passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	02:57:34	0°	130° (SE)	2.909	6,1	-23,7°
raggiunge l'altezza di 10°	02:59:50	10°	124° (SE)	2.004	5,4	-23,5°
Culmina	03:03:58	44°	53° (NE)	873	3,7	-23,2°
Cala sotto l'altezza di 10°	03:08:07	10°	342° (NNO)	2.013	5,4	-22,9°
Tramonta	03:10:23	0°	336° (NNO)	2.923	6,2	-22,7°

Tab. 19 COSMO Sky-Med Kiruna seventh passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	04:33:36	0°	171° (S)	2.905	6,0	-15,6°
raggiunge l'altezza di 10°	04:35:49	10°	175° (S)	2.002	5,1	-15,4°
Culmina	04:40:07	59°	255° (OSO)	730	2,6	-15,0°
Cala sotto l'altezza di 10°	04:44:27	10°	336° (NNO)	2.013	5,1	-14,6°
Tramonta	04:46:42	0°	340° (NNO)	2.923	5,9	-14,4°

Tab 20 COSMO Sky-Med Kiruna eighth passage details.

Evento	ora	Altezza	Azimut	Distanza (km)	Magnitudine	Altezza Sole
Sorge	06:11:23	0°	215° (SO)	2.907	5,7	-6,4°
raggiunge l'altezza di 10°	06:14:13	10°	234° (SO)	2.004	4,8	-6,2°
Culmina	06:17:11	18°	278° (O)	1.557	4,0	-5,9°
Cala sotto l'altezza di 10°	06:20:11	10°	321° (NO)	2.012	4,7	-5,6°
Tramonta	06:23:02	0°	341° (NNO)	2.923	5,7	-5,4°

Tab. 21 COSMO Sky-Med Kiruna ninth passage details.

In the table 22 we have fused all three station visibility time windows, cutting the time interval in which there are visibility time overlap between two or more station, and we have calculated the time and data volume performances, assuming an uncoded BPSK modulation for the data. So, for the hypothesis done before, we have used a data rate of 173 Mb/s to calculate system capacity without ISL. As you can see from the analysis results, COSMO performances (450 images a day) are essentially due to the compression and modulation algorithm, in fact with a simple BPSK modulation, in absence of coding and image compression algorithm, the performances in term of data volume are scarce. With the ISL in ka-band with tracking system or in SHF-band with a tracking system we can obtain a triple capacity than in this case. We also have a response time improvement: both for the growth of the capacity system with the same modulation and data processing algorithm, and for the

restriction of time latency necessary to have the satellite in visibility to uplink/downlink data. If you look at the figure number: 48,49 and 50 you can see that maximum latency time you have to wait between two consecutive COSMO passages is 1 hour and 28 minutes if you consider three stations. With the ISL in ka-band or SHF-band you have to wait at most for 40 minutes. This time latency is very important not only for visibility reasons, but also because you can have the worst case downlink condition in which the bits of a single images take more than a single passage to be downloaded, so to have the image you have to wait for the download time plus the time latency between two consecutive passages.

COSMO Sky-Med performances IN 24 H with three ground station						
TIME WINDOW	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED	NUMBER OF IMAGES	NUMBER OF TC
1	476	173000000	82348000000	41174000000	5,14675	164696
2	522	173000000	90306000000	45153000000	5,644125	180612
3	146	173000000	25258000000	12629000000	1,578625	50516
4	435	173000000	75255000000	37627500000	4,7034375	150510
5	303	173000000	52419000000	26209500000	3,2761875	104838
6	267	173000000	46191000000	23095500000	2,8869375	92382
7	383	173000000	66259000000	33129500000	4,1411875	132518
8	499	173000000	86327000000	43163500000	5,3954375	172654
9	209	173000000	36157000000	18078500000	2,2598125	72314
10	520	173000000	89960000000	44980000000	5,6225	179920
11	230	173000000	39790000000	19895000000	2,486875	79580
12	360	173000000	62280000000	31140000000	3,8925	124560
13	356	50000000	17800000000	8900000000	1,1125	35600
TOT	4706	173000000	8,14138E+11	4,07069E+11	50,883625	1628276

Tab. 22 COSMO Sky-Med performances without ISL.

