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Handbook on Small Satellites

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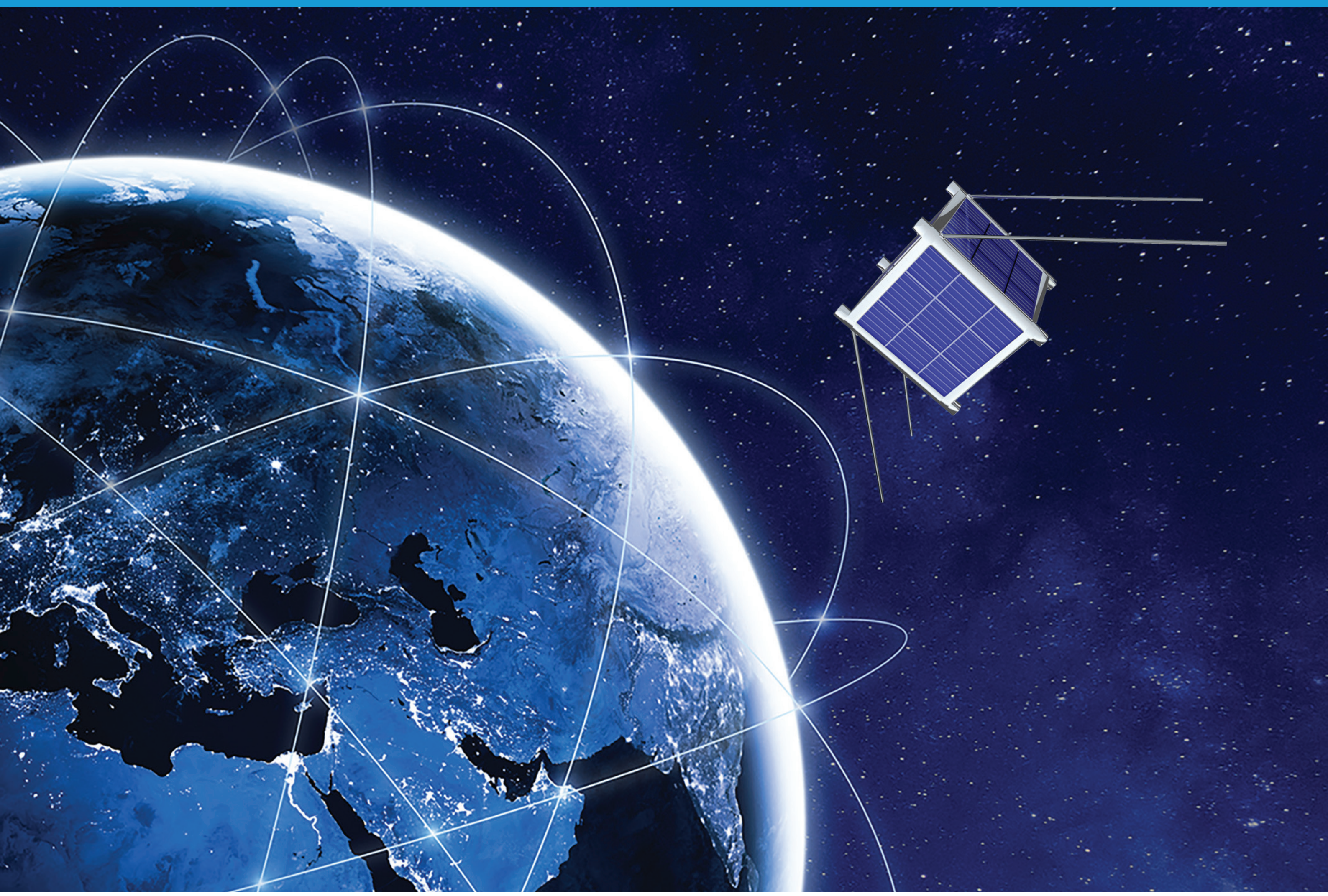

Handbook

on

Small Satellites

Edition of 2023
ITU-R

Preface

The ITU-R Handbook on Small Satellites was developed in response to Resolution ITU-R 68 on "Improving the dissemination of knowledge concerning the applicable regulatory procedures for small satellites, including nanosatellites and picosatellites". The use of small satellite technology is becoming an increasingly powerful tool with multi-missions, functions and capabilities, which can be fundamental to support the needs of those requiring seamless services on a worldwide basis. This trend in the adoption of small satellite technology, while "democratizing" space for all nations irrespective of their economic status, also plays a role in helping these nations achieve the UN sustainable development goals. Therefore, this stand-alone Handbook is intended to promote the development of small satellites effectively and better serve the needs of the membership and the entire satellite industry.

The Bureau published Circular Letter 4/LCCE/130 on 29 April 2021, inviting proposals for an ITU-R Small Satellite Handbook from both ITU-R members and non-members, with the purpose of increasing international cooperation, awareness-raising, regulatory guidance, technical assistance, and interference-free operations. In that regard, and considering that the work on the development of this ITU-R Small Satellite Handbook could highly benefit from the submission of proposals not only from Member States of the ITU, Radiocommunication Sector Members, ITU-R Associates participating in the work of Radiocommunication Study Group 4 and ITU Academia, but also from other organizations/entities which are not members of ITU-R, attention is drawn to the provisions of Resolution ITU-R 9-6 on "Liaison and collaboration with other relevant organizations, in particular ISO, IEC and CISPR".

The Bureau also established a webpage for the "Small Satellite Handbook" to facilitate the submission of proposals and to provide details of the on-going work, related resolutions/reports/documents, contact information and other relevant information on the development of the ITU-R Small Satellite Handbook.

This Handbook was developed within the ITU-R Working Party 4A (WP 4A) of Study Group 4 (SG 4) as the group responsible for this work.

This first edition of the Handbook on Small Satellites is the success story of international cooperation amongst qualified and skilled experts in the field of small satellites and its regulations. The nine chapters and two Annexes describe in detail the technology, regulatory elements and some practices of small satellites.

Chapter 1 highlights the purpose of the Handbook and provides a brief introduction on small satellite systems, including classification of small satellites by their mass.

Chapter 2 describes characteristics of space and ground segments of small satellite systems and orbital types where small satellites are typically deployed in.

Chapter 3 describes ITU radio regulatory procedures related to small satellites. It commences with a concise introduction of the International Telecommunication Union (ITU) and fundamental principles governing the utilization of radio-frequency spectrum. Additionally, it delineates the ITU regulatory procedures for non-geostationary (non-GSO) satellite systems that are both subject and not subject to coordination, along with various ITU filing processes, associated examinations of filings and thereafter the subsequent implementation of bringing into use of frequency assignments. The chapter also incorporates the World Radiocommunication Conference (WRC) decisions concerning regulatory matters on small satellites and highlights potential challenges that may be encountered by small satellite operators.

Chapter 4 describes the various services and radio-frequency spectrum that may be suitable for operations of small satellites, such as, but not limited to, space operation service, amateur-satellite service, Earth exploration-satellite service, meteorological service, space research service, fixed-satellite service and mobile-satellite service.

Chapter 5 provides an overview of the diverse range of missions that can be accomplished with small satellites, including scientific, educational, experimental, amateur-satellite, commercial missions. This Chapter also delves into missions related to the moon, inter-planetary and deep space exploration, as well as short-duration missions.

Chapter 6 focuses on the importance of space object registration as a crucial aspect of the responsibility and liability of a satellite mission, both at the national and international levels.

Chapter 7 provides an overview of current launch vehicle capabilities and considerations for launching small satellite. The chapter includes a discussion of various launch vehicles as well as its multi-launch services.

Chapter 8 explains space debris mitigation and emphasizes the guidelines that apply to mission planning, the operation of newly designed spacecraft and orbital stages and potentially to existing ones.

Chapter 9 shares some examples of small satellite systems related to various missions, such as scientific, educational, experimental, amateur-satellite and commercial missions. The chapter also includes national projects and missions.

Annex A lists the abbreviations used in this Handbook.

Annex B lists the references that can be consulted for additional details.

This Handbook, along with other relevant ITU publications, will serve as a valuable resource and practical tool to support countries in their endeavours to develop and advance their small satellite capabilities and enhance the quality of space services offered.

Foreword

The development of this ITU-R Handbook on Small Satellites is an important contribution to the common efforts of the Union to disseminate information, raise awareness and extend international cooperation among all ITU Member States, entities and organizations, on their current practices and applications. This Handbook will also be essential to promote the adoption of small satellite technologies on a worldwide basis.

It is fitting that, Dr Ali R. Ebadi, a veteran with more than 30 years' experience in the satellite industry and the key technical expert behind the development of the Malaysian satellite systems, has taken the lead for the development of this Handbook. He has done a commendable job of summarizing the collective knowledge about this interesting and complex subject. A readable volume which will be invaluable to administrations and new entrants with information on the relevant space services with allocated radio-frequency spectrum, types of small satellites, characteristics of space and earth segments, types of missions, space object registration, launch considerations, as well as space debris mitigation.

This ITU-R Handbook on small satellites should be considered as a dynamic document that will be continually updated based on new technologies and their applications, as well as evolving regulations and procedures related to the use of the radio-frequency spectrum and satellites orbits.

I am immensely grateful to Dr Ali R. Ebadi and all the individuals involved in the development of this remarkable Handbook, as it stands as a testament to their dedication and expertise. I hold firm confidence that this comprehensive resource will not only serve as a cornerstone for enhancing the understanding and utilization of small satellites, but also make a substantial contribution to the advancement of the global satellite industry.

Mario Maniewicz
Director, Radiocommunication Bureau (BR)

Acknowledgement

We would like to express appreciation to all ITU Member States, Sector Members and companies who supported the development of this Handbook for their contributions and participation at the WP 4A meetings.

We would like to express our sincere appreciation to Mr Victor Strelets, Chairman of the ITU-R Study Group 4 for his encouragement and confidence in me as the Editor of this Handbook. Special thanks and appreciation to Mr Jack Wengryniuk, Chairman of the ITU-R Working Party 4A (WP 4A) and Mr Nelson Malaguti, Counsellor of the WP 4A for their valuable guidance and support during the WP 4A meetings.

Sincere thanks to Ms Ellie Xiuqi Wang and her colleagues of the ITU Radiocommunication Bureau for their hardworking and valuable contributions to various sections, especially the regulatory parts, of the Handbook.

Special commendations to Ms Geetha Remy Vincent, my colleague at MEASAT, who worked diligently and tirelessly from the inception of the project to ensure that the draft of the Handbook conforms to ITU's impeccable standards and quality.

Appreciation is also extended to MEASAT Satellite Systems Sdn. Bhd. for supporting my work with the ITU to produce this Handbook.

We take this opportunity to acknowledge the following organizations and administrations (in alphabetical order) for their numerous voluntary contributions, their meticulous interventions, and diligent efforts:

- Administration of Saudi Arabia (Kingdom of)
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- Administration of the United States of America
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We would also like to thank many others who have contributed to the Handbook by participating in meetings and providing fruitful advice and comments.

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Editor of the ITU-R Handbook of Small Satellites

TABLE OF CONTENTS

Page

CHAPTER 1

1 Introduction

The launch of the first artificial Earth “small” satellite, Sputnik 1, triggered the space race in 1957. In the decades that followed, there were the development of increasingly larger satellites in order to provide reliable services from space over extended periods of time. Since then, with the increasing demand of radio-frequency spectrum and satellite-orbit usages and sustained growth of technological breakthroughs and innovation of space communication along with the booming capabilities in satellite manufacturing, a dramatic rise in the development of small satellites and systems has been witnessed, especially over the last ten years. The small satellite industry is experiencing an era of unprecedented change.

The term “small satellite”, including minisatellite, microsatellite, CubeSat, nanosatellite (nanosat), picosatellite (picosat), femto-satellite (femtosat) and others, is becoming increasingly common and widespread, even though there is no legal or regulatory definition of this term.

The term “small” generally refers to the size and/or mass, but these aspects are not relevant with respect to frequency and orbit regulations, and therefore does not have impact on the international regulatory framework. The agreed term or definition for “small satellite” will be elaborated in section 1.3 of this Handbook and may be sent to the Coordination Committee for Vocabulary (CCV) to be included in the relevant ITU vocabulary database.

In the field of small satellites, the technical and capital barriers to entry are often low, and small satellite development can be more affordable and rapid for various entities (start-ups, universities, research institutions, etc.) due to their lower cost, simpler design, flexible launching requirements and modular payload configurations. The development of small satellites is an evolution in the overall satellite industry, which provides opportunities for greater and easier access to, and use of, space services by all countries.

Governments and private enterprises are developing small satellite projects to promote not only the traditional satellite applications in data communications, Earth exploration, space research, monitoring of ground environment including climate change and global warming, space environment monitoring, satellite navigation and positioning, education, agriculture, forestry, disaster recovery, scientific experiments, testing innovative technologies, national defence, but also the development of multi-satellite fleets (constellation) for the satellite internet access, and further enabling integration with 5G, the Internet of Things (IoT), smart cities, business intelligence and many other areas in completing various difficult tasks in space. The vast range of possible diverse applications stems from a number of small satellite characteristics that can be summarised as follows:

– rapid build/launch cycle;
– affordable projects with low capital investment and operating costs;
– modular and standardized design (e.g. CubeSats standard);
– lower latency due to lower orbits;
– seamless coverage to all areas of the world when used in constellations;
– easy to expand, update, renew, augment and replenish the satellite fleet.

In recent years, small satellites have been steadily launched, which gradually proved the feasibility of small satellite constellations. The small satellite industry has seen an incredible surge in the number of small satellites launched over the last few years. Small satellites with advanced technology, artificial intelligence (AI), and machine learning in the future are likely to bring new features to the field of satellite communications.

The use of small satellite technology is also becoming an increasingly powerful tool with multi-missions, functions, capabilities, which can be fundamental to support those that need seamless services on a worldwide basis. This trend in the adoption of small satellite technology, while “democratizing” space for all nations irrespective of their economic status, also plays a role in helping these nations achieve the sustainable development goals (SDGs).

In view of the diverse usages of small satellites, this field may attract new entrants lacking knowledge of, or experience with, the ITU and the ITU Radio Regulations and related procedures. An ITU-R handbook addressing various elements including regulations, procedures, and key information of small satellites including short-duration mission satellites in similar applicable situations, would be useful to administrations, satellite operators, manufacturers and service providers interested in operating or utilizing such small satellites.

It is noted that there already exists a training mechanism in ITU for various areas. Training programs on radio communication have been organized and conducted on a regular basis, including the biennial ITU World Radiocommunication Seminar and thematic regional workshops. However, these seminars and workshops rarely target specifically the application of the Radio Regulations in the research, launch and application of small satellites.

Studies had been carried out under ITU-R Working Party 7B in response to Question ITU-R 254/7 and Reports, such as ITU-R SA.2312, ITU-R SA.2348, ITU-R SA.2425 and ITU-R SA.2426 (see section 4.9), have been generated focusing on the characteristics and spectrum requirements, as well as practice situation for notifying nano and pico-satellites. However, it has been expressed that a more detailed guidance on the regulatory environment and procedures for new operators and service providers in this field is needed in response to the provisions of Resolution ITU-R 68.

In view of the above, this stand-alone Handbook, separate from the more general Satellite Communications Handbook or Mobile-satellite service (MSS) Handbook, has been generated by the ITU-R to effectively promote development of small satellites and better serve the needs of the membership and the whole satellite industry.

1.1 Purpose of this Handbook

Based on the above reflections and observations, the purposes of this Handbook on Small Satellites are as follows:

– to extend international cooperation among all ITU Member States, entities and organizations for the development and rational use of small satellites;

– to promote the adoption of small satellite technologies on a worldwide basis while striving to meet in a rational, equitable, effective, efficient, economic, and timely way of use of radio-frequency spectrum and satellite-orbit resources;

– to provide a detailed guidance on the regulatory environment and procedures, specifically the application of the Radio Regulations, for administrations, small satellite operators and service providers in the study/research, design, launch and application of small satellites;

– to promote and to offer technical assistance to developing countries, enterprises and individuals in the field of small satellite utilization;

– to help administrations/new entrants with information on the relevant space services with allocated radio-frequency spectrum, characterization and description of small satellites, characteristics of space and Earth segments, types of missions, space object registration, launch considerations, as well as space debris mitigation;

– to raise international awareness on current practices and applications with key drivers, restraints, challenges, and opportunities;

– to ensure interference-free operations of small satellite systems by implementing the Radio Regulations and regional agreements, as well as updating the system in an efficient and timely manner through the processes of world and regional information sharing and cooperation;

– to provide a reference tool for satellite operators and service providers interested in operating or utilizing such satellites, as well as national regulators to manage the small satellite applications.

1.2 Vocabulary of key terms used in this Handbook

The abbreviations and acronyms used in this Handbook are defined in Annex A.

Typically, the radio-frequency spectrum within the frequency range 3 kHz to 3 000 GHz is subdivided into nine frequency bands as defined in RR Article **2**. However, the radio-frequency spectrum is also commonly referred to in terms of frequency bands in the Institute of Electrical and Electronics Engineers (IEEE) standard. Those following terms are included here because they are used often in this Handbook and their understanding should be unambiguous.

Band	**Frequency ranges**
L-band	1-2 GHz
S-band	2-4 GHz
C-band	4-8 GHz
X-band	8-12 GHz
Ku-band	12-18 GHz
K-band	18-26.5 GHz
Ka-band	26.5-40 GHz
Q-band	40-50 GHz

1.3 Historical perspectives on small satellite

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

In the late 1980s, a new satellite paradigm, modern small satellites arose and opened up a new class of space applications. The major design problems and constraints influencing the design of a small low-cost satellite bus are identified using the subsystem approach. Key design areas include the improvement of battery technology and the development of a deployable solar array, attitude control assemblies, onboard data processing/storage and ground station data acquisition. Although the eventual satellite would also have to be somewhat larger, more powerful and, above all, more sophisticated than the previous small satellites, this is considered to be a natural progression of research in this area, and form part of a more detailed future study.

Over the past few years, satellite industry has developed an integrated suite of satellite subsystems and small satellite buses. The subsystems include communications, attitude sensing and control, power conversion and distribution, and onboard data handling. They are inherently modular and readily adaptable to different satellite configurations, a concept known as semi-standardization. This concept has been adopted by two generic low-cost buses: MicroSIL for satellites in the mass range 40-80 kg; and MiniSIL for satellites in the range 100-500 kg. Their architecture is based on the semi-standard subsystems, but easily modified to utilize sub-systems from other manufacturers. They can support all stabilization methods including spinning, three-axis control and gravity gradient and are adaptable to a wide variety of missions including Earth exploration, space research, educational, scientific and experimental missions, communications and technology demonstrations.

Recently, a great many small satellite systems are based on a constellation of tens (in some cases hundreds) of small satellites launched or to be launched over the next few years. Consequently, large numbers of spacecraft need to be produced in a very short time. The traditional concept for space production is no longer adequate to meet the requirements of these new systems and so a new approach to Assembly, Integration and Testing (AIT) is needed that satisfies the intensive production rate demands but without introducing complete process automation. The space industry is moving towards a future with large constellations of small satellites capable of providing all types of services in large geographical areas or across the globe.

1.4 Types of small satellites

Presently, a legal or regulatory definition of a small satellite does not exist. However, satellites may be grouped into different categories based on their mass, mission duration, functional density and others.

The small satellite segment takes benefits from recent innovations in particular miniaturization and commercial off-the-shelf EEE (Electrical, Electronic and Electromechanical) part technologies (e.g. from automotive) providing highly integrated features with low power, low mass and compact form factor.

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

– Minisatellites: usually in the range 100-500 kg, this category generally targets cost effective operational missions; this form/ factor offering and enabling technical capacity together with low cost and also adapted to mass production for constellation-based systems.

– Microsatellites: usually with a wet mass of less than 100 kg; the satellites may have reduced capabilities (e.g. pointing, lifetime) though with payloads that support viable business cases. This category lends itself to multi-satellite applications, to achieve high revisit or improved availability for users.

– Nanosatellites: this category has been originally developed and promoted through the "CubeSat" family, starting from the 1U form factor (about 1 litre for a mass of about 1 to 1.2 kg). The nanosatellites have now evolved to greater satellite capacity through increased mass and volume up to 12 to 20 U form factor, allowing more ambitious missions.

– Picosatellites: very small satellites with a mass range from 0.1 to 1 kg, offering very limited individual capacity but can provide interesting mission features from formation flying configuration with multiple collaborative picosatellites working together, potentially in collaboration with a bigger "mother" satellite.

– Femto-satellites: Taking benefits from very advanced nanotechnology, very small-scale satellites of less than 100 grams have been designed over the last fifteen years. Most of these small satellites have been used as companion with "mother" satellites that provide operating signals (some recent femto-satellites being able to operate independently).

Report ITU-R SA.2312 (09/2014) also classifies satellites by their mass as shown in Table 1.

TABLE 1

Typical characteristics of small satellites

Denomination	Mass (kg)	Max. bus power (W)	Typical cost (USD)	Max. dimensions (m)	Development time (years)	Orbit	Mission duration (years)
Minisatellite	100-500	1 000	30-200 M	3-10	3-10	GEO MEO LEO HEO	5-10
Microsatellite	10-100	150	10-150 M	1-5	2-5	LEO (HEO)	2-6
Nanosatellite	1-10	20	100 k-10 M	0.1-1	1-3		1-3
Picosatellite	0.1- 1	5	50 k-2 M	0.05-0.1			
Femto-satellite	< 0.1	1	< 50 k	0.01-0.1	1		< 1

Note: This Table, based on the above Report, is dated 2014 and the figures mentioned may need to be updated based on statistics as much as available in future revisions of this Handbook.

It is also mentioned in the Report that size and/or mass are not really the issue from a frequency management viewpoint, while factors such as mission duration, orbital uncertainty, low satellite equivalent isotropic radiated power (e.i.r.p.) and speed of development are rather more important factors.

In addition to those categorizations mentioned in Table 1 above, CubeSat is a class of miniaturized satellite based around a standardized form factor consisting of 10 cm × 10 cm × 10 cm cube (1 unit or "1U"). The smallest existing CubeSat size is 0.25U and the largest is 27U. The most common form factor was the 3U. Larger form factors, such as the 6U and 12U, are composed of 3Us stacked side by side. CubeSats typically weigh between 0.2 and 40 kg and often employ commercial off-the-shelf (COTS) components for their electronics and structure.

The essential purpose of the CubeSat standard, established by California Polytechnic State University

(CalPoly) and Stanford Universities in 1999, was aimed at enabling affordable missions for educational goals. This standard definition allowed emergence of a dedicated eco system offering very low-cost standardized components such as structures, common functions electronics or launch canisters thanks to scaling effects. As a consequence, it also reduced CubeSats launch costs.

From the mission duration aspect, non-geostationary (non-GSO) satellite system could be divided by long and short-duration missions. Long duration missions are usually large constellations and commercial projects generally with significant capital investments. Short-duration missions have a maximum mission lifetime of three years and are generally consisted of one satellite or small number of satellites in the constellation, and normally for non-commercial usage or in early start-up phase.

1.5 Systems engineering of small satellites

Systems engineering is concerned with the overall performance of a system for multiple objectives (e.g. mass, cost, and power). The system engineering process is a methodical approach to balancing the needs and capabilities of the various subsystems in order to improve the performance of the system. The size, volume, and mass constraints often uncounted in small satellite development programs, combined with increasing pressure from customers to pack more capability into a given size, make system engineering methods particularly important for small satellites.

The characteristics of a small satellite can differ from those of traditional large satellites in a number of ways:

– small satellite often has fixed solar arrays instead of sun-tracking solar arrays;
– small satellite often does not have deployable solar panels and antennas;
– small mass leads to recurred thermal inertia;
– small size leads to reduced power generation and storage capabilities;
– volume can be tightly constrained;
– surface area for the payload or bus of a small satellite can be at a premium;
– small satellite uses smaller components, new technologies, e.g. micro-electromechanical system (MEMS), and non-traditional vendors.

These differences mean that although the process used to design small and large satellites is similar, the elements and development time required to be considered are extremely different.

CHAPTER 2

2 Characteristics of small satellite systems

Similar as large satellite system, small satellite system also consists of mainly two segments, space segment and ground segment. In comparison with large satellite system, typical characteristics of small satellite system include:

a) reasonably short development times;

b) relatively small development teams;

c) modest development and testing infrastructure requirements; and

d) affordable development and operation costs for the developers, in other terms “faster, cheaper and smaller”.

The small satellite form factor is considered to offer a new approach for fast deployment of low-cost space systems with increased risks compared to classical larger satellites, for example, small satellites have no or limited redundancy, reliability and quality from commercial parts. Accordingly, small satellites could be offered at lower price/performance level than larger satellites, and thus, greatly reducing the barrier to entry for new ideas to be implemented and increasing the space-related economy. Over time, the pace of technological innovation, and adoption of standards and procedures more akin to consumer electronics means that price continues to go down and performance continues to go up.

2.1 Space segment

The space segment of a satellite system is one of the two operational components (the other being the ground segment). It comprises the satellite or satellite constellation and the uplink and downlink satellite links.

The spacecraft itself constitutes the space segment, along with any other links with other space stations. A spacecraft is frequently described in terms of a payload and a service module or “bus”. The capability of a satellite bus relates to its ability to accommodate payloads and to meet mission requirements.

Payload accommodation requirements are many and include mass; geometry (volume, mechanical interfaces, fields of view); thermal interfaces; power (wattage, voltages, duty cycles); data (rates, interfaces); contamination environment; electromagnetic interference limits; and spacecraft pointing knowledge and control (slewing and settling rates, stability, jitter).

The mission architecture places further requirements on the spacecraft bus such as on-board data processing; data memory and communication links; battery capacity; and the need for propulsion (orbit insertion, orbit maintenance, formation flying, end-of-mission de-orbit). Additional mission requirements include spacecraft life (expendables, radiation dose, and solar array degradation); reliability; and degree of redundancy.

Generally, a spacecraft bus includes many subsystems: propulsion; thermal control; power and power distribution; attitude control; telemetry command and control; transmitters/antenna; computers/on-board processing/software; and structural elements.

All space missions are constrained by launch vehicle performance (mass to orbit) and fairing – i.e. the aerodynamic cover that protects the spacecraft as it travels through the atmosphere – volume. These constraints can be severe for small expendable launch vehicles and can lead to complex designs for “deployable” (such as the solar panels) in order to stow the satellite within the fairing. Within these constraints, the satellite designer generally wants to maximize resources available to the payload and minimize those required for the spacecraft bus. Consequently, much small satellite technology development effort has been directed toward reducing bus volume, mass, and power consumption, while providing robust capability by increasing battery capacity, solar array efficiency, data memory, processing rates, and so on. This trend is likely to continue in avionics as well as in the still embryonic field of microminiature electromechanical systems. Small satellite technology has already advanced to the point where a great deal of capability can be provided in a relatively small package.

Small satellites are naturally limited in the equipment, functions and capabilities that they can accommodate. Typically, the minimum functionalities in the platform are:

– The power control subsystem that generates, stores, regulates and distributes the electrical power for the operation of the spacecraft and especially of the payload. This includes the solar panels, often deployable to allow for larger area, and the batteries in small satellites can provide power of tens to hundreds W up to 1 kW maximum.

– The Attitude and Orbital Control System (AOCS) that determines and controls spacecraft attitude, pointing and orbit position.

– The Telemetry, Tracking and Command (TT&C) subsystem that communicates with the satellite control centre for remote control and also tracking of the satellite. For small satellites the TT&C link is mostly in the S-Band occasionally also in permitted UHF/VHF-bands.

– The propulsion subsystem to provide thrust capability to adjust orbit and attitude. Small satellites often have very limited chemical or electric propulsion systems (with a limited supply of propellant), if at all. This may put significant constraints on its lifetime and its ability to maintain its orbit precisely.

Depending on the mission, the small satellites carry dedicated payloads that are also limited by the allowable size, weight and power of the satellite. Typical payloads could include:

– Telescopes for electro-optical Earth observation – where typically the size of the telescope is limited by the satellite size

– Radio Frequency (RF) sensors and specifically Synthetic Aperture Radar (SAR) payloads, where both size as well as available power for active instruments like radar is constrained

– Satellite communications payloads with suitably sized and shaped antennas – for bidirectional links between the small satellite and user ground terminals on the one side and (feeder) gateway stations on the other side.

One means to overcome the size limitations is to implement deployable structures like antennas on the small satellites.

2.2 Ground segment

The Ground Segment includes all the ground-based elements that are used to collect and disseminate information from the satellite to the user. The primary elements of a ground system include ground stations which provide telemetry, tracking, and command interface with the spacecraft, ground networks which provide connection between multiple ground elements, control centres which manage the spacecraft operations, remote terminals which is the user interface to retrieve transmitted information for additional processing.

The ground segment design can depend on a number of factors which may include, but are not limited, to the following:

– data volume to satisfy mission requirements;

– location of the ground assets relative to mission orbit parameters;

– budget limitations;

– distribution of the team;

– affiliation of who controls the spacecraft;

– regulatory requirements.

The ground system is responsible for collecting and distributing the most valuable asset of the mission: the data. Using the proper ground system is key to the success of the mission.

2.2.1 Ground systems for high end of small satellites landscape (>100 kg)

For the high end of small satellites landscape (>100 kg), ground systems are very similar to the one of larger satellites.

A ground system includes all the ground-based elements that are used to command and control the spacecraft, prepare its payload and mission and collect, process and disseminate data from the satellite to the user.

– The ground-based communication is ensured by ground stations, which provide TT&C interface with the spacecraft.

– A ground network provides the connectivity between ground elements that can be located in different areas, depending on mission needs.

– The control centre manages the spacecraft command-control, health monitory and daily operations. It provides the means to acquire, store, display and manage satellite telemetry and to send telecommands to the satellite. It generally also includes the Flight Dynamics System (FDS) that is used to determine the satellite orbit using ranging data, as well as navigation data from Global Navigation Satellite System (GNSS) telemetry, and to define the orbit control manoeuvres parameters when satellite manoeuvres are needed (orbit maintenance, station keeping as well as collision avoidance manoeuvres).

In addition to this, a control centre generally contains some high-level management software that ease or automate operations (schedule management, ground station management among others). When needed, cyphering/deciphering units are also used to provide secured communication features.

The control centre is generally also connected to external services that provide collision avoidance information for debris avoidance.

The control centre is also used during the satellite Launch and Early Orbit Phase (LEOP) where additional ground stations can be used (supporting stations being temporarily connected through the ground network).

– The mission centre allows operators to manage users' needs and to configure the satellite payload or to program the satellite mission plan.

– A payload data processing centre acquires payload raw telemetry data received by data reception ground stations, processes it to produce end-user information, archives it and disseminates the processed information to the end-users.

– Some additional facilities are generally used. They can be either centralized at ground segment level or implemented in each of the centres defined above, e.g. hardware infrastructure management, user management, logs management, and security management.

When a high level of automation is needed, some specific automation tools can be defined and implemented to reduce the need for manual activities (in particular for satellite constellation flight management, in order to reduce the operational costs and operator's workload as well as secure routine operations).

2.3 Orbital types

Upon launch, a satellite or spacecraft is most often placed in one of several particular orbits around Earth – or it might be sent on an interplanetary journey, meaning that it does not orbit Earth anymore, but instead orbits the Sun until its arrival at its final destination, like Mars or Jupiter.

There are many factors that decide which orbit would be the best for a satellite to use, depending on what is designed for the satellite to achieve.

The small satellites are typically deployed in low Earth orbit (LEO) but some missions are launched also on medium Earth orbit (MEO), while some demonstration missions have been deployed on geosynchronous transfer orbit (GTO). New range of small satellites are now targeting geostationary Earth orbit (GEO) / geosynchronous Earth orbit (GSO) in order to explore new missions in particular in the telecommunication domain. Some science or exploration missions are now also contemplating use of small satellites combined to "mother" satellite to bring observation diversity.

The orbital parameters of small satellite systems are mostly not different from those of traditional satellites. For very small satellites, such as nanosatellites and picosatellites, they are typically not known with a high degree of precision until late in the satellite system design due to launch opportunities as secondary payloads, and the mission objective of those satellites is some form of technology demonstration like attitude control, tether manoeuvres or simply on orbit verification of materials or electrical components, therefore they are not restricted to special orbits, as long as the communication between the earth station and spacecraft is ensured on a regular basis.

2.3.1 Geostationary / Geosynchronous Earth Orbit (GSO)

In accordance with RR No. **1.188**, No. **1.189** and No. **1.190**, the abbreviation and meaning for geosynchronous satellite, geostationary satellite and geostationary-satellite orbit are described as follows:

> **1.188** *geosynchronous satellite*: An earth *satellite* whose period of revolution is equal to the period of rotation of the Earth about its axis.
>
> **1.189** *geostationary satellite*: A *geosynchronous satellite* whose circular and direct *orbit* lies in the plane of the Earth's equator and which thus remains fixed relative to the Earth; by extension, a *geosynchronous satellite* which remains approximately fixed relative to the Earth. (WRC-03).
>
> **1.190** *geostationary-satellite orbit:* The *orbit* of a *geosynchronous* satellite whose circular and direct *orbit* lies in the plane of the Earth's equator.

The Geostationary / Geosynchronous Earth Orbit (GSO) are prograde and high-altitude orbits at 36 000 km from Earth having a period of about 24 hours and mostly operated at low inclination on equatorial plan for fixed pointing of ground antennas toward the satellite.

A spacecraft in geosynchronous orbit appears to remain above Earth at a constant longitude, although it may seem to wander north and south. The spacecraft returns to the same point in the sky at the same time each day. At any inclination, a geosynchronous orbit synchronizes with the rotation of the Earth. If you are an observer on the ground, you would see the satellite as if it is in a fixed position without movement.

While geosynchronous satellites can have any inclination, the key difference to geostationary orbit is the fact that they lie on the same plane as the equator, with an eccentricity of zero, and an inclination of less than or equal to 15 degrees. For the purpose of this Handbook, a geostationary satellite is a geosynchronous satellite with an orbit the inclination of which is less than or equal to 15° (see RR No. **A.9.6A**).

In order to perfectly match Earth's rotation, the speed of GSO satellites should be about 3 km per second at an altitude of 35 786 km. From the centre of the Earth, this is approximately 42 164 km. This is much farther from Earth compared to many satellites.

GSO is used by satellites that need to stay constantly above one particular place over Earth, such as telecommunication satellites. This way, an antenna on Earth can be fixed to always stay pointed towards that satellite without moving. It can also be used by weather monitoring satellites because they can continually observe specific areas to see how weather trends emerge there.

Satellites in GSO cover a large range of Earth so as few as three equally spaced satellites can provide near global coverage. This is because when a satellite is this far from Earth, it can cover large sections at once. This is akin to being able to see more of a map from a metre away compared with if you were a centimetre from it. So, to see all of Earth at once from GEO/GSO far fewer satellites are needed than at a lower altitude.

This GSO orbit is not really suitable for small-satellite missions, because to date the payload performance achievable from small satellites (e.g. resolution for Earth exploration instruments, or bandwidth and power for communications) is rather limited compared to that offered by classical large satellites. However, increasing numbers of small satellite (even microsat/nanosat) are now adapted or designed to enable operations on GSO, for telecommunication missions. Operations on GSO are obviously more constraining since enhanced communication are required to operate at 36 000 km, propulsion capacity also being mandatory for these missions.

Small satellites will take benefits from launch services able to provide direct GSO injection (shared ride) since the propulsion capacity (mass of propellant or electrical power, depending on the propulsion technology) to circularise the Geosynchronous Transfer Orbit (GTO) to GSO is very significant.

2.3.2 Low Earth Orbit (LEO)

A low Earth orbit (LEO) is, as the name suggests, an orbit that is relatively close to Earth's surface. It is normally at an altitude of less than 2 000 km but could be as low as 160 km above sea level[1], which is low compared to other orbits, but still very far above Earth's surface.

By comparison, most commercial aeroplanes do not fly at altitudes much greater than approximately 14 km, so even the lowest LEO is more than ten times higher than that.

Unlike satellites in GEO 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 that 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 Earth, meaning the ISS travels around Earth about 16 times a day.

Individual LEO satellites are less useful for tasks such as telecommunication because they move so fast across the sky and therefore require a lot of effort to track from ground stations. Instead, communications satellites in LEO often work as part of a large combination or constellation, of multiple satellites to give constant coverage. In order to increase coverage, sometimes constellations, consisting of several of the same or similar satellites, are launched together to create a "net" around Earth. This allows them to cover large areas of Earth simultaneously by working together.

Most small satellites are targeting LEO as more launch opportunities are offered at low altitude, in the range 500-600 km, for an affordable price compared to higher altitude orbits. The evolution of the launch market means that many more opportunities are available, from rideshare with classical primary missions to dedicated multi-satellite launches. See Chapter 7.

LEO is also well adapted to small-satellite massive constellation for broadband telecommunication when low latency is desired but global coverage requires several thousands of satellites in orbit e.g. 550 km altitude used for Starlink.

The radiation environment is less severe compared to other orbits, providing better conditions with respect to the use of commercial EEE parts (Electrical, Electronic and Electromechanical) for small satellites.

More recently, very Low Earth Orbits (vLEO) at 300 to 400 km altitude have received increasing interest especially for small satellites as they promise to offer lower latencies as well as better link budgets and signal to noise ratio due to the reduced distance to the region of interest. As the drag from the remnants of the atmosphere at these altitudes is quite large measures like a more "aerodynamic" spacecraft design and additional fuel for orbit keeping, possibly using "air-breathing" electric propulsion need to be considered to achieve suitably large lifetimes.

The popularity of LEO for satellites of all sizes, but increasingly small ones, brings its own problem of physical congestion as satellites may approach and pass each other at high speed, and if they collide, they will not only be destroyed but will create a cloud of debris that presents a risk to other satellites. The number of such conjunctions is increasing alarmingly fast, and many of the smallest satellites have no ability to manoeuvre to avoid or evade.

In the longer-term LEO orbits can be considered as "self-cleaning" orbits with high altitude degradation from residual atmospheric drag, enabling a natural re-entry of the small satellite generally in less than 25 years; but the growth in the number of satellites in LEO exceeds the number re-entering by orders of magnitude.

1 Recommendation ITU-R S.673-2.

A further problem engendered by the explosion in small satellite numbers is that of orbital pollution, especially of impingement on the field of view of astronomical ground telescopes. Engineering, regulatory and procedural efforts are all being undertaken to attempt to mitigate this phenomenon.

There are also some system studies being undertaken regarding the use of satellites in ultra-low orbits, i.e. essentially near to the "top" of what we think of as the atmosphere. These might be for communications, observation or science missions. The satellites would have to be "small" for cost reasons and to minimise drag; however, they would also require continuous propulsion systems and would diverge significantly from what is normally thought of as a conventional small satellite.

2.3.3 Medium Earth Orbit (MEO)

A medium Earth orbit comprises a wide range of orbits anywhere between LEO and GEO, generally with an altitude of about 10 000 km above sea level[2]. It is similar to LEO in that it also does not need to take specific paths around Earth, and it is used by a variety of satellites with many different applications.

It is very commonly used by navigation satellites, like the European Galileo system. Galileo powers navigation communications across Europe, and is used for many types of navigation, from tracking large jumbo jets to getting directions to smartphones. Galileo uses a constellation of multiple satellites to provide coverage across large parts of the world all at once.

MEO orbit is also well adapted to small-satellite massive constellation for broadband telecommunication, with a small latency penalty compared to LEO, but with a reduced number of satellites to guarantee global Earth coverage compared to LEO around 1 200 km altitude.

The radiation environment is more severe compared to LEO and less adapted to low end small satellite missions e.g. nanosat, cubesat and picosat.

2.3.4 Highly Elliptical Orbit (HEO)

A highly elliptical orbit (HEO) is an elliptic orbit with high eccentricity, usually referring to one around Earth. Examples of inclined HEO orbits include Molniya orbits, named after the Molniya Soviet communication satellites which used them, and Tundra orbits.

Such extremely elongated orbits have the advantage of long dwell times at a point in the sky during the approach to, and descent from, apogee. Bodies moving through the long apogee dwell appear to move slowly and remain at high altitude over high-latitude ground sites for long periods of time. This makes these elliptical orbits useful for communications satellites.

2.3.5 Sun-Synchronous Orbit (SSO)

Satellites in polar orbits usually travel past Earth from north to south rather than from west to east, passing roughly over Earth's poles. Satellites in a polar orbit do not have to pass the North and South Poles precisely; even a deviation within 20 to 30 degrees is still classed as a polar orbit. Polar orbits are a type of low Earth orbit, as they are at low altitudes from 200 to 1 000 km.

Sun-synchronous orbit (SSO) is a particular kind of polar orbit. Satellites in SSO, travelling over the polar regions, are synchronous with the Sun. This means they are synchronised to always be in the same "fixed" position relative to the Sun. This means that the satellite always visits the same spot at the same local time – for example, passing the city of Paris every day at noon exactly.

A sun-synchronous orbit is a nearly polar orbit around the Earth, in which the satellite passes over any given point of the Earth surface at the same local time. More technically, an orbit will be sun-synchronous if the precession rate equals the angular rate of the motion of the Earth about the Sun, which is 360° per year, i.e. approximately 1.99×10^{-7} (rad/s). An example of a system using sun-synchronous orbit is an Earth observation mission.

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[2] Recommendation ITU-R S.673-2.

For such missions it is important that the satellite will always observe a point on the Earth as if constantly at the same time of the day, which serves a number of applications that uses satellite images to compare how somewhere changes over time.

Scientists use image series like these to investigate how weather patterns emerge, to help predict weather or storms; when monitoring emergencies like forest fires or flooding; or to accumulate data on long-term problems like deforestation or rising sea levels.

Often, satellites in SSO are synchronised so that they are in constant dawn or dusk – this is because by constantly riding a sunset or sunrise, they will never have the Sun at an angle where the Earth shadows them. A satellite in a sun-synchronous orbit would usually be at an altitude of from 600 to 800 km.

So far most small satellites operate in LEO, and a little of them operate in MEO, SSO and even in GEO. The orbital parameters of small satellite systems are mostly not different from those of traditional satellites. For very small satellites, such as nanosatellites and picosatellites, they are typically not known with a high degree of precision until late in the satellite system design due to launch opportunities as secondary payloads, and the mission objective of those satellites is some form of technology demonstration like attitude control, tether manoeuvres or simply on orbit verification of materials or electrical components, therefore they are not restricted to special orbits, as long as the communication between the earth station and spacecraft is ensured on a regular basis.

See more information of SSO in section 3.9.1.3.

2.3.6 Orbital period and apogee/perigee

The orbital period (also known as revolution period) is the time a given space station takes to complete one orbit around another object. The length of time required for the satellite to make one complete revolution is known as the period of orbit.

The apogee is the point in the orbit of an earth satellite which is situated at the maximum distance from the centre of the Earth, and the perigee is the point in the orbit of an earth satellite which is situated at the minimum distance from the centre of the Earth.

The orbital period for a satellite may normally be computed from the values of the altitude of the apogee and perigee. Since the period as well as the altitudes of the apogee/perigee are provided in a satellite network filing as required by Appendix **4** of the Radio Regulations when the reference body is Earth, these values should be ensured to be consistent.

For exceptional orbits such as those using Lagrange points, where the orbital period cannot be simply computed from the values of the altitude of the apogee and perigee, explanation should be provided in an attachment with the submission (see section 2.1.8).

2.3.7 Geosynchronous Transfer Orbit (GTO)

The Geosynchronous Transfer Orbit (GTO) has been considered for micro-satellite demonstration missions in the past since many launch opportunities can be proposed as shared ride. Nevertheless, the radiative environment is very severe (Van Allen radiation belt) and mission lifetime can be rather limited due to the orbital environment constraints.

2.3.8 Other orbits or trajectories

Small satellites, even nanosats, are also now considered for space exploration such as comet interception and science mission e.g. solar observatory and cosmic observatory, mostly as a companion of a “mother” satellite benefiting from its satellite communication features and propulsion capacity as well as in-orbit injection service on arrival at a desired area of interest or trajectory. Small satellite companions offer flexible cost-effective space mission deployment together with observation diversity from multiple locations; though again accepting a different balance of price/performance/ reliability/risk than the primary missions. Some of these orbits are deep space missions (e.g. HERA mission to an asteroid), lunar transfer and lunar orbit; while in due course there will be small satellite missions to Lagrange points such as L1 and L5, specific regions where a satellite can be quasi-stable in relative location to Earth and Sun. Other orbits, like halo orbit, near-rectilinear halo orbit (NRHO), are also possible for small satellite missions.

Lagrange points are points of equilibrium for small-mass objects under the influence of two massive orbiting bodies, where the gravitational forces of the two large bodies and the centrifugal force balance each other. Lagrange points therefore provide the possibility of a stable location for satellites, as few orbit correction manoeuvres are needed to maintain the satellite in the desired orbit. There are five possible Lagrange points in the orbital plane of the two large bodies, for each given combination of two orbital bodies. Common orbits utilizing Lagrange points include those in the Sun–Earth system and Earth–Moon system.

CHAPTER 3

3 Radio regulatory procedures for small satellite

Only relevant ITU regulations are presented in this chapter, while national regulations will still need to be taken into account by operators of small satellite.

3.1 Brief introduction of the International Telecommunication Union (ITU)

3.1.1 Brief history

On 17 May 1865, the first International Telegraph Convention was signed in Paris by its twenty founding members, and the International Telegraph Union (the first name of ITU) was established to supervise subsequent amendments to the agreement.

Since 1865, to promote cooperation among international telegraphy networks of the day, ITU has predated many other standardization bodies and its long and distinguished history contains a number of important "firsts", such as the standardization of the use of the Morse code and the world's first radiocommunication and fixed telecommunication networks. Over the years, the Union's mandate has expanded to cover the invention of voice telephony, the development of radiocommunications, the launch of the first communications satellites, and most recently, the telecommunications-based information age.

3.1.2 Key roles of ITU

The ITU fosters international cooperation and solidarity in the delivery of technical assistance and in the creation, development and improvement of telecommunication and Information and Communication Technology (ICT) equipment and networks in developing countries, so as to facilitate and enhance telecommunication / ICT development. It plays crucial roles in the field of telecommunications and information and communication technology (ICT), especially focusing on radio-frequency spectrum management, global telecommunication standardization, emergency telecommunications, developing policy and regulatory frameworks for telecommunications and ICT, bridging the digital divide, capacity building and technical assistance to its Member States and serving as a platform for international cooperation and coordination.

3.1.3 ITU legal instruments

The ITU legal regime, in the domain of international frequency management of the spectrum/orbit resources, is incorporated in the Constitution (CS) and Convention (CV), as well as in the Radio Regulations (RR) and the related Rules of Procedures (RoP). Only national administrations representing ITU Member States can request, either for their own benefit or on behalf of a satellite operator, the use of radio-frequency spectrum and orbit resources to the ITU.

See more details from the ITU website: https://www.itu.int

3.1.4 ITU membership

ITU membership includes 193 Member States, more than 900 public and private sector companies, universities, research institutes as well as international and regional telecommunication entities, known as Sector Members and Associates, including Small and Medium Enterprises (SMEs) and Academia.

ITU members represent a diverse group of individuals and organizations from governments, small and large companies, academia, and international organizations worldwide. It varies in size, structure, nature and purpose. However, what brings them together at ITU is a shared belief in the importance of technology as a force for good. They work together to shape the future of ICT, from big data, 5G and the Internet of Things to artificial intelligence, broadcast and multimedia, smart cities, quantum information technologies and intelligent transport systems. ITU sets international standards, harmonizes the use of radio-frequency spectrum and satellite orbits, and supports digital infrastructure development and policy and regulatory reform.

There are three sectors in the ITU: Radiocommunication, Telecommunication Standardization, and Telecommunication Development. Each "Sector Member" (private sector or academia) belongs to at least one of those three sectors of ITU's work.

Sector Members can participate fully across broad areas of ITU work, as they are entitled to participate in all Study Groups within whichever ITU Sector they join. Some companies and organizations opt to join more than one ITU Sector.

Entities that have a specific focus, meanwhile, may choose to participate in a single Study Group by joining ITU as an Associate. Small and medium-sized enterprises (SMEs) can participate as an Associate in any given Study Group with reduced fees. Sector Members from developing countries also benefit from reduced rates.

Academia, universities, and their associated research establishments that join ITU can participate in all three sectors based on a single fee with preferential rates.

More details are available at: https://www.itu.int/hub/membership/our-members/

To become a member of ITU, please apply via the following webpage:

https://www.itu.int/hub/membership/become-a-member/

Please note that it is important to review the Benefits, Fees, Participation, and Membership Terms and Conditions listed on the webpage before applying.

3.1.4.1 ITU Telecommunication Information Exchange Service

Telecommunication Information Exchange Service (TIES) is a set of networked information resources and services offered to ITU Members only without any charge to support their participation in the activities of the Union.

A user account with TIES access allows access to ITU information resources including contributions and other working documents. To submit satellite network filings to the Radiocommunication Bureau through the e-Submission system, it is required to have a TIES account (see section 3.5.1.4.1).

Advance online registration is required to be granted access to an event's virtual session(s). For most ITU statutory events, obtaining the corresponding registration focal point approval is also a requirement.

For more details, please see https://www.itu.int/en/ties-services/Pages/default.aspx.

3.1.5 ITU structure

According to Article 7 of the Constitution of the ITU, the Union is comprised of:

a) the Plenipotentiary Conference (PP), which is the supreme organ of the Union;

b) the Council, which acts on behalf of the Plenipotentiary Conference;

c) world conferences on international telecommunications;

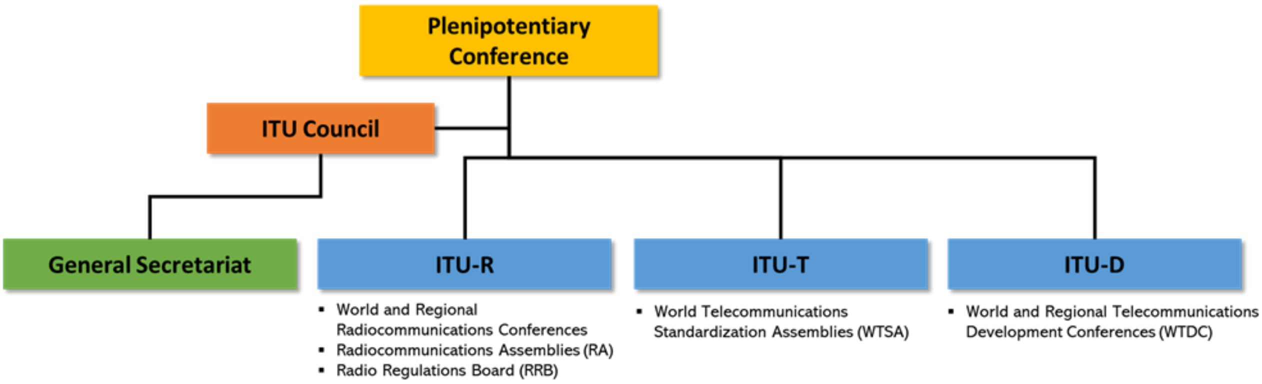
d) the Radiocommunication Sector (ITU-R), including world and regional radiocommunication conferences, Radiocommunication Assemblies (RA) and the Radio Regulations Board (RRB);

e) the Telecommunication Standardization Sector (ITU-T), including World Telecommunication Standardization Assemblies (WTSA);

f) the Telecommunication Development Sector (ITU-D), including world and regional telecommunication development conferences;

g) the General Secretariat (GS).

A chart of the ITU structure is shown below:



3.1.6 ITU-R

The functions of the Radiocommunication Sector (ITU-R) shall be, bearing in mind the particular concerns of developing countries, to fulfil the purposes of the Union, as stated in Article 1 of the ITU Constitution, relating to radiocommunication:

– by ensuring the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including those using the geostationary-satellite or other satellite orbits, subject to the provisions of Article 44 of this Constitution, and

– by carrying out studies without limit of frequency range and adopting recommendations on radiocommunication matters.

The Radiocommunication Sector (ITU-R) works through:

a) world and regional radiocommunication conferences, including the World Radiocommunication Conference (WRC);

   – Conference Preparatory Meeting (CPM), which prepare a consolidated Report on the ITU-R preparatory studies and possible solutions to the WRC agenda items, to be used in support of the work of World Radiocommunication Conferences.

b) Radio Regulations Board (RRB);

   – The RRB is composed of not more than either twelve members, or of a number corresponding to 6% of the total number of Member States, whichever is the greater;

   – The duties of the RRB consists of:

      ○ the approval of Rules of Procedure (RoP), which include technical criteria, in accordance with the Radio Regulations and with any decision which may be taken by competent radiocommunication conferences. These Rules of Procedure shall be used by the Director and the Bureau in the application of the Radio Regulations to register frequency assignments made by Member States.

      ○ the consideration of any other matter that cannot be resolved through the application of the above Rules of Procedure;

      ○ any additional duties, concerned with the assignment and utilization of frequencies, as indicated in No. 78 of the ITU Constitution, in accordance with the procedures provided for in the Radio Regulations, and as prescribed by a competent conference or by the Council with the consent of a majority of the Member States, in preparation for, or in pursuance of the decisions of, such a conference.

c) Radiocommunication Assemblies (RA);

   – It is responsible for the structure, programme and approval of radiocommunication studies. They are normally convened every three or four years and may be associated in time and place with World Radiocommunication Conferences (WRCs).

d) Radiocommunication Study Groups (SG);

– More than 1 500 specialists, from telecommunication organizations and administrations throughout the world, participate in the work of the Study Groups concerned with:
  - ○ drafting technical bases for radiocommunication conferences;
  - ○ developing draft Recommendations;
  - ○ compiling Handbooks.

e) the Radiocommunication Advisory Group (RAG);

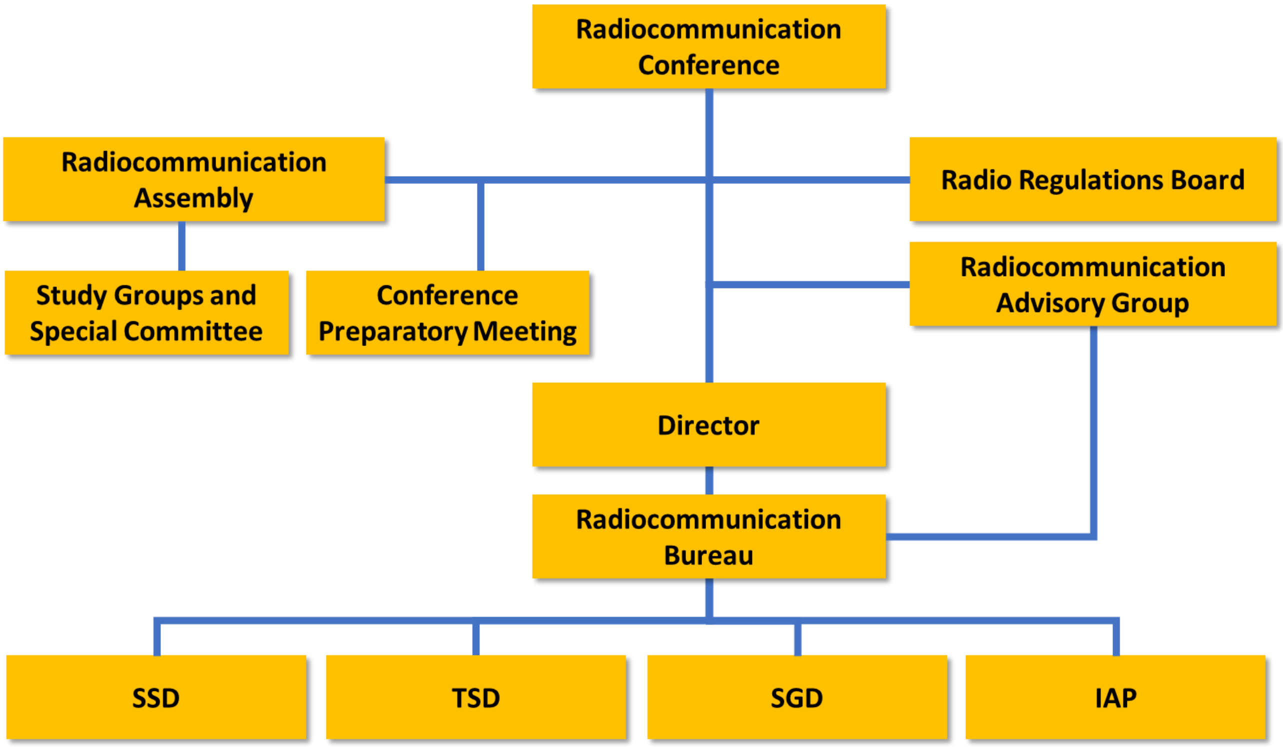
– the RAG is tasked to:
  - ○ review the priorities and strategies adopted in the Sector;
  - ○ provide guidance for the work of the Study Groups;
  - ○ recommend measures to foster cooperation and coordination with other organizations and with the other ITU Sectors.

– The RAG provides advice on these matters to the Director of the Radiocommunication Bureau. RA may refer specific matters within its competence to RAG (Convention No. 137A).

f) the Radiocommunication Bureau (BR), headed by the elected Director.

– The Bureau (BR) comprises Space Services Department (SSD), Terrestrial Services Department (TSD), Radiocommunication Study Group Department (SGD), and Informatics, Administration and Publications Department (IAP).

The structure of the ITU-R is illustrated in the chart below.



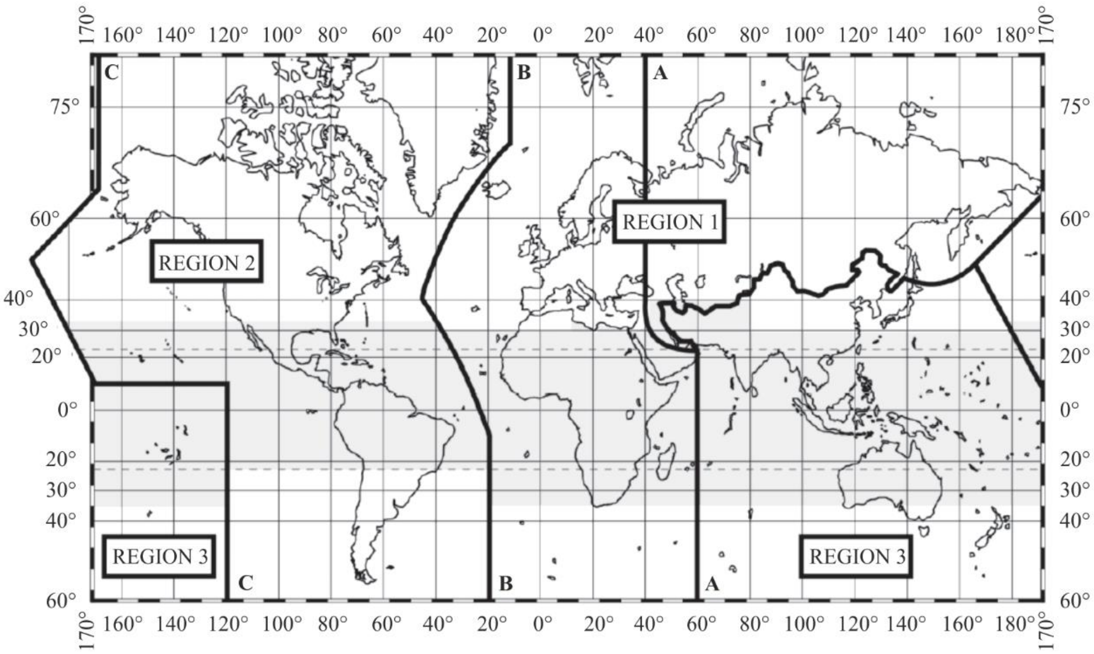
3.2 Frequency allocations

One of the key issues to be considered in the early stages of a small satellite program is the selection of radio frequencies. All frequencies allocated for space services used by non-GSO satellites are equally applicable for use by small satellites. Typical services and radio-frequency spectrum used by small satellites are described in Chapter 4.

The Table of Frequency Allocations (RR Article **5**) and associated principles represent a basis for the planning and implementation of radiocommunication services. For the allocation of frequencies purpose, this Table is organized into three Regions of the world as shown on the following map (see Fig. 1) and described in RR Nos. **5.3** to **5.9**. The current approach is based on a block allocation methodology with footnotes. The regulated frequency band (8.3 kHz – 3 000 GHz) is segmented into smaller bands and allocated to over forty defined radiocommunication services (RR Article **1**). The radio services are identified as primary or secondary (the latter shall not cause harmful interference to, or claim protection from, the former) and footnotes are used to further specify how the frequencies are to be assigned or used.

FIGURE 1

ITU Regions for purposes of frequency allocation of the RR



Handbook on Small Satellites-1

Region 1: Region 1 includes the area limited on the east by line A (lines A, B and C are defined below) and on the west by line B, excluding any of the territory of the Islamic Republic of Iran which lies between these limits. It also includes the whole of the territory of Armenia, Azerbaijan, the Russian Federation, Georgia, Kazakhstan, Mongolia, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan, Turkey and Ukraine and the area to the north of Russian Federation which lies between lines A and C.

Region 2: Region 2 includes the area limited on the east by line B and on the west by line C.

Region 3: Region 3 includes the area limited on the east by line C and on the west by line A, except any of the territory of Armenia, Azerbaijan, the Russian Federation, Georgia, Kazakhstan, Mongolia, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan, Turkey and Ukraine and the area to the north of Russian Federation. It also includes that part of the territory of the Islamic Republic of Iran lying outside of those limits.

Refer to RR Article **5** for more details. The Bureau has made available a useful tool called the RR5 Table of Frequency Allocations (TFA) Software. This user-friendly program enables users to easily identify the frequency bands assigned to specific space services and vice versa across all ITU regions. For more information on accessing this software, please refer to section 3.5.5.2.

3.3 General principles for utilization of spectrum and orbit resources

ITU Member States are bound to abide by and to take the necessary steps to impose the observance of the provisions of the ITU Constitution, the Convention and the administrative regulations upon operating agencies in all telecommunication offices and stations established or operated by them which engage in international services, or which are capable of causing harmful interference to radio services of other countries.

When assigning frequencies to stations, Member States shall note that such assignments are to be made in accordance with the Table of Frequency Allocations and other provisions of the Radio Regulations.

Any planned satellite network or system must have been submitted to the ITU by its Administration at the design stage before launch, even though it is for experimental purpose, in order to obtain international recognition, to protect its frequency assignments, and to resolve potential difficulties, if any, in advance, so as to ensure that there will be no harmful interference when the space station is deployed.

Administrations shall ensure that sufficient telecommand earth stations are established before launch when authorizing space stations to ensure that any harmful interference caused by emissions from the space station can be terminated immediately (see RR No. **22.1**).

Considering space sustainability, administrations shall have the ability to identify and track their own space stations to avoid threats to other space assets.

Using the Table of Frequency Allocations under RR Article **5** as a starting point, the frequency spectrum management authority of each Administration selects appropriate frequencies with a view to assigning them to stations of a given radiocommunication service in each country.

Before taking the final decision to assign a frequency to a station in a given radiocommunication service, in a given frequency band, and to issue an appropriate licence, the authority concerned should be aware of all other conditions regulating the use of frequencies in the band concerned, e.g.:

– Is the frequency band concerned allocated for the radiocommunication service concerned in conformity with the Table of Frequency Allocations under ITU RR Article **5**?
– Are there other ITU RR provisions governing the use of the frequencies?
– Is there a need for effecting the coordination procedure prior to notification of the concerned frequency assignment(s) to the ITU Radiocommunication Bureau and/or bringing into use?

Getting a frequency assignment recorded in the Master Register with a favourable finding under RR No. **11.31** acquires the right for the assignment to international recognition. For such an assignment, this right means that other administrations shall take it into account when making their own assignments, in order to avoid harmful interference (see RR No. **8.3**).

A frequency assignment shall be known as a non-conforming assignment when it is not in accordance with the Table of Frequency Allocations or the other provisions of the Radio Regulations. Such an assignment shall be recorded for information purposes, only when the notifying administration states that it will be operated in accordance with RR No. **4.4** (see RR No. **8.4** and Rules of Procedures on RR No. **4.4**).

If harmful interference to the reception of any station whose assignment is in accordance with RR No. **11.31** is actually caused by the use of a frequency assignment which is not in conformity with RR No. **11.31**, the station using the latter frequency assignment must, upon receipt of advice thereof, immediately eliminate this harmful interference (see RR No. **8.5**).

In addition, if the operating agency of the satellite system is not yet listed in Tables 12A/12B of the Preface to the BR IFIC (Space Services), the name should be provided through the concerned Administration, and the Bureau will assign a new symbol and update the Preface accordingly. It is also recommended that contact details of the operating agency are provided to the Bureau.

The use of some frequency bands and services for satellite networks could either be subject to coordination procedures or not, as spelt out in Sections II or IA of RR Article **9**, respectively. Before frequency assignments of the satellite networks that are subject to coordination can be recorded in the Master Register, they must undergo the coordination process. The regulatory procedures for satellite networks subject to coordination are different from those for satellite networks that are not subject to coordination, and they are described in the following sections.

3.4 Determination of whether a satellite network is subject to coordination

The formal coordination procedures are spelt out in Section II of RR Article **9**. To determine whether a frequency band/service used by a non-GSO satellite network is subject to these procedures, one should check the Radio Regulations, in particular the footnotes to the Table of Frequency Allocations under RR Article **5**.

In general, geostationary (GSO) -satellite networks are subject to coordination under Section II of RR Article **9**, except that the use of inter-satellite links of a geostationary space station communicating with a non-geostationary space station which is not subject to the coordination procedure, will require the application of the advance publication procedure.

The coordination procedures, most common to non-geostationary satellite networks, are identified by reference to RR Nos. **9.21** and **9.11A** (including the sub provisions RR Nos. **9.12** and **9.12A**) which stems from a footnote in RR Article **5**.

– One example is RR No. **5.364**: "The use of the band 1 610-1 626.5 MHz by the mobile-satellite service (Earth-to-space) and by the radiodetermination-satellite service (Earth-to-space) is subject to coordination under No. **9.11A**".

– Another example is RR No. **5.286**: "The band 449.75-450.25 MHz may be used for the space operation service (Earth-to-space) and the space research service (Earth-to-space), subject to agreement obtained under No. **9.21**".

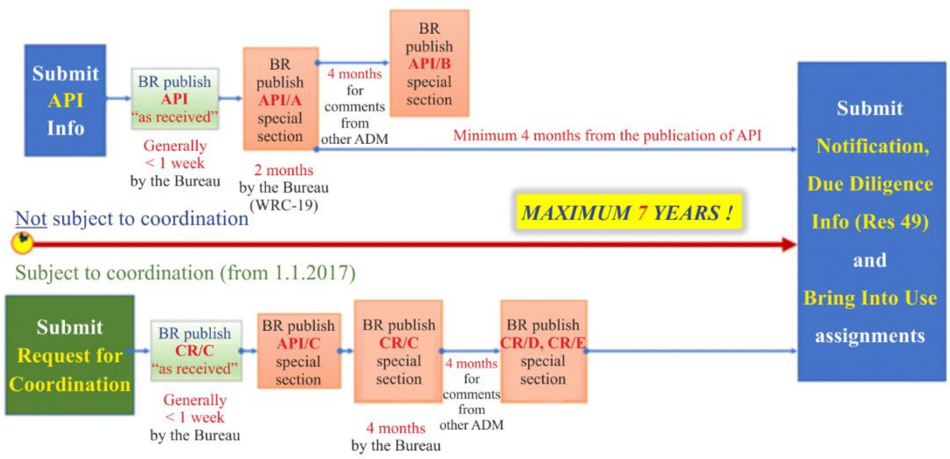
It should be noted that coordination under RR No. **9.11A** (including RR Nos. **9.12** and **9.12A**) is required not only for the service specified in the footnote, but it is also required for other services having allocations with equal rights (see Rules of Procedure related to RR No. **9.11A**). As a quick reference, Table 9.11A-1 of the Rules of Procedure provides a list of all frequency bands/direction and services that are subject to RR No. **9.11A**.

3.5 Overall ITU regulatory procedures

The overall ITU regulatory procedures are illustrated as the following:

FIGURE 2

Overall ITU regulatory procedures



Handbook on Small Satellites-2

The filing procedures for satellite networks not subject to coordination under Section II of RR Article **9** is described in section 3.5.1, while section 3.5.2 describes the filing procedures for satellite networks subject to coordination under Section II of RR Article **9**.

3.5.1 Procedures for satellite networks not subject to coordination

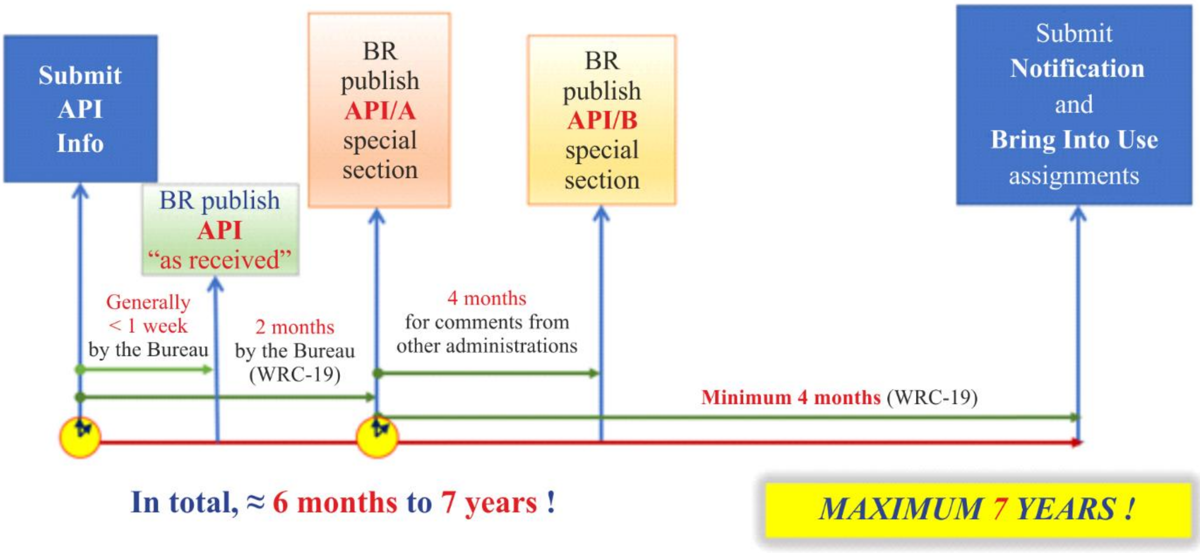
Small satellites are frequently designed to use frequency bands that are not subject to coordination.

ITU WRC-15 suppressed the submission of advance publication information (API) for satellite systems that are subject to coordination procedure in Section II of RR Article **9** by administrations and modified the provisions Nos. **9.1** and **9.2** accordingly, with provision No. **9.2B** applicable only to API for satellite systems that are not subject to coordination procedure in Section II of RR Article **9**.

The ITU API filing process procedures applying to frequency bands and services which are not subject to coordination procedure under Section II of RR Article **9** is described in Fig. 3 below.

FIGURE 3

ITU filing process for satellite networks not subject to coordination



Handbook on Small Satellites-3

As illustrated in Fig. 3, once the ITU Radiocommunication Bureau receives an API submission, it will publish it "as-received" shortly, generally within one week, via the "e-Submission" system (as described in section 3.5.1.4 of this Handbook), and follow up with a full API/A special section publication within two months from the official date of receipt of the notice, if there is no need for any clarification from the notifying administration (see details in the Rules of Procedure on Receivability).

After the publication of the API/A special section, any administration, believing that unacceptable interference may be caused to its existing or planned satellite networks or systems, shall submit a comment to the notifying Administration, with a copy to the Bureau, within four months from the date of publication of the special section.

The ITU Radiocommunication Bureau will publish an API/B special section including all comments received in accordance with RR Nos. **9.3.1** and **9.5** subsequently.

Any frequency assignment to a transmitting station and to its associated receiving stations, except for those mentioned in RR Nos. **11.13** and **11.14**, shall be notified to the Bureau and be brought into use within seven years from the date of receipt of complete API information.

At the notification stage, the notice will be examined by the Bureau under RR No. **11.31** (see section 3.5.4).

3.5.1.1 Submission of the Advance Publication Information

For such systems that are not subject to coordination, the provisions of RR Article **9**, Sub-Section IA (*Advance publication of information on satellite networks or satellite systems that are not subject to coordination procedure under Section II*) are applicable, and the submission of the advance publication information (API) to the Bureau is a mandatory procedure as per RR No. **9.1**. Such information is processed by the Bureau and published in an API/A special section in an ITU BR IFIC.

With the revision of the ITU Radio Regulations which came into effect on 1 April 2017, there is no longer a need to submit API for GSO satellite networks subject to coordination. According to RR No. **9.1A**, the Bureau will make available the advance publication information for these satellite networks from the information submitted for a coordination request and publish them in an API/C special section in an ITU BR IFIC.

The majority of API submissions for satellite networks not subject to coordination are non-geostationary-satellite (non-GSO) networks.

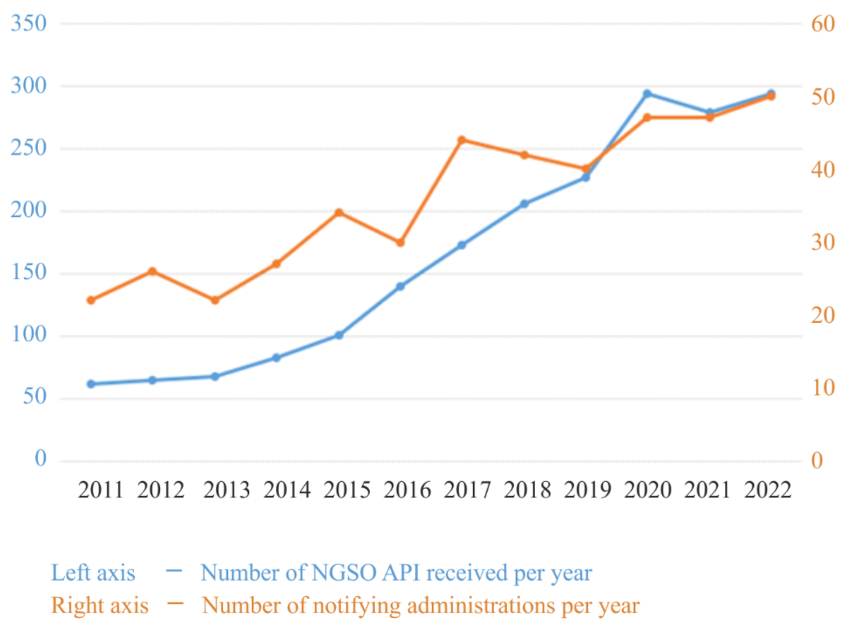
For geostationary-satellite networks using inter-satellite links of a geostationary space station communicating with a non-geostationary space station which are not subject to the coordination procedure, the RR Appendix **4** characteristics to be provided for advance publication information (API) in the BR IFIC shall be the same as those listed for the coordination of a geostationary-satellite (GSO) network.

3.5.1.1.1 Submission trend for non-GSO API

In recent years, there has been a significant surge in the number of API submissions for non-geostationary satellite networks that are not subject to coordination procedures. While the number of such submissions has been moderately increasing since 2011, the rate of increase has accelerated since 2015, and currently ITU BR is receiving six times the number it was receiving in 2011. This increase from approximately 50 cases in 2011 to nearly 300 cases per year since 2020 appears likely to continue to be growing. In addition, the number of administrations submitting API information for non-GSO systems has also been steadily increasing, with the number of administrations submitting since 2020 being twice that of those submitting in 2011 (see Fig. 4).

FIGURE 4

Submission of Non-GSO API for satellite networks or systems not subject to coordination



Handbook on Small Satellites-4

As of May 2023, there are 90 Administrations that have submitted APIs to the Bureau, which represents a significant number of Member States either currently possessing or planning to launch satellites into space. Additionally, there are some APIs for constellations of satellites submitted by one administration on behalf of multiple other administrations. In addition to the Earth, APIs have been submitted with the Moon, Sun, Jupiter, Venus or Mars as celestial reference bodies, as well as for deep space.

3.5.1.2 Information required for API

A complete submission for advanced publication information (API) generally includes:

– a notice database containing RR Appendix **4** required information captured via the BR software SpaceCap;

– a GIMS database containing graphical information captured via the Graphical Interference Management Software (GIMS);

– relevant attachments or notes.

3.5.1.2.1 SNS notice database and GIMS diagram database

Information to be provided for the API is specified in RR Appendix **4** and shall be submitted in an electronic format to the Bureau (see Resolution **55 (Rev.WRC-19)**). The format for submission is the SNS database format specified in the Preface to the BR IFIC (Space Services) (https://www.itu.int/en/ITU-R/space/Pages/prefaceMain.aspx) for the characteristics of the frequency assignments, and the GIMS mdb format for any graphical information.

To assist administrations in capturing the required information for an API and validate the completeness of the data, the Bureau has made available the following software tools: SpaceCap, GIMS and BRSIS Validation. These software tools can be downloaded from the webpage below:

https://www.itu.int/en/ITU-R/software/Pages/space-network-software.aspx

Administrations shall use the latest BR data capture software SpaceCap to capture the SNS format notice database and use the latest BR software GIMS (Graphical Interference Management System) to capture the GIMS format diagram database.

3.5.1.2.2 Antenna radiation pattern

With regard to the GIMS format diagram database, the important information concerning the antenna radiation pattern is mandatory for all non-GSO notices, for all beams, and for all associated earth stations, and they can be submitted as:

– a pattern ID, available in the APL online, captured in SNS notice database via SpaceCap (available at https://www.itu.int/en/ITU-R/software/Pages/ant-pattern.aspx), or

– a diagram in GIMS database

If neither of the above is possible, then the antenna pattern can be provided in the form of equations / formulas. If found compliant with the rules mentioned below, the Bureau will then assign a pattern ID and capture it in the SNS notice database accordingly for publication.

See also section 3.5.4.1.2.

General Rules for antenna patterns submitted as images or equations / formulas

To submit the characteristics of the antenna radiation patterns for the space station and associated earth station, please study the details from the Antenna Pattern Library (APL) available at the webpage http://www.itu.int/en/ITU-R/software/Pages/ant-pattern.aspx. Select an appropriate antenna pattern ID from the APL and enter it in the SNS notice database if possible.

However, if there is not an antenna pattern listed in the APL that could appropriately describe the antenna used for the satellite network, the user should then submit the antenna pattern as a diagram, which shall be submitted in graphics data format compatible with BR's data capture software GIMS (graphical interference management system) in accordance with Resolution **55 (Rev.WRC-19)**.

When submitting antenna pattern diagrams as images, the following guidelines have to be taken into consideration. A submitted antenna radiation pattern, other than a pattern ID defined in the APL, should comply with the following:

– the co-polar antenna radiation pattern must be plotted as the antenna gain (dBi) as a function of the off-axis angle in degrees;
– the antenna gain must be defined for all off-axis angles in the range between 0 and 180 degrees;
– the maximum co-polar antenna gain must correspond to the respective maximum antenna gain for the same beam / associated earth station as it is captured in the notice database;
– for any off-axis angle, only one gain value shall be defined.

3.5.1.3 Check before submission

Prior to submission, the Administration should remember to run the latest version of the BRSIS Validation software, with cross validation between the electronic notice database and the GIMS format database, to ensure that all mandatory information specified in RR Appendix **4** have been captured in both databases concerned. If there is any fatal error, it should be corrected prior to submission to the Bureau.

If fatal errors identified by BRSIS Validation could not be corrected, the Administration may request for assistance from the Bureau in the cover letter accompanying the submission (or by email to brmail@itu.int before the submission).

If a notice is not validated by the latest version of the BRSIS Validation software, it may result in missing mandatory information or incorrect data format. If this is identified by the Bureau after receipt of the submission, in accordance with §§ 3.5 to 3.8 of the Rules of Procedure on Receivability, the notice might be considered to be incomplete, and the Bureau will not establish a formal date of receipt of the notice. A new formal date of receipt will only be established when the complete information is received.

3.5.1.4 Submission to the BR

In accordance with the Rules of Procedure on Receivability, the final electronic notice mdb file in SNS format, together with the GIMS format database, and any additional attachments, shall be submitted through the Bureau's online submission system "e-Submission of satellite network filings", available at https://www.itu.int/en/ITU-R/space/e-submission (see section 3.5.1.4.1 for more details).

Notices submitted using "e-Submission of satellite network filings" for space services do not require any separate confirmation by telefax or mail. However, it is a good idea to attach a cover letter for the submission together with the upload of the electronic filing, so as to highlight some pertinent points concerning the filing, e.g. the information concerning the operating agency, the address where the invoice for cost recovery should be issued to.

Prior to submitting electronic notices to the Bureau, administrations shall run the latest BR SIS validation software (available at http://www.itu.int/ITU-R/software/space/) in order to identify any fatal error and correct all errors identified for the notices before they are submitted to the Bureau in accordance with § 3.4 of the Rules of Procedure on Receivability.

If any graphical information, for example the antenna radiation pattern, has been captured in the GIMS database, a cross validation checking of graphical data against the SNS data for a given network, must be ran using the latest version of the BR SIS Validation software.

A guide to capture diagrams and attachments for non-GSO using BR software SpaceCap and BR-SIS Validation is available at the webpage for submission of graphical information below:

www.itu.int/go/space/non-GSO/graphical-submission

The API that has been successfully submitted to the Bureau will be published shortly after in "as-received" via the e-Submission system on the ITU website.

3.5.1.4.1 e-Submission system

As explained in section 3.5.1.4, according to the Rules of Procedure on Receivability, effective from 1 August 2018, all filings under RR Articles **9** and **11**, RR Appendices **30**, **30A** and **30B** and Resolutions **49 (Rev.WRC-19)**, **552 (Rev.WRC-19)** and **553 (Rev.WRC-15)**, or SpaceCom comments related to a BR IFIC, shall be submitted by notifying administrations to the Bureau using the ITU web interface "e-Submission of satellite network filings": https://www.itu.int/en/ITU-R/space/e-submission

The e-Submission system has six categories of user roles:

(1) Administration Manager,

(2) Administration User,

(3) Operator Manager,

(4) Operator User,

(5) Intergovernmental Satellite Organization Manager,

(6) Intergovernmental Satellite Organization User.

For each administration, the Bureau is responsible for registering the Administration Manager, based on a formal request from the Administration. The Administration Manager, once registered by the Bureau, can then register other Administration Users and user accounts for Operators.

Only Administration Managers and Administration users can submit satellite notices to the Bureau. Users from Operator and Intergovernmental Satellite Organization (IGSO) can only submit notices to the Administration.

More details of the various user account permissions are available at: https://www.itu.int/en/ITU-R/space/e-submission/Pages/User-categories.aspx.

For security reasons, access to the e-Submission system is restricted only to the registered TIES users. The detail information related to the ITU TIES services is described in section 3.1.4.1. In general, a TIES account is needed to submit the filing to the e-Submission system as an operator to the administration, and then the administration can validate the filing and submit it to the ITU. The TIES account will have to be authorized by the national administration. Only ITU members can have a TIES account.

In order to get access to the system, administrations are requested to first designate an Administration Manager with TIES account to the Bureau via e-communication system, available at https://www.itu.int/en/ITU-R/space/e-submission, or via the telefax (+41 22 730 5785). This designated Administration Manager can then authorize access to the system for other Administration Users, Operator Managers and Operator Users.

Administrations and intergovernmental satellite organizations which have not yet nominated the initial list of one or more person (or entity) assigned for the Administration Manager role or Intergovernmental Satellite Organization Manager role, are invited to communicate to the Bureau by e-Communications available at https://www.itu.int/ITU-R/go/space-communications or by email: brmail@itu.int indicating the person's name, title, email address, telephone number and TIES user name.

Please note that only those operating agencies listed in Table 12A/12B of the Preface to the BR IFIC (Space Services) can be given Operators accounts. If the operating agency is not listed in the said Table, the administration can request to add it by sending the request with indicating the name of operating agency and contact addresses such as postal address and email address by email: brmail@itu.int or by e-Communications available at https://www.itu.int/ITU-R/go/space-communications to the Bureau.

Similarly, only the Intergovernmental Satellite Organizations listed in Table 2 of the Preface to the BR IFIC (Space Services) can be given IGSOs user accounts.

3.5.1.4.2 e-Communication system

The "e-Communications" system is an online communication platform to allow administrations and the Bureau to send and receive administrative correspondences related to space services through an online interface instead via emails or telefaxes. This system has been developed under Resolution **907 (Rev.WRC-15)** by the Bureau, and is available at https://www.itu.int/ITU-R/go/space-communications.

All users need a specific user account to get access to e-Communications.

The e-Communications system has two types of user role: (1) Administration Manager, and (2) Administration User. Other user types will be added in future versions.

In this regard, administrations who have not yet been registered are invited to communicate to the Bureau by email: brmail@itu.int the initial list of one or more person (or entity) assigned for the Administration Manager role indicating the person's name, title, email address, telephone number and TIES user name.

Please note that the Bureau is the only responsible entity registering accounts for the Administration Manager role. The Administration Manager can authorize access to the system for other Administration Users for "e-Communications".

For security reasons, access to e-Communications is restricted to registered TIES users only.

More detailed information about e-Communication system can be found in BR Circular Letter CR/450 dated 25 October 2019 and the system website: https://www.itu.int/ITU-R/go/space-communications.

3.5.1.5 Receivability of the notice

The following are some additional points concerning the checks related to the receivability of the notice:

– Frequency bands/services included in the API should be not subject to coordination, otherwise the Bureau will inform the administration to submit them separately as a request for coordination.

– If a notice does not contain all the mandatory information as defined in RR Appendix **4**, further processing of the notice will remain in abeyance and a date of receipt will not be established until the missing information is received.

– If all mandatory data have been submitted and further clarification is required concerning the correctness of the mandatory data, the Bureau shall request the notifying administration to provide the required clarification within 30 days.

– If the complete and correct information is received within this 30-day period, the original date of receipt is retained, otherwise, a new date of receipt will be established when the required information is received.

– When the Bureau has determined that the information is complete and correct, it will publish in two months the corresponding API/A special section in a BR IFIC.

3.5.1.6 Publication of API/A special section

The API/A special section publication contains advance publication information on a planned satellite network, in accordance with the provisions of RR No. **9.2B**.

The description of the data items used in the publications is available at the webpage:

http://www.itu.int/ITU-R/space/brific/legend/

The following is a sample abstract of a non-GSO publication in an API/A special section:

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS
BUREAU DES RADIOCOMMUNICATIONS

INTERNATIONAL TELECOMMUNICATION UNION
RADIOCOMMUNICATION BUREAU

UNIÓN INTERNACIONAL DE TELECOMUNICACIONES
OFICINA DE RADIOCOMUNICACIONES

RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	JANUS-1			SECTION SPÉCIALE Nº SPECIAL SECTION No. SECCIÓN ESPECIAL N.º	API/A/13036
				BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA	2969 / 19.04.2022
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE	D	LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL	NGSO	NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN	122545048
RENSEIGNEMENTS REÇUS PAR LE BUREAU LE / INFORMATION RECEIVED BY THE BUREAU ON / INFORMACIÓN RECIBIDA POR LA OFICINA EL					10.03.2022

Ces renseignements reçus par le Bureau des radiocommunications, en application du numéro 9.1/9.2 du Règlement des radiocommunications, sont publiés conformément au numéro 9.2B.

This information, received by the Radiocommunication Bureau pursuant to No.9.1/9.2 of the Radio Regulations, is published in accordance with No. 9.2B.

Esta información, recibida por la Oficina de Radiocomunicaciones con arreglo al número 9.1/9.2 del Reglamento de Radiocomunicaciones, se publica de acuerdo con lo dispuesto en el número 9.2B.

Une administration qui estime que des brouillages inacceptables risquent d'être causés à ses réseaux ou à ses systèmes à satellites existants ou en projet communique à l'administration qui a demandé la publication des renseignements ses observations, avec copie au Bureau des radiocommunications, dans le délai indiqué ci-après.

Any administration which believes that unacceptable interference may be caused to its existing or planned satellite networks or systems shall communicate its comments to the publishing administration, with a copy to the Radiocommunication Bureau, by the deadline indicated below.

Cualquier administración que estime que se podría causar interferencia perjudicial a sus redes o sistemas de satélites existentes o planificados deberá comunicar sus comentarios a la administración que publica, con copia a la Oficina de Radiocomunicaciones, en el plazo que se indica más abajo.

DATE LIMITE POUR LA RÉCEPTION DES COMMENTAIRES EXPIRY DATE FOR THE RECEIPT OF COMMENTS FECHA LÍMITE PARA LA RECEPTIÓN DE LOS COMENTARIOS	19.08.2022

国际电信联盟
无线电通信局

МЕЖДУНАРОДНЫЙ СОЮЗ ЭЛЕКТРОСВЯЗИ
БЮРО РАДИОСВЯЗИ

الاتحاد الدولي للاتصالات
مكتب الاتصالات الراديوية

卫星网络 СПУТНИКОВАЯ СЕТЬ الشبكة الساتلية	JANUS-1			特节编号 СПЕЦИАЛЬНАЯ СЕКЦИЯ № القسم الخاص رقم	API/A/13036
				无线电通信局国际频率信息通报 / 日期 ИФИК БР / ДАТА النشرة الإعلامية الدولية للترددات/ رقمها وتاريخها	2969 / 19.04.2022
负责主管部门 ОТВЕТСТВЕННАЯ АДМ. الإدارة المسؤولة	D	标称经度 НОМИНАЛЬНАЯ ДОЛГОТА خط الطول الاسمي	NGSO	识别号 ИДЕНТИФИКАЦИОННЫЙ НОМЕР رقم تعرف الهوية	122545048
通信局收到资料的日期 / ДАТА ПОЛУЧЕНИЯ ИНФОРМАЦИИ БЮРО / معلومات استلمها المكتب في					10.03.2022

无线电通信局根据《无线电规则》第9. 1/9. 2款收到的该资料将按照第9. 2B款得到公布。

Данная информация, полученная Бюро радиосвязи в соответствии с п. 9.1/9.2 Регламента радиосвязи, публикуется в соответствии с п. 9.2B.

استلم مكتب الاتصالات الراديوية هذه المعلومات بموجب الرقم 2.9/1.9 من لوائح الراديو، وتُنشر هذه المعلومات طبقاً للرقم 2B.9.

如果任何主管部门认为对其现有的或规划的卫星网络或系统可能产生无法接受的干扰，请在下述截止日期前将其意见寄送公布主管部门，副本抄送无线电通信局。

Любая администрация, которая считает, что ее существующим или планируемым спутниковым сетям или системам могут быть причинены неприемлемые помехи, должна направить свои замечания публикующей администрации с копией Бюро радиосвязи к указанному ниже предельному сроку.

كل إدارة ترى أن تداخلات غير مقبولة قد تؤثر في شبكاتها أو أنظمتها الساتلية، الموجود منها أو المخطط له، عليها أن ترسل تعليقاتها إلى الإدارة التي طلبت النشر مع نسخة منها إلى مكتب الاتصالات الراديوية قبل الموعد النهائي المبين أدناه.

接收意见的截止日期: ПРЕДЕЛЬНАЯ ДАТА ДЛЯ ПОЛУЧЕНИЯ ЗАМЕЧАНИЙ: الموعد النهائي لاستلام التعليقات	19.08.2022

On trouvera la description des éléments de données utilisés dans les publications dans le document: - ItemsDescription_F.pdf - http://www.itu.int/ITU-R/space/brific/legend/	The description of the data items used in the publications can be found in the document: - ItemsDescription_E.pdf - http://www.itu.int/ITU-R/space/brific/legend/	La descripción de los datos empleados en las publicaciones figura en el documento: - ItemsDescription_S.pdf - http://www.itu.int/ITU-R/space/brific/legend/
出版物中使用的数据项说明，见文件: - ItemsDescription_C.pdf - http://www.itu.int/ITU-R/space/brific/legend/	Описание элементов данных, используемых в данной публикации, содержится в документе: - ItemsDescription_R.pdf - http://www.itu.int/ITU-R/space/brific/legend/	يمكن الاطلاع على وصف عناصر المعطيات المستعملة في المنشورات في الوثيقة: ItemsDescription_A.pdf http://www.itu.int/ITU-R/space/brific/legend/

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A | *A1a* Sat. Network: JANUS-1 | *A1f1* Notif. adm.: D | *A1f3* Inter. sat. org.: | *BR1* Date of receipt: 10.03.2022 | *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 | *BR3a* Provision reference: 9.1/IA | *BR2* Adm. serial no.:

Résumé / Summary / Resumen / 綜述 / Резюме / خلاصة

Article 9, sous-section IA / Article 9, sub-section IA / Artículo 9, sub-sección IA
第9条第1A分节 / Статья 9, подраздел IA / المادة 9، القسم الفرعي IA

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	BR47 Frequency band (MHz)	BR62 Expiry date for bringing into use	C4a Class of station
SRX	R		122618336		2040 - 2055	10.03.2029	ET, EW
STX	E		122618335		2240 - 2255	10.03.2029	ET, EW
XTX	E		122618334		8025 - 8400	10.03.2029	EW

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A | *A1a* Sat. Network: JANUS-1 | *A1f1* Notif. adm.: D | *A1f3* Inter. sat. org.: | *BR1* Date of receipt: 10.03.2022 | *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 | *BR3a* Provision reference: 9.1/IA | *BR2* Adm. serial no.: | SRX | R

A1f2 Submitted on behalf:

A1g Short Mission Duration Res 32: N

A4b1 No. of orbital planes: 1 | *A4b2* Ref. body: T

A4b1a Constellation: N | *A4b1b* Configuration type: | *A4b1c* Number of sub-sets mutually exclusive: | *A4b1d* Attachment no.:

A4b3a No. of space stations simult. trans. on Northern Hemisphere: | *A4b3b* No. of space stations simult. trans. on Southern Hemisphere:

Orbital plane id. no.	*A4b4a Inclination angle*	*A4b4b No. of satellites in this plane*	*A4b4c Period*	*A4b4d Apogee*	*A4b4e Perigee*	*A4b4f Min. altitude*	*A4b4i Arg. of perigee*	*A4b4j Long. asc. node*	*A4b4m,n,o Sun synchronous Y/N*	*Node reference time*	*Node local time*
1	97.4	1	0-01:35	5e2	5e2	5e2			Y	D	10:30:00

Orbital plane no.	*Satellite no.*	*A4b4h Initial phase angle*	*A4b4k Date*	*A4b4l Time*	*B4a Orbit link / List of beams*
1	1				

B1a/BR17 Beam designation: SRX | *B1b* Steerable: | *B2* Emi-Rcp: R | *B3a1* Max. co-polar gain: 1

B2a1 Transmit only when visible from notified service area: Y | *B2a2* Min. Elev. Angle:

B3c1 Co-polar antenna pattern						
Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
ND-SPACE						

List of orbital planes
ALL

B4a3a1 Angle alpha: | *B4a3a2* Angle beta:

BR92 Attach. for missing angle alpha/beta:

BR7a/BR7b Group id.: 122618336 | *BR1* Date of receipt: 10.03.2022 | *C2c* RR No. 4.4:

BR14 Special Section: API/A/13036

C4a Class of station: ET, EW | *C3a* Assigned freq. band: | *C5a* Noise temperature: 330

C4b Nature of service: CV, CV | *C6a* Polarization type: L | *C6b* Polarization angle: 0

C11a2 Service area: XAA | *C11a3* Service area diagram:

A2b Period of valid.: 3 | *A3a* Op. agency: 178 | *A3b* Adm. resp.: M | *BR16* Value of type C8b:

BR96 Start date for 9.1/9.1A: 10.03.2022

BR60 Regulatory deadline(s) 11.44/11.44.1: 10.03.2029

C1 Frequency Range			
C1a Lower limit		*C1b* Upper limit	
2040	MHz	2055	MHz

	C7a Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.	*C8f2* E.i.r.p. on the beam axis
1	5M00G1D--	10	-57	-10		-77		10		
2	2M50G1D--	10	-54	-10		-74		10		
3	1M30G1D--	10	-51	-10		-71		10		

Page / Página / 页 / стр. / 5 الصفحة

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A — *A1a* Sat. Network: JANUS-1 — *A1f1* Notif. adm.: D — *A1f3* Inter. sat. org.: — *BR1* Date of receipt: 10.03.2022 — *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 — *BR3a* Provision reference: 9.1/IA — *BR2* Adm. serial no.: — SRX — R

C7b Carrier frequency of the emissions (5M00G1D--)

2042.5	MHz	2047.5	MHz	2052.5	MHz

C7b Carrier frequency of the emissions (2M50G1D--)

2042.5	MHz	2047.5	MHz	2052.5	MHz

C7b Carrier frequency of the emissions (1M30G1D--)

2042.5	MHz	2047.5	MHz	2052.5	MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.		*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.			*C10d3* Max. iso. gain	*C10d4* Bmwdth
SEOUL	S	127E01 03	36N44 27	KOR	1	TT	CV	42.3	1.2
					2	TW	CV		
HAWAII	S	158W05 25	21N20 13	HWA	1	TT	CV	42.3	1.2
					2	TW	CV		
PORTLAND	S	119W37 55	45N51 16	USA	1	TT	CV	42.3	1.2
					2	TW	CV		
COLUMBUS	S	083W11 51	40N06 03	USA	1	TT	CV	42.3	1.2
					2	TW	CV		
DUBLIN	S	006W13 28	53N24 24	IRL	1	TT	CV	42.3	1.2
					2	TW	CV		
STOCKHOLM	S	016E35 05	59N38 57	S	1	TT	CV	42.3	1.2
					2	TW	CV		
CAPE TOWN	S	018E43 07	34S01 39	AFS	1	TT	CV	42.3	1.2
					2	TW	CV		
BAHRAIN	S	050E30 11	26N03 05	BHR	1	TT	CV	42.3	1.2
					2	TW	CV		
SYDNEY	S	150E46 01	34S02 12	AUS	1	TT	CV	42.3	1.2
					2	TW	CV		
PUNTA ARENAS	S	070W50 59	52S56 28	CHL	1	TT	CV	42.3	1.2
					2	TW	CV		

C10d5a Co-polar antenna pattern

C10b1 Assoc. earth station id.	Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SEOUL	REC-465-5						
HAWAII	REC-465-5						
PORTLAND	REC-465-5						
COLUMBUS	REC-465-5						
DUBLIN	REC-465-5						
STOCKHOLM	REC-465-5						
CAPE TOWN	REC-465-5						
BAHRAIN	REC-465-5						
SYDNEY	REC-465-5						
PUNTA ARENAS	REC-465-5						

13C Remarks:

B1a/BR17 Beam designation: STX — *B1b* Steerable: — *B2* Emi-Rcp: E — *B3a1* Max. co-polar gain: 1

B2a1 Transmit only when visible from notified service area: Y — *B2a2* Min. Elev. Angle:

Page / Página / 页 / стр. / 6 الصفحة

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A — *A1a* Sat. Network: JANUS-1 — *A1f1* Notif. adm.: D — *A1f3* Inter. sat. org.: — *BR1* Date of receipt: 10.03.2022 — *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 — *BR3a* Provision reference: 9.1/IA — *BR2* Adm. serial no.: — STX — E

B3c1 Co-polar antenna pattern

Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
ND-SPACE						

List of orbital planes: ALL

B4a3a1 Angle alpha: — *B4a3a2* Angle beta:

BR92 Attach. for missing angle alpha/beta:

BR7a/BR7b Group id.: 122618335 — *BR1* Date of receipt: 10.03.2022 — *C2c* RR No. 4.4:

BR14 Special Section: API/A/13036

C4a Class of station: ET, EW — *C3a* Assigned freq. band:

C4b Nature of service: CV, CV — *C6a* Polarization type: L — *C6b* Polarization angle: 0

C8d1 Max. tot. peak pwr.: — *C8d2* Contiguous bandwidth:

C11a2 Service area: XAA — *C11a3* Service area diagram:

A2b Period of valid.: 3 — *A3a* Op. agency: 178 — *A3b* Adm. resp.: M — *BR16* Value of type C8b:

BR96 Start date for 9.1/9.1A: 10.03.2022

BR60 Regulatory deadline(s) 11.44/11.44.1: 10.03.2029

C1 Frequency Range

C1a Lower limit		*C1b* Upper limit	
2240	MHz	2255	MHz

	C7a Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.	*C8f1* E.i.r.p. on the beam axis
1	5M00G1D--	3	-64	-10		-77		10		
2	2M50G1D--	3	-61	-10		-74		10		
3	1M30G1D--	3	-58	-10		-71		10		

C7b Carrier frequency of the emissions (5M00G1D--)

2242.5	MHz	2247.5	MHz	2252.5	MHz

C7b Carrier frequency of the emissions (2M50G1D--)

2242.5	MHz	2247.5	MHz	2252.5	MHz

C7b Carrier frequency of the emissions (1M30G1D--)

2242.5	MHz	2247.5	MHz	2252.5	MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.		*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.			*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d6* Noise temp.
SYDNEY	S	150E46 01	34S02 12	AUS	1	TT	CV	42.8	1.15	292
					2	TW	CV			
DUBLIN	S	006W13 28	53N24 24	IRL	1	TT	CV	42.8	1.15	292
					2	TW	CV			
STOCKHOLM	S	016E35 05	59N38 57	S	1	TT	CV	42.8	1.15	292
					2	TW	CV			
PUNTA ARENAS	S	070W50 59	52S56 28	CHL	1	TT	CV	42.8	1.15	292

Page / Página / 页 / стр. / 7 الصفحة

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A — *A1a* Sat. Network: JANUS-1 — *A1f1* Notif. adm.: D — *A1f3* Inter. sat. org.: — *BR1* Date of receipt: 10.03.2022 — *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 — *BR3a* Provision reference: 9.1/IA — *BR2* Adm. serial no.: — STX | E

SEOUL	S	127E01 03	36N44 27	KOR	2 1 2	TW TT TW	CV CV CV	42.8	1.15	292
CAPE TOWN	S	018E43 07	34S01 39	AFS	1 2	TT TW	CV CV	42.8	1.15	292
BAHRAIN	S	050E30 11	26N03 05	BHR	1 2	TT TW	CV CV	42.8	1.15	292

	C10d5a Co-polar antenna pattern						
C10b1 Assoc. earth station id.	Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SYDNEY	REC-465-5						
DUBLIN	REC-465-5						
STOCKHOLM	REC-465-5						
PUNTA ARENAS	REC-465-5						
SEOUL	REC-465-5						
CAPE TOWN	REC-465-5						
BAHRAIN	REC-465-5						

13C Remarks:

B1a/BR17 Beam designation: XTX — *B1b* Steerable: — *B2* Emi-Rcp: E — *B3a1* Max. co-polar gain: 12

B2a1 Transmit only when visible from notified service area: Y — *B2a2* Min. Elev. Angle:

B3c1 Co-polar antenna pattern						
Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
						1

List of orbital planes: ALL

B4a3a1 Angle alpha: — *B4a3a2* Angle beta:

BR92 Attach. for missing angle alpha/beta:

BR7a/BR7b Group id.: 122618334 — *BR1* Date of receipt: 10.03.2022 — *C2c* RR No. 4.4:

BR14 Special Section: API/A/13036

C4a Class of station: EW — *C3a* Assigned freq. band:

C4b Nature of service: CV — *C6a* Polarization type: CR — *C6b* Polarization angle:

C8d1 Max. tot. peak pwr.: — *C8d2* Contiguous bandwidth:

C11a2 Service area: XAA — *C11a3* Service area diagram:

A2b Period of valid.: 3 — *A3a* Op. agency: 178 — *A3b* Adm. resp.: M — *BR16* Value of type C8b:

BR96 Start date for 9.1/9.1A: 10.03.2022

BR60 Regulatory deadline(s) 11.44/11.44.1: 10.03.2029

C1 Frequency Range			
C1a Lower limit		*C1b* Upper limit	
8025	MHz	8400	MHz

Page / Página / 页 / стр. / 8 الصفحة

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — API/A/13036

A — *A1a* Sat. Network: JANUS-1 — *A1f1* Notif. adm.: D — *A1f3* Inter. sat. org.: — *BR1* Date of receipt: 10.03.2022 — *BR20* BR IFIC no.: 2969

BR6a/BR6b Id. no.: 122545048 — *BR3a* Provision reference: 9.1/IA — *BR2* Adm. serial no.: — XTX | E

	C7a Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.	*C8f1* E.i.r.p. on the beam axis
1	30M0G1D--	0	-75	-10		-85		9		
2	20M0G1D--	0	-73	-10		-83		9		
3	10M0G1D--	0	-70	-10		-80		9		

C7b Carrier frequency of the emissions (30M0G1D--)											
8050	MHz	8100	MHz	8150	MHz	8200	MHz	8250	MHz	8300	MHz

C7b Carrier frequency of the emissions (20M0G1D--)											
8050	MHz	8100	MHz	8150	MHz	8200	MHz	8250	MHz	8300	MHz

C7b Carrier frequency of the emissions (10M0G1D--)											
8050	MHz	8100	MHz	8150	MHz	8200	MHz	8250	MHz	8300	MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.		*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.			*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d6* Noise temp.
SYDNEY	S	150E46 01	34S02 12	AUS	1	TW	CV	55.2	0.3	200
DUBLIN	S	006W13 28	53N24 24	IRL	1	TW	CV	55.2	0.3	200
STOCKHOLM	S	016E35 05	59N38 57	S	1	TW	CV	55.2	0.3	200
PUNTA ARENAS	S	070W50 59	52S56 28	CHL	1	TW	CV	55.2	0.3	200
SEOUL	S	127E01 03	36N44 27	KOR	1	TW	CV	55.2	0.3	200
HAWAII	S	158W05 25	21N20 13	HWA	1	TW	CV	55.2	0.3	200
PORTLAND	S	119W37 55	45N51 16	USA	1	TW	CV	55.2	0.3	200
COLUMBUS	S	083W11 51	40N06 03	USA	1	TW	CV	55.2	0.3	200
CAPE TOWN	S	018E43 07	34S01 39	AFS	1	TW	CV	55.2	0.3	200
BAHRAIN	S	050E30 11	26N03 05	BHR	1	TW	CV	55.2	0.3	200

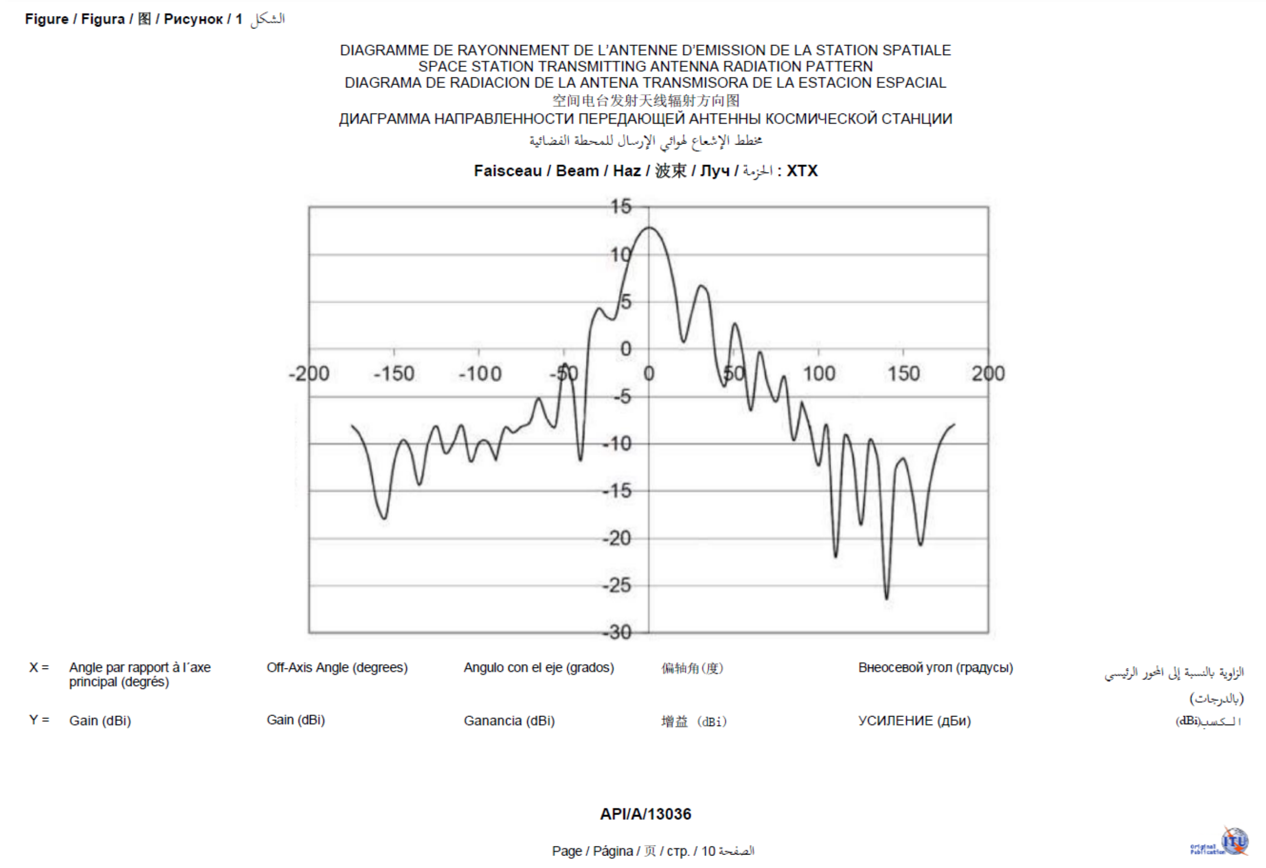
	C10d5a Co-polar antenna pattern						
C10b1 Assoc. earth station id.	Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SYDNEY	REC-465-5						
DUBLIN	REC-465-5						
STOCKHOLM	REC-465-5						
PUNTA ARENAS	REC-465-5						
SEOUL	REC-465-5						
HAWAII	REC-465-5						
PORTLAND	REC-465-5						
COLUMBUS	REC-465-5						
CAPE TOWN	REC-465-5						
BAHRAIN	REC-465-5						

13C Remarks:

BR22 Administration remarks:

BR23 Radiocommunication Bureau comments:

Page / Página / 页 / стр. / 9 الصفحة



3.5.1.7 Commenting procedures and resolution of difficulties

Although those satellite networks published in the API/A special sections are not subject to the coordination procedure under Section II of RR Article **9**, there is still a commenting procedure and resolutions of difficulties specified under RR No. **9.3**.