What you see in violet are kiruna visibility windows, in light blu you can see Pratica di Mare passages and in green the only one time interval of Cordoba station. The amount of downloaded images is calculated by halving the total amount of downloaded bits, because we have taken into account the Viterbi coding, and by dividing the amount of useful downloaded bits by 8 Gb which is the number

of bits which composes an image. The amount of uplinked telecommand (TC) is calculated assuming for the uplink the same performances of the downlink, so by dividing the amount of useful downloaded bit by 250 kb which is the amount of bit (without coding) which composes a TC message. We have done the analysis on a single COSMO Sky-Med satellite to find the best design for the payload antennas which optimizes a single satellite performances. Obviously, the design upgrade could be applied to all the satellites of the constellations to get a greater performances improvement.

COMPARYING DAILY SYSEMS PERFORMANCES							
SYSTEM	DURATION (s)	DATA RATE (b/s)	DOWNLOADED BITS	USEFUL DOWNLOADED BITS	NUMBER OF IMAGES	NUMBER OF TC	MAX DT BETWEEN TWO PASSAGES (s)
COSMO Sky-Med without ISL	4706	173000000	8,14138E+11	4,07069E+11	50,883625	1628276	5280
COSMO Sky-Med with SHF-band ISL	60822	400000000	2,43288E+12	1,21644E+12	152,055	4865760	2400
COSMO Sky-Med with Ka-band ISL	60822	500000000	3,0411E+12	1,52055E+12	190,06875	6082200	2400

Tab. 23 Comparison between COSMO Sky-Med actual performances and ISL technologies application.

As you can see from the table 23, ISL gives a precious contribution both in response time performances (thanks to DT reduction and time windows visibility duration improvement) and, consequently, in daily downloaded data volume. If you notice that, for the Tasking Mission, only one station is enabled to uplink the mission plans (Fucino station), the ISL contibution appear more and more important. In fact, Fucino station, whose visibility windows are reported in figure 54, has a latency time (DT), in the worst case, of 13 hours and 20 minutes. So reaction time, that takes part in response time formula, gets worst and worst because of both data latency necessary for the images download (which can use three station so DT in this case il lower than for the tasking missions) and the time interval for uplinking a new mission plan.

25 feb	5,0	19:11:14	10°	NNO	19:14:43	24°	ONO	19:18:11	10°	OSO	visibile
26 feb	4,7	04:30:16	10°	SE	04:33:55	27°	ENE	04:37:35	10°	N	visibile
26 feb	3,5	06:06:16	10°	SSO	06:09:59	28°	O	06:13:45	10°	NO	visibile
26 feb	5,6	19:29:55	10°	NNO	19:32:36	16°	ONO	19:35:15	10°	OSO	visibile

Figure 54 Fucino station visible passages of COSMO Sky-Med satellite in 24h.

Conclusions and Future Developments

ISL contribution on time performances in uplink/downlink data to and from LEO Earth monitoring satellite is very precious: the reduction of tasking and data relay time performances is the added value of an ISL. We have demonstrated that tasking mission is possible for each RF studied band (UHF, S, SHF, Ka) and that data relay mission could be performed in an optimal way by using an RF Ka ISL tracking payload. In addition, with reference to COSMO time performances, we have demonstrated that with the simplest modulation (BPSK) and without any coding and compression algorithm, the same system could have a triple capacity in term of data volume even if we have use a lower data rate than the one allowable for LEO-ground stations links. Data rate maximum value in the RF ISL, which we have designed, is limited by SICRAL existing payload. We have decided to use in a dual way the technologies that we already have in order to cut costs in term of both design and implementation costs and maintenance costs (which is the main cost factor of the usage of several ground stations for data download). The paper shows that our idea is an actuable solution to implement the ISL with a great savings instead of OISL technology. Surely, future Defence Earth monitoring satellite should have ISL technology, but the possibility to implement this function with an RF link should be taken into account for the extreme flexibility which permits an halving of costs because of the double use of the same payload, which with OISL could not be possible. Future developments could be done with the aim of increasing ISL performances in terms of data rate and timing: higher frequency and so higher bandwidth can be considered, for example Q/V or W bands; better technology in terms of antenna tracking and power managing could be used; innovative and optimized modulation and coding, within compression algorithm, should be developed.

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