After the publication of the API/A special section, any administration, believing that unacceptable interference may be caused to its existing or planned satellite networks or systems, shall submit a comment to the notifying Administration, with a copy to the Bureau, within four months from the date of publication of the special section. The copy of comments to the Bureau shall be captured using SpaceCom software and submitted via the e-Submission system (see section 3.5.1.4.1).

If no such comments from an administration are received for the published API within the four-month commenting period, it is assumed that the administration concerned has no objections to the published satellite network(s) or system(s).

In order to implement the requirements of RR No. **9.3.1**, the Bureau makes these comments available "as-received" on the ITU website. The Bureau consolidates the comments received at the end of the four-month period and publishes the list of administrations which have sent comments in an API/B special section of a BR IFIC.

The procedure for cooperation and resolution of difficulties is described in RR Nos. **9.3** and **9.4**, as follows:

– Both administrations shall endeavour to cooperate in joint efforts to resolve any difficulties and shall exchange any additional relevant information that may be available.

– Either party can request the assistance of the Radiocommunication Bureau.

– In case of difficulties, the administration responsible for the planned satellite network shall explore all possible means to resolve the difficulties without considering the possibility of adjustment to satellite networks of other administrations.

– If no such means can be found, it may request the other administrations to explore all possible means to meet its requirements.

– The administrations concerned shall make every possible effort to resolve the difficulties by means of mutually acceptable adjustments to their satellite networks.

For satellite networks operating in the amateur-satellite service, the operator or notifying administration should contact the International Amateur Radio Union (IARU) for assistance in the frequency coordination process (https://www.iaru.org/reference/satellites/). See section 3.5.1.10 for more details.

Finally, the attention of administrations is brought to the BR Circular Letter CR/420 concerning the application of RR No. **9.3** in the bands 2 025-2 110 MHz (Earth-to-space) and 2 200-2 290 MHz (space-to-Earth).

3.5.1.7.1 Publication of API/B special section

Publication in special section API/B contains a list of administrations which have sent comments under RR No**. 9.3**, published in accordance with RR No. **9.5**.

The description of the data items used in the publications is available at the webpage:

http://www.itu.int/ITU-R/space/brific/legend/

The following is a sample abstract of a publication in an API/B special section.

UIT ITU

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS
BUREAU DES RADIOCOMMUNICATIONS | INTERNATIONAL TELECOMMUNICATION UNION
RADIOCOMMUNICATION BUREAU | UNIÓN INTERNACIONAL DE TELECOMUNICACIONES
OFICINA DE RADIOCOMUNICACIONES

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RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	USASAT-30M	SECTION SPÉCIALE N° SPECIAL SECTION No. SECCIÓN ESPECIAL N.°	API/B/1701
		BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA	2955 / 21.09.2021
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE USA	LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL NGSO	NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN	121545046

RÉFÉRENCE DE LA SECTION SPÉCIALE (BR IFIC / DATE) SPECIAL SECTION REFERENCE (BR IFIC / DATE) REFERENCIA DE LA SECCIÓN ESPECIAL (BR IFIC / FECHA)	API/A/12786 (BR IFIC 2943 / 06.04.2021)

1. La présente Section spéciale est publiée conformément au numéro 9.5 du Règlement des radiocommunications, et concerne la demande de coordination publiée dans la section spéciale API/A indiquée ci-dessus. 2. Les administrations qui ont soumis des observations au titre du numéro 9.3 dans le délai de quatre mois suivant la date de publication de la Section spéciale API/A précitée, sont indiquées ci-dessous et le tableau contient un résumé de ces observations.	1. This Special Section is published in accordance with No. 9.5 of the Radio Regulations, in respect of the request for coordination published in the API/A Special Section referenced above. 2. Administrations that have submitted comments under No. 9.3 within four months of the date of publication of the mentioned API/A Special Section are listed below and the table contains a summary of the comments.	1. Esta Sección Especial se publica de conformidad con lo dispuesto en el número 9.5 del Reglamento de Radiocomunicaciones, en lo que respecta a la solicitud de coordinación publicada en la Sección Especial API/A antes citada. 2. Las administraciones que han presentado comentarios conforme al número 9.3 dentro de un plazo de cuatro meses a partir de la fecha de publicación de la Sección Especial API/A mencionada, se indican a continuación y en el cuadro se presenta un resumen de los comentarios.

ALG, ARG, ARS, AUS, AZE, BUL, CAN, CHN, CYP, D/EUM, D, E, EGY, F/ESA, F, G, HOL, I/GLS, I, IND, IRN, J, KAZ, KOR, LIE, LTU, LUX, MCO, MRC, NOR, PAK, PNG, QAT, RUS, SLM, SUI, THA, TUR, UAE

Tableau / Table / Cuadro / 表 / Таблица / الجدول

RÉSUMÉ DES OBSERVATIONS / SUMMARY OF COMMENTS / RESUMEN DE LOS COMENTARIOS
意见摘要 / РЕЗЮМЕ ЗАМЕЧАНИЙ / ملخص بالتعليقات

	ADM
E	ALG, ARS, EGY, IRN, QAT, THA
T	ALG, EGY, IRN, J, QAT, THA, UAE
S	ALG, ARG, AUS, AZE, BUL, CAN, CHN, CYP, D/EUM, D, E, EGY, F/ESA, F, G, HOL, I/GLS, I, IND, IRN, J, KAZ, KOR, LIE, LTU, LUX, MCO, MRC, NOR, PAK, PNG, QAT, RUS, SLM, SUI, THA, TUR, UAE

Symboles utilisés dans le résumé des observations / Symbols used for the Summary of comments / Símbolos utilizados en el resumen de los comentarios / 意见摘要使用的符号 / Условные обозначения, используемые в резюме замечаний / الرموز المستعملة في ملخص التعليقات

ADM: Administration / Administration / Administración / 主管部门 / Администрация / الإدارة

E: Exclusion du territoire / Excluding territory / Territorio excluido / 领土除外 / Исключая территорию / باستثناء أراضي

T: Brouillage causé aux services de Terre / Interference to the terrestrial services / Interferencia a los servicios terrenales / 对地面业务的干扰 / Помехи наземным службам / تداخل في خدمات الأرض

S: Brouillage causé aux services spatiaux / Interference to the space services / Interferencia a los servicios espaciales / 对空间业务的干扰 / Помехи космическим службам / تداخل في الخدمات الفضائية

3.5.1.8 Modifications to the characteristics of the satellite network

Any amendments to the information published in an API/A special section should be sent to the Bureau as soon as they become available. It is a good practice to submit a modification to the API including any change in characteristics like orbital characteristics, service areas, addition of associated earth stations, etc. because this will allow other administrations and operators to submit comments before the modifications are notified for recording in the Master Register.

In particular, amendments to the following information for non-GSO satellite filings shall require a new API:

– additional frequency band;

– modification of the direction of transmission;

– modification of reference body.

If, in the notification submission, there are other changes in the characteristics as compared to the information published in API/A, other administrations can submit comments following the publication of the Part I-S (RR No. **11.28.1**).

3.5.1.9 Non-GSO satellites with short-duration missions

In recent years, an increasing number of academic institutions, amateur satellite organizations and government agencies have been developing non-GSO satellite systems with short-duration missions using nano- and picosatellites. Short-duration mission refers to a mission having a limited period of validity of not more than typically three years. Reports ITU-R SA.2425 and ITU-R SA.2426 clarify that the term “short-duration mission” is not directly tied to the lifetime of the satellite. For example, a single satellite with a lifetime of less than three years, where the operator does not launch a replenishment or replacement satellite, is a short-duration mission. However, in the case of a (or multiple) satellite with a lifetime of less than three years, where the operator launches a (or multiple) replenishment or replacement satellite such that the operator has a persistent frequency assignment longer than three years, is not a short-duration mission.

Considering that non-GSO satellites with short-duration missions (non-GSO SDM) utilizing low-Earth orbits (LEO) are being used for a wide variety of applications including remote sensing, space weather research, upper atmosphere research, astronomy, communications, technology demonstration and education, and therefore may operate under various radiocommunication services, and that advances in the field of satellite technology have resulted in non-GSO SDM becoming a means for developing countries to become involved in space activities, WRC-19 adopted the new procedures contained in Resolution **32 (WRC-19)** for non-geostationary-satellite networks or systems identified as short-duration mission.

When submitting such a network or system, the administration must identify it in the notice database, by checking the indicator for data item **A.1.g** of RR Appendix **4** via the BR capture software SpaceCap for the API as well as the notification notices.

3.5.1.9.1 Constrains for non-GSO satellites with short-duration missions

For non-GSO SDM, there are several additional constrains listed in the Resolution, including the following:

– Non-GSO SDM shall operate under any space radiocommunication service in the frequency bands that are not subject to the application of Section II of RR Article **9**.

– The total number of satellites in non-GSO-SDM shall not exceed ten satellites.

– The maximum period of operation and validity of frequency assignments of the non-GSO SDM shall not exceed three years from the date of bringing into use of the frequency assignments, and further extension is not allowed, after which the recorded assignments shall be cancelled.

– Non-GSO SDM shall comply with the conditions for use of the frequency band that is allocated to the service within which they operate.

– Non-GSO SDM networks or systems shall have the capability to cease transmitting immediately in order to eliminate harmful interference.

With respect to the notification for recording for satellite networks:

– An additional commitment (data item **A.24.a** of RR Appendix **4**) is required from the administration that, in the case that unacceptable interference caused by non-GSO SDM is not resolved, the administration shall undertake steps to eliminate the interference or reduce it to an acceptable level.

– The notification information can only be submitted after the launch of a first satellite, but not more than two months after the date of bringing into use of the frequency assignments.

– The date of bringing into use of the frequency assignments of non-GSO SDM shall be defined as the launch date of the first satellite.

– Provisions relating to modifications of characteristics of recorded assignments and suspension of assignments (RR Nos. **11.43A**, **11.43B** and **11.49)** cannot be applied for non-GSO SDM.

– At the expiry date of period of validity, BR shall publish a suppression of the related special section and cancel the recording in the Master Register.

The above constrains are in addition to the other RR provisions that normally apply to all satellite networks. Note that although any non-geostationary satellite network that is using any space radiocommunication service in any frequency bands that are not subject to the application of Section II of RR Article **9** may be submitted as non-GSO-SDM, it may not be beneficial to do so due to the additional constraints listed above.

3.5.1.9.2 Space Operation Service frequency allocations for non-GSO satellites with short-duration missions

The frequency bands 137.175-137.825 MHz (space-to-Earth) and 148-149.9 MHz (Earth -to-space), allocated to the space operation service (SOS) on the condition that they are submitted as non-GSO SDM in accordance with RR Resolution **32 (WRC-19)**, are exempt from coordination procedures with some conditions stated in RR Nos. **5.203C**, **5.209A**, **5.218A** and Resolution **660 (WRC-19)** in addition to those listed in Resolution **32 (WRC-19)**.

If not submitted as SDM, the band 137.175-137.825 MHz (space-to-Earth) for SOS is subject to coordination procedure under RR No. **9.11A**, and the band 148-149.9 MHz (Earth-to-space) for SOS is subject to coordination procedure under RR No **9.21**.

3.5.1.9.2.1 Use of SOS (s-to-E) in the frequency band 137.025-138 MHz by non-GSO SDM

As per Resolution **660 (WRC-19)**, in the frequency range of 137-138 MHz, the use of the space operations service (SOS) (space-to-Earth) for non-GSO satellites with short-duration missions shall be limited to the range of 137.025-138 MHz. The overall occupied bandwidth of any emission should be maintained completely within the frequency band allocated to the application identified in the SOS with short-duration missions, including any offsets such as Doppler shift or frequency tolerances.

Resolution **660 (WRC-19)** also specifies that, in the frequency band 137.025-138 MHz, the power flux-density (pfd) at any point on the Earth's surface produced by a space station of the non-GSO SOS systems used for short-duration missions in accordance with RR Appendix **4** shall not exceed −140 dB(W/($m^2 \cdot$ 4 kHz)).

The pfd calculation shall be executed under the worst-case orbital condition with regards to altitude and elevation (i.e. with the space station closest to Earth), therefore assuming the minimum expected altitude of the orbit during the satellite operations lifetime, and the highest elevation, over the proposed ground station.

The general expression for the calculation of the PFD (dB(W/($m^2 \cdot$ 4 kHz))) at any point on the Earth's surface is given in equation (1).

$$PFD = P_{Tx} + G_{Tx} - 20\log(d) - 71 \quad (1)$$

where:

G_{Tx}: maximum antenna gain in the direction of the Earth's surface (dBi)

P_{Tx}: maximum power in any 4 kHz bandwidth (dB(W/4 kHz))

d: distance from the space station to the Earth's surface (km).

The maximum power in the reference 4 kHz bandwidth, P_{Tx}, may be obtained from equation (2):

$$P_{Tx} = PSD_{Max} + 36 \quad (2)$$

where:

PSD_{Max}: maximum power spectral density (dB(W/Hz)).

For the calculation of the maximum power spectral density, integrated over 4 kHz, of angle-modulated, digital or tracking, telemetry and telecommand (TT&C) carriers, the most recent version of Recommendation ITU-R SF.675 should be used. For the case of a digital carrier with necessary bandwidth greater than 4 kHz, the PSD_{Max} may be obtained as follows:

$$PSD_{Max} = P_c - 10\log(B_{Nec}) \quad (3)$$

where:

P_c: total power of the carrier (dBW)

B_{Nec}: necessary bandwidth of the digital emission (Hz).

For those cases with multiple identical carriers with a bandwidth less than 4 kHz where it is known that any 4 kHz will not be completely filled with such carriers, equation (4) should be applied:

$$PSD_{Max} = 10\log(N) + P_c - 36 \quad (4)$$

where:

N: maximum number of carriers, or portions of carriers, with a bandwidth less than 4 kHz to occupy any given 4 kHz band

P_c: total power of a single carrier (dBW).

When narrow-band TT&C carriers are involved in frequency bands below 15 GHz, care must be taken in assessing the maximum power per 4 kHz for such carriers. This is due to the fact that such carriers can have multiple distinct and significant spectral components. As such, it is important to consider the actual spectral shape of such TT&C carriers when selecting the 4 kHz bandwidth with highest transmit power in order to assess the maximum power density.

3.5.1.9.2.2 Use of SOS (Earth-to-space) in the frequency band 148-149.9 MHz by non-GSO SDM

Under RR No. **5.218A**, the frequency band 148-149.9 MHz in the space operation service (Earth-to-space) may be used by non-GSO SDM. Such use, in accordance with Resolution **32 (WRC-19)**, is not subject to agreement under RR No. **9.21**. At the stage of coordination, the provisions of RR Nos. **9.17** and **9.18** also apply.

In the frequency band 148-149.9 MHz, non-GSO SDM shall not cause unacceptable interference to, or claim protection from, existing primary services within this frequency band, or impose additional constraints on the space operation and mobile-satellite services.

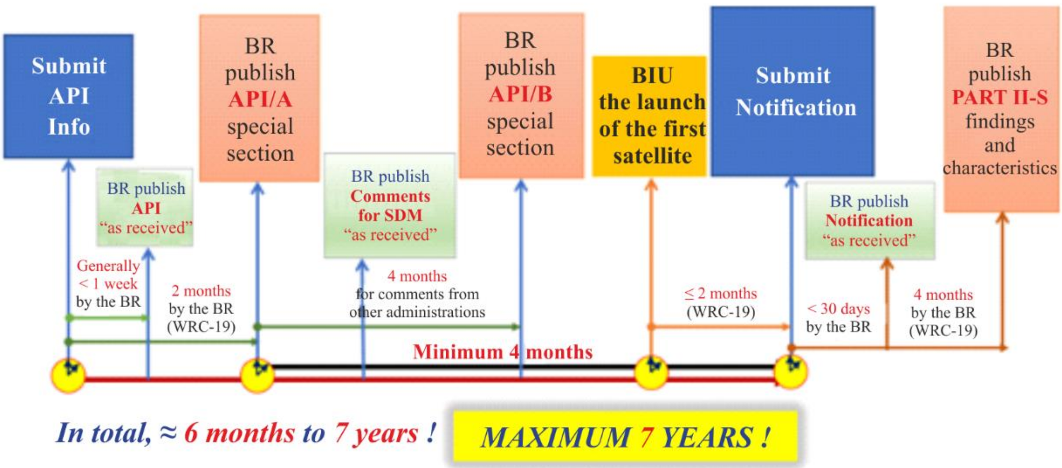
In addition, earth stations in non-GSO SDM in the space operation service in the frequency band 148-149.9 MHz shall ensure that the pfd does not exceed −149 dB(W/(m^2 · 4 kHz)) for more than 1% of time at the border of the territory of the following countries: Armenia, Azerbaijan, Belarus, China, Korea (Rep. of), Cuba, Russian Federation, India, Iran (Islamic Republic of), Japan, Kazakhstan, Malaysia, Uzbekistan, Kyrgyzstan, Thailand, Viet Nam. In case this pfd limit is exceeded, agreement under RR No. **9.21** is required to be obtained from countries mentioned in this footnote.

3.5.1.9.3 ITU filing process for non-GSO satellites with short-duration missions

The ITU filing process for non-GSO SDM satellite networks or systems not subject to coordination under Resolution **32 (WRC-19)** is shown in Fig. 5 below.

FIGURE 5

ITU filing process for non-GSO SDM satellite networks or systems submitted under Resolution 32 (WRC-19)



Handbook on Small Satellites-5

As illustrated in Fig. 5, once the ITU Radiocommunication Bureau receives an API submission, it will publish it "as-received" shortly, generally within one week, via the "e-submission" system, and follow up with a full API/A special section publication within two months from the official date of receipt of the notice, if there is no need for any clarification from the notifying administration (see details in the Rules of Procedure on Receivability).

After the publication of the API/A special section, any administration, believing that unacceptable interference may be caused to its existing or planned satellite networks or systems, shall submit a comment to the notifying Administration, with a copy to the Bureau, within four months from the date of publication of the special section.

Comments to API/A special sections for non-GSO SDM satellite networks are also made available "as-received", shortly on the ITU website, in accordance with RR No. **9.3.1**. The ITU Radiocommunication Bureau will publish an API/B special section including all comments received subsequently (see section 3.5.1.7 for more details).

The date of bringing into use of the frequency assignments of non-GSO SDM shall be defined as the launch date of the first satellite.

In the application of RR No. **9.1**, the notification information cannot be communicated to the ITU Bureau at the same time and can only be submitted after the launch of a satellite in the case of a network or of the first satellite in the case of a system with multiple launches. Notices relating to non-GSO networks or systems identified as short-duration mission shall be communicated to BR only after the launch of a satellite in the case of a satellite network or of the first satellite in the case of a system requiring multiple launches, and not later than two months after the date of bringing into use. The ITU Radiocommunication Bureau publish the "as-received" for notification submission shortly on website.

Irrespective of the date of receipt of the notified characteristics of the non-GSO network or system with a short-duration mission under Resolution **32 (WRC-19)**, the maximum period of validity of frequency assignments of the system shall not exceed three years from the date of bringing into use of the frequency assignments. At the expiry date of period of validity, the ITU BR shall publish a suppression of the related special section.

For non-GSO SDM satellite networks or systems, the findings and the characteristics of the system will be published in the BR IFIC and on the ITU website within four months from the date of receipt of complete notification information.

3.5.1.10 Specific requirements for amateur-satellite service in the Radio Regulations

The frequency bands allocated to amateur-satellite service have been used heavily by small satellites in the past 20 years. However, a number of applications and operations in these frequency bands do not comply with all the requirements for amateur use and have been authorized only for experimental operation.

The use of amateur or amateur-satellite service, is only appropriate when the definitions of the amateur service (RR No. **1.56**) and amateur-satellite service (RR No. **1.57**) are strictly met: "A radiocommunication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest". Therefore, the amateur-satellite service shall be used in a non-commercial and non-profit way which is incompatible with business operations.

In many ways, the approach that is taken within the bands allocated to the amateur-satellite service is nearly ideal as there is a simple, clearly defined process to be followed and the costs associated with this approach are minimal.

Satellite systems in the amateur-satellite service are generally non-geostationary satellite systems which are not subject to any form of coordination. For such systems, the provisions of RR Article **9**, Sub-Section IA (Advance publication of information (API) on satellite networks or satellite systems that are not subject to coordination procedure under Section II), are applicable. Frequency assignments to space stations in the amateur-satellite service shall be notified to the Bureau, while as an exception, frequency assignments to earth stations in the amateur-satellite service are not required to be notified for recording in the Master Register.

In the same way as for other space services, an API must be prepared for frequencies and services that are not subject to coordination and must be submitted to the ITU for satellite networks operating in the amateur-satellite service. Such API is encouraged to be submitted to the ITU before requesting for frequency coordination with IARU. It is however possible to do the IARU coordination before the ITU submission if the Administration prefers to do so.

Administrations preparing an API for the amateur-satellite service have to consider possible change in frequency bands following the frequency coordination and consultation process with IARU and avoid submitting a very narrow frequency band at the API stage. If the frequency finally selected is outside of the band filed in the API, a new or modified API will have to be submitted. It is encouraged that all administrations make utmost efforts in resolving any difficulties before notification in order to prevent the possibility of harmful interference.

Administrations authorizing space stations in the amateur-satellite service shall ensure that sufficient earth command stations are established before launch to ensure that any harmful interference caused by emissions from the station can be terminated immediately (see RR Nos. **22.1** and **25.11**).

Amateur-satellite service is exempted from cost recovery fee, noting that, for a filing to benefit from this fee exemption, there should be only one main service (class of station EA) in the filing without any other main space services (e.g. class of stations EW for Earth exploration-satellite service, EH for space research service, ET for space operation service) being present.

Furthermore, if there is no allocation for space operation service in the frequency band selected for the amateur-satellite, the space operation functions (space tracking, space telemetry, space telecommand) with class of stations EK, ER, ED separately, could be normally provided with the main service of amateur-satellite service (class of station EA) in which the space station is operating, with a similar exemption from cost recovery fee (see section 3.5.6).

In order to help administrations planning submissions of "small satellite" operating in frequency bands allocated to the amateur-satellite service, the Bureau issued Circular Letter CR/303 (https://www.itu.int/md/R00-CR-CIR-0303/en) related to the amateur-satellite service and created a support webpage: https://www.itu.int/en/ITU-R/space/support/smallsat/Pages/default.aspx

3.5.1.10.1 Coordination with the International Amateur Radio Union

Small satellite systems operating in amateur-satellite spectrum are generally not subject to the coordination procedure under Section II of RR Article **9**. Uncoordinated satellites will highly likely cause harmful interference to stations around the world and receive interference from others, which could result in mission failure. To resolve any potential difficulties, the process described by IARU at https://www.iaru.org/spectrum/ is useful.

Frequency Coordination Requests for the amateur-satellite service shall be made using the specific form. See details in the webpage https://www.iaru.org/reference/satellites/

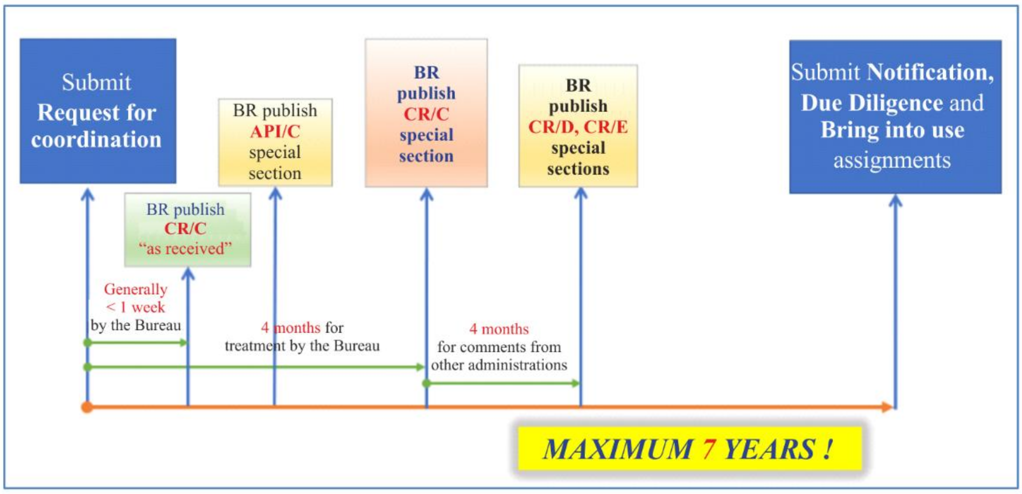
With the IARU coordination team meeting every two weeks, the typical processing time for coordination requests could be less than four weeks, provided that all necessary information is being made available.

3.5.2 Procedures for satellite networks subject to coordination

In brief, the ITU filing process procedures applying to frequency bands and services which are subject to the coordination procedure under Section II of RR Article **9** is shown in Fig. 6.

FIGURE 6

ITU process for satellite networks subject to coordination



Handbook on Small Satellites-6

As shown in Fig. 6 above, for satellite networks subject to coordination under Section II of RR Article **9**, it is required to first submit a request for coordination (CR).

A complete submission for coordination request (CR) generally includes:

– a notice database containing RR Appendix **4** required information captured via the BR software SpaceCap;

– a GIMS database containing graphical information captured via the Graphical Interference Management Software (GIMS);

– commitments, demonstrations, pfd and e.i.r.p. masks, if necessary;

– relevant attachments or notes.

A guide to capture diagrams and attachments for non-GSO using BR software is available at the webpage www.itu.int/go/space/non-GSO/graphical-submission

In accordance with the Rules of Procedure on Receivability, the final electronic notice mdb file in SNS format, together with the GIMS format database, and any additional attachments, shall be submitted through the Bureau's online submission system "e-Submission of satellite network filings".

Upon receipt of the complete CR information, the BR will publish the "as-received" for CR shortly and then extract the basic characteristics from the CR and publish them in the API/C special section.

The BR will carry out examination of the satellite network in accordance with RR No. **9.35**, identify in accordance with RR No. **9.36** any administrations with which coordination may need to be effected and publish the result of the examinations in a CR/C special section within four months.

There is a four-month commenting period from the date of the publication for other administrations to submit comments under the various coordination provisions. At the end of the four months, the BR will consolidate and publish all comments from other administrations in the relevant CR/D and CR/E special sections.

Within seven years from the date of receipt of the CR, the administration must submit the notification, the due diligence and bring into use the frequency assignments accordingly, otherwise the satellite network will be suppressed. At both coordination and notification stages, the notice will be examined by the Bureau under RR No. **11.31** (see section 3.5.4). In addition, for notification notices subject to coordination, it will be examined also under RR No. **11.32** and **11.32A** as appropriate, see contents elaborated in sections below.

Any satellite network or satellite system of the fixed-satellite service, mobile-satellite service or broadcasting-satellite service with frequency assignments that are subject to coordination would also need to submit the relevant administrative due diligence under Resolution **49 (Rev.WRC-19)** within 30 days following the end of the period established as a limit to bringing into use in RR No. **11.44**.

3.5.2.1 Submission of coordination request

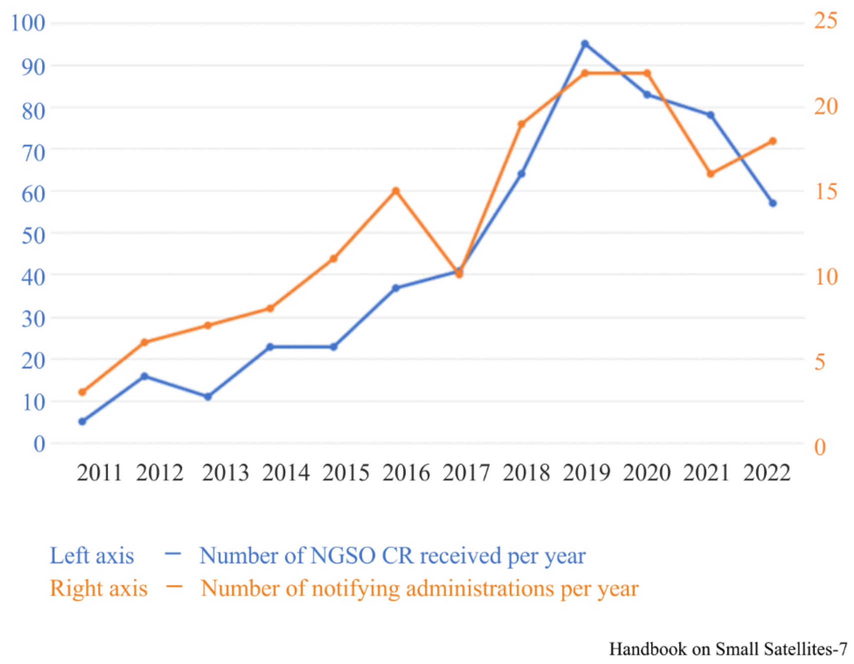
3.5.2.1.1 Submission trends for non-GSO coordination request (CR/C)

With regard to coordination requests for non-geostationary (non-GSO) satellite systems, prior to 2011, the number of requests remained relatively constant and extremely low with just few cases per year, as very few administrations were submitting such requests.

Since 2011, the Bureau has observed a generally upward trend in the number of coordination requests received. As shown in Fig. 7 below, there were five non-GSO coordination requests received by the Bureau in 2011, but 95 cases in 2019, and 83 cases in 2020. In the last two years, the number has decreased slightly, but still remain at a fairly elevated level. Currently, the number of non-GSO coordination requests is approximately three times the amount submitted in 2014 and 2015.

FIGURE 7

Submission of Non-GSO coordination requests for satellite networks or systems subject to coordination



3.5.2.2 Publication of CR/C special section

The CR/C special section publication contains requests for coordination submitted under RR Nos. **9.7** to **9.14** and **9.21** of frequency assignments to a space station or an earth station of a satellite network, published in accordance with the provision RR No. **9.38**.

The description of the data items used in the publication can be found at the webpage:

http://www.itu.int/ITU-R/space/brific/legend/

The following is a sample abstract of a non-GSO publication in a CR/C special section.

UIT ITU

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS BUREAU DES RADIOCOMMUNICATIONS	INTERNATIONAL TELECOMMUNICATION UNION RADIOCOMMUNICATION BUREAU	UNIÓN INTERNACIONAL DE TELECOMUNICACIONES OFICINA DE RADIOCOMUNICACIONES	© I.T.U.

RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	**GOCS-T**	**SECTION SPÉCIALE Nº SPECIAL SECTION No. SECCIÓN ESPECIAL N.º**	**CR/C/5520**
STATION TERRIENNE EARTH STATION ESTACIÓN TERRENA	**---**	**BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA**	**2954 / 07.09.2021**
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE **CHN**	**LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL** **NGSO**	**NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN**	**121520012**
RENSEIGNEMENTS REÇUS PAR LE BUREAU LE / INFORMATION RECEIVED BY THE BUREAU ON / INFORMACIÓN RECIBIDA POR LA OFICINA EL			**20.01.2021**

Cette demande de coordination, reçue par le Bureau des radiocommunications en vertu du numéro 9.30 du Règlement des radiocommunications, a été examinée au titre des numéros 9.35 et 9.36 et est publiée conformément au numéro 9.38. Elle est subordonnée au type de coordination indiqué dans la colonne de gauche par un X dans la case pertinente.	This request for coordination, received by the Radiocommunication Bureau pursuant to No. 9.30 of the Radio Regulations, has been examined under Nos. 9.35 and 9.36 and is published in accordance with No. 9.38. It is subject to the form of coordination indicated in the left-hand column by an X in the relevant box	Esta solicitud de coordinación, recibida por la Oficina de Radiocomunicaciones de conformidad con el punto Nº 9.30 del Reglamento de Radiocomunicaciones, se ha examinado de conformidad con los Nos 9.35 y 9.36 y se publica de conformidad con el Nº 9.38. Está sujeta al formulario de coordinación indicado en la columna de la izquierda con una X en la casilla correspondiente.

Type de coordination mentionné dans le Tableau I / Form of coordination referred to in Table I / Forma de coordinación mencionada en el cuadro I

	9.7 9.7A 9.7B AP30#7.1 AP30A#7.1	Conformément aux numéros **9.50** à **9.52** du Règlement des radiocommunications, les Administrations identifiées dans le Tableau I ci-après sont priées de communiquer leur décision à l'Administration responsable et au Bureau avant la date limite indiquée ci-dessous.	In accordance with Nos. **9.50-9.52** of the Radio Regulations, the Administrations identified in Table I below are requested to communicate their decision to the Responsible administration and the Bureau by the deadline indicated below.	De conformidad con los Nos **9.50-9.52** del Reglamento de Radiocomunicaciones, se solicita a las administraciones señaladas en el cuadro I a continuación que comuniquen su decisión a la administración responsable y a la Oficina antes del plazo indicado más abajo.

Type de coordination mentionné dans le Tableau II / Form of coordination referred to in Table II / Formulario de coordinación remitido al cuadro II

        X	9.11 9.11A 9.12 9.12A 9.13 9.14 9.21/A 9.21/B 9.21/C	Les Administrations, énumérées ou non dans le Tableau II ci-après, qui n'acceptent pas la demande de coordination au titre des numéros **9.11** à **9.14** et **9.21**, sont priées de communiquer leurs observations à l'Administration responsable et au Bureau avant la date limite indiquée ci-dessous. Toute Administration qui ne réagira pas au titre du numéro **9.52** avant cette date limite sera considérée comme n'étant pas affectée et, dans les cas couverts par les numéros **9.11** à **9.14**, les dispositions des numéros **9.48** et **9.49** s'appliqueront.	Administrations listed or not listed in Table II below, which do not agree to the request for coordination under Nos. **9.11** to **9.14** and **9.21** are requested to communicate their comments to the responsible administration and the Bureau by the deadline indicated below. Any administration not responding under No. **9.52** within this deadline shall be regarded as unaffected and, in the cases of Nos. **9.11** to **9.14**, the provisions of Nos. **9.48** and **9.49** shall apply.	Se ruega a las Administraciones que figuran en la lista del Cuadro II siguiente, que no están de acuerdo con la solicitud de coordinación con arreglo a los números **9.11** a **9.14** y **9.21** que comuniquen sus comentarios a la administración responsable y a la Oficina dentro del plazo que se indica más adelante. Se considerará que toda administración que no responda con arreglo a lo dispuesto en el núm. **9.52** dentro del plazo indicado no se ve afectada y, en los casos de los números **9.11** a **9.14**, se aplicarán las disposiciones de los números **9.48** y **9.49**.

DATE LIMITE POUR LA DÉCISION / EXPIRY DATE FOR DECISION / FECHA LÍMITE PARA LA DECISIÓN	**07.01.2022**

Tableau I /Table I /Cuadro I /表一 /Таблица I / الجدول I

	Disposition / Provision / Disposición / 条款 / Положение / الحكم	Résumé des conditions régissant la coordination 协调要求概述	Summary of coordination requirements Сводные потребности в координации	Resumen de los requisitos de coordinación موجز بمتطلبات التنسيق
	9.7			
	9.7A			
	9.7B			
	AP30#7.1			
	AP30A#7.1			

Tableau II /Table II /Cuadro II /表二 /Таблица II / الجدول II

	Disposition / Provision / Disposición / 条款 / Положение / الحكم	Administrations susceptibles d'être défavorablement influencées (à titre d'information uniquement, voir numéro 9.36.1) 可能受影响的主管部门(仅供参考，见第 9.36.1款)	Potentially affected administrations (for information only, see No. 9.36.1) Потенциально затрагиваемые администрации (исключительно для информации, см. п. 9.36.1)	Administraciones posiblemente afectadas (sólo para información, véase el N° 9.36.1) إدارات يحتمل أن تتأثر تأثراً غير مؤات (انظر الرقم 1.36.9، على سبيل الاطلاع فقط)
	9.11			
	9.11A			
	9.12			
	9.12A			
	9.13			
	9.14			
	9.21/A[1]			
	9.21/B[1]			
X	9.21/C[1]	AZE, BLR, CUB, KOR, RUS, VTN		

[1] 9.21/A, 9.21/B et 9.21/C – au titre du numéro 9.21, administrations ayant des réseaux OSG, des réseaux non-OSG et des stations de Terre, respectivement.
[1] 9.21/A, 9.21/B and 9.21/C – Under No. 9.21, administrations with GSO networks, Non-GSO networks and terrestrial stations, respectively.
[1] 9.21/A, 9.21/B y 9.21/C – De conformidad con el Nº 9.21, administraciones con redes OSG, redes no OSG y estaciones terrestres, respectivamente.
[1] 9.21/A, 9.21/B 和 9.21/C – 根据第9.21款, 分别为有对地静止卫星轨道网络、非对地静止卫星轨道网络和地面站的主管部门
[1] 9.21/A, 9.21/B и 9.21/C – в соответствии с п. 9.21 администрации, имеющие сети ГСО, сети НГСО и наземные станции, соответственно.
[1] 9.21/A و9.21/B و9.21/C – بموجب الرقم 21.9، إدارات لها شبكات مستقرة بالنسبة إلى الأرض وشبكات غير مستقرة بالنسبة إلى الأرض ومحطات للأرض على التوالي.

SECTION SPECIALE / SPECIAL SECTION / SECCIÓN ESPECIAL / 特节 / СПЕЦИАЛЬНАЯ СЕКЦИЯ / القسم الخاص — CR/C/5520

A | *A1a* Sat. Network GOCS-T | *A1f1* Notif. adm. CHN | *A1f3* Inter. sat. org. | *BR1* Date of receipt 20.01.2021 | *BR20/BR21* BR IFIC no./part 2954/

BR6a/BR6b Id. no. 121520012 | *BR3a/BR3b* Provision reference 9.6 C | *BR2* Adm. serial no.

Résumé / Summary / Resumen / 综述 / Резюме / خلاصة

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	13A Conformity with RR	C3a Assigned freq. band	BR47 Frequency band (MHz)	BR62 Expiry date for bringing into use	BR15 Provision reference	BR53 Nb of freq.	C4a Class of station	BR54 Nb of emiss.	BR55 Nb of units
VDE1	E		121618015		A-----	150	161.7875 - 161.9375	20.01.2028	9.21	1	EG	1	1
			121618016		A-----	150	157.1875 - 157.3375	20.01.2028	9.21	1	EG	1	1

BR57 Category	C1
BR56 Total number of units	2

Résumé des caractéristiques orbitales du réseau à satellitte non OSG
NGSO卫星网络轨道特性总结

Summary of orbital characteristics for NGSO satellite network
Резюме орбитальных характеристик НГСО спутниковой сети

Resumen de las características orbitales para red de satélites no geoestacionarios
ملخص الخصائص المدارية للشبكة الساتلية غير المستقرة بالنسبة إلى الأرض (NGSO)

A4b1 No. of orbital planes 3 | *A4b2* Ref. body T | *BR43* Orbital configuration 4

A4b1a Constellation Y | *A4b1b* Configuration type S | *A4b1c* Number of sub-sets mutually exclusive | *A4b1d* Attachment no.

A4b6bis Limited or Extended set

Orbital plane id. no.	*A4b4a Inclination angle*	*A4b4b No. of satellites in this plane*	*A4b4c Period*	*A4b4d Apogee*	*A4b4e Perigee*	*A4b4f Min. altitude*	*A4b4g Right asc.*	*A4b4i Arg. of perigee*
1	97.8	1	0-01:36	600e0	600e0	600e0		0
2	88	4	0-01:36	600e0	600e0	600e0		0
3	88	4	0-01:36	600e0	600e0	600e0		0

OBSERVATIONS DU BUREAU DES RADIOCOMMUNICATIONS

Relatives à la Conclusion conformément au Nº 9.35 / 11.31

FAVORABLE pour toutes les assignations de fréquence.

RADIOCOMMUNICATION BUREAU COMMENTS

Relating to the Findings with respect to No. 9.35 / 11.31

FAVOURABLE for all frequency assignments.

OBSERVACIONES DE LA OFICINA DE RADIOCOMUNICACIONES

Relativas a la Conclusión según N.º 9.35 / 11.31

FAVORABLE para todas las asignaciones de frecuencia.

Ces assignations ont un statut secondaire.

These assignments are of secondary category.

Estas asignaciones son a título secundario.

Sens de transmission Direction of transmission Dirección de transmisión	Fréquence assignée (MHz) Assigned frequency (MHz) Frecuencia asignada (MHz)	Largeur de la bande (kHz) Bandwidth (kHz) Anchura de banda (kHz)	Bande de fréquences (MHz) Frequency band (MHz) Banda de frecuencias (MHz)	Classe de station Class of station Clase de estación
E	157.2625; 161.8625	150	157.1875 - 161.9375	EG

La coordination au titre du numéro **9.21/C** s'applique vis-à-vis des services de Terre de AZE, BLR, CUB, KOR, RUS, VTN (voir le numéro 5.228AC).

Coordination under No. **9.21/C** applies with respect to the terrestrial services in AZE, BLR, CUB, KOR, RUS and VTN (No. 5.228AC refers).

Se aplica la coordinación con arreglo al núm. **9.21/C** respecto de los servicios terrenales en AZE, BLR, CUB, KOR, RUS, VTN (véase el núm. 5.228AC).

根据第**9.21/C**款进行的协调适用于AZE、BLR、CUB、KOR、RUS、VTN的地面业务（参见第5.228AC款）。

Применяется координация согласно п. **9.21/C** в отношении наземных служб в AZE, BLR, CUB, KOR, RUS, VTN (см. п. 5.228AC).

ينطبق التنسيق بموجب الرقم **9.21/C** فيما يتعلق بخدمات الأرض في أذربيجان وبيلاروس وكوبا وكوريا وروسيا وفيتنام (انظر الرقم 5.228AC).

Sens de transmission Direction of transmission Dirección de transmisión	Fréquence assignée (MHz) Assigned frequency (MHz) Frecuencia asignada (MHz)	Largeur de la bande (kHz) Bandwidth (kHz) Anchura de banda (kHz)	Bande de fréquences (MHz) Frequency band (MHz) Banda de frecuencias (MHz)	Classe de station Class of station Clase de estación
传输方向 Направление передачи اتجاه الإرسال	指配频率 (MHz) Присвоенная частота (МГц) التردد المخصص (MHz)	带宽 Ширина полосы (кГц) عرض النطاق (kHz)	频段(MHz) Полоса частот (МГц) نطاق التردد (MHz)	台站类别 Класс станции صنف المحطة
E	157.2625; 161.8625	150	157.1875 - 161.9375	EG

Les dispositions suivantes s'appliquent aux bandes de fréquences listées dans le tableau ci-dessous:

The following provisions apply to the frequency bands listed in the table below:

Las siguientes disposiciones se aplican a las bandas de frecuencias listadas en la tabla a continuación:

以下条款适用于下表列出的频带：

Следующие положения применяются к полосам частот, перечисленным в таблице ниже:

تنطبق الأحكام التالية على نطاقات التردد المدرجة في الجدول أدناه:

Disposition relative à la coordination Coordination provision Disposición de coordinación 协调条款 Положение о координации الحكم المتعلق بالتنسيق	Renvois faisant référence à cette disposition relative à la coordination Footnotes referring to this coordination provision Notas que se refieren a esta disposición de coordinación 参引此协调条款的脚注 Примечания, в которых содержится ссылка на это положение о координации الحواشي التي تشير إلى هذا الحكم المتعلق بالتنسيق	Gamme de fréquences (MHz) Frequency range (MHz) Gama de frecuencias (MHz) 频率范围 (MHz) Диапазон частот (МГц) (MHz) مدى التردد	Sens de transmission Direction of Transmission Dirección de transmisión 传输方向 Направление передачи اتجاه الإرسال
9.21/C	5.228AC	157.1875 - 157.3375	E
	5.228AC	161.7875 - 161.9375	E

III. Administrations susceptibles d'être défavorablement influencées au niveau du groupe (à titre d'information uniquement, voir N° 9.36.1)

三、在组的层面潜在的受干扰的主管部门（仅供参考，见第9.36.1款）

III. Potentially affected administrations at group level (for information only, see No. 9.36.1)

III. Потенциально затрагиваемые администрации на уровне группы (исключительно для информации, см. п. 9.36.1)

III. Administraciones posiblemente afectadas a nivel de grupo (sólo para información, véase el N.° 9.36.1)

III. الإدارات التي يحتمل أن تتأثر تأثراً غير مؤات على مستوى المجموعة (انظر الرقم **1.36.9** للعلم فقط)

B1a Beam designation	B2 Emi-Rcp	BR7a Group id.	GHz	Administrations susceptibles d'être défavorablement influencées au titre du N° 9.21/C 潜在的受干扰的主管部门 9.21/C	Potentially affected administrations under No. 9.21/C Администрации, потенциально затрагиваемые согласно № 9.21/C	Administraciones posiblemente afectadas según N.° 9.21/C الإدارات التي يحتمل أن تتأثر بموجب الرقم 9.21/C
VDE1	E	121618015	0	AZE BLR CUB KOR RUS VTN		
		121618016	0	AZE BLR CUB RUS		

3.5.2.3 Identifying coordination requirements

RR Appendix **5** indicates the technical criteria to be used for the purpose of effecting coordination or seeking agreement under RR Article **9**, and for identifying the administrations with which coordination is to be effected or agreement required.

Table 5-1 of RR Appendix **5** describes the technical conditions for coordination based on (and not limited to):

– regulatory provision which contains forms of coordination;
– sharing scenario associated to the notice;
– Type of station;
– frequency bandwidth overlap;
– service area region;
– service;
– threshold and condition;
– calculation method.

Tables 5-1, 5-2 and Annex 1 to RR Appendix **5** present a detailed description of different cases to determine the needs for coordination.

3.5.2.3.1 Criteria to effect coordination

Several criteria, such as frequency overlap, pfd as well as equivalent power flux-density (epfd) coordination threshold used under RR Nos. **9.7A** and **9.7B** can be found in RR Appendix **5** and is elaborated as follows:

3.5.2.3.1.1 Frequency overlap criterion

For coordination between non-GSO and GSO (RR Nos. **9.12A**, **9.21** (**9.21/A** in Preface)) and between non-GSOs (RR Nos. **9.12**, **9.21** (**9.21/B** in Preface)), only frequency overlap is used to trigger coordination, which includes affected networks or systems operating in opposite direction of transmission.

The software FOS (Frequency Overlap Software) in the Graphical Interface for Batch Calculations (GIBC) developed by the Radiocommunication Bureau can be used to determine the coordination requirements under Nos. **9.12**, **9.12A**, **9.21/A** and **9.21/B** which is based on frequency overlap.

In addition, the program produces the list of affected satellite networks or systems as required by RR No. **9.36.1**. The software can be downloaded from the webpage:

https://www.itu.int/ITU-R/go/space-software/en

For coordination between non-GSO and terrestrial services (RR Nos. **9.14**, **9.21** (**9.21/C** in Preface)):

– frequency overlap is used to trigger coordination in the bands where there is no pfd coordination trigger limit;

– frequency overlap in combination with a pfd limit are used to trigger coordination in the bands where there is a pfd coordination trigger limit.

3.5.2.3.1.2 pfd criterion

The pfd method is to evaluate the compatibility between non-GSO satellite networks and terrestrial services and consists of comparing the pfd level produced at the Earth's surface with a specific trigger limit. If it is exceeded, coordination under RR Nos. **9.11**, **9.14** or **9.21** is required or, in the case of application of RR No. **11.32A**, it is considered to have the potential to cause harmful interference.

3.5.2.3.1.3 Determination of the need for coordination between MSS and RDSS space stations (space-to-Earth) and terrestrial stations

Generally, pfd thresholds were used to determine the need for coordination between space stations of the MSS (space-to-Earth) and terrestrial services and for coordination between space stations of the RDSS (space-to-Earth) and terrestrial services. However, to facilitate sharing between digital fixed service stations and non-GSO MSS space stations, the concept of fractional degradation in performance (FDP) was adopted.

The method for the determination of the need for coordination between MSS and RDSS space stations (space-to-Earth) and terrestrial services sharing the same frequency band in the 1 to 3 GHz range as explained by Annex 1 to RR Appendix **5** is described here.

Coordination of assignments for transmitting space stations of the MSS and RDSS with respect to terrestrial services is not required if the pfd produced at the Earth's surface or the fractional degradation in performance (FDP) of a station in the fixed service does not exceed the threshold values shown in Table 5-2 of RR Appendix **5**, reproduced hereafter. See Annex 1 of RR Appendix **5** for method for calculating the value of FDP.

TABLE 5-2 (Rev.WRC-19)

Frequency band (MHz)	Terrestrial service to be protected	Coordination threshold values				
		GSO space stations		Non-GSO space stations		
		pfd (per space station) calculation factors (NOTE 2)		pfd (per space station) calculation factors (NOTE 2)		% FDP (in 1 MHz) (NOTE 1)
		P	*r* dB/ degrees	*P*	*r* dB/ degrees	
1 518-1 525	Analogue FS telephony (NOTE 5)	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	
	All other cases FS telephony (NOTES 4 and 8)	−128 dB(W/m²) in 1 MHz	0.5	−128 dB(W/m²) in 1 MHz	0.5	25
1 525-1 530	Analogue FS telephony (NOTE 5)	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	
	All other cases	−128 dB(W/m²) in 1 MHz	0.5	−128 dB(W/m²) in 1 MHz	0.5	25
2 160-2 200	Analogue FS telephony (NOTE 5)	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	−141 dB(W/m²) in 4 kHz and −123 dB (W/m²) in 1 MHz (NOTE 6)	0.5	
(NOTE 3)	All other cases	−128 dB(W/m²) in 1 MHz	0.5	−123 dB(W/m²) in 1 MHz (NOTE 6)	0.5	25
2 483.5-2 500 (mobile-satellite service)	All cases	−146 dB(W/m²) in 4 kHz and −128 dB(W/m²) in 1 MHz	0.5	−144 dB(W/m²) in 4 kHz and −126 dB(W/m²) in 1 MHz (NOTE 9)	0.65	
2 483.5-2 500 (radiodetermination-satellite service) (NOTE 10)	All cases except the radiolocation service in the countries listed in No. **5.398A**	−152 dB(W/m²) in 4 kHz −128 dB(W/m²) in 1 MHz	–	−153 dB(W/m²) in 4 kHz −129 dB(W/m²) in 1 MHz (NOTE 9)		
2 500-2 520 (SUP - WRC-07)						
2 520-2 535 (SUP - WRC-07)						

3.5.2.3.1.4 epfd coordination threshold

As specified in RR Appendix **5**, for the identification of coordination requirements under RR Nos. **9.7A** and **9.7B**, the epfd threshold is used.

See also section 3.5.4.2.

3.5.2.3.2 Parameters which affect coordination

There are pfd limits specified in the Radio Regulations for space services to protect the terrestrial services. Specific parameters of the satellite network or system such as the orbital characteristics, service area, earth station minimum elevation operating angles and power levels could affect coordination with terrestrial services.

– Specifying standard antenna pattern or non-standard antenna pattern which closely represent actual antenna radiation pattern will lead to the most efficient use of radio-frequency spectrum. Some known standard antenna patterns include Recommendation ITU-R S.1528 – Satellite antenna radiation patterns for non-geostationary orbit satellite antennas operating in the fixed-satellite service below 30 GHz;

– Recommendation ITU-R S.672 – Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites. Although this antenna pattern is provided for GSO satellites, it may be considered also for non-GSO employing highly-elliptical orbits having active arc close to GSO orbit altitude;

– Recommendation ITU-R M.1091 – Reference off-axis radiation patterns for mobile earth station antennas operating in the land mobile-satellite service in the frequency range 1 to 3 GHz.

The set of parameters specified below will define coverage area of non-GSO and thus could affect list of affected countries:

Orbital shell

Certain type of orbits like equatorial orbit, or highly elliptical orbit could have its coverage confined to specific regions.

For example, highly elliptical orbit having its active arc above northern hemisphere (argument of perigee is equal to 270 degrees) would serve northern hemisphere and countries located at southern hemisphere may not be affected.

For circular orbits, orbit inclination would also define visible part of the Earth. For specific case of equatorial orbit (inclination equals 0) only countries located close to equator are visible.

Service area and continuous transmission indicator

Radio Regulations Appendix **4** data item ***B.2.a.1*** *an indicator specifying whether the space station only transmits when visible from the notified service area,* and item ***B.2.a.2*** *if the non-geostationary-satellite beam's transmissions are non-continuous, the minimum elevation angle above which transmissions occur when the space station is visible from the notified service area,* indicate whether space station will transmit only when visible from the notified service area and the minimum elevation at which this transmission occurs.

In case of non-continuous transmission, only the period of time when actual transmission could occur (when visible from the notified service area above the minimum elevation angle) should be considered to define other visible geographical area which can be potentially affected. This approach of specifying exact service area and minimum elevation angle could help the limit coordination burden.

As the use of steerable beams is becoming widespread, it is worthwhile to mention that when submitting filing with steerable beams, the frequency assignments in steerable beams will only receive favourable regulatory findings for compliance to such pfd limits if the following conditions as specified in the Rules of Procedure of No. **21.16** of the Radio Regulations are met:

(a) there is at least one position of the steerable beam where the applicable pfd limits are met without any reduction of the notified power density; and

(b) the administration states that the applicable pfd limits will be met by applying a method, the description of which should be submitted to the ITU.

3.5.2.4 Coordination approaches

The current regulations for coordinating the use of frequencies and orbits by non-GSO satellite systems operating non-planned services are based on the Articles **9** and **11** provisions of the Radio Regulations. There is an obligation for the notifying administration to resolve difficulties or coordinate their system with other administrations.

The coordination discussions involving satellite networks or systems have been so far based on bilateral meetings between involved parties on the assumption that the resulting constraints would be sufficient to guarantee a mutual acceptable interference environment for all involved networks.

Some coordination techniques that may be used by non-GSO systems to facilitate sharing between such networks:

a) At coordination stage, use of homogenous orbits:
   - Agree on operational parameters, transponder loading and coverage area.
   - Agree on acceptable level of interference.
   - Band segmentation i.e. use of non-overlapping frequencies.

b) At operational stage, agree on acceptable level of interference:
   - Power control and adaptive coding and modulation.
   - Satellite diversity to avoid in line events, operators can hand off traffic to satellites that avoid beam alignment, and therefore avoid interference.
   - Geographic isolation diversity i.e. sufficient isolation between each other's coverage area.

The best outcome can only be achieved through coordination between all parties in good faith.

At the same time, the nature of the non-GSO FSS systems filed in ITU so far containing very large numbers of satellites, a wide diversity of orbital characteristics (plane altitude and inclination) and global visible Earth coverages may require new innovative approaches for the coordination. Administrations and operators may agree on a more dynamic coordination approach based e.g. on orbit synchronization and the usage of the systems in real-time, taking account of all non-GSO systems in operation.

In such a case, beyond the traditional bilateral coordination approach and to ensure that the data for such dynamic coordination approach be easily available and regularly updated, a new coordination process might be considered that would include regular multilateral meetings involving the relevant parties with milestone on the development of the constellation similar to consultation meetings (as in Resolutions **609 (Rev.WRC-07)** and **769 (WRC-19)**) or reassessment meetings (as in Resolution **222 (Rev.WRC-12)**).

Some ITU-R Recommendations (https://www.itu.int/rec/R-REC-S/en) provide methods to enhance sharing of the spectrum between services or methodology to assess the interference, such as:

- Recommendation ITU-R S.1431 – Method to enhance sharing between non-GSO FSS systems (except MSS Feeder links) in the frequency bands between 10-30 GHz.
- Recommendation ITU-R S.1526 – Methodology to assess the interference environment in relation to Nos. **9.12**, **9.12A**, and **9.13** of the Radio Regulations when non-geostationary-satellite orbit fixed-satellite service systems are involved.
- Recommendation ITU-R S.1595 – Interference mitigation techniques to facilitate coordination between non-geostationary fixed-satellite service systems in highly elliptical orbit and non-geostationary fixed-satellite service systems in low and medium Earth orbit.
- Recommendation ITU-R S.1419 – Interference mitigation techniques to facilitate coordination between non-geostationary-satellite orbit mobile-satellite service feeder links and geostationary satellite orbit fixed-satellite service networks in the bands 19.3-19.7 GHz and 29.1-29.5 GHz.

3.5.3 Notification for recording in the Master Register

The ultimate aim to have frequency assignments recorded into the Master International Frequency Register (MIFR), also called Master Register, is to obtain the right to international recognition. This is because in accordance with the Radio Regulations, the international rights and obligations of administration in respect of their own and other administrations' frequency assignments are derived from the recording of the frequency assignments in the Master Register (see RR No. **8.1**). Having the right to international recognition also means that other administrations shall take the recorded frequency assignments into account when making their own assignments, in order to avoid harmful interference (see RR No. **8.3**). It is also equally important to note that while there are rights derived from the recorded assignments, similarly there are also reciprocal obligations to avoid harmful interference to recorded frequency assignments of other administrations and to accommodate the new entry of frequency assignments into the Master Register.

In general, Article **11** of the Radio Regulations states that any frequency assignments of transmitting and receiving earth and space stations is required to be notified if:

– capable of causing harmful interference; or

– used for international radiocommunication; or

– subject to a world or regional frequency allotment or assignment plan which does not have its own notification procedure; or

– seeking to obtain international recognition; or

– seeking to record for information purposes only; or

– seeking to record for non-conforming assignment, which use is not in accordance with the Table of Frequency Allocations or other provisions of the Radio Regulations (see RR No. **8.4**). As an exception, frequency assignments to earth stations in the amateur-satellite service are **not** required to be notified for recording in the Master Register. It should however be noted that frequency assignments to space stations in the amateur-satellite service **shall** be notified to the Bureau.

The information required for the submission of a notification is listed in the RR Appendix **4**. The capture, validation and submission of a notification notice is similar to what is described in sections 3.5.1.2 to 3.5.1.5 for the capture, validation and submission of an API notice.

The earliest date that a notification submission can be considered receivable is four months after the date of publication of the corresponding API/A special section. In other words, if a notification is received by the Bureau earlier than the prescribed four months, the official date of receipt will be established as four months after the publication of the API since this is earliest date that a notification can be considered receivable.

However, in order to accommodate the process of cooperation and resolution of difficulties with other administrations that have provided comments in response to the API publication as described in section 3.5.1.7 of this Handbook, administrations should as much as possible complete the process of resolving difficulties with other administrations before notifying space station frequency assignments that are not subject to coordination procedures under RR Article **9**.

In the case of space stations frequency assignments that are subject to coordination under Section II of RR Article **9**, administrations should make effort to complete coordination with other administrations before submitting the frequency assignments for notification.

In the case of frequency assignments to earth stations, the notification should be carried out after completing coordination of the frequency assignments of the earth station with administrations whose stations lies within the coordination area of the earth station, and after the associated space station have been notified and recorded in the MIFR. This is in consideration of § 2.1.2 of the Rules of Procedure for RR No. **11.32**. Starting from the principle that the leading element of a satellite network is the space station and that it would be misleading to record in the Master Register earth stations for which a space station (network) is not recorded, an earth station cannot be recorded in the Master Register before its associated space station.

In accordance with the Rules of Procedure on Receivability, the final electronic notice mdb file in SNS format, together with the GIMS format database, and any additional attachments, shall be submitted through the Bureau's new online submission system "e-Submission of satellite network filings".

When a notification is submitted via the "e-Submission" system, the "as-received" information from the administrations is made available by the Bureau in the ITU website. The "as-received" information has not undergone check for completeness and may or may not be considered complete. It is simply information as it was at the time when it was submitted to the Bureau.

The formal date of receipt is established when the Bureau confirms that the information submitted by the administration is complete and correct. Accordingly, where a notice received by the Bureau does not contain all the mandatory information as defined in Annex 2 of RR Appendix **4**, the notice is regarded as incomplete, and the Bureau will immediately inform the administration to seek the information that has not been provided. Further processing of the notice by the Bureau remains in abeyance. The formal date of receipt will not be established until the missing information is received. In such a case, the formal date of receipt will be the date when the complete information in the correct format is received.

If upon the establishment that all mandatory data information has been submitted but there is further clarification required concerning the correctness of the mandatory data submitted, the Bureau shall request the administration to provide the clarification within 30 days.

If the satisfied clarification is received within the 30 days period, the original date of receipt is retained. If the clarification is received beyond the 30 days period, a new date of receipt will be established. When no clarification is received, the notice is considered not receivable, and the notice will not be further processed.

After the information has been ascertained as complete, the notification is published in the Part I-S of a BR IFIC, with an official date of receipt. The notification will then be examined in detail under RR Nos. **11.31**, **11.32** and **11.32A**, as appropriate, and findings will be established accordingly.

The results of the findings will be published in Part II-S of the BR IFIC if the finding is favourable, and in a Part III-S of the BR IFIC if the finding is unfavourable.

– Part I-S: Notifications received concerning new frequency assignments or modifications or cancellations of recorded assignments;
– Part II-S: Frequency assignments recorded in the Master Register;
– Part III-S: Frequency assignments returned to the notifying administration.

The description of the data items used in the publications is available at the webpage:

http://www.itu.int/ITU-R/space/brific/legend/

Examples of notification publications in the BR IFIC can be found below.

3.5.3.1 Publication of the Part I-S to the BR IFIC

The Part I-S publication is to be considered the acknowledgement of receipt of the complete information of notification received and published in accordance with the provision RR No. **11.28** and contains particulars of frequency assignments for stations in the space radiocommunication services received by the Bureau for recording in the Master Register.

The following is a sample abstract of a Part I-S publication.

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS BUREAU DES RADIOCOMMUNICATIONS	INTERNATIONAL TELECOMMUNICATION UNION RADIOCOMMUNICATION BUREAU	UNIÓN INTERNACIONAL DE TELECOMUNICACIONES OFICINA DE RADIOCOMUNICACIONES	© I.T.U.

RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	HYSIS			PARTIE PART PARTE	I-S
STATION TERRIENNE EARTH STATION ESTACIÓN TERRENA	---			BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA	2971 / 17.05.2022
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE	IND	LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL	NGSO	NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN	122500037
RENSEIGNEMENTS REÇUS PAR LE BUREAU LE / INFORMATION RECEIVED BY THE BUREAU ON / INFORMACIÓN RECIBIDA POR LA OFICINA EL					24.02.2022

Notifications reçues au titre de		Notifications received under		Notificaciones recibidas en virtud de lo dispuesto en	
X	Article 11 du Règlement des radiocommunications	X	Article 11 of the Radio Regulations	X	Artículo 11 del Reglamento de Radiocomunicaciones
	Article 5 des Appendices 30 et/ou 30A		Article 5 of Appendices 30 and/or 30A		Artículo 5 de los Apéndices 30 y/o 30A
	Article 8 de l'Appendice 30B		Article 8 of Appendix 30B		Artículo 8 del Apéndice 30B

Pour plus d'informations sur les dispositions réglementaires et l'explication des codes ou symboles utilisés dans cette publication, veuillez consulter la Préface.	For more details on the regulatory provisions and the explanation of the codes or symbols used in this publication, please consult the Preface.	Para más detalles sobre las disposiciones reglamentarias y la explicación de los códigos o símbolos utilizados en esta publicación, sírvase consultar el Prefacio.

国际电信联盟 无线电通信局	МЕЖДУНАРОДНЫЙ СОЮЗ ЭЛЕКТРОСВЯЗИ БЮРО РАДИОСВЯЗИ	الاتحـاد الدولـي للاتصـالات مكتب الاتصـالات الراديويـة	© I.T.U.

卫星网络 СПУТНИКОВАЯ СЕТЬ الشبكة الساتلية	HYSIS			部分 ЧАСТЬ الجزء	I-S
地球站 ЗЕМНАЯ СТАНЦИЯ المحطة الأرضية	---			无线电通信局国际频率信息通报 / 日期 ИФИК БР / ДАТА النشرة الإعلامية الدولية للترددات/ رقمها وتاريخها	2971 / 17.05.2022
负责主管部门 ОТВЕТСТВЕННАЯ АДМ. الإدارة المسؤولة	IND	标称经度 НОМИНАЛЬНАЯ ДОЛГОТА خط الطول الاسمي	NGSO	识别号 ИДЕНТИФИКАЦИОННЫЙ НОМЕР رقم تعرف الهوية	122500037
通信局收到资料的日期 / ДАТА ПОЛУЧЕНИЯ ИНФОРМАЦИИ БЮРО / معلومات استلمها المكتب في					24.02.2022

根据以下条款收到的通知		Заявления, полученные согласно		بطاقات تبليغ مستلمة بموجب	
X	《无线电规则》第11条	X	Статья 11 Регламента радиосвязи	المادة 11 من لوائح الراديو	X
	附录30和/或30A第 5条		Статья 5 Приложений 30 и/или 30A	المادة 5 من التذييلين 30 و/أو 30A	
	附录30B第 8条		Статья 8 Приложения 30B	المادة 8 من التذييل 30B	

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On trouvera la description des éléments de données utilisés dans les publications dans le document: - ItemsDescription_F.pdf - http://www.itu.int/ITU-R/space/brific/legend/	The description of the data items used in the publications can be found in the document: - ItemsDescription_E.pdf - http://www.itu.int/ITU-R/space/brific/legend/	La descripción de los datos empleados en las publicaciones figura en el documento: - ItemsDescription_S.pdf - http://www.itu.int/ITU-R/space/brific/legend/
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PARTIE I-S / PART I-S / PARTE I-S / 第I-S部分 / ЧАСТЬ I-S / I-Sالجزء

A | *A1a* Sat. Network: HYSIS | *A1f1* Notif. adm.: IND | *A1f3* Inter. sat. org.: | *BR1* Date of receipt: 24.02.2022 | *BR20/BR21* BR IFIC no./part: 2971/1

BR6a/BR6b Id. no.: 122500037 | *BR3a/BR3b* Provision reference: 11.2 | N | *BR2* Adm. serial no.: 011

Résumé / Summary / Resumen / 綜述 / Резюме / خلاصة

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	C3a Assigned freq. band	BR47 Frequency band (MHz)	BR53 Nb of freq.	C4a Class of station	BR54 Nb of emiss.
S1R	R		122622785		750	2081.079 - 2081.829	1	ED, EK	1
S1T	E		122622783		500	2262.61 - 2263.11	1	EK, ER	1
X1T	E		122622784		320000	8040 - 8360	1	EW	1

A1f2 Submitted on behalf:

A1g Short Mission Duration Res 32: N | *A24a* SDM commitment: N

A4b1 No. of orbital planes: 1 | *A4b2* Ref. body: T

A4b1a Constellation: N

A4b3a No. of space stations simult. trans. on Northern Hemisphere: 1 | *A4b3b* No. of space stations simult. trans. on Southern Hemisphere:

A4b7a Max. sat. rcv. simult.: | *A4b7b* Avg. no. of As. E-stn: | *A4b7c* Avg. distance:

A4b7d1 Excl. zone type: | *A4b7d2* Excl. zone width:

A4b6bis Limited or Extended set:

Orbital plane id. no.	*A4b4a Inclination angle*	*A4b4b No. of satellites in this plane*	*A4b4c Period*	*A4b4d Apogee* / *A4b4e Perigee*	*A4b4f Min. altitude*	*A4b4m,n,o Sun synchronous* Y/N	*Node reference time*	*Node local time*	*A4b4g Right asc.* / *A4b4i Arg. of perigee*	*A4b6c Station keeping* / *A4b6d Repeat period*	*A4b6e Specific modelled station* / *A4b6f Precession rate*	*A4b4j Long. asc. node* / *A4b6j Long. tolerance*
1	97.9	1	0-01:38	630e0 630e0	630e0	Y						

Orbital plane no.	*Satellite no.*	*A4b4h Initial phase angle*	*A4b4k Date*	*A4b4l Time*	*B4a Orbit link / List of beams*
1	1				

A17a Compliance with PFD limit dB(W/(m²·1MHz)) in the band 1164 - 1215 MHz

A17a.bis Calculated EPFD value in the band 1610.6 – 1613.8 MHz — dB(W/(m²·20 kHz))

A17b2 Calculated aggregate PFD value in the band 5030.0 - 5150.0 MHz — dB(W/(m²·150 kHz))

A17b3 EPFD in the band 4990.0 - 5000.0 MHz — dB(W/(m²·10 MHz))

A17d Mean PFD — dB(W/(m²·1 MHz))

A17e1a Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT — dB(W/(m²·1 GHz))

A17e1b Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT — dB(W/(m²·500 kHz))

A17e1c Calculated EPFD value in the band 42.5 - 43.5 GHz at RA VLBI — dB(W/(m²·500 kHz))

A15a EPFD compliance: | *A18a* Aircraft earth station commitment:

BR104 Commitment Res 770: | *BR103* Demonstration Res 770:

B1a/BR17 Beam designation: S1R | *B1b* Steerable: | *B2* Emi-Rcp: R | *B3a1* Max. co-polar gain: 0

B2a1 Transmit only when visible from notified service area: | *B2a2* Min. Elev. Angle:

B3c1 Co-polar antenna pattern

Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
ND-SPACE						

List of orbital planes: ALL

B4a3a1 Angle alpha: | *B4a3a2* Angle beta:

BR92 Attach. for missing angle alpha/beta:

BR7a/BR7b Group id. 122622785 | *BR1* Date of receipt 24.02.2022 | *C2c* RR No. 4.4 | *BR97* No. 11.43A | *BR98* For use in accordance with Res 163/164
A2a Date of bringing into use 29.11.2018 | *A2b* Period of valid. 30 | *A3a* Op. agency 011 | *A3b* Adm. resp. A | *BR16* Value of type C8b | *A4b7cbis* Min. elevation angle
BR62 Expiry date for bringing into use 23.10.2024 | *BR63* Confirmed date of bringing into use | *BR64* Date of receipt of 1st Res49
BR14 Special Section
C4a Class of station ED EK | *C3a* Assigned freq. band 750 | *C5a* Noise temperature 1200 | *B4b5* Peak of pfd
C4b Nature of service CO CO | *C6a* Polarization type M | *C6b* Polarization angle
C11a1 Service area no. | *C11a2* Service area IND | *C11a3* Service area diagram
A5/A6 Coordinations/Agreements

C2a1 Assigned frequency
2081.454 MHz

A13 Ref. to Special Sections		*C7a* Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.
API/A/12080	1	750KG2D--	30	-28.8	17		-41.8		15	

C7b Carrier frequency of the emissions (750KG2D--)
2081.454 MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.	*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.		*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d7* Ant. diameter	*C8g1* Max. aggr. pwr.	*C8g2* Aggr. bandwidth	*C8g3* Transp. bandwidth = Aggr. bandwidth
SGS10	T			1 TD 2 TK	CO CO	43.2	1.05				

C10d5a Co-polar antenna pattern

C10b1 Assoc. earth station id.	Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SGS10	REC-465-5						

13C Remarks

B1a/BR17 Beam designation S1T | *B1b* Steerable | *B2* Emi-Rcp E | *B3a1* Max. co-polar gain 0
B2a1 Transmit only when visible from notified service area | *B2a2* Min. Elev. Angle
B3b1b Applicable PFD will be met by applying the method in Annex 1 of ROP 21.16 | Attach. no.

B3c1 Co-polar antenna pattern

Co-polar ref. pattern	Coef. A	Coef. B			Co-polar rad. diag.
ND-SPACE					

List of orbital planes
ALL
B4a3a1 Angle alpha | *B4a3a2* Angle beta
BR92 Attach. for missing angle alpha/beta

BR7a/BR7b Group id. 122622783 | *BR1* Date of receipt 24.02.2022 | *C2c* RR No. 4.4 | *BR97* No. 11.43A | *BR98* For use in accordance with Res 163/164
A2a Date of bringing into use 29.11.2018 | *A2b* Period of valid. 30 | *A3a* Op. agency 011 | *A3b* Adm. resp. A | *BR16* Value of type C8b | *A4b7cbis* Min. elevation angle

PARTIE I-S / PART I-S / PARTE I-S / 第I-S部分 / ЧАСТЬ I-S / الجزء I-S
A | *A1a* Sat. Network HYSIS | *A1f1* Notif. adm. IND | *A1f3* Inter. sat. org. | *BR1* Date of receipt 24.02.2022 | *BR20/BR21* BR IFIC no./part 2971/1
BR6a/BR6b Id. no. 122500037 | *BR3a/BR3b* Provision reference 11.2 N | *BR2* Adm. serial no. 011 | S1R R

BR7a/BR7b Group id. 122622785 | *BR1* Date of receipt 24.02.2022 | *C2c* RR No. 4.4 | *BR97* No. 11.43A | *BR98* For use in accordance with Res 163/164
A2a Date of bringing into use 29.11.2018 | *A2b* Period of valid. 30 | *A3a* Op. agency 011 | *A3b* Adm. resp. A | *BR16* Value of type C8b | *A4b7cbis* Min. elevation angle
BR62 Expiry date for bringing into use 23.10.2024 | *BR63* Confirmed date of bringing into use | *BR64* Date of receipt of 1st Res49
BR14 Special Section
C4a Class of station ED EK | *C3a* Assigned freq. band 750 | *C5a* Noise temperature 1200 | *B4b5* Peak of pfd
C4b Nature of service CO CO | *C6a* Polarization type M | *C6b* Polarization angle
C11a1 Service area no. | *C11a2* Service area IND | *C11a3* Service area diagram
A5/A6 Coordinations/Agreements

C2a1 Assigned frequency
2081.454 MHz

A13 Ref. to Special Sections		*C7a* Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.
API/A/12080	1	750KG2D--	30	-28.8	17		-41.8		15	

C7b Carrier frequency of the emissions (750KG2D--)
2081.454 MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.	*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.		*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d7* Ant. diameter	*C8g1* Max. aggr. pwr.	*C8g2* Aggr. bandwidth	*C8g3* Transp. bandwidth = Aggr. bandwidth
SGS10	T			1 TD 2 TK	CO CO	43.2	1.05				

C10d5a Co-polar antenna pattern

C10b1 Assoc. earth station id.	Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SGS10	REC-465-5						

13C Remarks

B1a/BR17 Beam designation S1T | *B1b* Steerable | *B2* Emi-Rcp E | *B3a1* Max. co-polar gain 0
B2a1 Transmit only when visible from notified service area | *B2a2* Min. Elev. Angle
B3b1b Applicable PFD will be met by applying the method in Annex 1 of ROP 21.16 | Attach. no.

B3c1 Co-polar antenna pattern

Co-polar ref. pattern	Coef. A	Coef. B			Co-polar rad. diag.
ND-SPACE					

List of orbital planes
ALL
B4a3a1 Angle alpha | *B4a3a2* Angle beta
BR92 Attach. for missing angle alpha/beta

BR7a/BR7b Group id. 122622783 | *BR1* Date of receipt 24.02.2022 | *C2c* RR No. 4.4 | *BR97* No. 11.43A | *BR98* For use in accordance with Res 163/164
A2a Date of bringing into use 29.11.2018 | *A2b* Period of valid. 30 | *A3a* Op. agency 011 | *A3b* Adm. resp. A | *BR16* Value of type C8b | *A4b7cbis* Min. elevation angle

PARTIE I-S / PART I-S / PARTE I-S / 第I-S部分 / ЧАСТЬ I-S / I-Sالجزء

A *A1a* Sat. Network HYSIS *A1f1* Notif. adm. IND *A1f3* Inter. sat. org. *BR1* Date of receipt 24.02.2022 *BR20/BR21* BR IFIC no./part 2971/1

BR6a/BR6b Id. no. 122500037 *BR3a/BR3b* Provision reference 11.2 N *BR2* Adm. serial no. 011 S1T E

BR62 Expiry date for bringing into use 23.10.2024 *BR63* Confirmed date of bringing into use *BR64* Date of receipt of 1st Res49

BR14 Special Section

C4a Class of station EK ER *C3a* Assigned freq. band 500 *B4b5* Peak of pfd

C4b Nature of service CO CO *C6a* Polarization type M *C6b* Polarization angle

C8d1 Max. tot. peak pwr. -6.5 *C8d2* Contiguous bandwidth

C11a1 Service area no. *C11a2* Service area IND *C11a3* Service area diagram

A5/A6 Coordinations/Agreements

C2a1 Assigned frequency: 2262.86 MHz

A13 Ref. to Special Sections		*C7a* Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.
API/A/12080	1	500KG2D--	-6.5	-63.5	-6.5		-63.5		15	

C7b Carrier frequency of the emissions (500KG2D--): 2262.86 MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.	*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.	*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d6* Noise temp.	*C10d7* Ant. diameter
SGS10	T			1 TK CO 2 TR CO	43.2	1.08	282	

C10b1 Assoc. earth station id.	C10d5a Co-polar antenna pattern: Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SGS10	REC-465-5						

13C Remarks

B1a/BR17 Beam designation X1T *B1b* Steerable *B2* Emi-Rcp E *B3a1* Max. co-polar gain 21

B2a1 Transmit only when visible from notified service area *B2a2* Min. Elev. Angle

B3b1b Applicable PFD will be met by applying the method in Annex 1 of ROP 21.16 Attach. no.

B3c1 Co-polar antenna pattern: Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
						1

List of orbital planes: ALL

B4a3a1 Angle alpha *B4a3a2* Angle beta

BR92 Attach. for missing angle alpha/beta

BR7a/BR7b Group id. 122622784 *BR1* Date of receipt 24.02.2022 *C2c* RR No. 4.4 *BR97* No. 11.43A *BR98* For use in accordance with Res 163/164

A2a Date of bringing into use 29.11.2018 *A2b* Period of valid. 30 *A3a* Op. agency 011 *A3b* Adm. resp. A *BR16* Value of type C8b *A4b7cbis* Min. elevation angle

BR62 Expiry date for bringing into use 23.10.2024 *BR63* Confirmed date of bringing into use *BR64* Date of receipt of 1st Res49

BR14 Special Section

C4a Class of station EW *C3a* Assigned freq. band 320000 *B4b5* Peak of pfd

C4b Nature of service CP *C6a* Polarization type M *C6b* Polarization angle

C8d1 Max. tot. peak pwr. 3 *C8d2* Contiguous bandwidth

C11a1 Service area no. *C11a2* Service area IND XAX *C11a3* Service area diagram

A5/A6 Coordinations/Agreements

C2a1 Assigned frequency: 8200 MHz

A13 Ref. to Special Sections		*C7a* Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.
API/A/12080	1	320MG2D--	3	-82.1	3		-82.1		15	

C7b Carrier frequency of the emissions (320MG2D--): 8200 MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.	*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.	*C10d3* Max. iso. gain	*C10d4* Bmwdth	*C10d6* Noise temp.	*C10d7* Ant. diameter
XGS7.5	T			1 TW CP	52.8	0.34	126	

C10b1 Assoc. earth station id.	C10d5a Co-polar antenna pattern: Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
XGS7.5	REC-465-5						

13C Remarks

NOTE DU BUREAU DES RADIOCOMMUNICATIONS

En ce qui concerne le faisceau d'émission X1T, l'administration a soumis le diagramme de rayonnement copolaire de l'antenne pour la station spatiale (élément **B.3.c.1** de l'Appendice **4**) sous la forme d'un diagramme saisi dans une base de données GIMS. Les plages des angles hors axe qui ne sont pas couvertes dans ce diagramme conserveront une valeur uniforme correspondant à la valeur des angles hors axe maximaux ou minimaux indiqués dans le diagramme.

RADIOCOMMUNICATION BUREAU NOTE

With respect to the transmitting beam X1T, the administration has submitted the co-polar antenna radiation pattern for the space station (item **B.3.c.1** of Appendix **4**) in the form of diagram captured in a GIMS database. The ranges of the off-axis angles that are not covered in this diagram will retain a flat value corresponding to the value at the maximum/minimum off-axis angles shown in the diagram.

NOTA DE LA OFICINA DE RADIOCOMUNICACIONES

Con respecto al haz de transmisión X1T, la administración ha presentado el diagrama de radiación de antena copolar para la estación espacial (punto **B.3.c.1** del Apéndice **4**) en forma de diagrama recogido en una base de datos GIMS. Las gamas de los ángulos fuera del eje que no se contemplan en este diagrama conservarán el mismo valor uniforme correspondiente al valor en los ángulos fuera del eje máximos/mínimos indicados en el diagrama

无线电通信局的注解

关于发射波束X1T，主管部门以GIMS数据库中捕获的图表形式提交了空间电台的同极化天线辐射方向图（附录**4**的**B.3.c.1**项）。这些图表中未涵盖的偏轴角度范围将保留与图中所示的最大/最小偏轴角度值相对应的固定值。

ПРИМЕЧАНИЕ БЮРО РАДИОСВЯЗИ

В отношении передающего луча X1T администрация представила диаграмму направленности антенны космической станции для составляющих с совпадающей поляризацией (элемент данных **B.3.c.1** Приложения **4**) в виде диаграммы, введенной в базу данных GIMS. В диапазонах внеосевых углов, которые не охвачены этой диаграммой, сохраняется постоянное значение, соответствующее значению при максимальном/минимальном внеосевых углах, показанных на диаграммах.

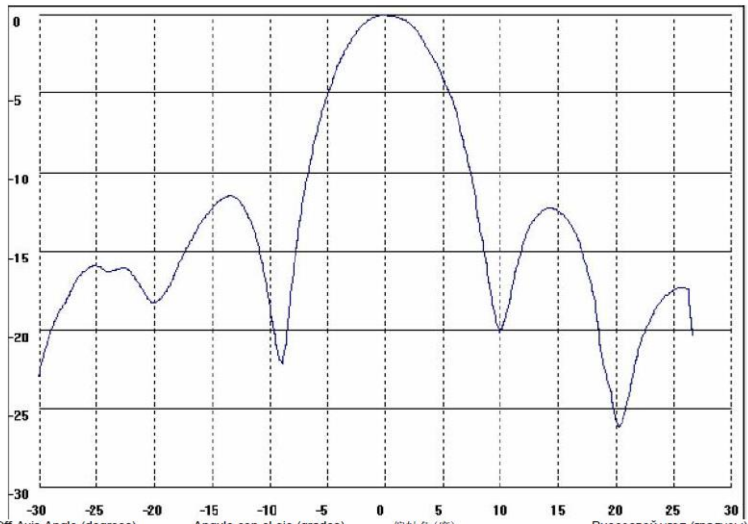
ملاحظة مكتب الاتصالات الراديوية

فيما يتعلق بحزمة الإرسال X1T، قدمت الإدارة مخطط الإشعاع للهوائي متحد الاستقطاب للمحطة الفضائية (البند **B.3.ج.1** من التذييل **4**) في نسق رسم بياني مدرج في قاعدة بيانات للنظام البياني لإدارة التداخل (GIMS). وستحتفظ مديات الزوايا خارج المحور التي لا يغطيها هذا المخطط بقيمة موحدة تقابل القيمة عند الزوايا القصوى/الدنيا خارج المحور على النحو المبين في المخطط.

Figure / Figura / 图 / Рисунок / 1 الشكل

DIAGRAMME DE RAYONNEMENT COPOLAIRE DE L'ANTENNE D'ÉMISSION DE LA STATION SPATIALE
SPACE STATION TRANSMITTING CO-POLAR ANTENNA RADIATION PATTERN
DIAGRAMA DE RADIACIÓN COPOLAR DE LA ANTENA DE TRANSMISIÓN DE LA ESTACIÓN ESPACIAL
空间电台发射天线同极辐射方向图
ДИАГРАММА НАПРАВЛЕННОСТИ ИЗЛУЧЕНИЯ ПЕРЕДАЮЩЕЙ АНТЕННЫ КОСМИЧЕСКОЙ СТАНЦИИ ДЛЯ СОВПАДАЮЩЕЙ ПОЛЯРИЗАЦИИ
مخطط الإشعاع متحد الاستقطاب لهوائي الإرسال للمحطة الفضائية

Faisceau / Beam / Haz / 波束 / Луч / الحزمة : X1T



X = Angle par rapport à l'axe principal (degrés) | Off-Axis Angle (degrees) | Angulo con el eje (grados) | 偏轴角(度) | Внеосевой угол (градусы) | الزاوية بالنسبة إلى المحور الرئيسي (بالدرجات)

Y = Gain (dBi) | Gain (dBi) | Ganancia (dBi) | 增益 (dBi) | УСИЛЕНИЕ (дБи) | الكسب (dBi)

Page / Página / 页 / стр. / 10 الصفحة

3.5.3.2 Publication of the Part II-S to the BR IFIC

The Part II-S publication concerns frequency assignments that will be recorded in the Master Register, following publication in Part I-S and after the detailed technical and regulatory examination has been completed. Generally, these are frequency assignments that have received favourable findings as well as those that are to be recorded under RR No. **11.41** or for information only.

The findings are formulated with respect to:

– their conformity with the Convention, the Table of Frequency Allocations and the other provisions of the Radio Regulations;

– the application of a coordination procedure in accordance with the Radio Regulations;

– the probability of harmful interference; as applicable.

When the need arises to review a finding with respect to a frequency assignment which has been recorded in the Master Register, either on the initiative of the Bureau or upon request of an administration, the resultant modified assignment is published in Part II-S of the BR IFIC.

The following is a sample abstract of a Part II-S publication.

UIT ITU

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS BUREAU DES RADIOCOMMUNICATIONS	INTERNATIONAL TELECOMMUNICATION UNION RADIOCOMMUNICATION BUREAU	UNIÓN INTERNACIONAL DE TELECOMUNICACIONES OFICINA DE RADIOCOMUNICACIONES	© I.T.U.

RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	NETSAT	PARTIE PART PARTE	II-S
STATION TERRIENNE EARTH STATION ESTACIÓN TERRENA	---	BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA	2955 / 21.09.2021
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE D	LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL NGSO	NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN	120500260
RENSEIGNEMENTS REÇUS PAR LE BUREAU LE / INFORMATION RECEIVED BY THE BUREAU ON / INFORMACIÓN RECIBIDA POR LA OFICINA EL			11.12.2020

Assignations de fréquence inscrites dans le Fichier de référence au titre de		Frequency assignments recorded in the Master Register under		Asignaciones de frecuencia inscritas en el Registro con arreglo al	
X	Article 11 du Règlement des radiocommunications	X	Article 11 of the Radio Regulations	X	Artículo 11 del Reglamento de Radiocomunicaciones
	Article 5 des Appendices 30 et/ou 30A		Article 5 of Appendices 30 and/or 30A		Artículo 5 de los Apéndices 30 y/o 30A
	Article 8 de l'Appendice 30B		Article 8 of Appendix 30B		Artículo 8 del Apéndice 30B

Pour plus d'informations sur les dispositions réglementaires et l'explication des codes ou symboles utilisés dans cette publication, veuillez consulter la Préface.	For more details on the regulatory provisions and the explanation of the codes or symbols used in this publication, please consult the Preface.	Para más detalles sobre las disposiciones reglamentarias y la explicación de los códigos o símbolos utilizados en esta publicación, sírvase consultar el Prefacio.

PARTIE II-S / PART II-S / PARTE II-S / 第II-S部分 / ЧАСТЬ II-S / الجزء II-S

A *A1a* Sat. Network NETSAT *A1f1* Notif. adm. D *A1f3* Inter. sat. org. *BR1* Date of receipt 11.12.2020 *BR20/BR21* BR IFIC no./part 2955/2

BR6a/BR6b Id. no. 120500260 *BR3a/BR3b* Provision reference 11.2 N *BR2* Adm. serial no.

Modification des caractéristiques techniques

Veuillez noter que les caractéristiques techniques

	ont été modifiées
X	n'ont pas été modifiées

depuis la publication de la fiche de notification dans la Partie I-S de la BRIFIC 2941 / 09.03.2021.

Changes in Technical Characteristics

Please note that the technical characteristics

	have been modified
X	have not been modified

since the publication of the notice in Part I-S of BRIFIC 2941 / 09.03.2021.

Cambios en las características técnicas

Sírvase tomar nota de que las características técnicas

	se han modificado
X	no se han modificado

desde la publicación de la notificación en la Parte I-S de la BRIFIC 2941 / 09.03.2021.

技术特性的变化

请注意，自BRIFIC 2941 / 09.03.2021
I-S 部分中的通知公布以来，技术特性

	已经修改
X	未经修改

Изменения в технических характеристиках

Просьба учесть, что технические характеристики

	были изменены
X	не были изменены

после публикации заявки в Части I-S BRIFIC 2941 / 09.03.2021.

تغييرات في الخصائص التقنية

يرجى ملاحظة أن الخصائص التقنية

خضعت للتعديل	
لم تخضع للتعديل	X

منذ نشر معلومات بطاقة التبليغ في الجزء I-S من النشرة الإعلامية الدولية للترددات : 2941BRIFIC / 09.03.2021.

PARTIE II-S / PART II-S / PARTE II-S / 第II-S部分 / ЧАСТЬ II-S / II-Sالجزء

A | *A1a* Sat. Network NETSAT | *A1f1* Notif. adm. D | *A1f3* Inter. sat. org. | *BR1* Date of receipt 11.12.2020 | *BR20/BR21* BR IFIC no./part 2955/2

BR6a/BR6b Id. no. 120500260 | *BR3a/BR3b* Provision reference 11.2 N | *BR2* Adm. serial no.

Résumé / Summary / Resumen / 綜述 / Резюме / خلاصة

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	13A Conformity with RR	C3a Assigned freq. band	BR47 Frequency band (MHz)	BR62 Expiry date for bringing into use	BR15 Provision reference	BR53 Nb of freq.	C4a Class of station
ISLRUHF	R		120730545		N-----	10	435.595 - 435.605	06.09.2023		1	ES
UPLUHF	R		120730546		A-----	10	435.595 - 435.605	06.09.2023		1	EA
DOWNLUHF	E		120730543		A-----	10	435.595 - 435.605	06.09.2023		1	EA
ISLTUHF	E		120730544		N-----	10	435.595 - 435.605	06.09.2023		1	ES

PARTIE II-S / PART II-S / PARTE II-S / 第II-S部分 / ЧАСТЬ II-S / II-Sالجزء

A | *A1a* Sat. Network NETSAT | *A1f1* Notif. adm. D | *A1f3* Inter. sat. org. | *BR1* Date of receipt 11.12.2020 | *BR20/BR21* BR IFIC no./part 2955/2

BR6a/BR6b Id. no. 120500260 | *BR3a/BR3b* Provision reference 11.2 N | *BR2* Adm. serial no. | ISLRUHF R

BR19 Ref. to BR IFIC I 2941

A1f2 Submitted on behalf

A1g Short Mission Duration Res 32 N | *A24a* SDM commitment X

A4b1 No. of orbital planes 1 | *A4b2* Ref. body T | *BR43* Orbital configuration

A4b1a Constellation N

A4b3a No. of space stations simult. trans. on Northern Hemisphere | *A4b3b* No. of space stations simult. trans. on Southern Hemisphere

A4b7a Max. sat. rcv. simult. | *A4b7b* Avg. no. of As. E-stn | *A4b7c* Avg. distance

A4b7d1 Excl. zone type | *A4b7d2* Excl. zone width

A4b6bis Limited or Extended set

Orbital plane id. no.	*A4b4a* Inclination angle	*A4b4b* No. of satellites in this plane	*A4b4c* Period	*A4b4d* Apogee / *A4b4e* Perigee	*A4b4f* Min. altitude	*A4b4m,n,o* Sun synchronous: Y/N	Node reference time	Node local time	*A4b4g* Right asc. / *A4b4i* Arg. of perigee	*A4b6c* Station keeping / *A4b6d* Repeat period	*A4b6e* Specific modelled station / *A4b6f* Precession rate	*A4b4j* Long. asc. node / *A4b6j* Long. tolerance
1	97	4	0-01:37	400e0 400e0	400e0							

Orbital plane no.	*Satellite no.*	*A4b4h Initial phase angle*	*A4b4k Date*	*A4b4l Time*	*B4a Orbit link / List of beams*
1	1				
	2				
	3				
	4				

A17a Compliance with PFD limit dB(W/(m^2·1MHz)) in the band 1164 - 1215 MHz

A17a.bis Calculated EPFD value in the band 1610.6 – 1613.8 MHz dB(W/(m^2·20 kHz))

A17b2 Calculated aggregate PFD value in the band 5030.0 - 5150.0 MHz dB(W/(m^2·150 kHz))

A17b3 EPFD in the band 4990.0 - 5000.0 MHz dB(W/(m^2·10 MHz))

A17d Mean PFD dB(W/(m^2·1 MHz))

A17e1a Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT dB(W/(m^2·1 GHz))

A17e1b Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT dB(W/(m^2·500 kHz))

A17e1c Calculated EPFD value in the band 42.5 - 43.5 GHz at RA VLBI dB(W/(m^2·500 kHz))

A15a EPFD compliance | *A18a* Aircraft earth station commitment

BR104 Commitment Res 770 X | *BR103* Demonstration Res 770

List of orbital planes
ALL

B4a3a1 Angle alpha | *B4a3a2* Angle beta

BR92 Attach. for missing angle alpha/beta

B1a/BR17 Beam designation UPLUHF | *B1b* Steerable | *B2* Emi-Rcp R | *B3a1* Max. co-polar gain 1.7

B2a1 Transmit only when visible from notified service area | *B2a2* Min. Elev. Angle

B3c1 Co-polar antenna pattern						
Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
ND-SPACE						

List of orbital planes
ALL

B4a3a1 Angle alpha | *B4a3a2* Angle beta

BR92 Attach. for missing angle alpha/beta

BR7a/BR7b Group id. 120730546 | *BR1* Date of receipt 11.12.2020 | *C2c* RR No. 4.4 | *BR97* No. 11.43A | *BR98* For use in accordance with Res 163/164

A2a Date of bringing into use 15.09.2020 | *A2b* Period of valid. 10 | *A3a* Op. agency 147 | *A3b* Adm. resp. M | *BR16* Value of type C8b | *A4b7cbis* Min. elevation angle

BR62 Expiry date for bringing into use	06.09.2023	*BR63* Confirmed date of bringing into use	15.09.2020	*BR64* Date of receipt of 1st Res49	
BR14 Special Section					
C4a Class of station	EA	*C3a* Assigned freq. band	10	*C5a* Noise temperature	200
C4b Nature of service	CP	*C6a* Polarization type	M	*C6b* Polarization angle	
C11a1 Service area no.		*C11a2* Service area	D XAA	*C11a3* Service area diagram	
A5/A6 Coordinations/Agreements				*B4b5* Peak of pfd	

C2a1 Assigned frequency: 435.6 MHz

A13 Ref. to Special Sections	*C7a* Design. of emission	*C8a1/C8b1* Max. peak pwr	*C8a2/C8b2* Max. pwr dens.	*C8c1* Min. peak pwr	*C8c2* Attch.	*C8c3* Min. pwr dens.	*C8c4* Attch.	*C8e1* C/N ratio	*C8e2* Attch.
API/A/11929	1 10K0F2D--	17	-23	17		-23		10	

C7b Carrier frequency of the emissions (10K0F2D--): 437.385 MHz

C10b1 Assoc. earth station id.	*C10b2* Type	*C10c1* Geographical coord.	*C10c2* Ctry	*C10d1/C10d2* Cls. / Nat.	*C10d3* Max. iso. gain	*C10d4* Bmwdth		*C10d7* Ant. diameter		*C8g1* Max. aggr. pwr.	*C8g2* Aggr. bandwidth	*C8g3* Transp. bandwidth = Aggr. bandwidth
UHF BAND ZFT	T			1 TA CP	10	44.9						

C10b1 Assoc. earth station id.	Co-polar ref. pattern (C10d5a Co-polar antenna pattern)	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
UHF BAND ZFT	ND-EARTH						

Findings					
2D Date of protection 11.12.2020	*13A* Conformity with RR A- -- --	*13B1* Prov. 5.282	*13B2* Remarks R	*13B3* Date of Review	
13C Remarks					

3.5.3.3 Publication of the Part III-S to the BR IFIC

Generally, the Part III-S publication concerns frequency assignments that have received unfavourable findings as they are found to be non-compliant with various provisions of the RR.

These frequency assignments published in Part III-S are returned to the responsible administration following the Part I-S publication and after the detailed technical and regulatory examination has been completed.

The following is a sample abstract of a Part III-S publication.

UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS BUREAU DES RADIOCOMMUNICATIONS	INTERNATIONAL TELECOMMUNICATION UNION RADIOCOMMUNICATION BUREAU	UNIÓN INTERNACIONAL DE TELECOMUNICACIONES OFICINA DE RADIOCOMUNICACIONES	© I.T.U.
RÉSEAU À SATELLITE SATELLITE NETWORK RED DE SATÉLITE	ARTHUR	PARTIE PART PARTE	III-S
STATION TERRIENNE EARTH STATION ESTACIÓN TERRENA	---	BR IFIC / DATE BR IFIC / DATE BR IFIC / FECHA	2954 / 07.09.2021
ADM. RESPONSABLE RESPONSIBLE ADM. ADM. RESPONSABLE: **BEL**	LONGITUDE NOMINALE NOMINAL LONGITUDE LONGITUD NOMINAL: **NGSO**	NUMÉRO D'IDENTIFICATION IDENTIFICATION NUMBER NÚMERO DE IDENTIFICACIÓN	121512084
RENSEIGNEMENTS REÇUS PAR LE BUREAU LE / INFORMATION RECEIVED BY THE BUREAU ON / INFORMACIÓN RECIBIDA POR LA OFICINA EL			10.03.2021

	Assignations de fréquence retournées à l'administration notificatrice au titre de		Frequency assignments returned to the notifying Administration under		Asignaciones de frecuencia devueltas a la Administración notificante en virtud del
X	Article 11 du Règlement des radiocommunications	X	Article 11 of the Radio Regulations	X	Artículo 11 del Reglamento de Radiocomunicaciones
	Article 5 des Appendices 30 et/ou 30A		Article 5 of Appendices 30 and/or 30A		Artículo 5 de los Apéndices 30 y/o 30A
	Article 8 de l'Appendice 30B		Article 8 of Appendix 30B		Artículo 8 del Apéndice 30B

Pour plus d'informations sur les dispositions réglementaires et l'explication des codes ou symboles utilisés dans cette publication, veuillez consulter la Préface.	For more details on the regulatory provisions and the explanation of the codes or symbols used in this publication, please consult the Preface.	Para más detalles sobre las disposiciones reglamentarias y la explicación de los códigos o símbolos utilizados en esta publicación, sírvase consultar el Prefacio.

PARTIE III-S / PART III-S / PARTE III-S / 第III-S部分 / ЧАСТЬ III-S / III-Sالجزء

A | *A1a* Sat. Network ARTHUR | *A1f1* Notif. adm. BEL | *A1f3* Inter. sat. org. | *BR1* Date of receipt 10.03.2021 | *BR20/BR21* BR IFIC no./part 2954/3

BR6a/BR6b Id. no. 121512084 | *BR3a/BR3b* Provision reference 11.2 N | *BR2* Adm. serial no.

Résumé / Summary / Resumen / 綜述 / Резюме / خلاصة

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	13A Conformity with RR	C3a Assigned freq. band	BR47 Frequency band (MHz)	BR62 Expiry date for bringing into use	BR15 Provision reference	BR53 Nb of freq.	C4a Class of station	BR54 Nb of emiss.	BR55 Nb of units
SDOWN	E		121677703		N-----	6000	2280 - 2286	21.03.2026		1	ET	1	1

Recouvrement des coûts / Cost recovery / Recuperación de costes / 成本回收 / Возмещение расходов / استرداد التكاليف

Il y a lieu de noter, dans le cas d'une fiche de notification qui est publiée à la fois dans la Partie II-S et dans la Partie III-S, qu'un seul droit au titre du recouvrement des coûts s'applique et que les renseignements complets correspondant au recouvrement des coûts seront publiés dans la Partie II-S pour la totalité de la fiche de notification avant qu'elle ne soit scindée en deux.	It should be noted that for a notice that is being published in both Part II-S and Part III-S, only one cost recovery fee applies and the complete corresponding cost recovery-related information will be published in Part II-S for the whole notice before the split.	Cabe señalar que en el caso de las notificaciones que se publican tanto en la Parte II-S como en la Parte III-S, se aplica sólo una vez el canon de recuperación de costes, y la correspondiente información relativa a la recuperación de costes se publicará en la Parte II-S de la notificación completa, antes de efectuarse la división.
应当指出，同时正在第II-S和III-S部分公布的通知，只收取一次成本回收费并且在分开之前，整个通知的相应完整成本回收信息将在第II-S部分公布	Следует отметить, что для заявки, публикуемой как в Части II-S, так и в Части III-S, применяется только один сбор в счет возмещения затрат, и полная соответствующая информация, касающаяся возмещения затрат, будет опубликована в Части II-S для всей заявки до ее разделения.	وجدير بالملاحظة، بالنسبة لتبليغ ينشر في كل من القسم II-S و III-S، أن رسوم استرداد التكاليف لا تستحق سوى مرة واحدة وأن المعلومات الكاملة المتعلقة باسترداد التكاليف المعنية سوف تنشر في القسم II-S للتبليغ بأكمله قبل الانقسام.

PARTIE III-S / PART III-S / PARTE III-S / 第III-S部分 / ЧАСТЬ III-S / III-Sالجزء

A | *A1a* Sat. Network ARTHUR | *A1f1* Notif. adm. BEL | *A1f3* Inter. sat. org. | *BR1* Date of receipt 10.03.2021 | *BR20/BR21* BR IFIC no./part 2954/3

BR6a/BR6b Id. no. 121512084 | *BR3a/BR3b* Provision reference 11.2 N | *BR2* Adm. serial no. | SDOWN E

BR19 Ref. to BR IFIC I: 2951

A1f2 Submitted on behalf:

A1g Short Mission Duration Res 32: N | *A24a* SDM commitment:

A4b1 No. of orbital planes: 1 | *A4b2* Ref. body: T | *BR43* Orbital configuration:

A4b1a Constellation: N

A4b3a No. of space stations simult. trans. on Northern Hemisphere: | *A4b3b* No. of space stations simult. trans. on Southern Hemisphere:

A4b7a Max. sat. rcv. simult.: | *A4b7b* Avg. no. of As. E-stn: | *A4b7c* Avg. distance:

A4b7d1 Excl. zone type: | *A4b7d2* Excl. zone width:

A4b6bis Limited or Extended set:

Orbital plane id. no.	A4b4a Inclination angle	A4b4b No. of satellites in this plane	A4b4c Period	A4b4d Apogee / A4b4e Perigee	A4b4f Min. altitude	A4b4m,n,o Sun synchronous: Y/N	Node reference time	Node local time	A4b4g Right asc. / A4b4i Arg. of perigee	A4b6c Station keeping / A4b6d Repeat period	A4b6e Specific modelled station / A4b6f Precession rate	A4b4j Long. asc. node / A4b6j Long. tolerance
1	97.5	1	0-01:35	525e0 525e0	525e0	Y	D	13:30:00		n		

Orbital plane no.	Satellite no.	A4b4h Initial phase angle	A4b4k Date	A4b4l Time	B4a Orbit link / List of beams
1	1				

A17a Compliance with PFD limit dB(W/(m²·1MHz)) in the band 1164 - 1215 MHz:

A17a.bis Calculated EPFD value in the band 1610.6 – 1613.8 MHz: dB(W/(m²·20 kHz))

A17b2 Calculated aggregate PFD value in the band 5030.0 - 5150.0 MHz: dB(W/(m²·150 kHz))

A17b3 EPFD in the band 4990.0 - 5000.0 MHz: dB(W/(m²·10 MHz))

A17d Mean PFD: dB(W/(m²·1 MHz))

A17e1a Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT: dB(W/(m²·1 GHz))

A17e1b Calculated EPFD value in the band 42.5 - 43.5 GHz at RA SDT: dB(W/(m²·500 kHz))

A17e1c Calculated EPFD value in the band 42.5 - 43.5 GHz at RA VLBI: dB(W/(m²·500 kHz))

A15a EPFD compliance: | *A18a* Aircraft earth station commitment:

BR104 Commitment Res 770: X | *BR103* Demonstration Res 770:

B1a/BR17 Beam designation: SDOWN | *B1b* Steerable: | *B2* Emi-Rcp: E | *B3a1* Max. co-polar gain: 6.2

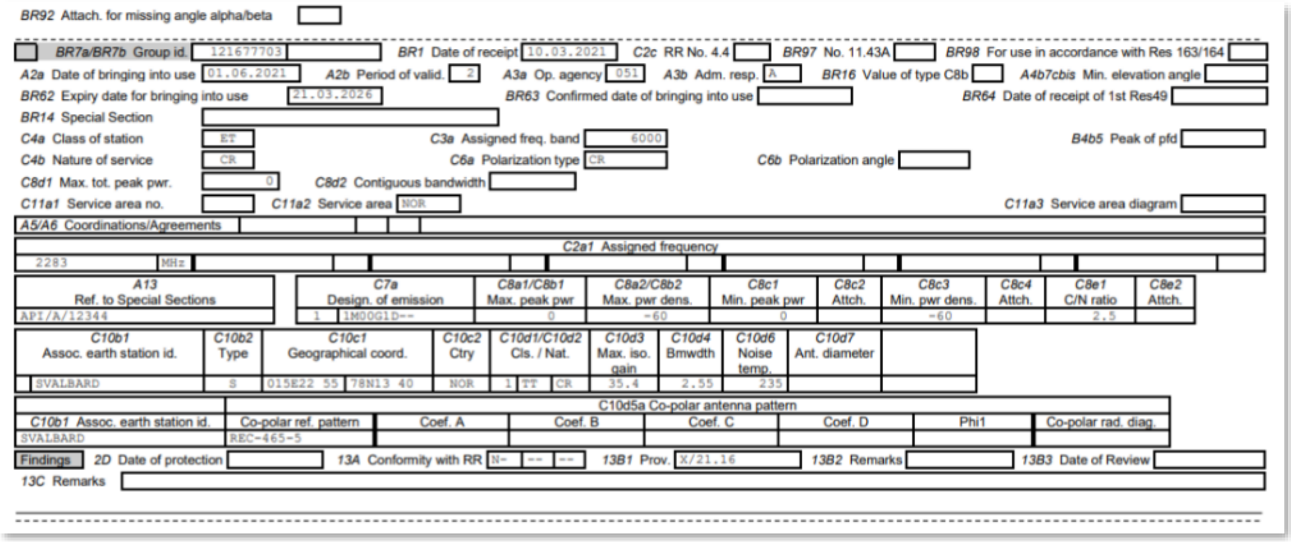
B2a1 Transmit only when visible from notified service area: Y | *B2a2* Min. Elev. Angle: 5

B3b1b Applicable PFD will be met by applying the method in Annex 1 of ROP 21.16: | Attach. no.:

B3c1 Co-polar antenna pattern						
Co-polar ref. pattern	Coef. A	Coef. B				Co-polar rad. diag.
						2

List of orbital planes
ALL

B4a3a1 Angle alpha: | *B4a3a2* Angle beta:


BR92 Attach. for missing angle alpha/beta
BR7a/BR7b Group id. 121677703 BR1 Date of receipt 10.03.2021 C2c RR No. 4.4 BR97 No. 11.43A BR98 For use in accordance with Res 163/164
A2a Date of bringing into use 01.06.2021 A2b Period of valid. 2 A3a Op. agency 051 A3b Adm. resp. A BR16 Value of type C8b A4b7cbis Min. elevation angle
BR62 Expiry date for bringing into use 21.03.2026 BR63 Confirmed date of bringing into use BR64 Date of receipt of 1st Res49
BR14 Special Section
C4a Class of station ET C3a Assigned freq. band 6000 B4b5 Peak of pfd
C4b Nature of service CR C6a Polarization type CR C6b Polarization angle
C8d1 Max. tot. peak pwr. 0 C8d2 Contiguous bandwidth
C11a1 Service area no. C11a2 Service area NOR C11a3 Service area diagram
A5/A6 Coordinations/Agreements
C2a1 Assigned frequency
2283 MHz

A13 Ref. to Special Sections	C7a Design. of emission		C8a1/C8b1 Max. peak pwr	C8a2/C8b2 Max. pwr dens.	C8c1 Min. peak pwr	C8c2 Attch.	C8c3 Min. pwr dens.	C8c4 Attch.	C8e1 C/N ratio	C8e2 Attch.
API/A/12344	1	1M00G1D--	0	-60	0		-60		2.5	

C10b1 Assoc. earth station id.	C10b2 Type	C10c1 Geographical coord.		C10c2 Ctry	C10d1/C10d2 Cls. / Nat.			C10d3 Max. iso. gain	C10d4 Bmwdth	C10d6 Noise temp.	C10d7 Ant. diameter
SVALBARD	S	015E22 55	78N13 40	NOR	1	TT	CR	35.4	2.55	235	

C10b1 Assoc. earth station id.	C10d5a Co-polar antenna pattern: Co-polar ref. pattern	Coef. A	Coef. B	Coef. C	Coef. D	Phi1	Co-polar rad. diag.
SVALBARD	REC-465-5						

Findings 2D Date of protection 13A Conformity with RR N- -- -- 13B1 Prov. X/21.16 13B2 Remarks 13B3 Date of Review
13C Remarks

The examination of the satellite networks not subject to coordination will be carried out with respect to its conformity with the Table of Frequency Allocations and other provisions (e.g. power limits) listed in the Rules of Procedure related to RR No. **11.31**. There will be no examination with respect to procedures relating to coordination with other administrations (RR No. **11.32**) or with respect to probability of harmful interference (RR No. **11.32A**).

The examination of the satellite networks subject to coordination will be conducted with respect to its conformity with the Table of Frequency Allocations and other provisions (e.g. power limits) listed in the Rules of Procedure related to RR No. **11.31**. There will also be examination with respect to coordination requirements (RR No. **11.32**) or probability of harmful interference (RR No. **11.32A**), if appropriate.

Assignments that have not completed coordination can be reconsidered under RR No. **11.41** for recording into the Master Register with an indication of those administrations whose assignments the coordination has not been completed.

For such recordings, should harmful interference be caused by the frequency assignments, the administration responsible for the frequency assignments recorded under RR No. **11.41** shall, upon receipt of a report providing the particulars relating to the harmful interference, immediately eliminate the harmful interference.

If all effort to resolve the harmful interference is unsuccessful this could result in the possible cancellation of the assignments recorded in the Master Register (see RR No. **11.42A**).

It should also be noted that if the frequency assignments are published with unfavourable findings with respect to RR No. **11.31**, any subsequent request to change the notified characteristics towards attaining a favourable finding will be considered as a modification to the notification and will be treated with a new date of receipt and issued with a new cost recovery invoice.

3.5.3.4 Submission of Notification

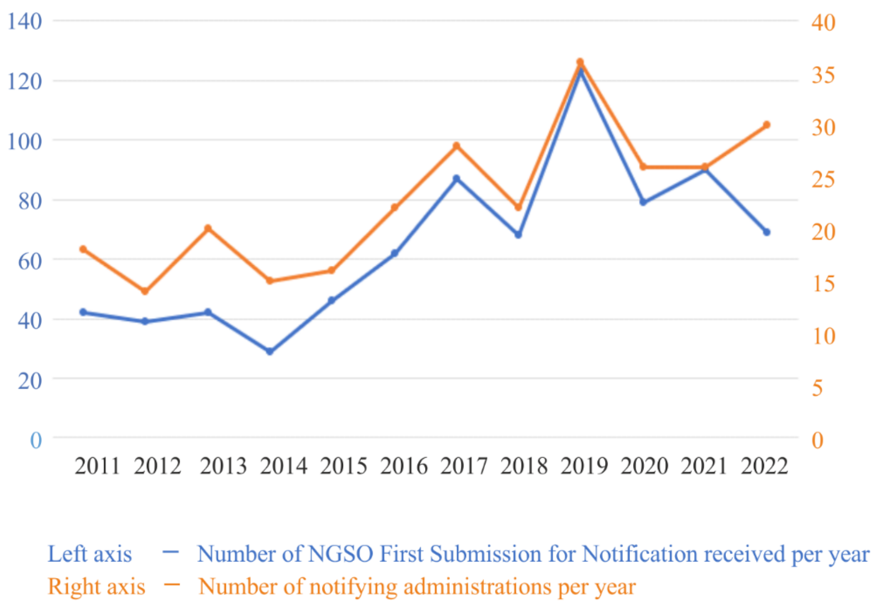
3.5.3.4.1 Submission trend for non-GSO Notification

There has been a general increase in the number of non-GSO notification submissions over the last ten years. Given the significant increase in API filing submissions over the past years, it is expected that the number of notification submissions will also steadily increase, particularly for non-GSO notices that are not subject to the coordination procedure.

The number of non-GSO notification notices received by the Bureau each year is illustrated in Fig. 8, which specifically focuses on the "first submissions" rather than "resubmissions" following notification notices returned due to non-completion of coordination.

FIGURE 8

Submission of Non-GSO Notification for satellite networks or systems



Handbook on Small Satellites-8

3.5.4 Regulatory examination under RR No. 11.31

Each coordination request and notification notice submitted to the Bureau is examined by the Bureau in accordance with the following provisions of RR:

TABLE 2

Types of examination

Step	Applicable submission
conformity with the Table of Frequency Allocations and the other[3] provisions of the Radio Regulations (RR No. **11.31**);	CR/C Notification of space station Notification of earth station
conformity with the coordination procedures (RR No. **11.32**);	Notification of space station Notification of earth station
the probability of harmful interference (RR Nos. **11.32A** and **11.33**), if requested.	Notification of space station

This section covers an examination carried out in accordance with RR No. **11.31**. This type of examination is applicable to both non-GSO satellite systems subject and not subject to coordination.

It is worthwhile to note that the examination of the notices is carried out at frequency assignment level since the findings are established at this level. Therefore, it is possible that within a group of assignments, different findings may exist for each assignment. These situations where different findings exist within a group of assignments are often referred to as “split findings” as the group of assignments will be split to appropriately

[3] The "other provisions" are identified in the Rules of Procedure on RR No. **11.31**.

reflect the finding associated to each assignment. As findings are established at assignment level, different frequency assignments may be notified at different times.

A general list of examinations which are carried out under RR No. **11.31** is provided in Table 3.

TABLE 3

Types of examination under RR No. 11.31

Provisions	**General Description of the Examination**
Article **5**	Checks if frequency is in compliance with Table of Frequency Allocations including footnotes
Article **21** Section III	Checks that power limits of earth stations are complied
Article **21** Section IV	Checks that minimum elevation angles of earth stations are complied
Article **21** Section V	Checks that limits of power-flux density (pfd) from space stations are complied
Article **22** Section II	Checks the epfd limits on non-GSO networks are complied
Article **22** Section III	Checks that station keeping of space stations are complied
Article **22** Section IV	Checks that pointing accuracies of antennae on geostationary satellites are complied
Article **22** Section VI	Checks that earth station off-axis power limitations in the fixed-satellite service are complied
Article **23** Section II	Checks that, if there is an objection from an administration to be included in the service area of a satellite network in accordance with RR No. **23.13B**, the territory of this administration is excluded of the service area
No. **9.21**	Checks if agreement has been achieved when applicable
No. **4.4**	To recognize when a station is operating with frequency in derogation of the Table of Frequency Allocations and Regulations and under non-interference and unprotected basis

When the examination with respect to RR No. **11.31** leads to a favourable finding, the assignment shall be recorded in the Master Register or examined further to RR Nos. **11.32** to **11.33**, as appropriate.

It should be noted that even if an assignment is found unfavourable under RR No. **11.31**, the assignment can be recorded in the Master Register for information purposes and subject to application of RR No. **8.5** (which is to immediately eliminate harmful interference upon advise that harmful interference is caused by the assignment), if the administration undertakes that the assignment will be operated in accordance to RR No. **4.4** which is on a non-interference and no protection basis.

3.5.4.1 Verifying compliance with hard limits (Article 21 pfd limits and e.i.r.p. limits)

Each satellite system may be subject to RR Article **21** pfd limits. Table **21-4** of this Article in RR lists the limits applicable to specific frequency bands and services.

Also, pfd limits are contained in several footnotes to RR Article **5** (for example, RR No. **5.268**).

It should be noted that the pfd limit is normally applicable to a single space station.

In general, pfd is calculated using equation (5):

$$pfd(\delta) = P + G_t(\delta) - 10\log\left(4\pi d^2(\delta)\right) \quad (5)$$

where:

P: RF peak power in the reference bandwidth of the limit (dBW)

δ: angle of arrival above horizontal plane

$G_t(\delta)$: transmit antenna gain of the satellite in the direction for the angle of arrival δ considered (dBi)

$d(\delta)$: distance between the satellite and the ground for the angle of arrival δ considered (m).

The following example extracted from Table **21-4** of the RR Article **21** shows a typical pfd limit defined for different angles of arrival.

TABLE 4

Example of pfd limit

Frequency band	**Service**	**Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane**			**Reference bandwidth**
		0°-5°	**5°-25°**	**25°-90°**	
10.7-11.7 GHz	Fixed-satellite (space-to-Earth) (non-geostationary-satellite orbit)	−126	−126 + 0.5(δ − 5)	−116	1 MHz

Validation of the pfd limit includes the calculation of the produced pfd on the Earth surface for each angle of arrival defined as the "limit" indicated in the table for that frequency band and service and comparing the calculated values against the given pfd limit.

Exceeding the pfd limit for any angle of arrival will indicate that the limit is exceeded, and unfavourable finding will be given under RR No. **21.16**.

It is also worth noting that where the agreement of other administrations is required for operating assignments which exceeds limits of RR Article **21** or **22** over their territories, the Bureau will formulate a favourable finding under RR No. **11.31** only if it is informed that such agreement exists with these other administrations. This agreement is treated separately from the coordination agreement required under RR No. **9.6**. The same approach is taken when checking agreement under RR No. **9.21** where the Bureau treats the agreement obtained under RR No. **9.21** as separate from the coordination agreement under RR No. **9.6**.

Hard limits on equivalent isotropically radiated power (e.i.r.p.) are applicable to transmitting earth stations. Table 5 lists different e.i.r.p. limits applicable to non-GSO.

TABLE 5

Limits applicable to transmitting earth stations

Source	**Ref. BW kHz**	**Service**	**Limit**	**Frequency ranges (MHz)**
5.364	4	Mobile-satellite	Mean EIRP <= −3 *mean_eirp = pep_max – 10 * Log10(emission_bandwidth) + 10 * Log10(4000) + GainMaxEarthStation*	1 610-1 626.5
5.502	-	Fixed-satellite	ES Antenna Diameter >=4.5 m	13 750-14 000
5.503	6 000	Fixed-satellite	EIRP/6 MHz <=51 dBW	13 772-13 778
5.532B	-	Fixed-satellite	ES Antenna Diameter >=4.5 m	24 650-25 250 (Region 1) 24 650-24 750 (Region 3)
5.260A	4 / whole band	Mobile-satellite Telecommand (only in 399.9-400.02 MHz)	5 dBW	399.9-400.05 MHz

Additional limits applicable to ship earth stations (class of station TG) in mobile-satellite service are given in RR No. **5.506A** and Resolution **902 (WRC-03)**.

In the band 14-14.5 GHz, ship earth station (class of station TG) with an e.i.r.p. greater than 21 dBW, operating in the maritime mobile-satellite service (Class of Station EG) or the mobile-satellite service (class of station EI), shall be subject to the limits described in Annex 2 to Resolution **902 (WRC-03)** as shown in Table 6 below. If any of these limits is not met, the finding is unfavourable.

TABLE 6

Limits applicable to transmitting earth stations (14-14.5 GHz)

Minimum antenna diameter (see Note below)	1.2 m	
Maximum e.i.r.p. spectral density toward the horizon	12.5 dB(W/MHz)	
Maximum e.i.r.p. toward the horizon	16.3 dBW	
Maximum off-axis e.i.r.p. density	Off-axis angle (degrees)	Maximum e.i.r.p. in any 40 kHz band dB(W/40 kHz)
	$2 \leq \varphi \leq 7$ $7 < \varphi \leq 9.2$ $9.2 < \varphi \leq 48$ $48 < \varphi \leq 180$	$33 - 25 \log \varphi$ 12 $36 - 25 \log \varphi$ -6

It should be noted that, it is not in all cases that, the limits in the Radio Regulations require computation of produced interference or transmitting power. There are certain limits in the Radio Regulations which are verified by comparing the value of the limit with the submitted RR Appendix **4** data. These limits are normally referred to as commitments, e.g. the notifying administration should provide commitment that certain level will be met or provide the value of produced interference level which will be then compared with the limits. Such commitments are given in Table 7.

TABLE 7

Compliance with commitments

If a value exists in the following field	**Compare with the following limits. If the limits are exceeded, finding is unfavourable, else favourable**	**Reference**
A17b3. The equivalent pfd value in the band 4 990-5 000 MHz (dB(W/($m^2 \cdot$ 10 MHz))) Required for non-GSO RNSS in 5 010-5 030 MHz Classes: EF EN EO EQ **Source: c_pfd**	–245 dB(W/($m^2 \cdot$ 10 MHz))	Resolution **741 (Rev.WRC-15)**
A17b2. Calculated aggregate pfd value in the band 5 030-5 150 MHz (dB(W/($m^2 \cdot$ 150 kHz))) Required for non-GSO RNSS in 5 010-5 030 MHz Classes: EF EN EO EQ **Source: c_pfd**	–124.5 dB(W/($m^2 \cdot$ 150 kHz))	**5.443B**
A17d. Mean PFD		
Required for non-GSO EESS (active)/SRS (active) in the band 35.5-36 GHz dB(W/(m^2)) Classes : EH EW E1 E3 **Source: c_pfd**	–73.3 dB(W/(m^2)) in 35.5-36 GHz	**5.549A**

TABLE 7 (*end*)

If a value exists in the following field	Compare with the following limits. If the limits are exceeded, finding is unfavourable, else favourable	Reference
Required for non-GSO EESS (active) in the band 9.9-10.4 GHz dB(W/(m^2 · 1 MHz)) Classes: EW E3 **Source: c_pfd**	No pfd to be provided RoP A.17.d apply: Administrations shall provide SAR emission bandwidth information under C.7.a (necessary bandwidth) for active sensors operating in the Earth exploration satellite service (active) in the frequency band 9 900-10 400 MHz instead of submitting the mean pfd	Article **21**, Table **21-4** RoP § A.17.d
A17e1. Calculated equivalent PFD value in the band 42.5-43.5 GHz Required for non-GSO FSS (space-to-Earth) and BSS in the band 42-42.5 GHz Classes: EB EV EC **Source: c_pfd**		**5.551H**
At any RA SDT (single dish telescope) **Source: c_pfd** **c_pfd.ra_stn_type==“S”**	–230 dB(W/(m^2 · 1 GHz)) –246 dB(W/(m^2 · 500 kHz))	
At any RA VLBI (very long baseline interferometry) **Source: c_pfd** **c_pfd.ra_stn_type==“V”**	–209 dB(W/(m^2 · 500 kHz))	
A17.XX [A17abis] Calculated equivalent PFD value in the band 1 610.6-1 613.8 MHz Required for non-GSO MSS in the band 1 613.8-1 626.5 MHz Classes: EI, EG, EJ, EU, E5, E6	–258 dB(W/m^2 · 20 kHz))	**5.372**
B4b5. Calculated peak value of power flux-density produced within +/–5 inclination of GSO Required for non-GSO FSS in the band 6 700-7 075 MHz Classes: EC ED EK ER **Source: grp.pfd_pk_7g**	–168 dB(W/(m^2 · 4 kHz))	**22.5A**
A17a. Commitment of compliance with per-satellite power flux density level of –129 dB(W/m^2 · MHz) Required for non-GSO RNSS in the band 1 164-1 215 MHz Classes: EF EN EO EQ **Source: non_geo.f_pfd_lim**	Flag	**11.31**

3.5.4.1.1 Calculation methods applicable to different types of satellite transmitting beam

Satellite transmitting beams can be defined as fixed or steerable beams.

For fixed beams, pfd calculation procedure is carried out for a single fixed position of the beam looking into nadir direction (the direction pointing directly below a satellite). Exceeding pfd limit for any angle of arrival will result in an unfavourable finding.

Steerable transmitting beams can be pointing to any direction below the satellite. pfd values produced by assignments in steerable beams may exceed the applicable hard pfd limits for some positions of a steerable beam but at the same time there could be a position or positions within the service area of a steerable beam when such applicable pfd limit is met.

To recognize such situation, the Rules of Procedure on RR No. **21.16** states that:

*In cases where frequency assignments in steerable beams of a satellite network, except the frequency assignments under the Appendix **30B**, exceed the applicable hard pfd limits, the Bureau will establish a favourable finding only if:*

a) *there is at least one position of the steerable beam where the applicable pfd limits are met without any reduction of the notified power density; and*

b) *the administration states that the applicable pfd limits will be met by applying a method, the description of which should be submitted to the Bureau. One possible example of such a method is described in the Annex to this Rule.*

The pfd-calculation invokes this Rule of Procedure on RR No. **21.16** in the case of pfd excess for steerable beams. For ITU submissions of satellite networks, it shall indicate in a relevant item **B.3.b.1** of RR Appendix **4** as shown below (see also RR No. **21.16** and its associated Rules of Procedure) that the method in Annex 1 of the Rules of Procedure or other method(s) (to be provided by the administration) should be applied for steerable transmitting beams.

> **B.3.b.1.b** code captured via the BR software SpaceCap indicating if method required in RoP **21.16** is applicable, as well as applicable PFD will be met by applying the method identified in the Annex 1 of RoP **21.16**, table ***s_beam***, field ***f_pfd_steer_default****, or other method(s) provided by the administration.*

According to the associated Rules of Procedure, as long as there is one single position of a steerable beam where pfd-limit is met, it is considered that frequency assignment subject to such pfd limit is complying with the limit.

3.5.4.1.2 Satellite beam antenna pattern

Satellite antenna pattern is an important factor affecting pfd-level produced. Indicating precise description of antenna pattern would help to avoid receiving unfavourable findings due to pfd limit excess in most of the cases.

There are several ways indicating antenna patterns in submission (see section 3.5.1.2.2):

1 Indicating standard antenna pattern by providing pattern IDs, available in the APL online;

2 Providing non-standard antenna pattern by capturing it in GIMS.

Some typical antenna patterns include:

1 ***ND-SPACE*** – non-directional antenna pattern, usually provided for low-gain satellite beams;

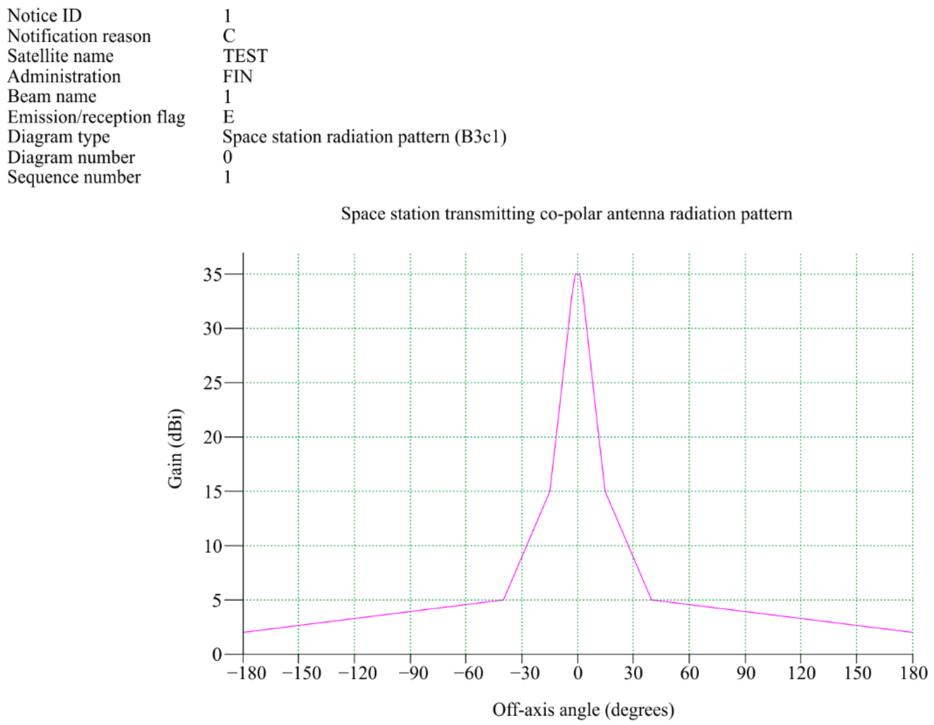
2 ***REC-1528*** – antenna pattern based on Recommendation ITU-R S.1528. It is widely applicable for LEO and MEO satellite systems.

3 ***REC-672*** – antenna pattern based on Recommendation ITU-R S.672 which is normally used as an antenna pattern for GSO space stations, can also be used for non-GSO space stations using orbits with an active arc close to the GSO (highly elliptical orbit systems).

It is also possible to capture antenna patterns in GIMS. One example is shown in Fig. 9.

FIGURE 9

Antenna pattern captured in GIMS



Handbook on Small Satellites-9

In case where the provided antenna pattern is not contained in the APL and not digitized in GIMS, a constant maximum gain is used for calculations.

Besides, when the antenna radiation pattern is provided as a picture, since the PFD-validation software cannot use such graphical representation, a constant maximum gain will be used for technical examination by the Bureau, which may lead to an unfavourable finding to the ITU submissions due to the imprecision in analyses.

When the correct description of antenna pattern is provided, the satellite gain will be calculated towards the point on the Earth where pfd limit is validated.

3.5.4.1.3 Derivation of transmitting power to be used in calculations

Equation (5) in section 3.5.4.1 requires peak power in reference bandwidth defined in the limit.

There are two different methods to calculate the transmitting power used in the pfd calculations.

Existing method

For certain pfd examinations, there is a choice between using the power density (P_{ds_max}), expressed in W/Hz, multiplied by the limit reference bandwidth (B_{ref}) expressed in Hz or the total peak envelope power (P_{ep_max}), expressed in W. The choice for any emission, the necessary bandwidth of which is B (Hz), is to be made according to the following rule:

If $B > B_{ref}$ then

If $P_{ds\_max} * B_{ref} > P_{ep\_max}$ then

$$P_{used} = P_{ep\_max}$$

else

$$P_{used} = P_{ds\_max} * B_{ref}$$

else if $B \leq B_{ref}$ then

$$P_{used} = P_{ep\_max}$$

Method in accordance with Recommendation ITU-R SF.675

At the same time, footnote 2 to Tables A, B, C and D of Annex 2 to RR Appendix **4** suggests the use of the most recent version of Recommendation ITU-R SF.675 to calculate the maximum power spectral density. In particular, for the identification of the maximum power spectral density of different type of carriers, it recommends considering the maximum possible number of carriers occupying a given averaging bandwidth.

Particular importance of this footnote 2 is that the maximum power density is averaged over 4 kHz for carriers below 15 GHz and 1 MHz for carriers above 15 GHz. It is important that administration follow this footnote when providing RR Appendix **4** data items.

For example, using Recommendation ITU-R SF.675-4 and considering an averaging bandwidth of 1 MHz and emission bandwidth 200 kHz, P_{ds_max} can be defined as follows:

$$P_{1\,\text{MHz}} = (P_t * N)\ (\text{W/MHz}) \tag{6}$$

where:

- P_t: total power of a single carrier (W)
- N: maximum number of carriers, including portions of carriers, with a necessary bandwidth less than 1 MHz to occupy any given 1 MHz band.

Within averaging bandwidth of 1 MHz, it is important to define the number of emissions which can be operating within 1 MHz. Let us consider that the system is designed to operate contiguous bandwidth populated with the maximum number of carriers with 200 kHz emissions having 50 kHz guard band bandwidth. In such a case, within 1 MHz bandwidth four carriers operating 200 kHz emissions ($N = 4$) can be fitted. Considering, for example, that the total power of a single carrier is −8 dBW, then:

$$P_{1\,\text{MHz}} = -8 + 10\log(4) = -2\ \text{dBW/1 MHz} \tag{7}$$

$$P_{ds\ max} = P_{1\,\text{MHz}}/1 \times 10^6 = -62\ \text{dBW/Hz} \tag{8}$$

Using this definition of P_{ds_max}, transmitting power used in pfd calculation will be evaluated as follows:

$$averagingbandwidth = B_{ref}$$

$$P_{used} = P_{ds\_max} * B_{ref} \tag{9}$$

$averagingbandwidth > B_{ref}$

if $emi\_bdwdth < B_{ref}$ then

$$P_{used} = P_{ep\_max}$$

else $P_{used} = P_{ds\_max} * B_{ref}$

$averagingbandwidth < B_{ref}$

Use existing method.

To avoid exceeding pfd limit it is important to define maximum power spectral density as recommended in the latest version of Recommendation ITU-R SF.675.

3.5.4.1.4 Using BR software to evaluate pfd limit

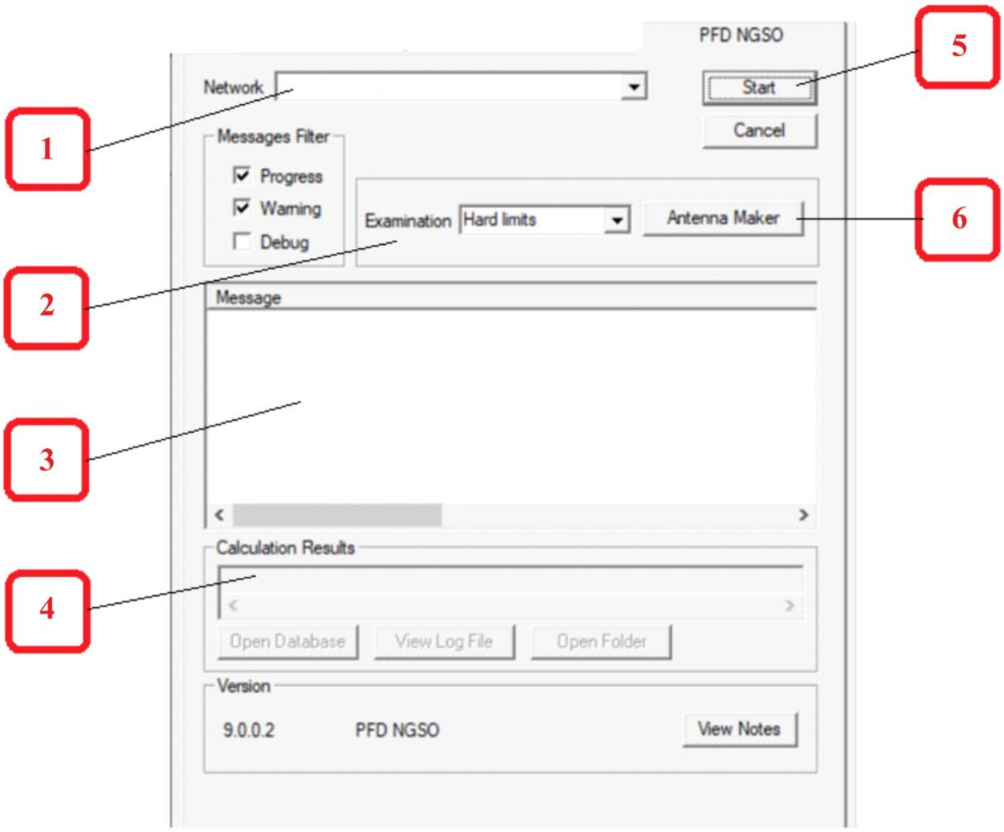
ITU BR software Graphical Interface for Batch Calculation software (GIBC) contains a module PFD NGSO providing validation of RR Article **21** limits.

PFD NGSO tab can be accessed from the main GIBC interface.

The main interface options are presented in Fig. 10.

FIGURE 10

GIBC pfd non-GSO interface



Handbook on Small Satellites-10

(1) Enter notice here

(2) Select type of examination:

- Hard Limits
- Trigger Limits
- REC608

(3) Progress messages

(4) Results location

(5) Start calculations

(6) Launch Antenna Maker program

Before running any examination, input SRS and GIMS database should be selected in Tools/Options tab.

To facilitate analyses of the results, the program generates upon each run a new database containing the calculations results.

– Results of hard-limit calculations are stored under users profile folder *…\TEX_RESULTS\[NOTICE_ID]\ PFD_NGSO_H_[CREATION_TIME]* under filename PFDNGSO_RESULTS.mdb

– Results of trigger-limits calculations are stored in *…\TEX_RESULTS\[NOTICE_ID]\ PFD_NGSO_T_[CREATION_TIME]* under filename PFDNGSO_RESULTS.mdb

These results databases contain the following information:

– Execution summary

– For trigger limits calculation, list of affected administrations (***provn*** table)

– Detailed results of calculations for downlink and uplink (where applicable).

3.5.4.2 Verifying compliance with RR Article 22 epfd limits

The epfd concept was adopted by WRC-97 in order to facilitate introduction of non-GSO systems in the fixed-satellite service in certain Ku and Ka bands shared with GSO FSS.

WRC-97 adopted "hard limits" on emissions from non-GSO systems and defined them differently from power flux-density (pfd). The WRC-97 definition of equivalent power flux-density (epfd) takes into account the aggregate of the emissions from all non-GSO satellites within a non-geostationary-satellite system in the direction of any GSO earth station, taking into account the GSO antenna directivity. Such hard limits enable non-GSO FSS systems to share frequencies with and protect GSO systems without requiring individual coordination with all the systems worldwide.

RR Article **22** defines epfd as:

> ***22.5C.1*** *The equivalent power flux-density is defined as the sum of the power flux-densities produced at a geostationary-satellite system receive station on the Earth's surface or in the geostationary orbit, as appropriate, by all the transmit stations within a non-geostationary-satellite system, taking into account the off-axis discrimination of a reference receiving antenna assumed to be pointing in its nominal direction. The equivalent power flux-density is calculated using the following formula:*

$$epfd = 10\log_{10}\left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}}\right]$$

where:

- N_a: *number of transmit stations in the non-geostationary-satellite system that are visible from the geostationary-satellite system receive station considered on the Earth's surface or in the geostationary orbit, as appropriate;*
- i: *index of the transmit station considered in the non-geostationary-satellite system;*
- P_i: *RF power at the input of the antenna of the transmit station, considered in the non-geostationary-satellite system (dBW) in the reference bandwidth;*
- θ_i: *off-axis angle between the boresight of the transmit station considered in the non-geostationary-satellite system and the direction of the geostationary-satellite system receive station;*
- $G_t(\theta_i)$: *transmit antenna gain (as a ratio) of the station considered in the non-geostationary-satellite system in the direction of the geostationary-satellite system receive station;*
- d_i: *distance (m) between the transmit station considered in the non-geostationary-satellite system and the geostationary-satellite system receive station;*
- φ_i: *off-axis angle between the boresight of the antenna of the geostationary-satellite system receive station and the direction of the i-th transmit station considered in the non-geostationary-satellite system;*
- $G_r(\varphi_i)$: *receive antenna gain (as a ratio) of the geostationary-satellite system receive station in the direction of the i-th transmit station considered in the non-geostationary-satellite system;*
- $G_{r,max}$: *maximum gain (as a ratio) of the antenna of the geostationary-satellite system receive station;*

epfd: *computed equivalent power flux-density (dB(W/m^2)) in the reference bandwidth.* *(WRC-2000)*

FIGURE 11

epfd calculation geometry on downlink

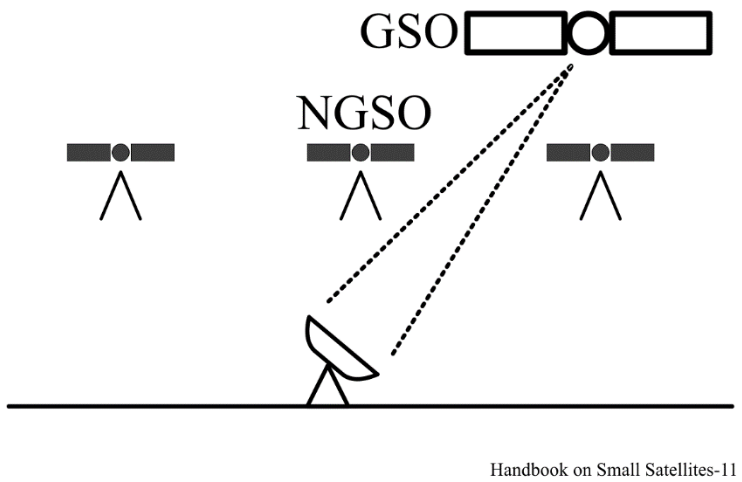


FIGURE 12

epfd calculation geometry on uplink

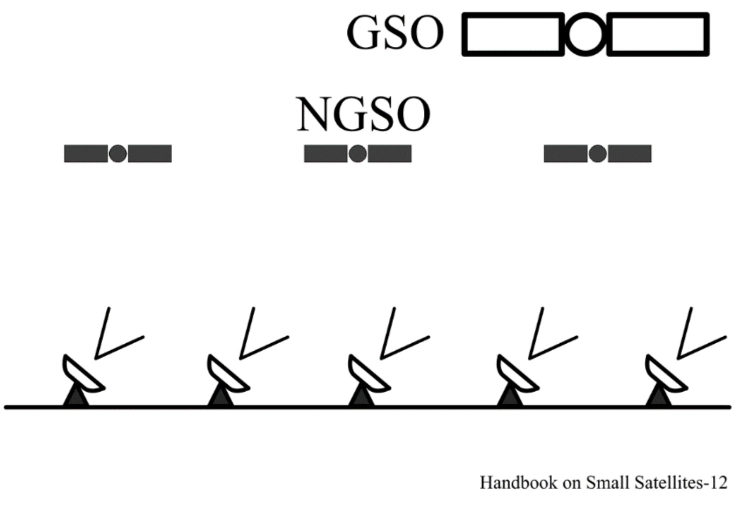
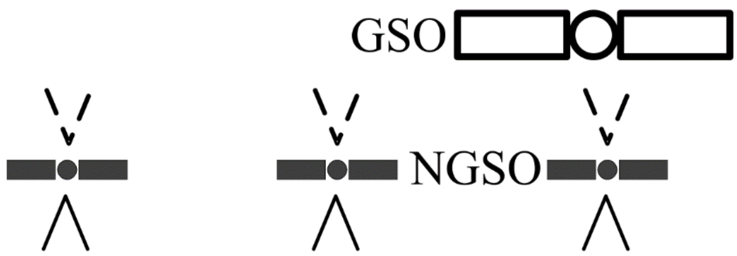


FIGURE 13

epfd calculation geometry on inter-satellite path



Handbook on Small Satellites-13

Same as a pfd, the epfd is calculated at the receiving antenna; however, contrary to pfd, it takes into account the pointing of antenna with respect to every source of interference. That is, when an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is equivalent to the pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

This concept allows very limited knowledge of parameters of receiving systems. In fact, only reference antenna pattern, antenna size and associated maximum antenna gain are needed to characterize interference for the specific class of receiving system, i.e. RR Article **22** contains limit masks for a number of receiving earth station configurations including antenna size ranging from 30 cm to 10 metres and up to 15 metres for the special case in the band 3 700-4 200 MHz.

Currently, epfd is widely used in Radio Regulations in the following cases:

1) epfd hard limits on FSS non-GSO satellite systems to protect GSO FSS/BSS in RR Article **22**.

2) epfd coordination trigger limits applicable for non-GSO FSS and GSO FSS under RR Nos. **9.7A** and **9.7B**.

3) epfd limits for systems in different radiocommunication services utilizing non-geostationary orbit to protect radioastronomy stations in a number of frequency bands. See Resolutions **739 (Rev.WRC-19)**, **741 (Rev.WRC-15)** and **743 (WRC-03)**.

4) Protection of aeronautical radionavigation service systems from the epfd produced by radionavigation-satellite service networks and systems in the 1 164-1 215 MHz frequency band. See Resolution **609 (Rev.WRC-07)**.

However, only for the first two cases mentioned above, there is a requirement for the Bureau to examine if the frequency assignments to non-GSO systems are in compliance with RR Article **22** and RR Appendix **5** limits.

For that purpose, WRC-2000 requested the Bureau to encourage administrations to develop the epfd validation software which would be used by the Bureau to establish findings in application of RR Article **22** and RR Nos. **9.7A** and **9.7B**.

The methodology for the epfd validation software is based on Recommendation ITU-R S.1503. This Recommendation contains detailed description of the input parameters for calculating epfd limits and coordination triggers contained in RR Article **22** and RR Appendix **5**.

The methodology is complex and in order to increase the confidence in any software tool, the Bureau felt that at least two independent implementations of Recommendation ITU-R S.1503 would be necessary. Accordingly, two commercial software development companies have developed epfd tools for checking compliance under RR Article **22** or coordination requirements under RR Nos. **9.7A** and **9.7B**. In 2016, the Bureau finalized the software tools in accordance with Recommendation ITU-R S.1503-2 (12/2013). Full details of the epfd validation software which the Bureau will use to conduct its examination in accordance with Resolution **85 (WRC-03)** can be found at:

https://www.itu.int/ITU-R/go/space-epfd

Most of the information required to run software examinations are contained in the SRS database. However, because of the complex configurations of different non-GSO constellations, it is difficult to simulate exact traffic configurations and transmitting parameters of the systems.

For that purpose, Recommendation ITU-R S.1503-2 establishes a concept of a mask for pfd/e.i.r.p. produced by interfering non-GSO network stations. The mask would account for all the features of specific non-GSO systems arrangements. Since these masks may contain very large amount of data in order for administrations to submit the mask data electronically and for the epfd software tool to use the submitted data directly, the Bureau has developed an XML-format for the pfd and e.i.r.p. masks.

The epfd validation software is integrated into BR GIBC software to conduct seamless examinations in a manner similar to current examinations in RR Appendix **8**/pfd modules of the GIBC software.

For further technical guidance, please check the user guide and workshop materials dedicated to epfd validation, available online at:

https://www.itu.int/ITU-R/go/space-epfd, https://www.itu.int/epfdsupport

For any technical questions, please contact the Radiocommunication Bureau by e-mail:

epfd-support@itu.int

ITU-R Circular Letter CR/414 dated 6 December 2016 contains details of the epfd review process for the cases that previously received qualified favourable findings. The results of the review and input data submitted for review can be found here:

https://www.itu.int/ITU-R/go/space-epfd-data

The latest in-force version of Recommendation ITU-R S.1503 is available at: https://www.itu.int/rec/R-REC-S.1503/en. This Recommendation is regularly updated to reflect improvements in the modelling of non-geostationary satellite systems, so readers are advised to check whether Working Party 4A of ITU-R Study Group 4 (https://www.itu.int/en/ITU-R/study-groups/rsg4/rwp4a/Pages/default.aspx) is in the process of revising this Recommendation.

3.5.5 List of the BR software used for filing space notices to the Bureau

The latest BR software used for filing of space notices to the Bureau are shown in the webpage below:

https://www.itu.int/ITU-R/go/space-software/en

BR software tools and aids	Description
Space Capture Software (SpaceCap) (mandatory)	PC-based software for the electronic capture of information identified in the RR Appendix **4** in SNS format for API, Coordination and Notification notices
Graphical Interference Management Software (Gims) (mandatory)	Software package which allows the capture and modification of graphical data relating to the electronic notices of satellite networks
Space filing Validation Software (BRSIS-Validation) (mandatory)	PC-based software for validating electronic notices captured by the SpaceCap and Gims software
Space data Query Software (BRSIS-SpaceQry)	PC-based software package which allows the query/access to any SNS formatted database
Space Publication Software (SpacePub)	PC-based software utility for printing satellite networks / earth stations data from a SNS formatted database. It creates an RTF (Rich Text Format) file readable by Microsoft Word. It also allows the user to specify that the associated graphical data taken from the GIMS database be included in the document.

BR software tools and aids	Description
Capture system for comments on special sections (SpaceCom)	SpaceCom software package is a stand-alone application designed to assist administrations and the Bureau in the management of the comments on four types of special sections: CR/C, API/A, AP30-30A Part A, AP30-30A/F/C
Graphical Interface for Batch Calculations (GIBC)	Software package which provides the user with the ability to carry out calculations on satellite networks which allow determining the coordination requirements.

Under Resolution **55 (Rev.WRC-19)**, as well as described in section 3.5.1.2.1, all specified notices for satellite networks and earth stations submitted to the Bureau pursuant to RR Articles **9** and **11** shall be submitted in electronic format compatible with the BR electronic notice form capture software (SpaceCap); all graphical data associated with the submissions addressed should be submitted in graphics data format compatible with the BR data capture software (graphical interference management system (GIMS)).

Administrations shall use the latest BR data capture software SpaceCap to capture the SNS format notice database and use the latest BR software GIMS (Graphical Interference Management System) to capture the GIMS format diagram database.

The latest version of the validation software available to administrations is used by the Bureau when assessing the completeness of RR Appendix **4** Forms of Notice. The cross-validation option of the BRSIS Validation software must be executed when validating the SNS notice format database against the GIMS format database, if any, in order to overcome any difficulties identified in the validation report for the satellite network notice before it is submitted to the Bureau in accordance with § 3.4 of the Rules of Procedure on Receivability of forms of notice.

An online guide containing information on how to capture diagram numbers and/or attachment numbers using SpaceCap, and cross-validate this information with the GIMS database using BRSIS Validation, which applies to SpaceCap V9.0.33.25 and BR SIS Validation V9.0.2 and later versions, is available at: www.itu.int/go/space/non-GSO/graphical-submission

3.5.5.1 The Radio Regulations Navigation Tool

Developed by the Radiocommunication Bureau, the Radio Regulations Navigation Tool (RRNT) is a Java-based desktop application for browsing the Radio Regulations (RR) and the Rules of Procedure (RoP). It also allows users to navigate from the provisions of these documents to other associated documents like the ITU Constitution, the ITU Convention, ITU Plenipotentiary Conference Resolutions, and ITU-R Recommendations cited but not incorporated in the RR. It is designed to help countries and industries navigate through these documents more easily.

The Navigation Tool offers a pure PDF viewing solution, running on all widely used operating systems including Windows, Mac OS X and Linux, without requiring any further download. It helps users to navigate over 15 000 references including articles, provisions and annexes. To enable this, the tool keeps the user's navigation history for easy reference and offers a powerful search capability across all four volumes of the RR and quick access to the RoP applicable to a given provision.

The tool is available for purchase from the ITU websites at:

https://www.itu.int/en/publications/ITU-R/Pages/default.aspx

https://www.itu.int/hub/publication/r-reg-rrx-2021/

An introductory video is available at:

https://www.youtube.com/watch?v=9aZnTMcbLmA&t=13s&ab_channel=ITU

3.5.5.2 The RR5 Table of Frequency Allocations (TFA) software

3.5.5.2.1 General

The RR5 Table of Frequency Allocations (TFA) software is a stand-alone application that provides a mechanism to electronically use, query and analyse the Table of Frequency Allocations and its associated footnotes, as they appear in the Article **5** of Radio Regulations, as well as some other related texts (Resolutions, ITU-R Recommendations, Rules of Procedure). This software application runs on individual user's PC and requires neither network nor Internet connection. It is limited to the scope and boundaries of the Article **5** of the RR and is the perfect complement to the RR that incorporates the decisions of the World Radiocommunication Conferences (WRCs).

Built around a relational database model, the software is equipped with various tools and utilities that allow, among others, for advanced and complex search functions, data export to various formats, as well as for the tracing and comparison of the evolution of the Article **5** Table and its associated footnotes (from the 2001 Edition onward).

For comprehensive details and in-depth instructions, please consult the online guidelines here:

RR5FATViewer_User's_Guide.pdf (available at: https://www.itu.int/en/ITU-R/space/support/smallsat/sshandbook/Documents/RR5FATViewer_UsersGuide.pdf)

A simplified Guide on RR5FATViewer for space services (available at: https://www.itu.int/en/ITU-R/space/support/smallsat/sshandbook/Documents/RR5FATViewer_GuideForSpaceServices.pdf)

3.5.5.2.2 Acquiring the software

The software is available for download under the ITU-R Publications website, or alternatively by contacting the ITU Sales (sales@itu.int). Upon purchase and download of the software, the user will be prompted to request a license –on up to three separate personal devices– prior to using the software. To upgrade to a 2-10 or organizational-wide license, please contact ITU Sales, separately. For any technical questions or support, post-purchase, please email BR Tools Tech Support (BR-RRTools@itu.int) with the description of the problem encountered. For more details, please check the webpage here: https://www.itu.int/en/publications/ITU-R/Pages/publications.aspx?lang=en&media=electronic&parent=R-REG-RR5-2020

3.5.5.2.3 Package updates

Major releases of the package correspond to the new editions of Radio Regulations. The active major release is associated with the **RR 2020 (WRC-19)** edition. **A new license is required for every new major release** (usually following the holding of a WRC). The next major release is expected after **WRC-23**.

Between two major releases (approximately four years), the packages will be subject to updates concerning both data and software. These will be **released freely to subscribers holding licensed packages**.

3.5.6 Cost recovery principles and fees for the processing of satellite network filings

The ITU Council determines the cost recovery principles and fees for the processing of the satellite network filings by the Radiocommunication Bureau (BR).

Satellite network filings concerning advance publication and notification for recording of frequency assignments in the Master International Frequency Register are subject to cost-recovery charges, as defined in ITU Council Decision 482, available at the webpage:

http://www.itu.int/ITU-R/go/space-cost-recovery/en

As defined in ITU Council Decision 482 modified (C2020), which is the version in force at the time of writing:

– for satellite networks or systems not subject to coordination, the fees are described as follows:
  - API: 570 CHF
  - Notification: 7 030 CHF

– for satellite networks or systems subject to coordination, the fees are as follows:
  - Coordination request:
    - from 5 560 CHF to 33 467 CHF, depending on the categories and units
    - kindly note that, since 2019, in accordance with ITU Council Decision 482 modified (C2019 and C2020), for a coordination request of a non-geostationary satellite network containing different mutually exclusive sub-sets of orbital characteristics, cost recovery charges will be separately computed for each of the sub-sets.
  - Notification:
    - 7 030 CHF, for those subject to RR No. **9.21** alone
    - from 15 910 CHF to 57 920 CHF, depending on the categories and units (except those notification that are subject to RR No. **9.21** alone).

As mentioned above, for those subject to coordination, the fee is variable depending on the category and the number of units. The category is determined from the number of applicable coordination provisions for that notice, and the number of units is a measure of the size of the satellite network calculated as the product of the number of frequency assignments, number of emissions and number of classes of stations summed up for all groups.

For GSO satellite networks, this variable fee consists of a start fee and a fee per unit for 1 to 100 units, after which the fee is flat regardless of the units beyond 100 units.

For non-GSO satellite networks, similarly, this variable fee consists of a start fee and a fee per unit for 1 to 100 units, after which the fee is flat up to 25 000 units, and then increases again for a fee per unit up to 75 000 units, after which the fee remains flat regardless of the units beyond 75 000 units.

For the coordination requests for non-GSO satellite networks, it is possible to submit different mutually exclusive sub-sets of orbital characteristics. For such networks, cost recovery charges will be separately computed for each of the sub-sets and thereafter added to produce the overall charge of the satellite network.

There is no cost recovery charge for a submission of satellite notice in the amateur-satellite service.

For a filing to benefit from this fee exemption, there should be only one main service (class of station EA) in the filing without any other main space services being present.

If there is no allocation for space operation service (class of station ET) in the frequency band selected for amateur-satellite, the functions of the space operation service (space tracking, space telemetry, space telecommand) with class of stations EK, ER, ED separately, could be normally provided with the main service of amateur-satellite service (class of station EA) in which the space station is operating (see section 4.1.1), with the exemption from cost recovery fee. However, if the band submitted is allocated to ET, then the filing with two main space services EA and ET is chargeable. (See section 3.5.1.10.)

Each Member State is entitled to the publication of special sections or parts of the BR IFIC (Space Services) for one satellite network filing each year without the charges referred to above. Each Member State in its role as the notifying administration may determine which network shall benefit from the free entitlement.

The nomination of the free entitlement for the calendar year of receipt by the Bureau of the satellite network filing based on the formal date of receipt of the filing shall be made by the Member State no later than the end of the period for payment of the invoice.

If payment for the invoice is not received by the due date, the satellite network will be cancelled. It should be noted that even after the cancellation of the satellite network, the invoice remains payable.

The free entitlement cannot be applied to a filing previously cancelled for non-payment.

3.6 Non-conformity with the Table of Frequency Allocations (RR No. 4.4)

When assigning frequencies to stations, Member States shall note that such assignments are to be made in accordance with the Table of Frequency Allocations under RR Article **5** and other provisions of these

Regulations (see RR No. **4.2**). Administrations are therefore discouraged to use assignments that are not made in accordance with the Table of Frequency Allocations and other provisions of the Radio Regulations.

However, if such use is still desired, the provision RR No. **4.4** states that "*Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.*"

Therefore, administrations intending to authorize the use of spectrum under RR No. **4.4** still have the obligation, under Sections I and II of RR Article **9**, RR Nos. **11.2** and **11.3**, to notify to the Bureau any frequency assignment if its use is capable of causing harmful interference to any service of another administration.

This is because whether or not a frequency assignment to a transmitting station is capable of causing harmful interference to the stations of another administration operating in accordance with the Radio Regulations does not lie only on the side of the administration operating the transmitting station that may be producing the interference. Other administrations should also have information about a use under RR No. **4.4** to assess its interference potential or identify the source of harmful interference.

As the use of assignment under RR No. **4.4** is under the condition that such use "shall not cause harmful interference" to other stations which use is in compliance with the Radio Regulations, the recording of an assignment with a reference to RR No. **4.4** requires the notifying administration to immediately eliminate any harmful interference caused to other frequency assignments operated in accordance with the Radio Regulations upon receipt of advice thereof.

In accordance with the Rules of Procedure related to RR No. **4.4**, administrations, prior to bringing into use any frequency assignment to a transmitting station operating under RR No. **4.4**, shall determine:

a) that the intended use of the frequency assignment to the station under RR No. **4.4** will not cause harmful interference into the stations of other administrations operating in conformity with the Radio Regulations;

b) what measures it would need to take in order to comply with the requirement to immediately eliminate harmful interference pursuant to RR No. **8.5**.

Therefore, administrations when notifying the use of frequency assignments under RR No. **4.4** are required to provide at the time of notification of these frequency assignments a confirmation that it has determined that the frequency assignments meet the conditions referred to in a) and b) above.

3.7 Bringing into use of notified frequency assignments

The regulatory time-limit for bringing into use a frequency assignment to a space station of a satellite network not subject to a Plan is seven years, as specified in RR No. **11.44**.

In the case of satellite networks or systems not subject to the coordination procedure under Section II of RR Article **9**, the seven-year regulatory time-limit is counted from the date of receipt by the Bureau of the advance publication information (special section API/A) under RR Nos. **9.1** or **9.2**.

In the case of satellite networks or systems subject to the coordination procedure under Section II of RR Article **9**, the seven-year regulatory time-limit is counted from the date of receipt of the advance publication information (special section API/C) referred to in RR No. **9.1A**, which is an extract from the Request for Coordination (CR) received under RR No. **9.30**.

Any frequency assignment that has not been brought into use within the required period will be cancelled by the Bureau after having informed the administration at least three months before the expiry of this period. The reminder by the Bureau sent to administration is in the form of an ITU-R circular telegram (CTITU) under the CTITU series (available at https://www.itu.int/md/R00-CTITU-CIR/en).

The information concerning the date of bringing into use (DBIU) is to be provided at the following occasions:

– at notification using RR Appendix **4** notice forms (RR No. **11.15**); and

– when confirming the date of bringing into use (RR Nos. **11.47**, **11.44B**, **11.44C**, **11.44D** and **11.44E**).

As the first information of the DBIU is provided at the time of the notification of the frequency assignments for recording under RR No. **11.2** as part of the RR Appendix **4** information, this information should be provided for each assignment or group of assignments.

In accordance with RR No. **11.25**, notices relating to assignments to stations in space services, shall reach the Bureau not earlier than three years before the assignments are brought into use. This means that the DBIU indicated in the notification for a space station should not be later than three years from the date of receipt of the notification.

If the DBIU indicated in the notification for a space station is later than three years from the date of receipt of the notification, the notice will be considered not receivable and shall be returned to the administration responsible for the network (see § 4.1 of the Rules of Procedure on Receivability).

In the case when the DBIU indicated in the notification notice is a date earlier than the date of receipt of the notice, the indicated DBIU is considered as the actual DBIU.

Any information concerning the bringing into use received by the Bureau without a notification submission cannot be accepted by the Bureau.

3.7.1 Provisional recording

If a frequency assignment to a satellite network at notification have a DBIU that is later than the date of receipt of the notice, the DBIU is considered as the expected DBIU of the frequency assignments. Such frequency assignment is processed under RR No. **11.47**, leading to a provisional entry of the frequency assignment in the Master Register.

3.7.2 Confirmation of DBIU of a provisionally recorded frequency assignment

When the assignments that have been provisionally recorded are brought into use, the administration shall communicate the information to the Bureau.

The information on the actual bringing into use of assignments must be received by the Bureau no later than 30 days after the end of the seven-year regulatory period and the DBIU must be within the regulatory seven-year time-limit.

If the confirmation of bringing into use has not been received by the Bureau within the prescribed time, a reminder will be sent to the notifying administration no later than 15 days before the end of the seven-year regulatory period.

If the Bureau still does not receive any confirmation within 30 days following the end of the seven-year regulatory period, the entry in the Master Register will be cancelled.

3.7.3 Non-GSO in FSS, MSS or BSS

For a frequency assignment to a space station in a non-GSO satellite network or system in the fixed-satellite service (FSS), the mobile-satellite service (MSS) or the broadcasting-satellite service (BSS), there are additional considerations regarding the bringing into use as stipulated in RR Nos. **11.44C**, **11.44.2**, **11.44C.1**, **11.44C.3** and **11.44C.4**.

In general, for such cases, the confirmation of the DBIU is carried out in two steps:

– First step: providing the initial DBIU information

– Second step: confirmation that the assignments have been brought in to use for a continuous 90-day period within 30 days from the end of the 90-day period.

The initial DBIU information is the communication that a frequency assignment to a space station has been brought into use. However, at this stage the assignment has not yet been operated continuously for a 90-day period as described in RR No. **11.44C**. In the case the initial information has been provided, a reminder for the confirmation under RR No. **11.44C** will be sent to the administration 90 days after the communicated DBIU.

The confirmation of bringing into use of the frequency assignment will be considered as communicated to the Bureau when the administration informs the Bureau that a space station with the capability of transmitting or receiving that frequency assignment has been deployed and maintained on one of the notified orbital plane(s) of the non-geostationary satellite network or system for a continuous period of 90 days, irrespective of the notified number of orbital planes and satellites per orbital plane in the network or system, as described in RR No. **11.44C**.

The notifying administration shall inform the Bureau of the confirmation of bringing into use as stated above within 30 days from the end of the 90-day period, as described in RR No. **11.44.C**. The notified DBIU of a frequency assignment to a space station of a satellite network or system shall be the date of commencement of 90-day period, as described in RR No. **11.44.2**.

For cases where the frequency assignment was brought into use more than 120 days prior to the date of receipt of the notification information, this frequency assignment shall be considered as having been confirmed brought into use if the notifying administration confirms that a space station in a non-geostationary-satellite orbit with the capability of transmitting or receiving that frequency assignment has been deployed and maintained on one of the notified orbital planes for a continuous period from the notified date of bringing into use until the date of receipt of the notification information for this frequency assignment, as described in RR No. **11.44C.3**.

When the notifying administration informs the Bureau of the bringing into use of non-GSO system, it shall identify the orbital plane number corresponding to the latest notification information received and/or published by the Bureau in which the space station has been deployed to bring into use the frequency assignments, as described in RR No. **11.44C.4**.

Specifically, a milestone-based approach for systems subject to Resolution **35 (WRC-19)** is described below.

3.7.3.1 Milestone-based approach for deploying non-GSO systems

The Radiocommunication Bureau reported to WRC-15 on increased number of submissions for non-GSO FSS satellite systems having multiple orbital planes. The non-GSO FSS systems filed contained very large numbers of satellites, a wide diversity of orbital characteristics (plane altitude and inclination) and global visible earth coverages which require new innovative approaches for the coordination.

The bringing into use of frequency assignments to a space station of a satellite network is regulated by the provisions of RR No. **11.44**. As a practice by the Bureau, for a satellite network using non-geostationary satellite orbits, a frequency assignment to such a satellite network is considered as having been brought into use when a single satellite with the capability of transmitting or receiving that frequency assignment has been deployed on one of the notified orbital planes, irrespective of the number of satellites and orbital planes in the satellite network constellation. A continuous period of at least three months of operation of that satellite is considered necessary to confirm the bringing into use.

Taking into account of the numerous non-GSO systems received by the Bureau, and the possible speculative nature of such submissions that could lead to spectrum warehousing and resurgence of so-called “paper satellite networks”, the Bureau suggested to consider a possible approach for the bringing into use of a non-GSO satellite network which could be, for example, a phased approach with milestones based on either one satellite or a percentage of the total number of satellites deployed at the end of the seven-year time limit (RR No. **11.44**) and the completion of the total deployment within a reasonable period after the bringing into use.

The outcome of such consideration was the adoption of Resolution **35 (WRC-19)**. The main principles established by this Resolution **35 (WRC-19)** are as follows:

– Non-GSO systems subject to Resolution **35 (WRC-19)** will have to deploy 10% of their constellation within two years after the end of the current regulatory period for bringing into use, 50% within five years, and complete the deployment within seven years (see Table 8).

TABLE 8

Milestone-based approach for deploying non-GSO systems

	1st Milestone	**2nd Milestone**	**3rd Milestone**
Years	2	5	7
Percentage	10	50	100

– The approach will help ensure that the Master International Frequency Register is aligned with the actual deployment of non-GSO satellite systems.

– Procedure is to establish the balance between the prevention of spectrum warehousing, the proper functioning of coordination, notification and registration mechanisms, and the operational requirements related to the deployment of non-GSO systems.

– Establishes basic principle for modifying orbital parameters in case satellite system is not fully deployed.

It should be noted that this Resolution **35 (WRC-19)** is only applicable to frequency bands and services listed in Table 9.

TABLE 9

Frequency bands and services for application of the milestone-based approach

Frequency bands (GHz)	**Space radiocommunication services**		
	Region 1	**Region 2**	**Region 3**
10.70-11.70	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (space-to-Earth)	
11.70-12.50	FIXED-SATELLITE (space-to-Earth)		
12.50-12.70	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (space-to-Earth)	BROADCASTING-SATELLITE FIXED-SATELLITE (space-to-Earth)
12.70-12.75	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (Earth-to-space)	BROADCASTING-SATELLITE FIXED-SATELLITE (space-to-Earth)
12.75-13.25	FIXED-SATELLITE (Earth-to-space)		
13.75-14.50	FIXED-SATELLITE (Earth-to-space)		
17.30-17.70	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)	None	FIXED-SATELLITE (Earth-to-space)
17.70-17.80	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (space-to-Earth)	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)
17.80-18.10	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)		
18.10-19.30	FIXED-SATELLITE (space-to-Earth)		
19.30-19.60	FIXED-SATELLITE (space-to-Earth) FIXED-SATELLITE (Earth-to-space)		
19.60-19.70	FIXED-SATELLITE (space-to-Earth) (Earth-to-space)		

TABLE 9 (*end*)

Frequency bands (GHz)	Space radiocommunication services		
	Region 1	**Region 2**	**Region 3**
19.70-20.10	FIXED-SATELLITE (space-to-Earth)	FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth)	FIXED-SATELLITE (space-to-Earth)
20.10-20.20	FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth)		
27.00-27.50		FIXED-SATELLITE (Earth-to-space)	
27.50-29.50	FIXED-SATELLITE (Earth-to-space)		
29.50-29.90	FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (Earth-to-space) MOBILE-SATELLITE (Earth-to-space)	FIXED-SATELLITE (Earth-to-space)
29.90-30.00	FIXED-SATELLITE (Earth-to-space) MOBILE-SATELLITE (Earth-to-space)		
37.50-38.00	FIXED-SATELLITE (space-to-Earth)		
38.00-39.50	FIXED-SATELLITE (space-to-Earth)		
39.50-40.50	FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth)		
40.50-42.50	FIXED-SATELLITE (space-to-Earth) BROADCASTING-SATELLITE		
47.20-50.20	FIXED-SATELLITE (Earth-to-space)		
50.40-51.40	FIXED-SATELLITE (Earth-to-space)		

From the Table above, this milestone-based approach does not apply to the same or other services operating below 10.7 GHz or above 51.4 GHz. It should be noted, in particular, that it does not apply to the radionavigation-satellite service (RNSS) and science services (such as the Earth exploration-satellite and space research services). It mainly applies for FSS, and also applies for 12.5-12.75 GHz (in Region 3) and 40.5-42.5 GHz for BSS; and 19.7-20.2 GHz, 29.5-30 GHz, 39.5-40.5 GHz bands in certain Regions for MSS as mentioned in the Table.

For more details, see ITU-R CR Circular 475, concerning the implementation of Resolution **35 (WRC-19)** – A milestone-based approach for the implementation of frequency assignments to space stations in a non-geostationary satellite system, available on 17 May 2021, at webpage:

https://www.itu.int/md/R00-CR-CIR-0475/en

3.7.4 Non-GSO not in FSS, MSS or BSS

For a frequency assignment to a space station in a non-GSO satellite network or system not in the FSS, MSS or BSS, there are additional considerations regarding the bringing into use that as stipulated in RR Nos. **11.44D**, **11.44D.1**, **11.44D.3** and **11.44E**.

For a network or system with "Earth" as reference body, the confirmation of bringing into use of the frequency assignment will be considered as communicated to the Bureau when the administration informs the Bureau that a space station with the capability of transmitting or receiving that frequency assignment has been deployed and maintained on one of the notified orbital plane(s) of the non-geostationary satellite network or system, irrespective of the notified number of orbital planes and satellites per orbital plane in the network or system, as described in RR No. **11.44D**.

When the notifying administration informs the Bureau of the bringing into use, it shall identify the orbital plane number corresponding to the latest notification information received and/or published by the Bureau in which the space station has been deployed to bring into use the frequency assignments, as described in RR No. **11.44D.3**.

For a network or system with a reference body that is not “Earth”, the confirmation of bringing into use of the frequency assignment will be considered as communicated to the Bureau when the administration informs the Bureau that a space station with the capability of transmitting or receiving that frequency assignment has been deployed in accordance with the notification information, as described in RR No. **11.44E**. Since information concerning the orbital planes are not required for such network or system, there is no requirement to identify and communicate the orbital plane id in which the space station has been brought into use.

3.7.5 Extension for BIU frequency assignments by the Radio Regulations Board

In cases of *force majeure* or co-passenger delay concerning the launch of the satellite, the notifying administration may submit a request to the Radio Regulations Board (RRB) to consider an extension of the regulatory time-limit for bringing into use frequency assignments.

See more details related with RRB in section 3.1.4.b).

3.8 Suspension of a recorded assignment

Wherever the use of a recorded frequency assignment to a space station is suspended for a period exceeding six months, the notifying administration shall inform the Bureau of the date on which such use was suspended. When the recorded assignment is brought back into use, the notifying administration shall, subject to the provisions of RR No. **11.49**, **11.49.1**, **11.49.2**, **11.49.3** or **11.49.4**, as applicable, so inform the Bureau, as soon as possible. The date on which the recorded assignment is brought back into use shall be not later than three years from the date on which the use of the frequency assignment was suspended, provided that the notifying administration informs the Bureau of the suspension within six months from the date on which the use was suspended. If the notifying administration informs the Bureau of the suspension more than six months after the date on which the use of the frequency assignment was suspended, this three-year time period shall be reduced. In this case, the amount by which the three-year period shall be reduced shall be equal to the amount of time that has elapsed between the end of the six-month period and the date that the Bureau is informed of the suspension. If the notifying administration informs the Bureau of the suspension more than 21 months after the date on which the use of the frequency assignment was suspended, the frequency assignment shall be cancelled.

3.9 WRC Decisions related to regulatory matters on non-GSO satellites

ITU World Radiocommunication Conference in 2019 (ITU WRC-19) considered several important regulatory aspects of using non-geostationary orbits for different services and applications.

Some concepts raised by ITU WRC-19 like short-duration missions (SDM) and milestone-based approach for deploying non-GSO systems are addressed in section 3.5.1.9 and section 3.7.3.1 above separately.

Other areas of interest addressed by ITU WRC-19 include, in particular “mega-constellations” and small satellite projects. From 2013 a steady increase was observed for submissions to ITU of non-geostationary satellite systems. This was due to emerging trends in development of so-called “mega-constellations” and small satellite projects. Both “mega-constellation” projects and small satellites demanded further improvement of international regulations of orbit-spectrum use.

3.9.1 New RR Appendix 4 data items for non-GSO satellite systems

3.9.1.1 "Constellation"

The term "constellation" was introduced for non-GSO satellite systems having more than one orbital plane where mutual relative position of each orbital plane and each satellite in its orbital plane is important. This means that for such system, continuity of coverage is established by all satellites in all orbital planes and misalignment of certain orbital parameters may result in loss of continuity of coverage for the system as a whole.

Constellations are generally designed so that the satellites have similar orbital parameters. As a consequence, any perturbations affect each satellite in approximately the same way. In this way, the geometry can be preserved without excessive station-keeping thereby reducing the fuel usage and hence increasing the life of the satellites.

Another consideration is that the phasing of each satellite in an orbital plane maintains sufficient separation to avoid collisions or interference at orbit plane intersections.

Circular orbits are popular because the satellite is at a constant altitude requiring a constant strength signal to communicate.

ITU WRC-19 added mandatory data item **A.4.b.1.a** of RR Appendix **4** – an indicator of whether the non-GSO satellite system represents a "constellation". Non-GSO systems in frequency bands subject to the provisions of RR Nos. **9.12**, **9.12A**, **22.5C**, **22.5D**, **22.5F** or **22.5L** are always considered as "constellations".

If a satellite system is deemed to be a "constellation", there are several other parameters as mandatory information to be provided with the non-GSO notice for ITU submission which includes:

- Indicator of single or multiple mutually exclusive configurations of whether all the orbital planes describe
  - a) a single configuration where all frequency assignments to the satellite system will be in use, or
  - b) multiple configurations that are mutually exclusive where a sub-set of the frequency assignments to the satellite system will be in use on one of the sub-sets of orbital parameters to be determined at the notification and recording stage of the satellite system;
  - ○ Required only for the:
    1) advance publication information for a non-geostationary-satellite system representing a constellation (item **A.4.b.1.a** of RR Appendix **4**), and
    2) coordination request for non-geostationary-satellite systems.
- the number of sub-sets of orbital characteristics that are mutually exclusive; the set orbital planes' id numbers for each orbital plane, if the orbital planes describe multiple mutually exclusive configurations:
  - ○ Required only for the:
    1) advance publication information for a non-geostationary-satellite system representing a constellation, and
    2) coordination request for non-geostationary-satellite systems
- the argument of perigee (ωp), measured in the orbital plane, in the direction of motion, from the ascending node to the perigee ($0° \leq \omega p < 360°$)
- the initial phase angle (ωi) of the i-th satellite in its orbital plane at reference time $t = 0$, measured from the point of the ascending node ($0° \leq \omega i < 360°$):
  - ○ The initial phase angle is the argument of perigee plus the true anomaly.
- the longitude of the ascending node (LAN):

  - ○ the longitude of the ascending node (θj) for the j-th orbital plane, measured counter-clockwise in the equatorial plane from the Greenwich meridian to the point where the satellite orbit makes its South-to-North crossing of the equatorial plane (0°≤ θj < 360°).
- – the right ascension of the ascending node (RAAN):
  - ○ the right ascension of the ascending node (Ωj) for the j-th orbital plane, measured counter-clockwise in the equatorial plane from the direction of the vernal equinox to the point where the satellite makes its South-to-North crossing of the equatorial plane (0°≤ Ωj <360°), determined at the reference time indicated in items **A.4.b.4.k** and **A.4.b.4.l** of the RR Appendix **4**;
  - ○ required only for space stations operating in a frequency band subject to the provisions of RR Nos. **9.12** or **9.12A**, specified in the coordination request and notification.
- – Reference date and time at which the satellite is at the location defined by the longitude of the ascending node (θj):
  - ○ All satellites in all orbital planes must use the same reference time;
  - ○ If no reference time is provided in items **A.4.b.4.k** and **A.4.b.4.l** of RR Appendix **4**, it is assumed to be *t* = 0.
- – Among above, the argument of perigee, initial phase angle and LAN are to be specified in:
  1) the advance publication information, for any frequency assignment not subject to the provisions of Section II of RR Article **9**;
  2) the coordination request, for any frequency assignment subject to the provisions of RR Nos. **9.12, 9.12A, 22.5C, 22.5D, 22.5F** or **22.5L**;
  3) the notification, in all cases.

3.9.1.2 Multiple orbital configurations

The non-GSO system design at coordination stage may not be definitive, and the parameters defining orbital characteristics may be found not optimal in the course of the coordination procedure.

For that reason, there may be a need to submit several sets of orbital characteristics for coordination with only one set to be notified and brought into use.

As mentioned in section 3.9.1.1 above, ITU WRC-19 added additional data items to allow the capture of information to describe multiple configurations.

In accordance with ITU Council Decision 482 (Modified 2020), for a coordination request of a non-GSO satellite network containing different mutually exclusive sub-sets, cost recovery charges will be separately computed for each of the sub-sets.

3.9.1.3 Sun-Synchronous Orbit

ITU WRC-19 added mandatory data item **A.4.b.4.m** of RR Appendix **4** – an indicator of whether the space station uses sun-synchronous orbit or not. Additional elements are also introduced to describe whether the satellite is passing the equator in ascending or descending trajectory, as well as the local time of the point where satellite is crossing the equator on ascending or descending trajectory. This data item is mandatory only in frequency bands not subject to the provisions of RR Nos. **9.12** or **9.12A**, i.e. subject to RR No. **9.21** only.

There are two other items **A.4.b.4.n** and **A.4.b.4.o** of RR Appendix **4** related with the Sun-synchronous orbit shown as follows:

- – **A.4.b.4.n** if the space station uses sun-synchronous orbit, indicator of whether the space station references the local time of the ascending node or the descending node, to be captured as A (ascending) or D (descending) in the notice database;

– **A.4.b.4.o** if the space station uses sun-synchronous orbit, the local time of the ascending node (or descending node, per **A.4.b.4.n)**, which is the solar local time when the space station is crossing the equatorial plane in the South-North (or North-South) direction in hours: minutes format;

These two items are optional for capturing in the notice database for ITU submission. However, if submitted, the information for both items will have to be provided.

See also section 2.3.5.

3.9.2 Regulatory provisions for Q/V bands

ITU WRC-19 addressed the development of technical, operational and regulatory provisions in the Q/V frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space), also called 50/40 GHz frequency bands, to facilitate sharing between non-GSO and GSO fixed-satellite services (FSS), broadcasting-satellite service (BSS), mobile-satellite service (MSS) systems.

ITU WRC-19 concluded that developing epfd limits based on the operational parameters for a single, specific, non-GSO system results in spectrum inefficiencies for other non-GSO systems. On the other hand, it adopted an alternative methodology that provides more flexibility on the design and operation of non-GSO systems operating in the 50/40 GHz frequency bands.

This methodology is based on the application of single-entry and aggregate limits for non-GSO in RR Article **22**, No. **22.5L** and No. **22.5M** for the fixed-satellite service in the Q/V frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space).

Non-GSO FSS shall not exceed (RR No. **22.5L**):

– a single-entry increase of 3% of the time allowance for the *C*/*N* value associated with the shortest percentage of time specified in the short-term performance objective of the generic geostationary-satellite orbit reference links; and

– a single-entry permissible allowance of at most 3% reduction in time-weighted average spectral efficiency calculated on an annual basis for the generic geostationary-satellite orbit reference links using adaptive coding and modulation.

The methodology to verify this limit is established in Resolution **770 (WRC-19)**. The approach is similar to RR Nos. **22.5C**, **22.5D**, **22.5F** but instead of using predetermined epfd limits, a set of GSO reference links is established which needs to be protected. This approach allows taking into consideration the protection in regions with different rain rates. Recommendation ITU-R S.1503 is to be used as a basis to generate interference statistics.

In addition to that, a new coordination under RR No. **9.12** is established:

– between non-GSO, FSS and MSS, in the band 39.5-40.5 GHz (space-to-Earth) (see RR No. **5.550E**);

– between non-GSO FSS systems in the bands 37.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space) (see RR No. **5.550C**).

The new coordination procedure under RR No. **9.12** established by ITU WRC-19 is not applicable to satellite systems notified to the Bureau before 23 November 2019. However, these systems are considered as affected when coordination requirements are established for satellite systems received on or after 23 November 2019.

In addition to the single-entry limits in RR No. **22.5L**, provision RR No. **22.5M** establishes aggregate limit to be respected by all non-GSO FSS systems.

Administrations shall ensure that the aggregate interference to geostationary-satellite FSS, MSS, and BSS networks caused by all non-GSO FSS systems operating in the Q/V bands does not exceed the followings, which are then used to determine the effect of the interference into each generic and supplemental GSO reference link.

– an increase of 10% of the time allowance for the *C*/*N* value associated with the shortest percentage of time specified in the short-term performance objective of the generic geostationary-satellite orbit reference links; and

– a reduction of at most 8% in a calculated annual time-weighted average spectral efficiency for the generic geostationary-satellite orbit reference links using adaptive coding and modulation.

Resolution **769 (WRC-19)** addresses the protection of GSO networks from aggregate emissions from non-GSO systems. Administrations operating or planning to operate non-GSO FSS systems will need to agree cooperatively through consultation meetings to share the aggregate interference allowance for all non-GSO FSS systems sharing the Q/V frequency bands in order to achieve the desired level of protection for GSO FSS, GSO MSS and GSO BSS networks that is stated in RR No. **22.5M**.

Resolution **769 (WRC-19)** establishes a consultation process between administrations operating non-GSO FSS to ensure that the aggregate limits are met. In the absence of agreement and in excess of the aggregate limits, each non-GSO FSS should reduce its single-entry contribution proportionally.

3.10 Regulatory challenges for small satellites

The Radio Regulations provides a framework for the use of frequency and orbit spectrum resources, with the objective of preventing the possibility of harmful interference. With the proliferation of the small satellite projects, there are various risks to be considered.

3.10.1 Delay in the commencement of regulatory procedure

It is imperative that the satellite operator initiate the regulatory process sufficiently early in the program. The minimum period between the publication of an API and the submission of a notification is now four months, and the maximum is seven years. So as long as the operator submits the API early in the project cycle, it should be able to get to the notification phase on time.

It is also possible that one can initiate the regulatory process too early in the project development, resulting in a filing that may not match the actual project requirements. However, the risk is more manageable in this case since a modification to the filing can be submitted at any time during the project lifecycle.

3.10.2 Insufficient spectrum to accommodate all operations

There is an insatiable demand for spectrum and given that spectrum is a scarce resource that is also heavily demanded by many radiocommunication services, there may be a time when the current spectrum allocated for these space services is insufficient for the number of satellites and satellite systems that are planned to be launched. However, the adequacy of available spectrum compared to spectrum requirements for many radio applications, including those provided by small satellites, is regularly reviewed by ITU World Radiocommunication Conferences (WRC). Operators of small satellites who foresee such a scarcity of spectrum should consult their national regulator in order to raise this issue during a future ITU World Radiocommunication Conference.

At the same time, some new rules adopted by a WRC might not be ready for immediate implementation. It may need relevant software tools to be developed, or additional detailed studies by ITU-R Study Groups or the RRB.

3.10.3 Non-compliant frequency bands

There is a growing tendency in satellite network filings of non-GSO satellite systems to employ frequency bands that are not allocated for the services that they intended to deploy. This poses a lot of risks to operators providing incumbent services who may experience harmful interference from these new satellite networks. Such practices are therefore <u>not</u> encouraged by the ITU Bureau.

As described in section 3.6, when notifying the use of frequency assignments to be operated under RR No. **4.4**, the notifying administration is required to determine:

– that the intended use of the frequency assignment to the station under RR No. **4.4** will not cause harmful interference into the stations of other administrations operating in conformity with the Radio Regulations,

– what measures needed to take to comply with the requirement to immediately eliminate harmful interference **pursuant** to ITU RR No. **8.5**, and

– such notifying administration cannot claim protection from any harmful interference that may be caused by frequency assignments operated in accordance with the ITU Radio Regulations.

To mitigate the risk of harmful interference, all administrations shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations or the other provisions of the ITU Radio Regulations.

Finally, it should be noted that satellite operators using frequencies under RR No. **4.4** are likely to face added difficulties to obtain national licenses to operate their satellite system and associated earth stations.

3.10.4 Potential interference from incomplete coordination

For those satellite networks using frequency bands not subject to coordination under Section II of RR Article **9**, they should carry out the process of resolution of difficulties with other administrations who have submitted comments. And since the completion of the procedure of RR No. **9.3** is not required to be verified at the time of the submission of notification to the ITU Bureau, there is the risk that some administrations may not undertake the procedure of resolution of difficulties seriously.

If this process is not properly implemented, there will be the risk that when the satellite is launched, there might be a possibility of causing harmful interference to other satellite networks already in operation.

3.10.5 Lack of adherence to international regulations

The barriers to entry for new players entering the small satellite industry have been decreasing rapidly over the recent years. With disruptive technology, there is always the danger of new players totally or to some extent disregarding the existing regulatory framework. In some cases, these may be due to their ignorance of the regulatory procedures, and they may not even be familiar with the role of ITU and its Radio Regulations.

Such disregard or unawareness of international regulations is likely to lead satellite operators into difficulties to obtain appropriate national authorizations to deliver their services.

For example, one of the main problems which small amateur satellite operators and academia (universities, researching institutions) are facing is a lack of the knowledge and understanding of international obligations relating to shared orbit-spectrum use. When developing their satellite projects, sometimes no consideration is given to the need to follow and comply with the ITU Radio Regulations and IARU provisions (see section 3.5.1.10 for more details).

Even though the API and Notification procedures are applicable to small or experimental satellite projects, and they are relatively simple, several reasons are identified why it may be cumbersome for small players to follow the procedures:

– Satellite duration mission is short, and the regulatory process would take more time than duration of the mission itself.

– Limited resources and knowledge to start the notification process.

– Orbital characteristics are not defined in advance and would depend on launcher/primary payload orbit destination.

While understanding and recognizing such difficulties, it is important that any interference potential is minimized through the application of the procedures of the Radio Regulations.

Satellite operators shall submit notices for the satellite network/space station through their administration to the ITU Bureau to get international recognition and protection in advance before launching, even though it is for experimental purpose.

Member States shall rely primarily on official data published by the ITU based on internationally recognized and transparent methodologies, to cooperate in sharing expertise and resources in the various regions to avoid harmful interference between radio stations of different countries.

The use of frequency assignments of any space services with the associated orbital characteristics, has to be registered in accordance with the relevant provisions of the ITU Radio Regulations, and shall be kept up to date in the ITU Master International Frequency Register (MIFR), in such a manner as to be identifiable by others with a view to designing satellite systems, amending technical parameters and eliminating potential interferences, as appropriate, ensuring that the whole world can continue to use and benefit from space services for the long term.

3.10.6 Differing national regulatory frameworks

ITU Member States have the authority to establish their own national regulations governing the utilization of frequency spectrum, while ensuring compliance with the provisions of the ITU Radio Regulations. The State must ensure that the radio-frequency spectrum, which is in the State's public domain, will be managed rationally, efficiently, economically and equitably with adequate security, monitoring system and free of interference within their own borders, so as to be of the greatest benefit to the entire population.

As the result of the State's right to manage the spectrum, authorized spectrum users derive the benefits of the right and associated obligations to access and use the spectrum. There is a guidance on the regulatory framework for national spectrum management in Report ITU-R SM.2093.

For a satellite network, in addition having an official registration with the ITU, every transmitting station within that network is required to obtain licenses from the national administrations in order to operate the service within the countries concerned, in accordance with the RR Article **18**. The licensing conditions may vary from country to country.

With the varying national regulations across different countries, which may sometimes be not sufficiently transparent nor easily accessible publicly, it can present a considerable challenge to satellite operators, especially those who wish to offer space services beyond their national territories, in particular on a worldwide basis.

To overcome this risk, there should be enhanced communications, improved cooperation between countries. Countries may get together to establish a common regional or international platform to achieve this objective.

To help national regulators, the ITU has always supported the dissemination of administrative "best practices" as a standard way of complying with legal or regulatory requirements. These practices have been shown to expand economic opportunities, to close the digital divide, and to provide more service options at affordable prices. For more details, please read the ITU webpage for the Global Symposium for Regulators (GSR), available at:

https://www.itu.int/en/ITU-D/Conferences/GSR/Pages/GSR.aspx

More information, including the (GSR) 2021 Best Practice Guidelines, may be found on the ITU webpage for the Global Symposium for Regulators (GSR), available at https://www.itu.int/en/ITU-D/Conferences/GSR/2021/Documents/GSR-21_Best-Practice-Guidelines_FINAL_E_V2.pdf.

The following part is presenting a non-exhaustive list of practices, some already implemented and others still under discussions with the international multi-stakeholder community as well as with national and foreign regulators, as suggested in the (GSR) 2021 Best Practice Guidelines:

Best practices for national regulators and policy makers

– Adhere to the principles of the ITU Constitution, Convention, and Radio Regulations when promulgating national policies, regulations, legislation, or licensing frameworks;

– Enhance the effectiveness of regulation, by considering simplifying or deregulating areas that no longer require extensive regulatory oversight and reconfigure regulatory capacity to address gaps and new areas. In this context, some regulators already apply the above principles for some services and associated spectrum (e.g. FCC Blanket Licensing of Satellite Earth Stations in the 17.7-20.2 GHz and 27.5-30.0 GHz Frequency Bands; ECC Decision 13(01) on the use, free circulation, and exemption from individual licensing of Earth stations on mobile platforms (ESOMPs) in the frequency bands available for use by uncoordinated FSS Earth stations within the ranges 17.3-20.2 GHz and 27.5-30.0 GHz.);
– Encourage the deployment of innovative and competitive technologies and service models;
– Promulgate overt policies to close the digital divide and have universal service;
– Maintain technology-neutral goals and policies by stimulating and supporting transparent and complementary use of terrestrial and space system for all types of applications;
– Cooperate and build a common understanding at the international level on issues surrounding anti-competitive behaviours and converge towards a certain level of regional harmonization in view of spearheading innovation and investment in digital;
– Publicize policies to promote the social inclusion;
– Reinforce regulatory agility and transparency by providing a clear rationale to and involvement of the public for how and why regulatory decisions are made;
– Write neutral regulations that encourage service quality;
– Facilitate service rollouts and fair coexistence among all competitors;
– Work closely with the international multi-stakeholder community as well as with other national and foreign regulators on transboundary issues.

Best practices for spectrum policy and licensing

– Adherence to ITU Radio Regulations and relevant coordination procedures when creating domestic regulations;
– Regarding spectrum access, especially for space-based technologies, to ensure that changes to spectrum allocations/licensing are handled in a timely manner as such changes cannot be technologically and operationally easily adapted in the short- to medium-term;
– Fairness regarding spectrum access: incumbent users of spectrum allocations need time to switch to different spectrum. Any changes must accommodate time for studies done by relevant groups (i.e. regulators, academia, operators including public consultations, as required);
– To foster harmonization of international and regional spectrum allocations to create economies of scale, roaming and interoperability.

CHAPTER 4

4 Type of services and spectrum

The ITU Radio Regulations (RR)[4] regulates radiocommunication services and the utilisation of radio frequencies and satellite orbits. Article **5** of RR has the Table of Frequency Allocations listing the frequency bands allocated to the different services either worldwide or regionally. Different small satellites, including short-duration mission satellites shall use different frequency bands due to the different radiocommunication services which the satellite is planned to provide.

It is important to note that each frequency band is allocated to specific radiocommunication services under certain conditions. Therefore, before opting for and assigning a specific frequency band to a small satellite, it is crucial to ensure that all the applications and operational requirements associated with the frequency bands are fully met. This ensures that the satellite's usage of the frequency band aligns with the specified regulations.

To determine whether a frequency band is allocated for a specific service, kindly consult the RR5 Table of Frequency Allocations (TFA) Software (see section 3.5.5.2).

The ITU Radio Regulations do not consider the size or mass of satellites to determine the spectrum that can be used.

It is important for administrations and operators of a small satellite to ensure that the nature of the intended service for the satellite network fits within the definition of the service as defined in Article **1** of the Radio Regulations. Small satellites have been launched or proposed that use almost all of the spectrum regions employed by larger satellites: radar, microwave, infrared, optical and Ultraviolet (UV). While their usage of the extremes of the frequency range has been limited to date, in some cases such as high frequency microwaves the planned usage by small satellites precedes that of instruments on large satellites. To put it another way, there is no fundamental difference in services and spectrum due to the size of the satellites, whether small or large.

Small satellites are being used for a wide variety of applications, including remote sensing, space weather research, upper atmosphere research, astronomy, communications, technology demonstration and education, and therefore may operate under various radiocommunication services and under various frequency bands that will not be listed in that section.

However, among the small satellites category there are non-GSO networks or systems with a short-duration mission as specified in Resolution **32 (WRC-19)** of the Radio Regulation. When assigning frequencies to such non-GSO network or system with a short-duration mission, administrations are invited to avoid heavily used frequency bands. See more details in section 3.5.1.9.

It is important to note that certain radiocommunication services defined in Article **1** of the Radio Regulation are composed of multiple sub-services. For submission to the Bureau, it is necessary to use the symbols for the classes of station as defined in the Preface (see Table 3). The class of station of the space station of the group must be in alignment with the class of station of the associated earth station.

For instance, the mobile-satellite service comprises the land mobile-satellite service, aeronautical mobile-satellite service, maritime mobile-satellite service. The aeronautical mobile-satellite service further encompasses the aeronautical mobile-satellite (R) service and aeronautical mobile-satellite (OR) service. This indicates that certain class of stations such as EI, consist of various subclasses, including EU, EJ and EG. Moreover, EJ is comprised of E5 and E6 subclasses. To determine the appropriate pairing in detail, please refer to reference Tables 3 and 4 in the Preface.

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[4] At the time of development of this Handbook, the current version of the ITU Radio Regulations is Edition 2020 (Source: https://www.itu.int/pub/R-REG-RR/en).

4.1 Space operation service

4.1.1 Space operation service and its functions

According to the terminology and technical characteristics of Chapter I of Radio Regulations, space operation service is a radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space telecommand.

According to RR No. **1.23**, the space operation functions will normally be provided with the service(s) in which the space station is operating. This means that space operations can be assigned to the frequency bands allocated to those space service(s), including but not limited to the space operation service, in conformity with the Table of Frequency Allocations of RR Article **5**.

In accordance with the Rules of Procedure relating to RR No. **1.23**, in the RR No. **11.31** examinations, notices concerned with space operation functions will be considered in conformity with the Table of Frequency Allocations (favourable finding) in the case where the assigned frequency (and the assigned frequency band) lies in a frequency band allocated to the:

– space operation service, or

– the main service in which the space station is operating (e.g. fixed-satellite service (FSS), broadcasting-satellite service (BSS), mobile-satellite service (MSS)).

In the case where the assigned frequency concerning space operation functions lies in a frequency band allocated to a service in which the space station has no operating function and is not allocated to the space operation service, RR No. **11.31** finding will be unfavourable.

For recording into the ITU Master International Frequency Register (MIFR) purpose, if there is an allocation to the space operation service for the frequency bands concerned in accordance with the Table of Frequency Allocations of RR Article **5**, the class of station shall be captured as ET for space stations and TT for earth stations. When the Table does not contain an allocation to the space operation service, the space operation functions ED, EK, ER for space stations and TD, TK, TR for earth stations shall be captured accordingly. It should be ensured that there is other main space service(s) allocated in the same band and such main service is submitted for the same satellite network in order to comply with the Rules of Procedure relating to RR No. **1.23** as mentioned above.

The detail descriptions of the class of stations are as indicated in the Table below.

Symbol of class of station for space station	Symbol of class of station for earth station	Description of the class of station	General direction
ET	TT	space operation service	Earth-to-space, space-to-Earth space-to-space
ED	TD	space telecommand function	Earth-to-space space-to-space
EK	TK	space tracking function	Earth-to-space, space-to-Earth space-to-space
ER	TR	space telemetering function	space-to-Earth space-to-space

4.1.2 RR No. 22.1

Under RR No. **22.1**, space stations shall be fitted with devices to ensure immediate cessation of their radio emissions by telecommand, whenever such cessation is required under the provisions of these Regulations. It is therefore highly recommended to have the space operation service (class of station ET) or the telecommand function (class of station ED), when appropriate, to be captured in the Earth-to-space or space-to-space direction for any notice submitted for a satellite network, in order to ensure that any harmful interference caused by emissions from the space station can be terminated immediately.

4.1.3 Frequency allocations for space operations

The realization of space operation functions of satellite systems can be divided into two ways: space-based and ground-based.

The frequency assignments used for space-based Telemetry, Tracking and Command (TT&C) system are the frequency bands allocated to the inter-satellite service or in the space-to-space direction for relative services.

The frequency bands allocated to the space operation service which can be used for ground-based TT&C system in the Earth-to-space and space-to-Earth directions, as well as the use for inter-satellite links in the space-to-space direction. They may be suitable for space operations of small satellites, noting that TT&C functions can also use frequency bands allocated to other main space services as mentioned in section 4.1.1.

It should be noted that, in the frequency bands allocated to the space operation service, there may sometimes be footnotes limiting the utilization scenarios of certain satellite networks. Examples are as follows:

– 137.025-138 MHz (space-to-Earth) and 148-149.9 MHz (Earth-to-space) frequency bands may be assigned to the space operation service for short-duration mission satellite networks in accordance with Resolution **32 (WRC-19)**;

– the use of 7 190-7 250 MHz (Earth-to-space) by the Earth exploration-satellite service shall be limited to tracking, telemetry and command for the operation of spacecraft in accordance with RR No. **5.460A**.

4.1.4 The use of the bands 2 025-2 110 MHz (Earth-to-space) and 2 200-2 290 MHz (space-to-Earth) for space operation

ITU-R Circular Letter CR/420, titled "Application of No. **9.3** of the Radio Regulations in the bands 2 025-2 110 MHz (Earth-to-space) and 2 200-2 290 MHz (space-to-Earth)", issued by the Bureau on 31 August 2017, was triggered by the fact that an increasing number of submissions, especially for Advance Publication Information under RR No. **9.1**, contain generic information. In particular, there was a trend to submit the whole S-band (2 025-2 110 MHz and 2 200-2 290 MHz) allocated to the space operation service in the notice of satellite network. In addition, some submissions declared the whole Earth surface as a service area and declared no specific earth stations (only typical ones) for the space operation service.

It is understandable that it may be necessary to submit a wider frequency range at the API stage due to anticipated difficulties in arriving at final agreed operating frequencies based on the coordination results. However, for those "generic" APIs with large frequency range in the S-band for TT&C, it creates problems for the consultation process between Administrations under RR Nos. **9.3** and **9.4**, by making it longer and more difficult. As such, it impedes the ability of ITU Member States to effectively coordinate their spectrum requirements.

The information provided for such operation at the API stage should not be based on generic parameters, especially, filing for the entire band should be avoided. In addition, it is suggested to submit realistic planned carrier frequencies in the API, with the possibility to modify them within the submitted frequency range during the coordination process under RR Nos. **9.3** and **9.4**; to avoid submitting global service area with typical earth stations, but instead to identify associated specific TT&C earth stations.

Administrations are encouraged to perform pre-coordination process for S-band TT&C prior to the submission of the ITU filing to the Bureau, to narrow the frequency ranges of S-band for the space operation service as much as possible, to cooperate and exchange any additional more precise information, to resolve any difficulties if so requested.

4.2 Amateur-satellite service

According to the terminology and technical characteristics of Chapter I of Radio Regulations, amateur-satellite service is defined in No. **1.57** of the RR as a radiocommunication service using space stations on earth satellites for the purpose of self-training, intercommunication and technical investigations carries out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

The Table of Frequency Allocations in Article **5** of the Radio Regulations shows a number of frequency bands as being allocated to stations in the amateur-satellite service with a primary or secondary service status (see RR Nos. **5.23-5.43A**) and a number of other frequency bands with a specific status as indicated in a footnote to the Table (e.g. RR No. **5.282**). Administrations should ensure that the choice of frequency bands for amateur-satellite networks is in conformity with the Table of Frequency Allocations in Article **5** of the Radio Regulations.

An example of the frequency allocation for amateur-satellite service in the RR is shown below, including those allocated under RR No. **5.282**, which may be suitable for operations of small satellites on this purpose.

<table>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">28-29.7 MHz AMATEUR
AMATEUR-SATELLITE</td></tr>
<tr><td colspan="3">144-146 MHz AMATEUR
AMATEUR-SATELLITE
5.216</td></tr>
<tr><td>435-438 MHz
AMATEUR
RADIOLOCATION
Earth exploration-satellite (active) 5.279A

5.138 5.271 5.276 5.277 5.280 5.281 5.282</td><td colspan="2">435-438 MHz
RADIOLOCATION
Amateur
Earth exploration-satellite (active) 5.279A

5.271 5.276 5.278 5.279 5.281 5.282</td></tr>
<tr><td colspan="3">1 260-1 270 MHz
EARTH EXPLORATION-SATELLITE (active)
RADIOLOCATION
RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space)
5.328B 5.329 5.329A
SPACE RESEARCH (active)
Amateur

5.282 5.330 5.331 5.332 5.335 5.335A</td></tr>
</table>

Amateur satellites operate around the world, and hence, amateur satellites can fully function only through the global frequency coordination. Uncoordinated satellites may cause harmful interferences to and receive interferences from other amateur radio stations around the world, which may lead to the satellites working improperly.

Within the amateur radio community, amateur radio operators usually conduct the communication and coordination in terms of the use of amateur satellite spectrum spontaneously. It is an act of self-regulation and is widely recognized. The International Amateur Radio Union (IARU) plays an effective role in this regard.

Different from the way in which the coordination status of other radio services is determined, amateur radio operators have the right to use the frequencies allocated to amateur and amateur-satellite services on an equal basis if they meet the requirements of their operating license class. The operating license class of an amateur radio operator is usually determined by the administration, after the operator passing certain examination.

See section 3.5.1.10 for more details.

4.3 Earth exploration-satellite service

According to the terminology and technical characteristics of Chapter I of Radio Regulations, Earth exploration-satellite service (EESS), is defined in RR No. **1.51** as a radiocommunication service between Earth stations and one or more space stations, which may include links between space stations, in which:

– information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active or passive sensors on Earth satellites;
– similar information is collected from airborne or Earth-based platforms;
– such information may be distributed to earth stations within the system concerned;
– platform interrogation may be included.

Earth exploration-satellite systems are used to gather data about the Earth and its natural phenomena. These satellites use active and/or passive sensors onboard the spacecraft to obtain data on the Earth's land, sea, and atmosphere to study and monitor the Earth's climate and environment, among many other related scientific applications.

Frequency bands allocated to Earth exploration-satellite service typically used for remote sensing, which may be suitable for operations of small satellites. TT&C for remote sensing satellite systems could be carried out by using the frequency allocated to the space operation service or the frequency allocated to the EESS.

Nowadays satellite observations include signals and spectrum that were not originally intended for this purpose; for example, Global Navigation Satellite System (GNSS) signals (limb sounding via occultation, or sea surface data via reflectometry) and monitoring of maritime Automatic Identification Systems (AIS) from ships in remote waters. These are passive instruments, with data backhaul via conventional downlink services.

Table 10 lists the frequency bands allocated to the Earth exploration-satellite service for which it is subject to coordination procedure under Section II of RR Article **9** (see section 3.5.2).

TABLE 10

Frequency bands allocated to the Earth exploration-satellite service

frequency from	frequency to	Services	emi_rcp	class of station	Subject to coordination under provision	RR footnote
137	137.025	meteorological-satellite (s-to-e)	E	EM	9.11A	
137.175	137.825	meteorological-satellite (s-to-e)	E	EM	9.11A	
400.15	401	meteorological-satellite (s-to-e)	E	EM	9.11A	
1260	1300	Earth exploration-satellite (active)	E	**E3**	9.11A	
1670	1675	meteorological-satellite (s-to-e)	E	EM	9.11A	
460	470	meteorological-satellite (s-to-e)	E	EM	9.21	**5.290**
1770	1790	meteorological-satellite		EM	9.21	**5.387**
9200	9300	Earth exploration-satellite (active)		**E3**	9.21	**5.474A**
9900	10400	Earth exploration-satellite (active)		**E3**	9.21	**5.474A**

4.4 Meteorological-satellite service

According to the terminology and technical characteristics of Chapter I of Radio Regulations, meteorological-satellite service (MetSat) is defined in RR No. **1.52** of the RR as "an earth exploration-satellite service for meteorological purposes".

Frequency bands allocated to MetSat service typical used for climate monitoring, which may be suitable for operations of small satellites.

Earth exploration-satellites used for weather-related purposes are known as meteorological-satellites (MetSats). MetSats can operate within the Earth exploration-satellite service or in their own more specialized service known as the meteorological-satellite service. MetSat system commonly collect a variety of data with visible and infrared imagers as well as with passive and active sensing instruments using also microwave frequencies allocated to that purpose.

4.5 Space research service

According to the terminology and technical characteristics of Chapter I of Radio Regulations, space research service is defined in RR No. **1.55** as a radiocommunication service in which spacecraft or other objects in space are used for scientific or technological research purposes.

Space research service is often targeted on key technologies for space science satellites and application, key technologies of payloads, ground calibrations as well as short-time flight demonstrations.

Small satellites performing space research service could use one or several of the following radio services:

– Space operation
– Space research
– Space research (deep space)
– Space research (active)
– Space research (passive).

Smaller satellites have been used in space research. Quite often this is still happening in coordination with larger satellites as these missions are often very challenging with respect to the needed resources for reaching the exploration objectives and communicating the results back to Earth. Just as for Earth observation optical or radar sensing missions can also be performed by small satellites – this also applies for space weather missions. An example is from the National Aeronautics and Space Administration (NASA) of the U.S. federal government, NASA's Double Asteroid Redirection Test (DART) mission, a demonstration of kinetic impactor technology, impacting an asteroid to adjust its speed and path, where the main (larger) spacecraft will crash into the moon of the Didymos asteroid with the Light Italian CubeSat for Imaging of Asteroids (LICIA) observing the impact and sending back images directly to Earth.

4.6 Fixed-satellite service / Mobile-satellite service

There has been an increasing number of small satellites telecommunication space missions using fixed-satellite service (FSS) and mobile-satellite service (MSS).

According to the terminology and technical characteristics of Chapter I of Radio Regulations, fixed-satellite service is defined in No. **1.21** of the RR as a radiocommunication service between earth stations at given positions when one or more satellites are used. Mobile-satellite service is defined in No. **1.25** of the RR as a radiocommunication service between mobile earth stations and one or more space stations, or between space stations used by this service, or between mobile earth stations by means of one or more space stations.

For fixed-satellite service, the earth stations are fixed in a given position, and they can operate with both GSO and Non-GSO satellites. For mobile-satellite service, the earth stations are mobile, and they can similarly operate with both GSO and Non-GSO satellites.

4.7 Other services

New generations of small satellites are starting to create a demand for new services and spectrum in the future, mainly around the development of in-orbit servicing. This includes satellites tasked with changing orbits, chasing, rendezvous, inspection, capture, manipulation and release or recovery/demise of client satellites in order to support debris removal services, life extension services, refuelling, repair and upgrade, assembly etc.

The class of "space tugs", a type of spacecraft used to transfer spaceborne cargo from one point to another point in space, across different orbits with different energy characteristics, is not adequately studied in ITU-R Study Groups to date, even if they might use the same spectrum for the same functions e.g. TT&C, orbit determination, data upload/download, as other satellites. The implications for frequency co-ordination with other services during orbit transfers has yet to be addressed. An additional class of observation services that fall naturally within the small satellites arena are on-orbit observations of space objects in support of identification and tracking – often known as Space Situational Awareness (SSA) although other acronyms are also used. An offshoot of this is detection of Near Earth Objects (NEOs), i.e. incoming asteroids, for Planetary Defence. Sensors would be infrared, optical and potentially radar; while some would be hosted payloads on larger satellites, it is likely that over time there would be a population of small satellites in the main orbital regions that are looking across the orbits to detect, characterise and track the population of other objects. These satellites would use the same spectrum bands and services (uplink, downlink, TT&C) as other observation satellites; they may also use inter-satellite links for more rapid exchange of data around a global network and so reduce information latency at user processing centres.

CHAPTER 5

5 Types of missions

5.1 Scientific missions

Scientific missions related to space science research satellites involve the research in astrophysics, heliospheric physics, planetary science, space geoscience, space astronomy, space life, and other exploration and research fields. Scientific missions include not only the satellites launched into orbit for exploration, but also some advanced research of space science missions and payloads, which is targeted for the advanced research on key technologies for future space science satellites and application, including innovative concepts of future space science missions, key technologies of payloads, ground calibrations as well as short-time flight demonstrations.

Space science is the science that takes space vehicles as the main platform to study the physical, astronomical, chemical, life and other natural phenomena and laws that occur in solar terrestrial space, interplanetary space and even the whole universe. Space science carries out the frontier exploration of the origin and evolution of the universe and life and the basic physical laws. Due to the experimental nature of space science satellite missions and the contingency of space science exploration, satellites for scientific missions often carry various detection payloads, and the amount of scientific detection data transmitted to the Earth is large. Therefore, scientific missions will occupy a wide frequency range. In order to avoid frequency interference from/to adjacent frequency services, space science satellites are allowed to adopt more advanced modulation methods to improve the efficiency of frequency assignments utilization, suppress out of band spurious, and improve in-orbit data processing capacity as much as possible.

Numerous scientific missions have been considered or developed using small satellites, balancing on one hand their limited capabilities due to their small size and, on the other hand, the involved cost which is often significantly cheaper than conventional satellites.

A strong motivation to consider small satellites as an alternative solution to conventional satellites comes from the scientific community itself as such small sat based missions are seen as a more accessible opportunity to be nominated as mission Principal Investigator as, for the same total budget, more missions can thus be developed and operated; and/or that the time to develop, build and launch the mission can be significantly reduced (thereby getting science data back much sooner).

Due to their lower per-unit cost and the increasing reduction in launch cost, more small satellites can be launched in support of the same mission than large ones, meaning for instance that, for Earth science missions operated in LEO, it is possible to balance potentially lower payload performance with higher temporal resolution, i.e. faster revisit over the same point on the ground. This allows to build up an aggregated picture of large areas, enabling both region- and local- scale insights such as change detection and shorter time to alert.

Another attractive aspect of small satellites-based missions is that, thanks to their lower cost, formation flying clusters can be more easily considered. This capacity maybe an enabler for some missions for which large observation baselines or large (but sparse) synthetic pupils are needed.

As an illustration, the following overview provides examples of some of the most relevant science domains that can be addressed by small satellites:

– Earth science, encompassing thematic such as Earth magnetic field monitoring, atmosphere limb and ionosphere spectral imagery e.g. in the Ultraviolet (UV) domain, Terrestrial Gamma Ray Bursts detection and monitoring, Transient Luminescent Events observation, "shooting stars" detection, gravity field mapping using large formation flying clusters, passive RF imagery also based on small satellites clusters flying in close proximity so as to provide attractive interferometric baseline and resulting ground resolution.

– Space weather missions, for instance aimed at improving radiative environment models via in-situ measurements of observables such as particle energy spectral densities, local plasma characteristics or local magnetic field. Other examples may include missions dedicated to ionosphere Total Electron Content (TEC) tomographic measurement using radiofrequencies sources, ground or space based, emitting in various frequencies affected by TEC. Such measurements may underpin significant improvements to operational models of missions such as GNSS or space telecommunications in L-band.

– Helio-physics missions including for instance X-ray solar eruptions monitoring using miniaturized detectors compatible with the payload volumes available to small satellites, Ultraviolet (UV) spectroscopic observation, and Corona Mass Ejections (CMEs) observation in the visible spectrum.

– Astronomy can also benefit from small satellites based missions, typically for observation domains for which the observation wavelengths of interest are compatible with the very limited payload volume. For instance, "hard" X-rays astronomy, gamma ray bursts detection, UV imagery and/or spectroscopy. Large constellation based missions, thanks to small satellites low cost, may also enable large baseline missions for low frequency radio observation, e.g. for frequencies below 10 MHz blocked by Earth atmosphere and for which the Orbiting Low Frequency Array (OLFAR) mission concept was formulated.

See section 9.1 for satellite networks or systems in the scientific missions.

5.2 Educational missions

Small satellites for educational missions provide an opportunity for students or other civilians to learn and do the research on satellite technology, satellite applications as well as the subject of geophysics, space physics and astronomy, etc. Moreover, small satellites for education missions could present scientific and technological knowledge to the public, demonstrating the extraordinary charm of aerospace and radio communication technology and encouraging the public to study on science and explore the unknown.

In most cases, small satellites for education mission are the satellites providing specific service with the short development cycle and short operational lifetime. The satellite systems for education mission consist of one satellite or a few satellites. The projects teams are usually small in size and the investment in the project are limited. Moreover, the projects are usually carried out for non-profit purposes. The owners and operators of small satellite systems are schools, universities and other educational institutions in most times. Besides, some small satellites for education missions are also owned and operated by amateur radio organizations and radio amateurs.

Small satellites for education missions may operate under various radiocommunication services, including space operation service, Earth exploration-satellite service, meteorological service and space research service. The orbits of these satellites usually depend on the needs of various services. Most small satellites utilize low-Earth orbits (LEO) with the altitude of several hundred kilometres. In addition, a few satellites utilize the highly elliptical orbits (HEO) with the perigee of several thousand kilometres and apogee of about 40 000 kilometres.

Moreover, these small satellites shall comply with the conditions for the use of frequencies that is allocated to the service within which they operate. Small satellites for education missions are encouraged to avoid utilizing the heavily used frequency bands to minimize the needs of resolving interference with other satellite networks.

The success of the standard CubeSat unit resulted in development of about a thousand CubeSat-based student programmes so far, conducted by nearly all universities in the world, and even high schools for education purpose. These missions address mainly the 1U to 3U CubeSat segment and mostly do not include a propulsion system. Since a significant part of them have been released from the International Space Station (ISS), their resulting lifetime do usually not exceed more than one year due to rapid altitude erosion.

See section 9.2 for satellite networks or systems in the education missions.

5.3 Experimental missions

Small satellites can be used for the experiments and demonstrations of space technology, enabling the new concepts, technologies, designs and products to be verified in the real space environment, and playing an important role in promoting the rapid development of space technology.

Small satellites may be an attractive vector for in orbit demonstration of concepts and/or technologies. Basically, in space demonstrations can be preferred to ground-based validation and/or qualification when:

– The complexity and/or accuracy of the environment relevant for the targeted mission is too hard to simulate in a representative manner. For instance, for RF surveillance missions such as aircrafts Automatic Dependent Surveillance – Broadcast (ADS-B) or sea vessels Automatic Identification Systems (AIS) monitoring, for which emitters density and Radio frequency (RF) properties are difficult to representatively simulate. This might be the case also for new Earth observation concepts for which models may be poorly accurate, for instance very accurate Earth or Sun radiative spectrum.
– The mission concept requires sustained micro gravity durations that cannot be achieved by other means such as free fall towers, 0 g aircraft flights or sounding rockets. Known examples include pharmaceutical drugs elaboration or manufacturing of particular optical fibres.
– Technology qualification against radiation environment is cheaper, easier and/or more representatively achieved through in orbit testing rather than going through sophisticated and expansive analysis and on ground testing using dedicated facilities. This is particularly relevant for space environment qualification of attractive commercial off-the-shelf (COTS) electronical components, usually developed by large volume markets such as automotive or consumer electronics that can bring significant capacity leaps for space missions that could embed such components.

Nanosats are particularly relevant to cover the first case. Their attractiveness for the two other cases is more questionable:

– The International Space Station is very often a more attractive platform for sustained micro gravity duration experiments which also offers appreciated risk mitigation capabilities as they are conducted by the ISS crew.
– Nanosats usually fly at low altitude and have a rather short lifetime compared to conventional operational missions. Therefore, their attractiveness for radiation qualification purposes is limited as the radiation spectrum and cumulated radiation exposure are lower than those actually expected according to qualification requirements.

As an illustration of experimental demonstrations worth being conducted on board a small satellite, some examples may include very low thrust propulsion systems demonstration, laser communications, Earth infra-red angular sensor for AOCS in orbit performance evaluation, ADS-B or AIS RF payloads in real RF environment performance assessment.

See section 9.3 for satellite networks or systems in the experimental missions.

5.4 Amateur-satellite missions

Amateur-satellite missions use satellites "self-training and communication", with no pecuniary interest and could be categorised under three broad types:

- Amateur missions that allow for two-way communications including transponders and repeaters among others.
- Amateur missions that might provide useful technology for future amateur missions.
- Amateur-educational missions where there is an amateur interest, not necessarily involving two-way communications, exposing students in Science, Technology, Engineering and Mathematics (STEM) projects with the aim to encourage these students to enter a career in a STEM topic.

Key points are that the mission must be related to *radio technique*, and that the mission will not offer a pecuniary interest. The mission must relate in some way to the advancement and understanding of the technical and operational aspects of radio and satellite systems and are relevant to the amateur and amateur-satellite services. This excludes more general science payloads within missions like earth-observation, biology, wildlife tracking, geology, etc. which should be operated under other radiocommunication services because they are not related to *radio technique*. Furthermore, any mission that proposes any sort of pecuniary (monetary or financial) return is specifically excluded from amateur and amateur-satellite service bands.

Radio technique means having a reasonable possibility of application to radio communication systems operated in the amateur satellite service. Missions that are classified as amateur-educational might study aspects within the following topics:

- Radiocommunication modulation methods and transmission protocols
- Attitude determination and control systems
- Command and control procedures
- Radio receivers, transmitters and transponders
- Satellite antennas systems
- Sensors to study spacecraft performance
- Power controls and supplies for use in space
- Spacecraft computers, memory, operating systems, programs and related items
- Radiation effects on electronic components
- Radio wave propagation
- Meteor trail reflection and other sporadic propagation mechanisms
- Measurements of the orbital environment
- Solar panel technologies
- Software Defined Radios
- Radiation tolerant electronics
- In-orbit spacecraft software updates.

Technology developed and information acquired by missions studying the above topic have direct relevance to the advancement of the amateur-satellite service.

Satellite missions that are purely amateur include:

- Linear transponders or FM repeaters for voice or data communications
- Digital voice repeaters
- Transmission of images using appropriate analogue or digital standards
- Amateur Packet Reporting System (APRS) transmissions
- Microwave beacons
- Digital Store-and-forward bulletin boards and global messaging systems.

Transmission of telemetry alone and without additional mission components is generally an insufficient reason for a mission to be considered for operation within frequency bands allocated to the amateur-satellite service.

See section 9.4 for satellite networks or systems in the amateur-satellite missions.

5.5 Commercial missions

Following the emergence of the CubeSat standard, several start up and small companies have started to take benefits of the attractive low cost of the nanosat concept to develop commercial services for applications compatible with their limited capacities but taking as much advantage as possible from the constellation dimension. The most noticeable commercial mission categories can be roughly segmented into the following:

– Earth imagery missions, based on passive optical or active Synthetic Aperture Radar (SAR) missions, providing modest geometric or radiometric resolutions but a very attractive temporal revisit due to significant constellation size effects, ranging from tens to hundreds of smallsats dedicated to the service. The probably most well-known examples are Planet, having launched hundreds of 3U optical observation CubeSat and IceEye, operating a fleet of about 10 nano SAR satellites.

– Low data rate communications missions, typically dedicated to the Internet of Things (IoT) market, not very demanding in terms of telecommunication payload capacities nor requiring a permanent coverage, for which nanosats are an attractive solution. The Kineis constellation about to be deployed is a typical example of such commercial low data rate mission.

– Radio Frequency (RF) intelligence missions, which essentially consist in observing anthropogenous RF signals for applications such as emitter's location, RF signal heatmap for a given band of interest, local RF regulations monitoring and enforcement, signal demodulation and decoding and also defence usages. Most frequent applications are AIS or ADS-B signals observation from space for respective tracking of sea vessels and commercial aircrafts located outside ground-based infrastructures coverage. Know precursor companies for such commercial services include Hawk Eye 360 and Spire.

Atmospheric sensing data for meteorological or climate monitoring purposes and related customers such as Met Offices or greenhouse gases regulation agencies. A very relevant example is GNSS radio occultation measurement data, providing very useful atmospheric state variables information for meteorological numerical models constraining and for which a large abundance of measurements is valuable. A CubeSat based large constellation is therefore a very adequate approach to provide such data service considering that a GNSS radio occultation measurement payload can easily fit within a volume of 1U, allowing affordable deployment of a massive, dedicated CubeSat constellation.

See section 9.4 for satellite networks or systems in the commercial missions.

5.6 Moon-based, inter-planetary or deep space missions

Launching probes into celestial bodies farther away than the Moon requires enormous energy, so it is an economic choice to use small satellites for the deep space exploration.

A small satellite can carry out deep-space exploration missions independently or cooperate with large probes such as manned spacecraft, landers, rovers, and returners for technical verification, process monitoring, remote sensing, communication support and other related tasks. Moreover, small satellites working on the lunar communications, navigation, lunar or deep space relay communications with the Earth in the constellation form are now under the research and development.

According to the allocation of RR, frequencies that could be used for near-earth-space missions, especially for lunar exploration include 2 025-2 110 MHz / 2 200-2 290 MHz with space operation and space research services as well as 7 190-7 235 MHz / 8 450-8 500 MHz / 22.55-23.15 GHz / 25.5-27 GHz with space research service. Deep-space exploration missions including planetary exploration missions, such as the Mars mission probe, are encouraged to utilize the frequency assignments of 2 110-2 120 MHz / 2 290-2 300 MHz / 7 145-7 190 MHz / 8 400-8 450 MHz / 34.2-34.7 GHz / 31.8-32.3 GHz with space research service (deep space).

Most Nanosat missions have been and are operated from Earth centred orbits, in the LEO domain, for the following essential reasons:

– The severity of the environment, above the LEO region and more particularly beyond the Earth magnetosphere, represents a major challenge for most nanosats using COTS electronical components, unable for most of them to endure the harsh radiation levels.

– The nanosatellite limited capacities: Most nano satellites, essentially due to their small size, cannot embark and/or supply with enough power the radio communication systems that are needed for very long-distance communications with a decent data rate. Also, they are usually not equipped with adequate propulsion capacities to provide the required delta-V for a beyond Earth mission and, for planetary orbiting missions, depending on the transfer trajectory approach, the required thrust for the insertion phase.

– Launch opportunities currently sole solution is the so called "piggyback" option to ride alongside a rare flagship mission, for which residual launch vehicle capacity in terms of mass or volume is often very limited. Hence such opportunities are scarce.

However, several beyond Earth missions based on nanosats have been or will be deployed, a significant part of them being developed by national space agencies, amongst which the Jet Propulsion Laboratory was a precursor.

Most famous past and coming examples are:

– The Mars Cube One (MarCO) programme developed by the Jet Propulsion Laboratory (JPL) and launched with the *Insight* Martian missions. MarCO consisted in 2 6U CubeSats that operated a Mars flyby and performed as low data rate transmission relays in UHF and X-band for *Insight* during its Entry, Descent and Landing (EDL) phase;

– Artemis 1 inaugural launch of Space Launch System (SLS) launch vehicle that will embark and inject in 2022 11 6U CubeSats on a Lunar Distant Retrograde Orbit (DRO).

See section 9.5 for satellite networks or systems in the Earth-based, moon-based, inter-planetary or deep space missions.

5.7 Short-duration missions

Considering the regulatory limitation and procedure for a non-geostationary satellite system with short-duration missions, the only benefits or relaxation in terms of frequency assignments for satellites of short-duration missions is 137.025-138 MHz (space-to-Earth) and 148-149.9 MHz (Earth-to-space), which are allocated to the space operation service on the condition that they are submitted as non-GSO-SDM in accordance with Resolution **32 (WRC-19)**, exempting from coordination procedures under RR Nos. **9.11A** and **9.21**. See section 3.5.1.9 for more details.

Based on this regulatory situation, the most suitable mission that may be identified as a non-GSO SDM is suggested as follows:

– satellite projects have a short (one to two years) development time and are of low cost, often using off-the-shelf components;

– the operation lifetime of the satellites ranges from several weeks up to not more than three years;

– the satellites utilize low-Earth orbits (LEO);

– the satellites utilize the frequency bands 137.025-138 MHz (space-to-Earth) and 148-149.9 MHz (Earth-to-space) to carry out the space operation.

Many 1U to 3U CubeSat missions can be considered as short-duration missions since:

– Their lifetime is below three years for most of them, due to their low injection altitude (on a non-GSO orbit) and their lack of propulsion system. The most representative case being CubeSat missions released from the ISS airlocks;

– They are being used for a wide variety of applications, including remote sensing, space weather research, upper atmosphere research, astronomy, communications, technology demonstration and education according to Resolution **32 (WRC-19)** definition.

CHAPTER 6

6 Space object registration

Legal issues relating to responsibility and liability at a national and international level should be considered at the "Project Definition" stage of a satellite mission design process.

Under the provisions of the 1967 Outer Space Treaty[5], a State bears "international responsibility" for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities. A State is also required to authorize and continually supervise the space activities of non-governmental entities.[6] In addition, a State is "internationally liable" for damage caused by a space object that it launches or procures the launching of or from whose territory or facility an object is launched.[7] The issues of liability for damage caused by space objects are expanded upon in the 1972 "Liability Convention".[8] When a space object is launched into Earth orbit or beyond, a State is required to register it with the Secretary-General of the United Nations under the 1976 "Registration Convention" or in accordance with General Assembly Resolution 1721B (XVI).[9]

The Registration Convention requires that when a satellite is launched into Earth orbit or beyond, the State of registry shall provide relevant information to the Secretary-General of the United Nations for entry in the United Nations Register of Objects Launched into Outer Space. The term State of registry means a launching State on whose registry a space object is carried in accordance with Article II of the Registration Convention. Article II stipulates conditions for when a launching State is to be considered a State of registry. While only a State may submit a satellite registration, the furnishing of the underlying information by non-governmental entity satellite operator may be part of that State's authorization/licensing mechanism.

If a State is not Party to the Registration Convention, meaning that it has not acceded to or ratified the Convention, it can voluntarily provide registration information on the space object under General Assembly Resolution 1721B (XVI) of 20 December 1961.

In cases where a satellite mission uses "foreign" launch services or when there is more than one State involved in the mission, the Registration Convention requires that the involved States jointly determine which of them should be the State of registry. In general, States providing launch services do not register satellites launched on behalf of foreign clients.

Those requirements also apply to an international intergovernmental organization which conducts space activities and has declared its acceptance of the rights and obligations under the Registration Convention.

It should be noted that only one State of registry may exist for a particular satellite.

General Assembly Resolution 68/74 stipulates in paragraph 6 that a national registry of objects launched into outer space should be maintained by an appropriate national authority; operators or owners of space objects for which the State is considered to be the launching State or the State responsible for national activities in outer space under the United Nations treaties on outer space should be requested to submit information to the authority to enable the State on whose registry such objects are carried to submit the relevant information to the Secretary-General of the United Nations in accordance with applicable international instruments, including

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5 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

6 Article VI of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

7 Article VII of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

8 Convention on International Liability for Damage Caused by Space Objects.

9 Convention on Registration of Objects Launched into Outer Space.

the Registration Convention, and in consideration of General Assembly Resolutions 1721B (XVI) and 62/101 of 17 December 2007; the State may also request information on any change in the main characteristics of space objects, in particular when they have become non-functional.

Upon launch of a satellite into Earth orbit or beyond, the national competent authority of the State of registry should send the relevant information to the Secretary-General through a Diplomatic Mission accredited to the United Nations.

It should be noted that registration information submitted directly to the United Nations by national agencies, private Corporations, academic institutions or individuals will not be considered valid submissions, and only information provided through Diplomatic Missions accredited to the United Nations will be considered valid registration submissions. The information should be addressed to the Secretary-General of the United Nations and sent to oosa@un.org or soregister@unoosa.org.

Article IV, paragraph 1 of the Registration Convention requires specific information to be provided to the Secretary-General. In addition, Article IV, paragraph 2 allows the State of registry to provide additional information on a particular satellite. The 2007 General Assembly Resolution 62/101 on "Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects" expands upon the types and formats of such additional information. Article IV, paragraph 3 requests that information on when a satellite is no longer in Earth orbit (date of decay/re-entry) be provided.

To assist States submitting registration information, the Office for Outer Space Affairs of the United Nations (UNOOSA) has produced registration forms in all official languages of the United Nations, see the UNOOSA website:

http://www.unoosa.org/oosa/en/spaceobjectregister/index.html

The form indicates what information is required under the Registration Convention, recommended units of measure, additional information recommended in Resolution 62/101 and other voluntary information that will facilitate the use of the United Nations Register of Objects Launched into Outer Space.

CHAPTER 7

7 Launch considerations

In the growing small satellite market, launch integration is moving toward launch options that are favourable to the small spacecraft, mainly: dedicated, piggyback and rideshare launches.

Dedicated Launches

A dedicated launch is a mission governed only by one company, and it can be carried out either by using the newest small launch vehicles, or by becoming a main payload on a conventional launch vehicle.

Launching on a dedicated mission gives control over all factors: launch date, specific orbit, interplanetary trajectories and environmental conditions. The cons of a dedicated launch is that, generally, it is more expensive than other launch options.

By choosing this type of launch, it is possible to place hundreds of satellites in the very same orbit on a single launch. This is an interesting option for small satellites mega constellations, as in the case of Starlink and Oneweb, who launched 1 273 small satellites in total, using, most of the time, dedicated launches. In these cases, the orbit at separation might not be the final one for all the satellites, which will have to reach their final orbit using their own propulsion system.

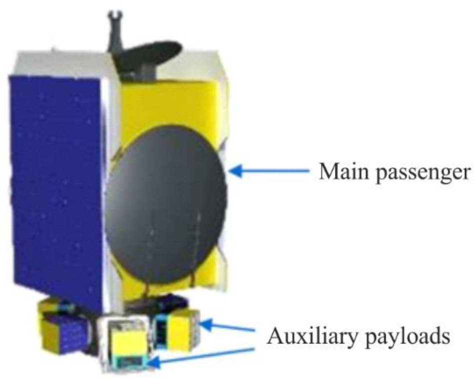
Piggyback launches

A piggyback launch is a mission where the primary payload does not use completely the launcher’s available capacity. Thus, an excess of capacity remains available for secondary payloads. The primary payload still decides all the mission requirements. Secondary payloads in piggyback mode will have to adhere to the mission, as defined for the primary payload. The secondary payloads have no influence over their destination orbit or even launch date – they can be simply left behind if not ready in time.

A typical piggyback configuration is illustrated in Fig. 14.

FIGURE 14

Typical piggyback configuration



Handbook on Small Satellites-14

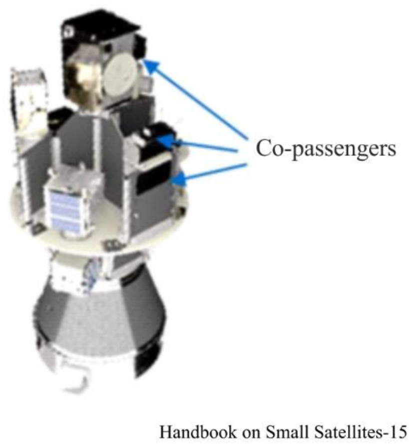
Rideshare launches

A rideshare is a multi-mission launch that uses a rocket to essentially deploy multiple small satellites. The small satellites are integrated on board compactly with adapters and dispensers. Sometimes the launcher provides different separation altitudes for releasing the satellites. That said, the separation altitude range is usually not very high.

An example of rideshare configuration is given in Fig.15.

FIGURE 15

Example of rideshare configuration



As these adapters and dispensers have become more developed, dedicated ridesharing missions are proposed on the market either by launch service providers or by integrators booking a partial or full capacity on a given launch and selling the available capacity to multiple spacecraft operators without the presence of a primary customer.

Additionally, CubeSat form factors are increasing in dimension, which leads to larger dispensers to accommodate larger CubeSat sizes while the general development of small spacecraft requires a capacity to address all classes of small spacecraft beyond CubeSats, from nanosatellites (< 60 kg) up to minisatellites (up to 500 kg or more).

Although not a new idea, using orbital manoeuvring systems to deliver small satellites to intended orbits is another emerging technology. Several commercial companies are developing orbital tugs to be launched with launch vehicles to an approximate orbit, which then propel themselves with their on-board propulsion system to another orbit where they will deploy their hosted small satellites. Such orbital tugs can lead to long orbital transfer durations (typically several months), especially when they perform an orbital plane change consisting of a first boost to trigger an orbital drift and a final boost to bring the hosted small satellites to its final orbit. The use of low thrust propulsion may even increase the duration of orbital transfers.

An alternative to orbital tugs accommodated on medium or large launchers is to consider micro/mini launchers with a performance adapted to dedicated launches of small satellites. Such a solution is well suited for missions that target a very specific orbit and/or that have a stringent deadline to meet, incompatible with the risk of delay from the main passenger in piggyback configuration or from co-passengers in rideshare configuration. Therefore, flying the satellites as a primary satellite maybe the best launch method for interplanetary missions, precisely timed rendezvous, responsive missions (e.g. for disaster monitoring or defence purposes) or for satellites whose design is not compatible with the long duration orbital transfer that would be necessary with a rideshare or piggyback launch option.

These different launch options, technology developers and hard sciences can take advantage of the quick iteration time and low capital cost of small satellites, to yield new and exciting advances in space capabilities and scientific understanding. At the same time, when it comes to use small satellites for large and mega non-geostationary constellations, the piggyback, rideshare and micro/mini launcher options are not consistent. To address huge projects, medium or large launch vehicles have to be considered in order to minimize the launch price per satellite and to deploy the constellation in due time, especially when one considers the ITU applicable rules related with the milestone approach for non-geostationary constellations that requires deploying (see section 3.7.3.1).

The constellation deployment strategy can be optimized considering:

– the constellation architecture (type of orbits, number of orbital planes),
– the manoeuvring capacity of the satellites (i.e. the amount of propellant they can use to perform the orbital manoeuvres to reach their operational orbit).

One can typically decide between dedicated launches for each orbital plane, inducing a quick arrival of the satellites in their operational orbit, and launches aggregating satellites for different orbital planes (in order to reach the maximum number of satellites per launch with respect to the available launcher performance and fairing capacity), leading to a later arrival of the satellites in their operational orbits as they would have to cope with an orbital drift for several weeks/months.

Usually, satellites of large constellations are mounted on a dedicated dispenser structure ensuring the optimal accommodation of the satellites under the fairing and including the separation systems. An alternative to this dispenser approach consists in having all the satellites stacked under the fairing. Such a solution allows for saving the mass of the dispenser structure but requires having the satellites specifically designed for the considered launch vehicle.

In the future, the expanding capabilities of small satellites will also demand dedicated launchers. For missions that need a very specific orbit, interplanetary trajectories, precisely timed rendezvous, or special environmental considerations, flying the satellites as a primary satellite may be the best method of ascent. Technology developers and hard sciences can take advantage of the quick iteration time and low capital cost of small satellites, to yield new and exciting advances in space capabilities and scientific understanding.

7.1 Launch services by Arianespace

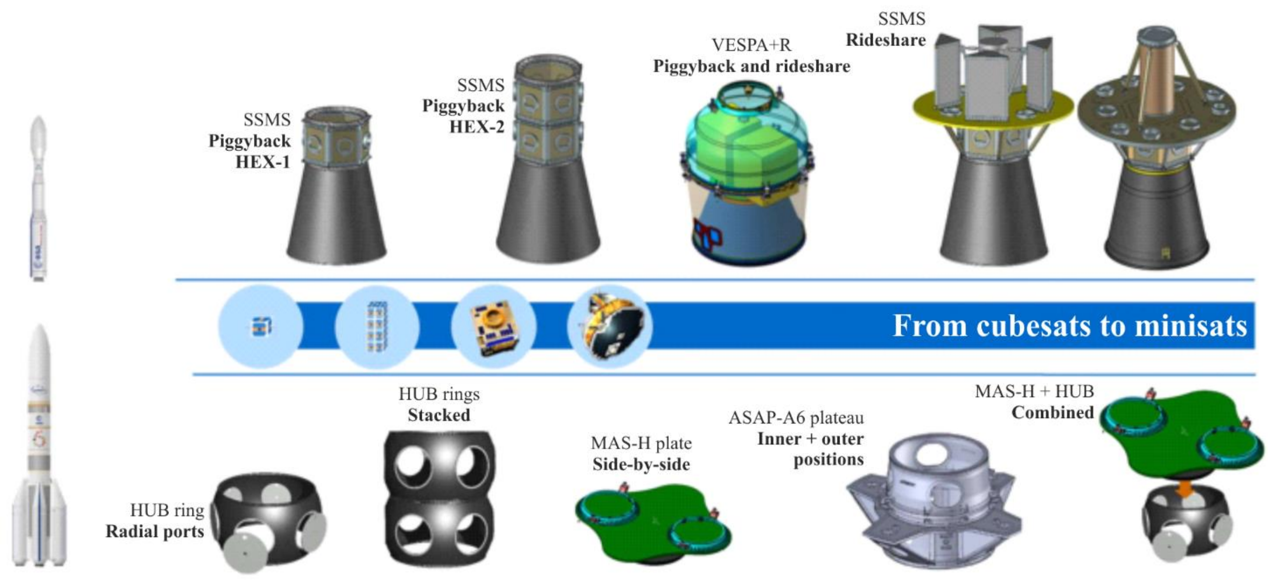
Two small satellite launch services are indeed implemented by Arianespace:

– Small Spacecraft Mission Service (SSMS) on the Vega- small launcher
– Multi-Launch Service (MLS) on the Ariane 6 launcher (for both medium and heavy versions of the launcher, respectively Ariane 62 and Ariane 64).

Figure 16 provides an overview of the main accommodation solutions that are proposed by Arianespace on a standard basis.

FIGURE 16

Arianespace smallsat launch service overview



Handbook on Small Satellites-16

7.1.1 Small Spacecraft Mission Service with Vega-C

The small satellite accommodation solutions on Vega-C include:

– The VESPA+ Reinforced structure for dual launch, allowing for the accommodation of a small satellite in lower position,

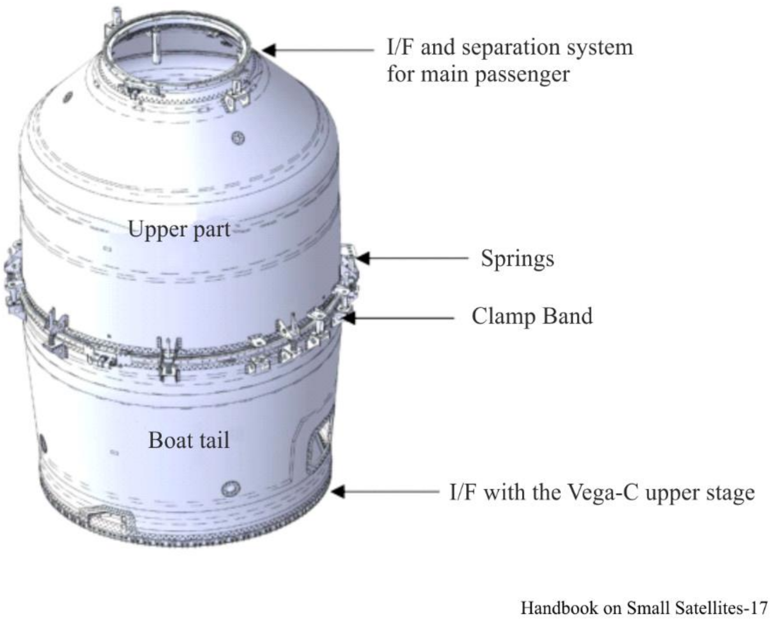
– The SSMS structures that can be combined in different configurations.

VESPA+ R

The VESPA+ R carrying system is inherited from the VESPA+ carrying system on Vega. It consists of the upper part, the boat tail, the inner cone and the inner platform. It also provides the interface and separation system to the main passenger. Inside the VESPA+ R, the payload is mounted on a Vampire adapter with an interface. See Fig. 17.

FIGURE 17

VESPA+ R system



SSMS

The SSMS carrying structures are a set of modular elements manufactured by SAB Aerospace, mainly composed of:

– sandwich panels with aluminum honeycomb core and with carbon fibre composite skins,

– aluminum machined I/F rings,

– aluminum connecting frames between the different panels and harness support parts (brackets and others).

The SSMS system includes the following elements: hexagon, main deck, central column, towers, shear webs, spacers and adapters as shown in Fig. 18.

FIGURE 18

SSMS system

By combining all these elements, a high number of carrying system configurations in piggyback or rideshare configurations can be obtained as illustrated in Fig. 19.

FIGURE 19

SSMS configurations

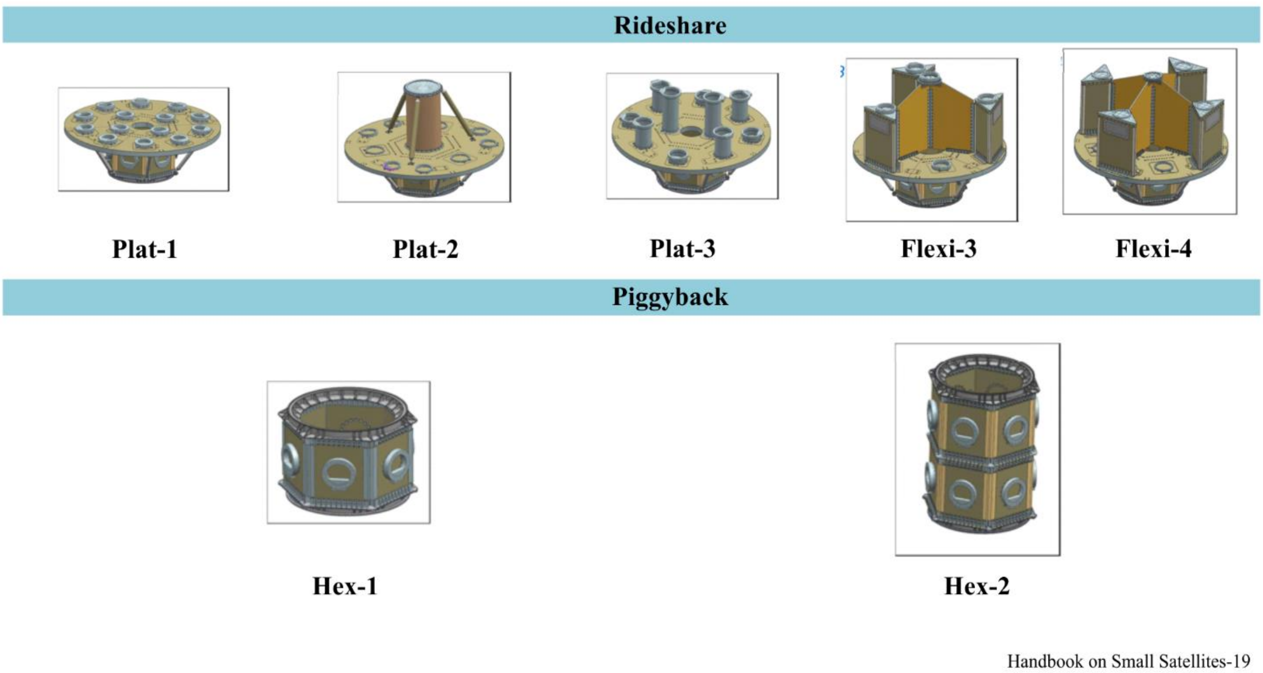
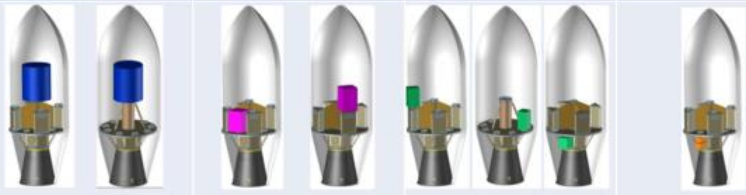


Table 11 provides an overview of typical accommodation solutions according to the smallsat class.

TABLE 11

Vega-C accommodation solutions vs smallsat class

	Mini S/C	Micro S/C	Nano S/C	Cubesat Deployers
Mass	500–200 kg	200–60 kg	60–30 kg	35–10 Kg
Max. dimensions	H1800 Ø1500	H1200 L800 W800	H1000 L600 W600 & H800 L500 W600 *	H600 L300 W300 *
Interface	MLB 24'' PAS610S 	MLB15&13'' PAS381S	MLB 11,732 & 8''	Bolted IF
Typical Positions			* On SSMS Hexa or VAMPIRE 937	* H: S/C dimension in the direction of separation

The interface requirements (mechanical, electrical, environments) are detailed in the SSMS User's Manual available online through the following link:

https://www.arianespace.com/wp-content/uploads/2020/10/SSMS-Vega-C-UsersManual-Issue-1-Rev0-Sept2020.pdf

7.1.2 Multi-Launch Service with Ariane 6

The small satellite accommodation solutions on Ariane 6 consist of three types of structures:

– The hub structure which can carry small payloads on its six ports, in a side-mounted configuration,

– The MAS-H which is a customizable plate,

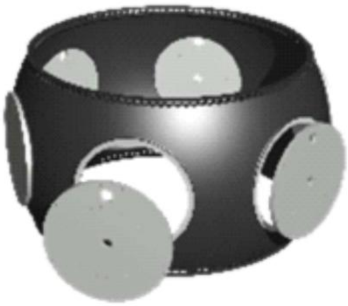
– The ASAP-A6 structure which can accommodate a large mini-satellite in a central canister and nano/micro-satellites on up to four lateral plates.

Hub

The Hub is a lightweight composite ring, offering six ports (300+ kg per port) which can be tuned, shared or combined. See Fig. 20. It can also carry in top position a payload of 5 500 kg.

FIGURE 20

Hub structure



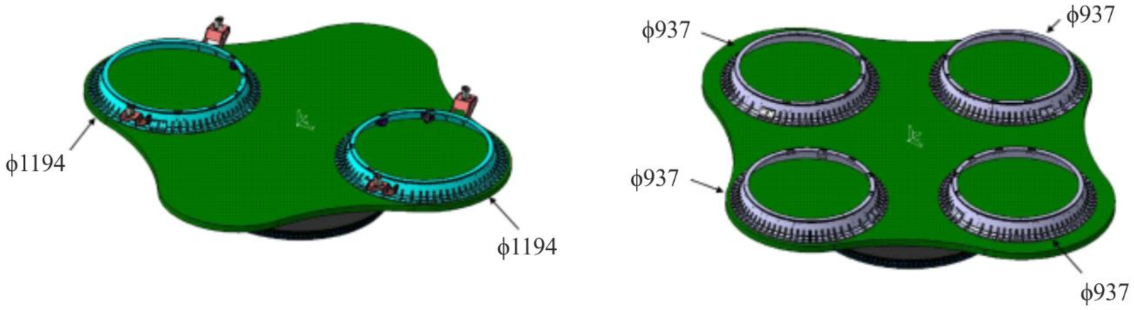
Handbook on Small Satellites-20

MAS-H

The MAS-H is a customizable plate, providing a maximum volume under fairing for a set of payloads up to five tonnes. See Fig. 21.

FIGURE 21

MAS-H structure



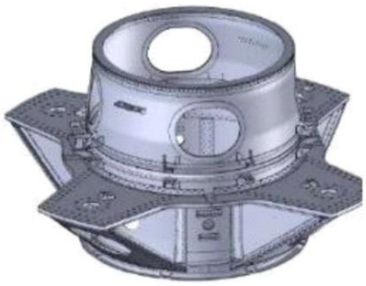
Handbook on Small Satellites-21

ASAP-A6

The automated structures analysis program (ASAP) is derived from the structure that has flown several times on Soyuz spacecraft in an "ASAP-S" version. It is composed of a central canister and up to four lateral plates that can respectively payloads of up to 600 kg and 300 kg. See Fig. 22. It can also carry in top position a payload of up to 3 100 kg.

FIGURE 22

ASAP-A6 structure

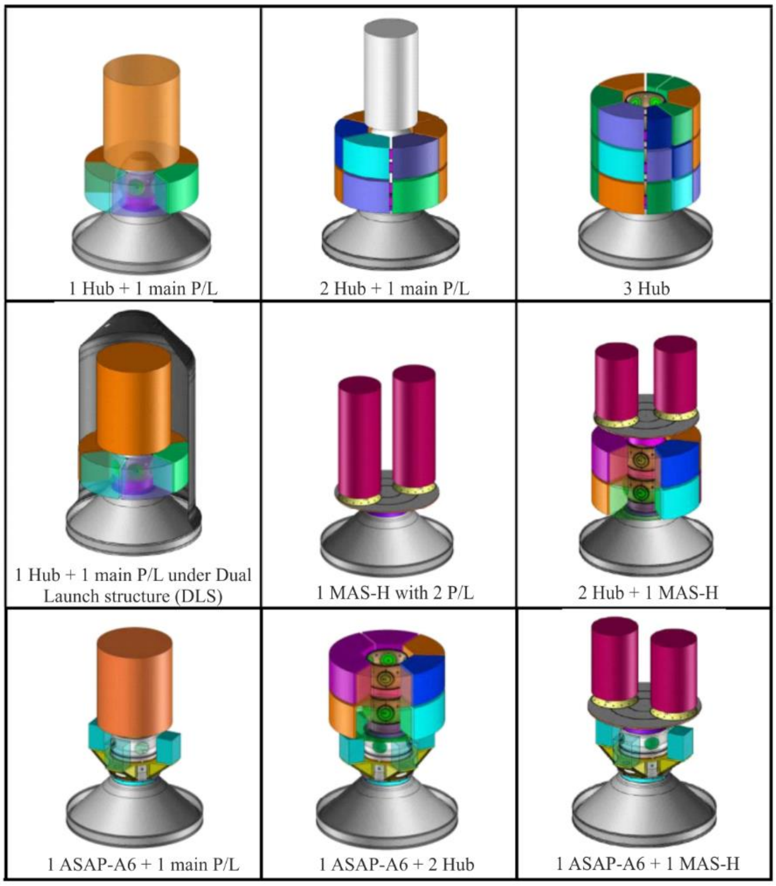


Handbook on Small Satellites-22

Figure 23 provides an overview of typical accommodation solutions under the Ariane 6 fairing.

FIGURE 23

ARIANE-6 accommodation solutions



Handbook on Small Satellites-23

The interface requirements (mechanical, electrical, environments) are detailed in the MLS User's Manual available online through the following link:

https://www.arianespace.com/wp-content/uploads/2021/07/MLSs-users-manual-ed0.0.pdf

7.1.3 Customized dispenser structures

For small constellations that would use Vega-C for their deployment, Arianespace liaising with Avio, develop and procure dispenser structures that would be specifically designed according to the satellites mass and dimensions. An example of dispenser structure (dubbed Clessidra) carrying eight small satellites attached radially is shown in Fig. 24.

FIGURE 24

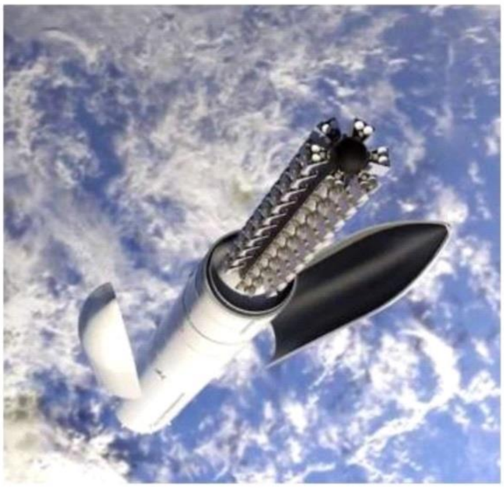
Dispenser structure with 8-side-mounted smallsats under Vega-C fairing

Handbook on Small Satellites-24

For medium and large constellations, Arianespace usually drives the development of specific dispenser structures that allow for an optimization of the accommodation under fairing, taking into account the satellites mass and dimensions. An example of accommodation of a large constellation under an Ariane 6 fairing is given in Fig. 25.

FIGURE 25

Dispenser structure for a large constellation under Ariane 6 fairing



Handbook on Small Satellites-25

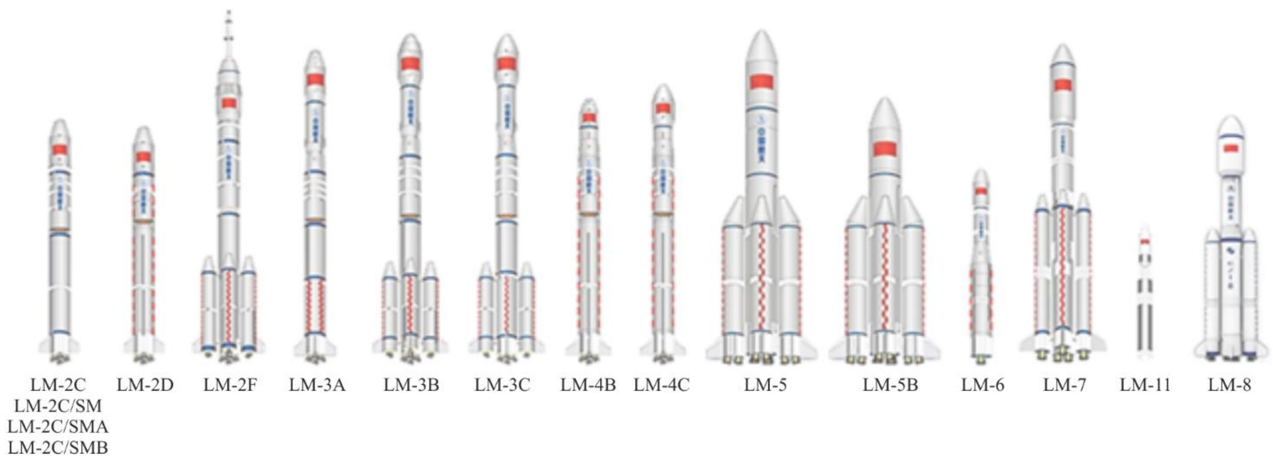
7.2 Launch services by China Great Wall Industry Corporation (CGWIC)

China Great Wall Industry Corporation (CGWIC) cooperates with its subcontractors, China Academy of Launch Vehicle Technology (CALT) and Shanghai Academy of Spaceflight Technology (SAST), for the Long March launch vehicles and China Satellite Launch and Tracking Control General (CLTC) for launch supports and TT&C services, to implement Launch Services programmes.

The modern LM has already extended into a series of launch vehicles that accommodate a full range of missions and payloads. The LM launch vehicles include the LM-2, LM-3A, LM-4, LM-5, LM-6, LM-7, LM-8, and LM-11 series of launch vehicles. See Fig. 26.

FIGURE 26

LM launch vehicles



Handbook on Small Satellites-26

– **Long March 2C (LM-2C)**, is the first Chinese liquid launch vehicle, with N2O4 and hydrazine for the 1st and 2nd stages. It has three configurations of 2-stage and 3-stage which is primarily designed for LEO, SSO and GTO launch missions.

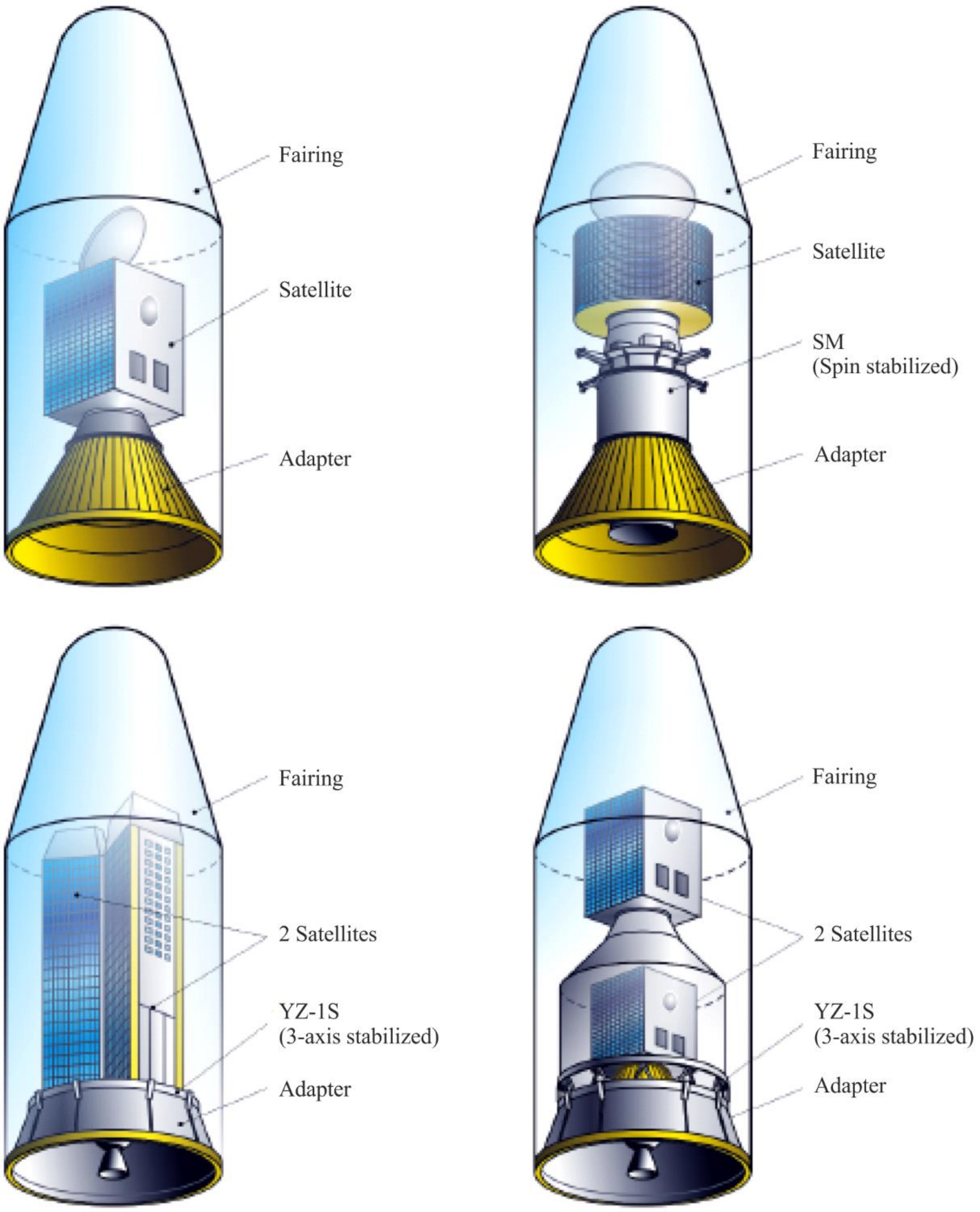
  LM-2C fairing has full RF transparency. The fairing which is made of glass fibre reinforced plastic and metal joist can meet diversified demands. The LM-2C launch system uses a wide variety of heritage-based fairings to meet the broad needs of customers.

– **Long March 2D (LM-2D)**, is a 2-stage launch vehicle, with N2O4 and hydrazine for the 1st and 2nd stages. It has two configurations of 2-stage and 3-stage which is primarily designed for LEO, SSO and GTO launch missions.

– **Long March 2F (LM-2F)**, is a 2-stage launch vehicle, with N2O4 and hydrazine for all stages and boosters. It is the only Chinese launch vehicle currently used for manned flight, which is primarily designed for the Shenzhou, and other spacecraft associated with space station missions.

FIGURE 27

Configuration in Fairing of LM-2C Series



Handbook on Small Satellites-27

- **Long March 3A (LM-3A)** is a 3-stage launch vehicle, with the 1st and 2nd stages with N2O4 and hydrazine, and the 3rd stage with liquid hydrogen and liquid oxygen, which is primarily designed for GTO launch missions.
- **Long March 3B (LM-3B)** is a 3-stage launch vehicle, with the 1st, 2nd stages and booster with N2O4 and hydrazine, and the 3rd stage with liquid hydrogen and liquid oxygen. It is primarily designed for GTO, MEO and GEO launch missions.

Payload Fairings of LM-3B uses two encapsulation methods:

a) Encapsulation-on-Pad: When the satellite is encapsulated on the pad the satellite and fairing are transported to launch pad separately, then the fairing is encapsulated following the mate of satellite to the launch vehicle.

b) Encapsulation-in-BS3: When the satellite is encapsulated in BS3 the satellite is mated to the Payload Adapter (PLA) and encapsulated in the fairing in BS3. The encapsulated satellite is shipped to the launch pad in the fairing and the complete assembly is mated to the launch vehicle.

– **Long March 3C (LM-3C)** is a 3-stage launch vehicle, with the 1st, 2nd stages and booster with N2O4 and hydrazine, and the 3rd stage with liquid hydrogen and liquid oxygen. The Long March 3C removed two boosters compared to the Long March 3B, which is primarily designed for GTO, MEO and GEO launch missions.

– **Long March 4B (LM-4B)** is a 3-stage launch vehicle, all stages are N2O4 and hydrazine. It is primary designed for SSO missions, and it is also capable of launching spacecraft to various orbits.

– **Long March 4C (LM-4C)** 4C is a 3-stage launch vehicle, with N2O4 and hydrazine for all stages, which is primary designed for SSO missions.

– **Long March 5 (LM-5)** 5 is a 2-stage launch vehicle. The 1st and 2nd stages are liquid hydrogen and liquid oxygen, strapped with four (4) oxygen and kerosene boosters. It is primary designed for large spacecraft to the GTO, LTO, it is also capable for MEO and GEO missions in the configuration where the upper stage is equipped.

– **Long March 5B (LM-5B)** is a 1-stage launch vehicle. The 1st stage are liquid hydrogen and liquid oxygen, strapped with four (4) liquid oxygen and kerosene boosters. The configuration of Long March 5B based on the Long March 5 launch vehicle by reducing a 2nd stage. It is primary designed for large spacecraft to the LEO.

– **Long March 6 (LM-6)** is a 3-stage launch vehicle, with both the 1st and 2nd second stages are liquid oxygen/kerosene, and the 3rd stage with N2O4 and hydrazine. It is primarily designed for LEO and SSO missions.

– **Long March 6A (LM-6A)** is a 2.5-stage launch vehicle, with the 1st and 2nd stages are liquid oxygen/kerosene, strapped with four (4) two-stage solid boosters of Φ2 m. It is primary designed for LEO and SSO launch missions. As a new generation of launch vehicle, the Long March 6A will mainly undertake Medium to Low Orbit launch missions.

– **Long March 6C (LM-6C)** is a 2-stage launch vehicle, with both the 1st and 2nd stages are liquid oxygen and kerosene. As a new generation of launch vehicle, the Long March 6C will mainly undertake Medium to Low Orbit launch missions.

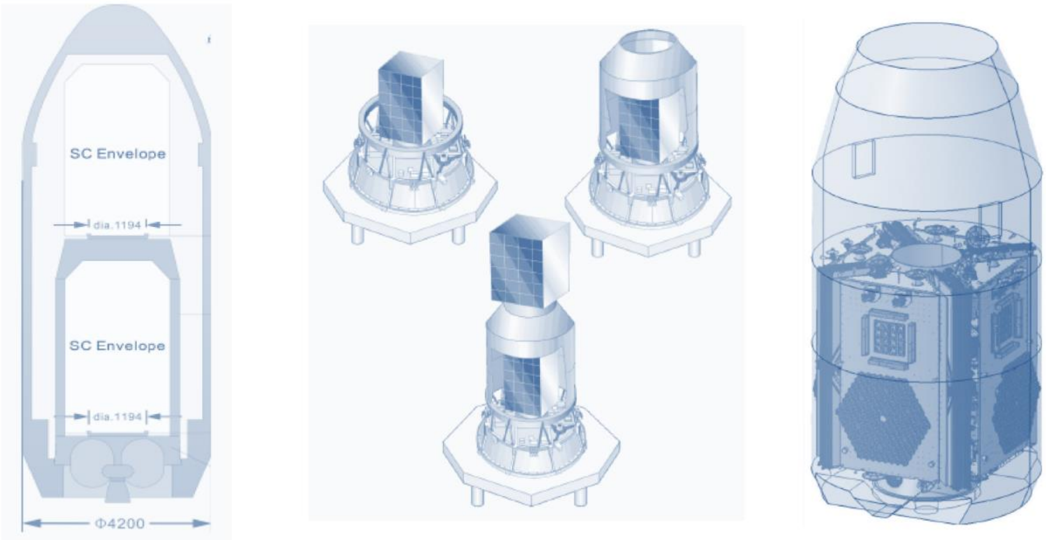
– **Long March 7 (LM-7)** is a 2-stages launch vehicle. Both the 1st, 2nd stages and boosters are liquid oxygen and kerosene. It is designed for LEO and SSO launch missions. The Long March 7 performed its maiden flight in June 2016.

– **Long March 7A (LM-7A)** is a 3-stage launch vehicle. Both the 1st, 2nd stages and boosters are liquid oxygen and kerosene, and the 3rd stage with liquid hydrogen and liquid oxygen. The configuration of Long March 7A based on the Long March 7 launch vehicle by adding a cryogenic 3rd stage. It is primary designed for GTO and LTO launch missions.

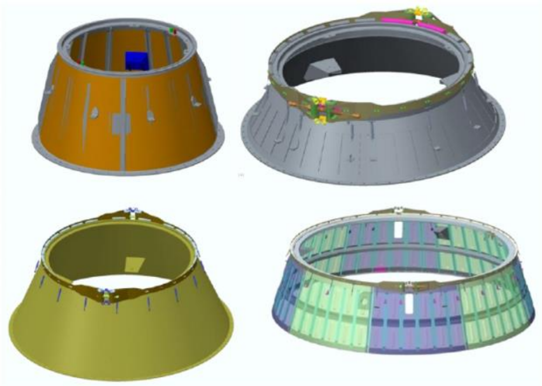
– **Long March 8 (LM-8)** is a 2-stage launch vehicle, which the 1st stage and boosters are liquid oxygen and kerosene, and the 2nd stage is liquid hydrogen and liquid oxygen. It is primary designed for LEO, SSO, and GTO launch missions.

FIGURE 28

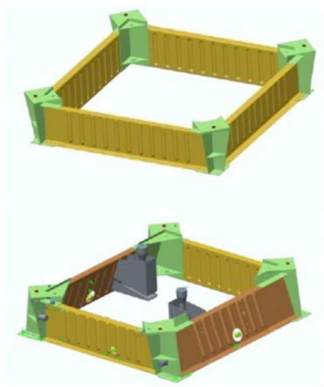
Mechanical interface of LM-8



Support for serial or parallel configuration to launch multiple satellites in a single mission



Clamp band



Point separation device

Handbook on Small Satellites-28

– **Long March 11 (LM-11)**, is a 4-stage solid launch vehicle, with HTPB solid propellant for the 1st, 2nd and 4th stages, and high-energy solid propellant for the 3rd stage. Designed primarily for LEO and SSO launch missions, it is a new generation of launch vehicles that can be launched for emergencies of rapid response.

Specific configurations of the Long March launch vehicles can be referred through the following link:

http://www.cgwic.com/Launchservice/LM2C.html

Satellite Launch Centres

Depending on the mission, satellites will be launched from one of the four launch centres of Jiuquan (JSLC), Taiyuan (TSLC), Xichang (XSLC), and Wenchang (WSLC).

All four satellite launch centres are subordinates to CLTC. Each satellite launch centre has several satellite buildings and cleanliness rooms that can meet operation requirement. All necessary operations such as testing, Assembly Integration Trailer (AIT), fuelling and lifting are supported by launch centre team.

FIGURE 29

CGWIC satellite launch centres

Handbook on Small Satellites-29

(a) Taiyuan Satellite Launch Centre

Taiyuan Satellite Launch Centre (TSLC) is located northwest of Shanxi province, 284 km from Taiyuan City, and is accessible by either railway or road. TSLC is at the height of 1 400-1 900 m above sea level, and is surrounded by mountains to the east, south, and north, with the Yellow River to its west. The annual average temperature is 4 to 10 °C, with a maximum of 28 °C in summer and a minimum of −39 °C in winter.

TSLC is suitable for launching a range of satellites, especially for LEO and SSO launch missions. TSLC has state-of-the-art facilities for launch vehicle and spacecraft testing, preparation, launch, in-flight tracking, and safety control, as well as for orbit predictions.

(b) Jiuquan Satellite Launch Centre

Jiuquan Satellite Launch Centre (JSLC) was established in 1958, which is the first and largest launch centre in China. JSLC lies in Jiuquan, Gansu province, northwest of China. Its headquarters is at Dongfeng Space Town. Jiuquan is of an inland, arid desert climate. It is dry all the year round with little rain and extended daylight hours, with an annual average temperature of 8.5 °C and relative humidity of 35 to 55%. The environmental conditions are ideal for satellite launches.

JSLC successfully launched China’s first satellite DFH-1 with LM-1 launch vehicle in 1970. JSLC completed its first international mission in October 1992 by using the LM-2C launch vehicle. The rideshare payload was Swedish Space Corporation’s Freja scientific satellite.

At present, JSLC is mainly responsible for high inclination SSO & LEO launch missions and manned missions. JSLC has a team of professional and technical personnel with excellent quality and advanced test facilities, equipment, and systems.

(c) Xichang Satellite Launch Centre

Xichang Satellite Launch Centre is located in Sichuan Province, southwest of China.

XSLC began its construction in the 1970s. It is now capable of launching the satellites by LM-3A, LM-2C and LM-4B/C serial launch vehicles. XSLC facilities mainly includes, tracking equipment, communications equipment, meteorological equipment and other technical support equipment for SC test, launching, tracking, safety control, communication, and meteorological support.

XSLC can provide technical services, including airport and roads transportation, meteorology, fuel and gas analysis, and measuring. If requested, compressed air, gaseous helium, nitrogen and training on the operations of the SC related equipment could also be provided.

(d) Wenchang Satellite Launch Centre

Wenchang Satellite Launch Centre (WSLC) is located in Longlou Town, Wenchang city, Hainan province. WSLC is the first coastal launch centre in China, and one of the few low-latitude Launch centres in the world.

WSLC is designed for LM-5, LM-7 and LM-8 and is mainly responsible for GEO missions, construction of space station, and deep-space exploration missions.

As low latitudes launch site along the coast, WSLC can make full use of linear velocity close to the equator, while the centrifugal inertia phenomenon, greatly reduces fuel consumption of LV (the capacity can be increased by 10% for the same LV) which can help accommodate the transportation problem of heavy LV by sea transportation.

7.3 SpaceX rideshare programme

Through its Rideshare Programme, SpaceX offers launch slots, as shown in Fig. 30, on its Falcon 9 launch vehicle to provide increased access to space for small satellite operators seeking a reliable, affordable ride to orbit. SpaceX frequently launches Falcon 9 rideshare missions to mid-inclination orbits in LEO, GTO and translunar injection orbit (TLI), while missions to sun-synchronous orbit (SSO) launch approximately every four months. Routine launches enable contract flexibility for customers that need to reschedule in the event of a payload delay.

FIGURE 30

Example mission configuration using Rideshare plates

Handbook on Small Satellites-30

Based on their mass-to-orbit requirements, customers select their desired payload volume and interface configuration on a SpaceX Rideshare Plate (see Table 12), which range in size from a ¼ Plate, ½ Plate, Full Plate, or Full Plate (XL Volume), and support payload masses between 50 to 300 kg. Customers also select their preferred bolt pattern (8", 15" or 24" diameter standard interfaces). As an optional service, SpaceX can provide alternative configurations for small spacecraft that are not compatible with these mechanical interfaces and require multiple deployments or use of an orbital transfer vehicle to reach their final altitude. To reduce the orbital debris footprint of the Rideshare Program, payloads must adhere to the Federal Communications Commission's (FCC) ruling to dispose of spacecraft as soon as practicable but no later than five years after mission end.

TABLE 12

SpaceX Rideshare payload configurations

Payload configuration	Standard interface	Mass to orbit
¼ Plate	8" Bolt Pattern	50 kg
½ Plate	8" or 15" Bolt Pattern	100 kg
Full Plate	15" or 24" Bolt Pattern	200 kg
Full Plate (XL Volume)	24" Bolt Pattern	300 kg

SpaceX has achieved low pricing for the rideshare launch services through pioneering recovery and reuse of first stage boosters on its Falcon 9 and Falcon Heavy launch vehicles. A single booster has demonstrated the capability to support up to 15 flights. As of November 2022, SpaceX rideshare missions are priced as low as $275 000 for 50 kg to SSO, with additional payload mass priced at the same standard rate of $5 500 per kg. This highly competitive launch service supports a full spectrum of customers from startups to institutional aerospace customers launching spacecraft for either developmental or operational purposes. By providing an affordable alternative to dedicated space launch, SpaceX seeks to facilitate and accelerate industry-wide and government-led advancement of space technologies.

CHAPTER 8

8 Space debris mitigation

Depending on national legislation, satellite missions may require licensing/authorization by a national authority. This agency may be the national radio-telecommunications regulatory entity, the national space agency or the national science and technology entity. For a list of online national legislation relating to space activities, see the UNOOSA website:

https://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/index.html

General Assembly Resolution 68/74 of 11 December 2013 "Recommendations on national legislation relevant to the peaceful exploration and use of outer space", provides elements for consideration, as appropriate, by States when enacting regulatory frameworks for national space activities, in accordance with their national law, taking into account their specific needs and requirements. The resolution covers the scope of space activities targeted by regulatory frameworks; national jurisdiction for regulating the space activities of governmental and non-governmental entities; procedures for authorization and licensing of national space activities, including to ensure continuing supervision and monitoring of authorized space activities; registration of objects launched into outer space and establishment of national registries; liability and indemnifications procedures; and procedures with regard to the change in status of the operation of a space object in orbit.

As part of the authorization mechanism, national authorities may also require implementation of space debris mitigation measures based on national standards and/or on the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (ST/SPACE/49). For a compendium of national space debris mitigation standards, see the UNOOSA website:

http://www.unoosa.org/oosa/en/ourwork/topics/space-debris/compendium.html

This compendium and the resources on the dedicated webpage of the website of the Office for Outer Space Affairs, serves as a collection of relevant regulative information provided by States and international or intergovernmental organizations, as well as relevant international instruments.

Implementation of space debris mitigation measures should be considered at the "Preliminary Design Review" stage, especially for missions that require deorbiting/passivation of on-board systems during the mission termination phase.

As agreed by the General Assembly in its Resolution 62/217 of 22 December 2007, the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space reflect the existing practices as developed by a number of national and international organizations. From a technical point of view, the guidelines are applicable to mission planning and the operation of newly designed spacecraft and orbital stages and, if possible, to existing ones. There is a total of seven guidelines:

a) to limit debris released during nominal spacecraft/orbital stages operations;

b) to minimize the potential for break-ups during operational phases;

c) to limit the probability of accidental collision in orbit;

d) to avoid intentional destruction and other harmful activities;

e) to minimize the potential for post-mission break-ups resulting from stored energy;

f) and g) to limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region/geosynchronous Earth orbit (GEO) region after the end of their mission.

The guidelines are not legally binding under international law, but under this Resolution the General Assembly invites Member States to implement those voluntary guidelines through relevant national mechanisms, to the greatest extent feasible, and through space debris mitigation practices and procedures.

For example, Inter-Agency Space Debris Coordination Committee (IADC) has collated guidelines, standards and norms for the mitigation of space debris from the world's leading space agencies[10]. Taking into account that any guidelines so far developed are not mandatory, but in view of the foreseen thousands of small satellites to be launched that would affect the space environment, Member States and regulators should be encouraged to consider requiring more responsible behaviour from their licensees. Many satellite operators themselves have already committed to follow some of the items as stated below.

Responsible Design

The most urgent space safety imperative is the adoption of responsible design and operational practices. Principal safety themes include:

– *Reliability:* Satellites should be subjected to rigorous ground qualification programs, particularly when developing large satellite systems.

– *Control:* Operators should be responsible for being able to identify their assets, know where they are, and control their trajectories.

– *Coordination:* Operators should share orbit information and manoeuvring plans with other operators and coordinate to avoid collisions.

– *Disposal:* Upon decommissioning, non-GSO operators should promptly, reliably, and safely deorbit their hardware.

– *Safety-by-Design:* Orbits and constellations should be designed to minimize the number of satellites in orbit.

Space Situational Awareness (SSA) and Space Traffic Management (STM)

– The key to effective SSA and STM remains the open cooperation between operators and SSA systems.

– Transparent coordination should include the publication of satellite Two Line Elements (TLE), ephemeris, and covariance with space controllers (e.g. JspOC) and publicly accessible platforms (e.g. CelesTrack).

– Operators should hold coordination/awareness briefings with each other to confirm the actions each will take in the event of a possible conjunction.

Assisted Disposal and Removal (ADR)

– Satellite operators must work together with regulators and ADR service providers to develop the legislative and technical ecosystem with the objective to foster diversity of technical solutions and new commercial business models.

– While satellite *reliability* and *safety-by design* remain the foundation of the behaviour of any responsible operator, several ADR mission demonstrations are advancing the technical developments required to deorbit an uncontrollable satellite.

Radio Astronomy

– Responsible operators should commit to finding ways to coexist with radio astronomy observatories, protecting radio astronomy sites, and – going forward – working together to find mutually acceptable, creative solutions regarding dynamic coordination.

Optical Astronomy

– Responsible operators must acknowledge that satellites and large constellations can potentially affect large-field-of-view observatories.

– Operators should strive to mitigate the brightness of the satellites as seen from the ground, minimizing the impact on night sky observers.

– Providing access to high accuracy public data on predicted locations of individual satellites (or ephemerides) is key. This will enable the real-time use of high-accuracy public data on satellite locations to adjust observational strategies and minimize the disruption on the observations.

10 https://www.iadc-home.org/references

The Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space adopted by the Committee in 2019 provide a further source of internationally agreed and voluntary guidance on a number of related topics. The full text of the Guidelines may be found on the UNOOSA website (ST/SPACE/79):

https://www.unoosa.org/oosa/en/oosadoc/data/documents/2021/stspace/stspace79_0.html

CHAPTER 9

9 Examples of small satellite networks or systems

9.1 Scientific missions

9.1.1 DIWATA-1, for Earth observations

The micro-satellite DIWATA-1 was developed by the joint team of the Department of Science and Technology (DOST) in the Philippines, University of the Philippines Diliman, Hokkaido University, and Tohoku University. This is the first micro-satellite by Philippines scientists and engineers and was deployed in a 400-km circular orbit on April 27, 2016, with the support of Kibo Japanese Experiment Module on the International Space Station (ISS). In April 2020, the DIWATA-1 satellite decayed by the effect of atmospheric drag, with an expected total orbital life of approximately four years, which could be changeable by solar activity. The satellite has four types of Earth observation sensors for daily monitoring of natural resources on lands and oceans in the Philippines, as well as climate and disaster observations.

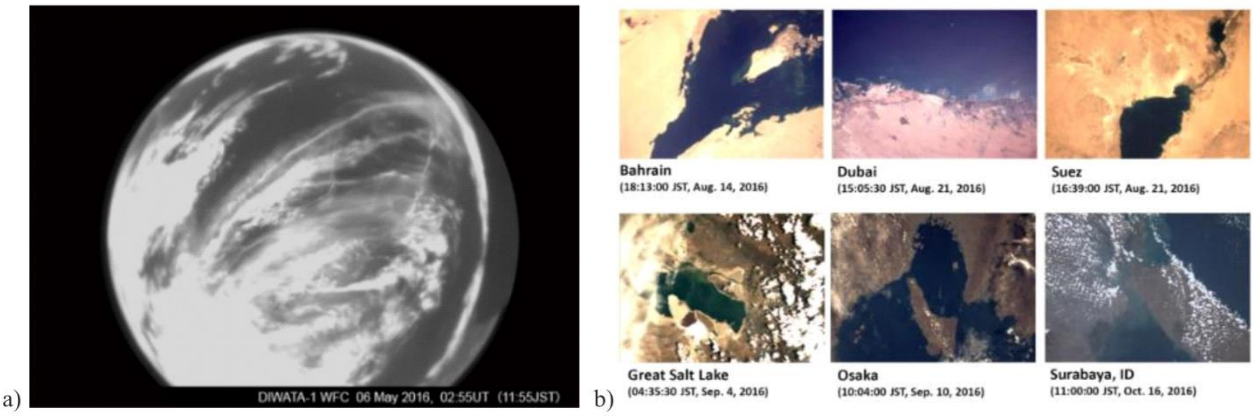
FIGURE 31

The flight model of DIWATA-1, flight operation started in April 2016

Handbook on Small Satellites-31

FIGURE 32

Example of observation images, a) nadir pointing image by WFC fish-eye sensor, b) MFC colour images for attitude calibration: other interesting images and articles by SMI and HPT are introduced in Blog of PHL Microsat



Handbook on Small Satellites-32

The first objective of the project is to cultivate young professional engineers of the Philippines through the completion of two satellites. Starting from the development of the satellite bus system and mission payloads, satellite operations and ground station management were also involved. The total duration of the development of DIWATA-1 was 14 months, commencing November 2014 until January 2016, a relatively short period of time to educate engineers from other professional fields. Nine students lived in Tohoku University and Hokkaido University for the development and the operations and the completion of a Master-degree course. Japanese universities had previously developed three microsatellites; SPRITE-SAT/RISING (2009), RISING-2 (2014), and RISESAT (2019), the experience and knowledge of which were inherited to DIWATA-1.

The mass of DIWATA-1 is 52.4 kg, and the dimensions are W55 × D35 × H55 cm. The satellite was deployed to a 400-km circular orbit with 51.6-degree inclination, which is typical orbit for deployed satellites by the ISS. A total of four types of mission instruments are used; High Precision Telescope (HPT) with 3-m spatial resolution, Spaceborne Multispectral Imager (SMI) with 61-m spatial resolution and selective wavelength from 430 to 1 020 nm, Wide Field Camera (WFC) with 180 degrees × 134 degrees FOV, and Middle Field Camera (MFC) with 121.9 × 91.4 km FOV. SMI is using Liquid Crystal Tunable Filter (LCTF), which was firstly demonstrated by RISING-2. The attitude determination and control system are including 4-skew reaction wheels (RW), two-star sensors (STT), fibre optical gyro (FOG), sun aspect sensors (SAS), geomagnetic aspect sensor (GAS), GPS receiver (GPSR), and 3-axis magnetic torquers (MTQ).

The power subsystem consists of solar cells with 28.3% efficiency and NiMH batteries (10.8 V, 7.4 Ah, 79.9 Wh). Power generation is 38.6 W on average during sunshine phase, and consuming power is 56.9 W at maximum in X-band communication mode for image download. It is operated most of the time with 6.1 W stand-by mode to keep the battery full, except for the observation target areas or for passes over ground stations. This satellite structure is a completely new concept to the team, so a body-mount solar panel was chosen to avoid a complex deployable solar paddle. Solar cells are mounted on five panels of the top and side. Table 13 summarizes the systems specifications of DIWATA-1.

Initial operation was fully carried out in Tohoku University ground station at Sendai, Japan, and later DOST-ASTI ground station at Metro Manila was mainly used. Uplink frequencies are UHF in Japan, and S-band in the Philippines. Downlink frequencies are S-band with limited bitrates for house-keeping status data and thumbnail mission images and X-band for full-scale mission images with 2.4 Mbit/s.

TABLE 13

System specifications of DIWATA-1

Size and Weight at Launch			Attitude Determination and Control	
size	W 550 x D 350 x H 550 mm		type	3-axis active control by reaction wheels
weight	52.4 kg		sensors	star sensors, fiber optical gyro sensors, sun sensors, magnetometers, GPS receiver
Orbit			actuators	3 reaction wheels 3 magnetic torquers
type	Circle		Power	
lifetime	18 months until orbital decay		solar cells	GaAs multijunction cell (28.3% efficiency) 8 series x 19 parallels (total) 18.8V, 0.433A, 8.1W @ series
height	400 km (92.6-min period, Biginning of Life)		batteries	NiMH, 9 series x 2 parallels 10.8V, 7.4Ah, 79.9Wh (total)
inclination	51.6 deg		P. generation	38.6 W (avg. in sunshine, spin)
Mission Sensors			P. consumption	56.9 W (at X-band data download, max.) 49.7 W (at SMI observation mode) 6.1 W (at power saving mode)
HPT	High Precision Telescope 3-m spatial resolution, 2.0 km x 1.5 km FOV 4 CCDs (R, G, B, NIR)		Communication	
SMI with LCTF	Spaceborne Multispectral Imager with Liquid Crystal Tunable Filter 61-m spatial resolution, 40 km x 30 km FOV 2 LCTFs (430-740nm, 730-1020nm) selective wavelength with 1-nm interval		location	Manila station with 3.7-m dish, Philippines Sendai station with 2.4-m dish, Japan
WFC	Wide Field Camera 7-km spatial resolution, 180 deg x 134 deg FOV panchromatic CCD		uplink	S-BAND, 1 kbps at Manila UHF, 1.2 kbps at Sendai
MFC	Middle Field Camera 185-m spatial resolution, 121.9 x 91.4 km FOV Bayer-array color CCD		downlink	X-BAND, 0.5W, 2.4 Mbps max. at Manila, Sendai S-BAND, 0.1W, 200 kbps max. at Manila, Sendai

The first difficulty of development was to design the new dimension structure with 55 × 35 × 55 cm dimensions, a task which took about six months. After the assembly of the flight model by skipping the engineering model, the flight model vibration test was held in September 2015. The test case was simplified to only one-minute random vibration in each axis. The level was 4.85 Grms and the peak PSD was 0.08 g2/Hz in 30-80 Hz.

Following the success of DIWATA-1, the team developed a successor, DIWATA-2, and launched it into Sun-synchronous orbit (SSO) at an altitude of 613 km by the H-IIA rocket in October 2018. The basic system inherits first satellite and tries to add some new elements such as solar array paddles, extended attitude control, and amateur radio function. As of June 2021, this satellite has been operating safely. Furthermore, the latest satellite launched into orbit in March 2021, developed by Hokkaido University and Tohoku University with other country inherits the functions of the DIWATA series with enhanced payload sensor resolution, attitude control performance, and downlink speed (20 Mbit/s).

Tohoku University and Hokkaido University are managing a ground station network in cooperation. As of June 2021, a total of five satellites are operated by three ground stations. It will extend to ten satellites and six ground stations by the end of 2022. The operations of ground stations and satellites are managed by an original system named Satellite Operation Management (SOM), consisting of a server database with API services and client applications. Multiple satellite operators can easily manage the communication passes over ground stations. This also has a function to manage the timings of Earth observations, data communications, and other various experiments to help the quick command generation.

FIGURE 33

Ground stations by Tohoku University and Hokkaido University, a) Sendai, JP, b) Hakodate, JP, c) Kiruna, Sweden

Handbook on Small Satellites-33

9.1.2 HORYU-4, for space research

HORYU-4 is a nano-satellite developed by the Kyushu Institute of Technology (Kyutech), Fukuoka, Japan. The objective of HORYU-4 is to acquire on-orbit data of discharge phenomena occurring on high voltage solar arrays to deepen the understanding of satellite charging, to contribute to the reliability improvement of current space systems, and to positively contribute to the realization of future high power space systems.

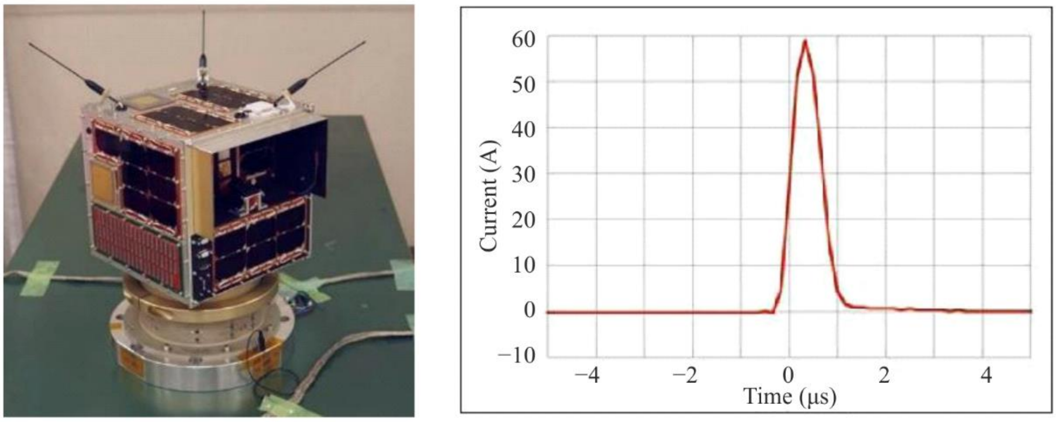
HORYU-4 is a successor of the HORYU-2 satellite that carried out in-orbit experiments of high voltage power generation. HORYU-2 was launched in May 2012 and made the world record of the highest photovoltaic power generation in orbit at the time, 350 V. Since HORYU-2, Kyutech has been developing nano-satellites to do various in-orbit scientific experiments related to space environment observation, spacecraft environment interaction, and others. The satellites are designed, built, and operated by Kyutech staff and students.

HORYU-4's main mission was to acquire an arc current waveform by an onboard oscilloscope and capture its image by a camera triggered by the oscilloscope. In addition, HORYU-4 carried out scientific experiments on the arc-mitigation high-voltage solar array, plasma measurement using a double Langmuir probe, vacuum arc thruster, photo-electron current measurement, and polymer material degradation.

The satellite was launched as a secondary payload on February 17, 2016 (08:45:00 UTC) on an H-IIA -F30 vehicle from Tanegashima Space Center (TNSC), Japan. The satellite succeeded in acquiring the arc current waveform and capturing the image at the same time (see Fig. 34). The HORYU-4 mission generated 16 papers in a peer-reviewed journal and helped seven students to obtain doctoral degrees.

FIGURE 34

HORYU-4 flight model (left) and arc current observed in orbit (right)



Handbook on Small Satellites-34

The satellite specification is listed in Table 14. The satellite mass is relatively small compared to its external dimensions. The satellite surface area is determined to fit into the maximum envelope allowed by H2A piggy-back launch specification while gaining more areas to do various scientific payloads. The satellite missions were mostly about spacecraft environment interactions and spacecraft charging. Therefore, many payloads needed to be placed at the external panels.

TABLE 14

System specification of HORYU-4

Size and weight at launch		
	Size	W450 x D420 x H430 mm
	Weight	10kg
Orbit		
	Type	Circular
	Lifetime	Less than 25 years until orbital decay
	Height	575 km
	Inclination	31 degree
Attitude determination and control		
	Attitude sensors	Gyro-sensor, Sun-sensor
	Orbit determination	GPS receiver
	Attitude control	Permanent magnet and hysteresis damper
Power		
	Solar cells	maximum power generation 9W
		average power generation 5.2W
	Batteries	Ni-MH, 3 parallels x 6 series, 5700mAh at 7.2V
	Power consumption	Nominal 5.1W
		Peak (all functions ON) 15.3W
Communication		
	Ground stations	UHF/VHF/L-band/S-band antenna at Kyutech, Japan
	Downlink	UHF (437.375 MHz), CW, beacon (20 wpm)
		UHF (437.375 MHz), FM, 1200 bit/s for data
		S-band (2400.3 MHz), 100 kbit/s for data
	Uplink	VHF (145-146 MHz)
		L-band (1.26 GHz)

Mission payloads	
1.	Onboard oscilloscope (OBO)
2.	Arc event capture camera (AVC)
3.	High voltage solar array (HVSA)
4.	Solar cell degradation measurement (DEG)
5.	Double Langmuir probe (DLP)
6.	Vacuum arc thruster (VAT)
7.	Electron-emitting film (ELF)
8.	Secret ink (INK)
9.	Photo-electrons current measurement (PEC)
10.	Camera for Earth photography (CAM)
11.	Digi-singer (SNG)

The satellite was operated by amateur bands including S-band to downlink the image data. The S-band communication was challenging as the frequency allocated was surrounded by various interference, including WiFi. A very narrow band-pass filter was mounted at the S-band ground station located at Kyutech.

Following the success of HORYU-2 and HORYU-4, various nano-satellites and CubeSats, have been developed at Kyutech. A series of 1U CubeSat constellations, BIRDS satellites, were released from the ISS since 2017. As of August 2021, four generations of BIRDS satellites, in total 14 satellites, were released. Each satellite carried scientific payloads to conduct various in-orbit experiments. The prime purpose of BIRDS satellites is toward human resource development, i.e. capacity building of space emerging countries, rather than the scientific missions. The BIRDS program involved satellites made by Kyutech students sent from Ghana, Nigeria, Bangladesh, Mongolia, Bhutan, Philippines, Malaysia, Sri Lanka, Nepal, and Paraguay. For many of those countries, BIRDS satellites were the first satellite of the country.

Kyutech has also developed CubeSats jointly with Nanyang Technological University (NTU), Singapore. Three CubeSats were already launched: AOBA-VELOX 3 (deployed by ISS, 2017), SPATIUM-I (deployed by ISS, 2018), AOBA VELOX-IV (launched by Epsilon-4, 2019). The satellite missions were to do in-orbit demonstration of technologies, such as thruster-controlled attitude control and a low-light camera needed for future lunar missions, as well as chip-scale atomic clocks to be used for ionospheric plasma measurement through the measurement of signal time delay.

Kyutech soon will launch a 6U CubeSat to do Earth Observation. A CubeSat lunar mission is now under investigation. Kyutech also assists other universities and small business to build CubeSats based on its experiences. All of those efforts are based on heritage of the past nano-satellite activities.

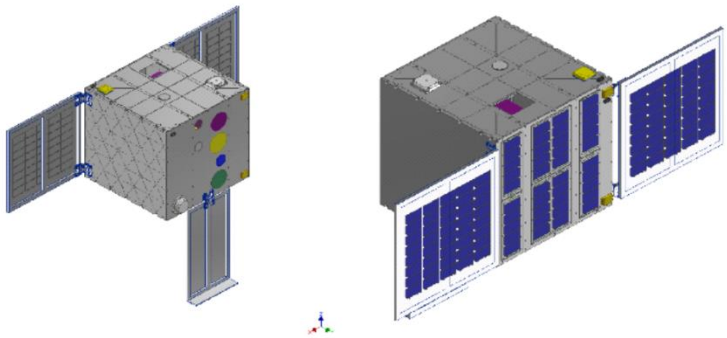
9.1.3 PETREL, for ultraviolet astronomy and Earth observation

“PETREL” is a microsatellite for UV astronomy and remote sensing conducted by an academia-industrial collaboration. For the astronomical mission, the satellite has an 8 cm refractor to find transient sources in the

UV sky. While for the Earth observation mission, two types of “tuneable” multi-spectral cameras making use of LCTF devices are employed. In addition, an ultra-compact hyper spectral camera is employed for filling the gaps of discrete colours. The satellite bus system is designed based on the Hibari satellite of Tokyo Tech and modified for enabling those multiple science and business missions. This remote-sensing project and ultraviolet astronomy mission were accepted as a small satellite project of JAXA’s Innovative Satellite Technology Demonstration program and as an ISAS/JAXA’s small-scale program in 2020, respectively. This satellite will be launched in 2022 with JAXA’s launching vehicle Epsilon rocket. See Fig. 35.

FIGURE 35

External view of PETREL



Handbook on Small Satellites-35

This project was originally proposed by an astronomer who desired a satellite for exploration of explosive objects in the ultraviolet waveband. To avoid the earthshine, the astronomical observations are scheduled only in the night-time. To utilize the daytime more effectively, “satellite sharing” was conceived with the industrial collaborators, which can also reduce the developing cost drastically. The daytime mission is spectroscopy, one of the potential fields in terms of data business, because that can provide chemical and biological information on the surface of the Earth.

The astronomical mission is exploration of short duration phenomena such as supernovae, gravitational wave events, and the other celestial powerful explosions. It is natural that those explosive phenomena are expected to have “blue” emissions in the very early phase due to the shock heating that raises the temperature of stellar material up to $\sim 10^5$ K immediately. UV is therefore one of the frontiers in time-domain astronomy. To avoid the background light and the ordinary stars, a waveband of 250-300 nm is selected. The gravitational wave telescopes, Ligo and Virgo, will have a sensitivity that can detect NS-NS merger within 200 Mpc from the Earth. The expected brightness of the electromagnetic counterparts will be $\sim$18 mag (AB) in UV-band based on the observations of GW170817. The required detection limit is therefore around 20 mag (AB) with a 30 min exposure. The other technical issue is the large error ranges of the gravitational wave telescopes, typically larger than 100 deg^2, that will be the requirement for the FoV of the instrument and survey area. Table 15 summarizes the specification of the UV telescope system. As an imaging sensor, a commercially available back-illuminated CMOS coupling with a specially designed optical-blind UV band pass filter is employed. Figure 36 shows the NET through-put ratio of the telescope system compared with the SDSS filter system and GALEX FUV/NUV. Taking into account the noise from electronics and sky background, even an 8 cm telescope can achieve the detection limit of 20 mag (AB) with a 30 min exposure.

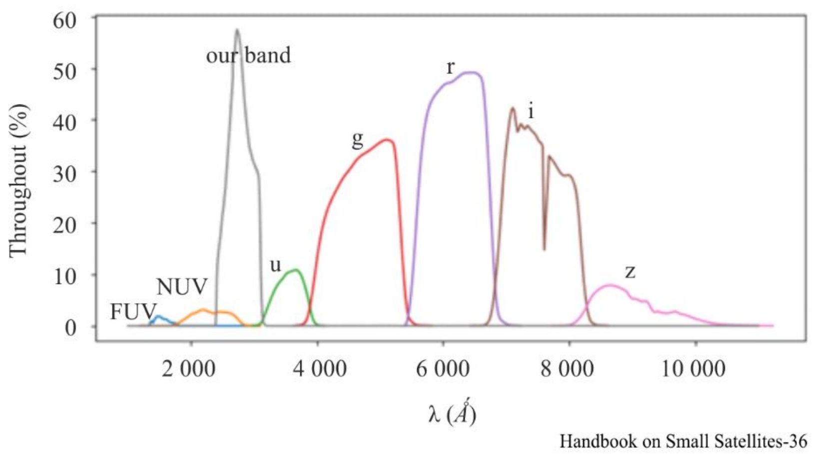
TABLE 15

Specification of UVTEL

Parameter	Requirement
Detector	2k × 2k BI CMOS
Optics	Ø 8 cm refractor (CaF_2 + Silica)
Wavelength	250-300 nm
FoV	7°2 × 7°2 (51.5 deg^2)
Survey area	200 deg^2/orbit (four-point tiling observation)
Detection limit	19 mag_{AB}/7 min 20 mag_{AB}/30 min
Cadence	1 scan/hour
Data link	Within 1 hour after trigger
Data rate	500 MB/day

FIGURE 36

NET through-put ratio of the telescope system



The goal of the Earth observation mission is a demonstration of observation and data analysis of spectral imaging from space. One of the potential targets are the coastal regions. Observing coastal regions to forecast red tides is planned. To evaluate the activities of marine organisms, including mangroves and sea grasses, namely "Blue Carbons", are also planned to be observed. To maintain the world climate issue, the understanding of those biological activities of the blue carbon is essential. Ocean colour observation missions do not require high spatial resolutions, but require wider swaths to cover the target area and higher SN ratio to investigate the plankton in water. In contrast, recognizing vegetation or composition of tree species, at minimum 10 m of spatial resolution is required. Therefore, to have two cameras with different focal lengths was decided, i.e. a high-resolution LCTF camera for visible band (HR) and a wide-field LCTF camera for visible band (VIS). PETREL also has an ultra-compact hyper spectral camera (HYP) to fill up the gaps between the discrete colours of multi-spectral cameras. Table 16 summarizes the specification of the mission instruments for land and sea observations.

TABLE 16

Summary of mission instruments for Earth observation

Camera	GSD (m)	Swath (km)	λ (nm)	Δ λ (nm)	Colours (ch)
HR	10	15	400-800	15	512
VIS	30	100	400-800	15	512
HYP	30	60	400-800	10	40

PETREL is designed based on the satellite bus system of the preceding technological demonstration satellite “Hibari” launched in 2021. For this mission, orthodox 3-axis control with reaction wheels was employed. The astronomical mission requires very high attitude stability better than 10 arcs during 10 s exposure for getting sharp star images. While the Earth observation mission requires the geocentric orientation with a high precision yow-steering. And the satellite should track the ground stations for high-speed RF communication to transfer a huge volume of image data. To achieve those required pointing accuracy and attitude stability, and to support various observation modes, a high-performance compact star tracker with an accuracy of ±5 arcs in boresight is newly developed.

For command uplink/HK downlink, a S-band receiver and transceiver was employed, the same as employed in Hibari. In addition, An X-band transceiver is used to enable a high-speed telemetry downlink. To achieve 20 Mbit/s downlink, a directional patch antenna with a beam width of 30 degrees is employed. The expected total data rate is amount to ~2 GB per day, therefore two or three downlink operations per day are needed. Table 17 summarizes the specification of the satellite bus system of PETREL.

TABLE 17

System specifications of PETREL

Parameter		Value
Structure	Size	600 → 600 →800 mm^3
	Weight	65 kg Two deployable SAPs
Comm	S (up)	10 kbit/s
	S (down)	100 kbit/s (0.5 W)
	X (down)	20 Mbit/s (1.0 W)
	GlobalStar	Alert message (0.07 W)
EPS	Battery	Li-ion Poly 28 V 200 Wh
	Power generation	130 W at EOF
ADCS	Non-biased 3-axis control with 3 RWs	
	Pointing accuracy	5 arcmin
	Attitude stability	10 $arcs_{p-p}$ at 10 s
Mission	Astronomy	UV Telescope (UVTEL)
	Sea and land	HR-LCTF (HR)
		VIS-LCTF (VIS)
		IR-LCTF (IR)
		Compact Hyper (HYP)
Orbit	565 km Sun-synchronous orbit	
	(9:30 at descending node)	
Mission life		2 years

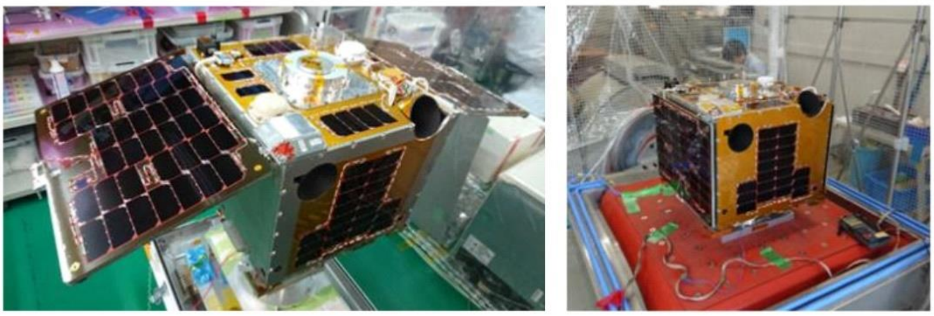
9.1.4 RISESAT, for scientific experiment

The micro-satellite Rapid International Scientific Experiment Satellite (RISESAT) was developed by the joint team of Tohoku University, Hokkaido University, Japanese National Institute of Information and Communication Technology (NICT), Tokyo University of Science and various international payload partners. NICT developed an optical communication experiment instrument VSOTA (Very Small Transmitter for Component Validation). The main scientific payloads are: 1) High Precision Telescope (HPT): National Central University (Taiwan, China) and Hokkaido University, 2) Dual-band Optical Transient Camera (DOTCam): National Cheng Kung University (Taiwan, China) and Hokkaido University, 3) Ocean Observation Camera (OOC): National Taiwan Ocean University (China), Hokkaido University, and Tohoku University, 4) Space Radiation micro-Tracker RISEPix: Czech Technical University in Prague.

RISESAT is a 60-kg-class microsatellite and has been launched by the Japanese Epsilon launch vehicle #4 on January 18, 2019, as one of the main payloads of the Innovative Satellite Technology Demonstration Program of JAXA. The orbit of RISESAT is a Sun-Synchronous Orbit with an orbit altitude of about 500 km with a local time of descending node of 9:30. The flight model of the RISESAT is shown in Fig. 37.

FIGURE 37

Flight model of RISESAT, flight operation started since January 2019



Handbook on Small Satellites-37

One of the main missions of RISESAT is high-ground-resolution multi-spectral Earth observations using a High Precision Telescope (HPT) which is equipped with two Liquid Crystal Tunable Filters (LCTF) with a 2D CCD sensor in each. The ground sampling distance is about 3.7 m and electrically selectable multi-spectral bands are 630 bands ranging from 420 to 1 050 nm with 1 nm intervals. For this observation, RISESAT performs accurate target pointing attitude control during the flyby over the target. The attitude control sensors, such as star trackers, attitude control actuators, and attitude control computers are developed by Tohoku University. A sample picture of the Sendai area in Japan taken by HPT is illustrated in Fig. 38.

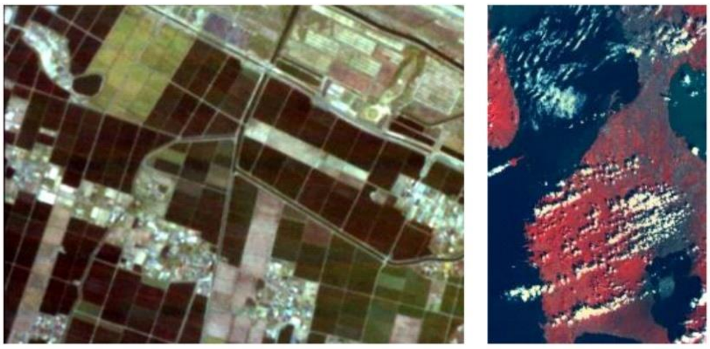
Another main mission of RISESAT is ocean observation with an Ocean Observation Camera (OOC) which is equipped with four spectral colours in order to observe Coloured Dissolved Organic Matter (CDOM). OOC could achieve a higher spatial resolution than traditional ocean observation instruments on larger satellites. A sample picture of the OOC is illustrated in Fig. 38.

The commands to RISESAT are uploaded through either UHF-band or S-band in a redundant configuration. The housekeeping data is downlinked through S-band to multiple ground stations depending on their availabilities. The mission data is downlinked mainly through the X-band and also through the S-band as a backup operation. The satellite is equipped with two deployable solar panels but they are not yet deployed as the power balance is sufficient in the current operations.

The development of RISESAT has been initiated in 2010 based on the technical background of predecessor microsatellites SPRITE-SAT and RISING-2. The aim of the RISESAT project was to establish a versatile high-performance microsatellite platform in order to enable advanced rapid science and technology demonstration missions in a short and cost-effective manner. By inheriting the bus system technology developed for RISESAT, successive missions of the team, such as international Earth observation microsatellite DIWATA-1 and DIWATA-2, aeronomy experiment microsatellites ALE-1 and ALE-2, and some more were developed in very short development schedules and successfully operated. The project DIWATA-1 and 2 aimed to provide space educations to young professional engineers of Philippines and Japanese Universities who welcomed those team members as graduate students. ALE-1 and ALE-2 were collaborative projects with an industrial partner as a spin-off from the research and development activities. See Fig. 38 and Table 18.

FIGURE 38

Example of observation images: left) A true colour composite image of Sendai, Japan, acquired by the High Precision Telescope and JSASS; right) Image of Taal Volcano, Philippines, acquired by the Ocean Observation Camera and Hokkaido University



Handbook on Small Satellites-38

TABLE 18

System specifications of RISESAT

Size and weight	
size	W 500 × D 500 × H 500 mm
weight	59.2 kg
Orbit	
type	Sun Synchronous Orbit (SSO)
local time	LTDN: 9:30
altitude	500 km
inclination	Approx. 98 degrees
Attitude determination and control	
method	3-axis stabilization
pointing accuracy	< 0.1° (3σ) (Reqs.), < 0.04° (3σ) (Objectives)
	6”/s for 200 ms
sensors	Star sensor (2), FOG (3-axes)
	Magnetometer (3-axes), GPS receiver (1), course and accurate sun sensor (4π)
actuators	Reaction wheels (4)
	Magnetic torquers (3-axes)

TABLE 18 (*end*)

Power supply	
solar cells	GaAs multijunction cell
	10 series × 5 parallel × 3 panels
	(Deployable panels and one body panel)
	10 series × 1 parallel + 10 series × 2 parallel
battery unit	9 series × 2 parallel NiMH (3.7 Ah, 10.8 V)
max. power generation	> 100 W
max. power consumption	> 50 W
Communication	
command uplink	UHF, 1 200 bit/s at Sendai station, Japan
	S-band, 1 kbit/s at Sendai station, Japan
HK downlink	S-band, 0.1 W, max. 100 kbit/s
	main: Sendai station, Japan
	sub: Kiruna station, Sweden
Mission data downlink	X-band, 0.5 W, max. 2.4 Mbit/s
	main: Sendai station, Japan

RISESAT is operated by utilizing a ground station network managed by Tohoku University and Hokkaido University in cooperation. Multiple satellite operators can easily manage the communication passes over ground stations through standardized interfaces. Some of the ground stations in the network is illustrated in section 9.1.1.

9.1.5 TeikyoSat satellite series, multi-purpose experiment on orbit

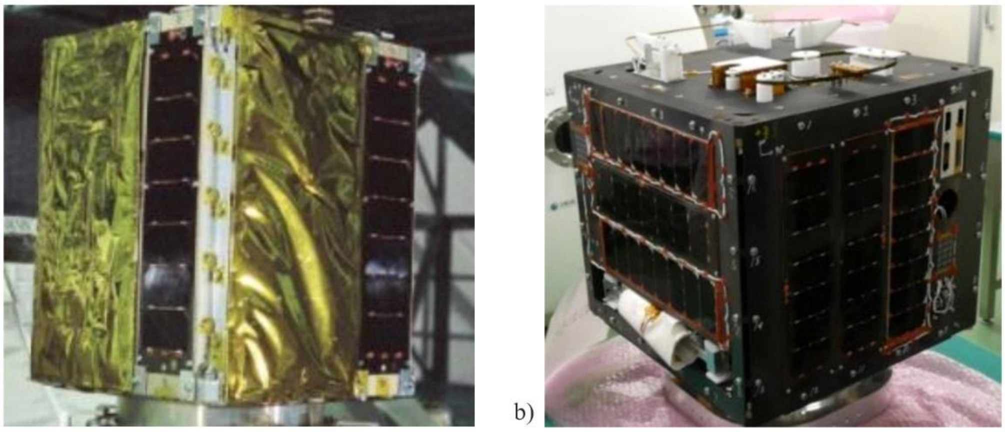
The micro-satellite TeikyoSat-4 was the latest satellite developed by the student team named “Space System Society” of Department of Aerospace Engineering, Faculty of Science and Engineering, Teikyo University. This Satellite project was funded by a grant from the private university strategic research infrastructure support project (S1511009) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) from FY2015 to FY2019. TeikyoSat-4 was selected as a piggy-back satellite of the 2nd Innovative Satellite Technology Demonstration program, 2020. Now, the team is preparing the operation. TeikyoSat-4 will be launched by Epsilon rocket No. 5 on 1 October 2021.

TeikyoSat Programme begun in 2009 as an educational programme. In this programme, TeikyoSat-1 and -2 were developed as CanSats for student training missions. TeikyoSat-3 was the first flight model of TeikyoSat Program (see Figs 39 and 40). This satellite was selected as a piggy-back satellite for GPM developed by JAXA and NASA, and launched by H-IIA rocket No. 23 on 28 February 2014.

FIGURE 39

Flight model of a) TeikyoSat-3 (2014) and b) TeikyoSat-4 (2021)

a) b)



Handbook on Small Satellites-39

The primary mission of TeikyoSat-3 was microbe observation on orbit. One of the main objectives of this on-orbit bio-experiment is to evaluate how orbital environments like microgravity and irradiation conditions affect the microbe. Additionally, another aspect is to establish the on-orbit bio-experiment satellite facility. The target microbe was a kind of cellular slime mold called "Dictyostelium discoideum", inhabiting similar environmental conditions as humans. This well-seen microbe is initially sleeping on the agar during launch. After the satellite is activated on orbit, this microbe is awakened by feeding a culture fluid triggered from a ground command. Then, this microbe moves and congregates into large spore masses, and finally, the stem will be grown vertically from the surface of the agar. This grown process will be captured by a microscope installed inside the module as still images. This on-orbit bio-experiment was planned and supported by the student team of "Biology Research Society" of Teikyo University.

The secondary missions were on-orbit engineering demonstration of the 1 atm pressurized module container, including microbe and its observation system consisted of the pumping mechanism of culture fluid to target microbe, microscope system, temperature monitoring system, and heaters, etc. To send the mission data from orbit to the ground station, amateur UHF (435 MHz) downlink frequency was used. To send the commands to the satellite, amateur VHF (145 MHz) uplink frequency was used. The telecommunications configuration has a similar concept as typical amateur radio satellite (CW Morse beacon and AFSK 1 200 bit/s AX.25 data packet downlink). TheikyoSat-3 had a single downlink transmitting system and a single uplink receiving system.

In the operation of TeikyoSat-3, the team had acquired various on-orbit engineering data like the internal pressure and temperature of the module container. It demonstrated the sealing performance keeping 1 atm inside the pressurized module container. The bio-experiment was aborted because the trigger command for the microbe awaking was not received and activated by the satellite. After nine months of operation, the satellite decayed on 25 October 2014.

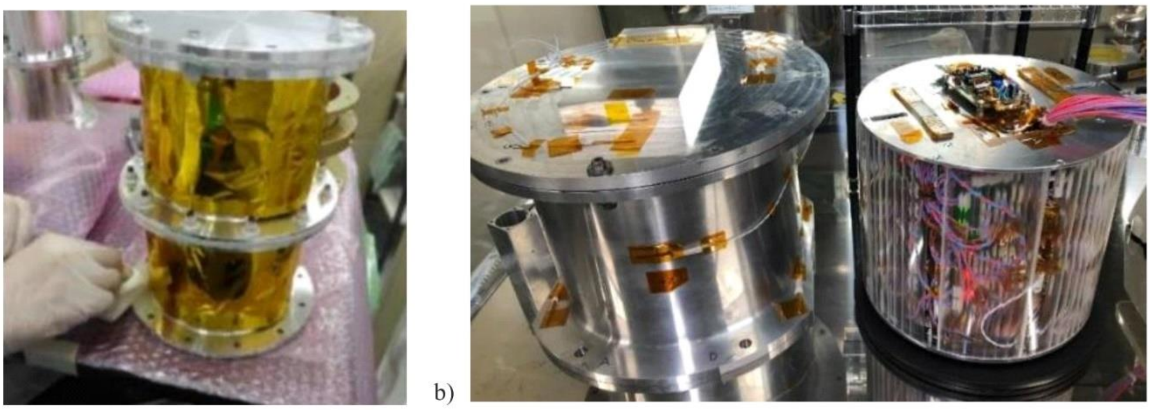
TABLE 19

Comparison of system major characteristics of TeikyoSat-3 and TeikyoSat-4

Satellite name	**TeikyoSat-3**	**TeikyoSat-4 (Japanese name: Ooruri)**
Launch	H-IIA Piggyback, 2014	Epsilon Piggyback, 2021
Launch date	28 February 2014	1 October 2021 (TBD)
Decay date	25 October 2014	
Orbit lifetime	239 days (in practice)	11 years (in prediction)
Mission term	1 month	3 to 12 months
Orbit condition	Alt. 407 [km]	Alt. 585 [km]
	i = 65 [degrees]	i = 97 [degrees]
Mass (kg)	21	51
Size (mm)	W 320 × D 320 × H 440	W 500 × D 500 × H 500
Communication band	Downlink [1]: 437.450 MHz	Downlink [1]: 437.450 MHz
	Uplink [1]: 145 MHz-band	Downlink [2]: 437.450 MHz
		Downlink [3]: 5 831 MHz
		Uplink [1]: 145 MHz-band
		Uplink [2]: 1 200 MHz-band
Communication properties	Downlink [1]: CW Morse, AFSK 1 200 bit/s AX.25 Packet	Downlink [1]: CW Morse, AFSK 1 200 bit/s AX.25 Packet
	Uplink [1]: AFSK 1 200 bit/s AX.25 Packet	Downlink [2]: CW Morse, AFSK 1 200 bit/s AX.25 Packet, GMSK 9 600 bit/s AX.25 Packet, SSTV
		Downlink [3]: Experimental purpose
		Uplink [1]: AFSK 1 200 bit/s AX.25 Packet
		Uplink [2]: Experimental purpose
Amateur Call Sign	JQ1ZKM	JS1YHH
Attitude control	Passive control by a permanent magnet	Magnetic Torquer based Active control

FIGURE 40

1 atm pressurized container, a) TeikyoSat-3, b) TeikyoSat-4 (outside and inside electronics)



a) b)

Handbook on Small Satellites-40

Analysing the mission results of TeikyoSat-3, the TeikyoSat-4 Project was started from 2015 (see Figs 39 and 40). The major mission and the secondary missions are similar to TeikyoSat-3. The main target microbe and observation concept is identical to the previous mission.

To improve the single point of failure or mission capability, the following design points were updated:

1) Dual Telecommunications system consisted of two UHF telemetry transmitting systems and two VHF command receiving systems for redundancy. (One is the heritage of TeikyoSat-3 consisted of deployable monopole and dipole antenna, and the other consists of non-deployable antenna.

2) Additional Telecommunications system consisted of amateur C-band (5.8 GHz) downlink, amateur L-band (1.2 GHz) uplink for technical demonstration purpose.

3) The number of microbe observation systems is increased from single to dual systems. The volume of the 1 atm pressurized container was increased to roughly two times larger.

4) Dual EPS (Electrical Power Supply) for redundancy. One is the heritage of TeikyoSat-3, and the other is a new component developed by a local industry of Tochigi, Japan.).

5) Solar cell area was increased to roughly three times larger to generate more power.

6) Attitude Control subsystem including magnetic torquer, magnetic sensor, sun sensor, gyro sensor.

7) Technical demonstration of deployable sail for accelerating orbit decaying rate.

To demonstrate the capability of multi-purpose experiment satellite, TeikyoSat-4 was an upgraded amateur radio service and outreach mission by adding the SSTV (Slow Scan Tele-Vision) transmission. Over 90 pictures (320 × 240 pixel) contained in an SD card from the SSTV Control Board inside the satellite will be selected and broadcasted by ground command (see Fig. 41). Nominal time to complete an image receiving is roughly 120 seconds.

FIGURE 41

Example of SSTV image of TeikyoSat-4

Handbook on Small Satellites-41

9.1.6 QUESS, for quantum experiments

The QUESS (Quantum Experiments at Space Scale) mission has been laid down for long-distance quantum communication and fundamental tests of the laws of quantum mechanics. Scientific objectives of QUESS are as follows: implementation of long-distance quantum communication network based on high-speed quantum key distribution (QKD) between the satellite and the ground station, to achieve major breakthroughs in the realization of space-based practical quantum communication.

The QUESS had been launched into the sun-synchronous orbit with an altitude of 600 kilometres and inclination angle of 97.79° on 16 August 2016. There are four kinds of payloads onboard: quantum key communicator, quantum entangled transmitter, quantum entangled photon source and quantum control processor. Operating frequency band range is 2 065-2 070 MHz (uplink), 2 284-2 290 MHz (downlink).

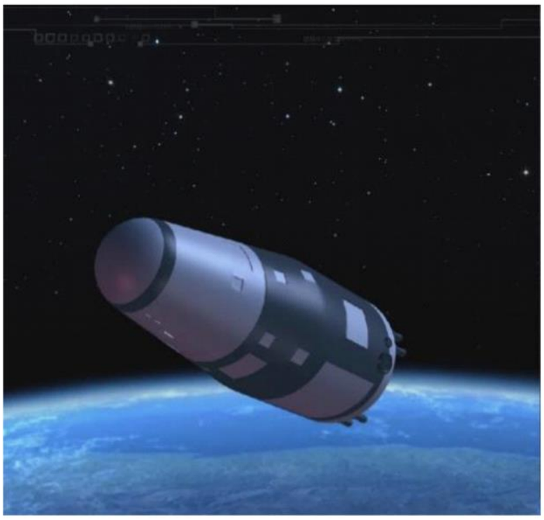
9.1.7 Shijian-10, for scientific experiments

The major scientific objectives of Shijian-10 are to get innovative achievements in kinetic properties of matter and rhythm of life by carrying out various scientific experiments in space. The satellite had been launched into the sun-synchronous orbit on April 6, 2016, and return to earth after its 12 days operating. The orbit inclination angle is 63 degrees, the perigee altitude is 220 km, the apogee altitude is 482 km. Nineteen scientific experiments had been carried out onboard the satellite. These experiments were involved in six different fields: microgravity fluid physics, microgravity combustion, space materials science, space radiation biology, gravity biology and space biotechnology.

Operating frequency band range is 2 032.5-2 037.5 MHz (uplink), 2 207.5-2 212.5 MHz (downlink), and the data transmitting frequency is 8 025-8 400 MHz.

FIGURE 42

Shijian-10 satellite scheme



Handbook on Small Satellites-42

9.1.8 SMART-1, for research in technology

SMART-1 is a lunar orbiting small mission for advanced research in technology. On 27 September 2003, the European Space Agency launched the SMART-1 probe into space with the "Ariana" 5g rocket. At 5:42 GMT on September 3, 2006, under the control of scientists, the impact test on the moon was carried out on time to complete its final mission.

Onboard payloads include camera, spectrometer, imager, electronic and dust tester, solar ion engine and electric propulsion diagnostic device. Operating frequency band range is 149.820-149.840 MHz.

9.1.9 DEMETER, for electromagnetic anomalies and ionospheric disturbances study

DEMETER was successfully launched at the end of June 2004. It is used to study electromagnetic anomalies and ionospheric disturbances related to earthquakes and volcanic eruptions, as well as the global electromagnetic environment related to human activities.

The satellite is equipped with five scientific loads: electromagnetic field detector, inductive magnetometer, Langmuir probe, plasma analyser and high-energy particle detector. Operating frequency bands are 10-20 kHz (LF frequency band) and 20 kHz-3 MHz (MF frequency band).

9.1.10 SPRINT-A, for imaging spectrometer

SPRINT-A was successfully launched on 14 September 2013. The main payload onboard is the extreme ultraviolet (EUV) imaging spectrometer. The main tasks were to observe the escape of the interplanetary outer atmosphere, and the extreme ultraviolet light emitted by IO and how to transmit energy in Jupiter's plasma environment by observing the outflow of sulfur ions from IO. The operating frequency bands include 2 079.900-2 082.100 MHz (uplink) and 2 258.160-2 261.660 MHz (downlink).

9.2 Educational missions

9.2.1 The world's first CubeSats XI-IV and XI-V

CubeSat is a project put forward by Professor Bob Twiggs from Stanford University in USSS 1999, involving standard-sized pico-satellites weighing 1 kg or less. The University of Tokyo succeeded in developing XI-IV (pronounced "sai four", short for "X-factor Investigator") and successfully launched it in June 2003, which was the world's first CubeSat in orbit (see Fig. 43). In 2021, XI-IV is still working perfectly, taking images of the earth and downlinking them.

FIGURE 43

CubeSat XI-IV flight model and specifications: almost the same as XI-V

Handbook on Small Satellites-43

Size	10 × 10 × 10 cm^3
Mass	1 kg
C&DH system OBC Storage	 PIC16LF877, 8 bit, 4 MHz EEPROM 256 kbyte
Communication system Uplink Telemetry downlink Beacon downlink Antenna	 144 MHz band, FM 1 200 bit/s 430 MHz band, FM 1 200 bit/s, 0.8 W 430 MHz band, CW, 80 mW Monopole (up) Dipole (down)
Power supply system Solar batteries Secondary batteries	 Single crystal silicone, 1.1 W (average) ion batteries, 6.2 AH
Attitude control	Passive magnetic field aligned control
Sensors	Temperature, voltage, current, CMOS camera

The main goals of the University of Tokyo's CubeSat program are to further space engineering education and to test ultra-small satellite bus technology in orbit. With the exception of its solar cells, it exclusively uses commercially available products and has the important mission of both verifying how they behave in orbit and laying the foundations for future micro/nano/pico-satellite development. Different from the current CubeSat situation, when everybody can buy CubeSat components easily from websites, no off-the-shelf commercial components for CubeSats were available at that time, which forced the development of all the components in-house or by collaboration with private companies (such as the communication module).

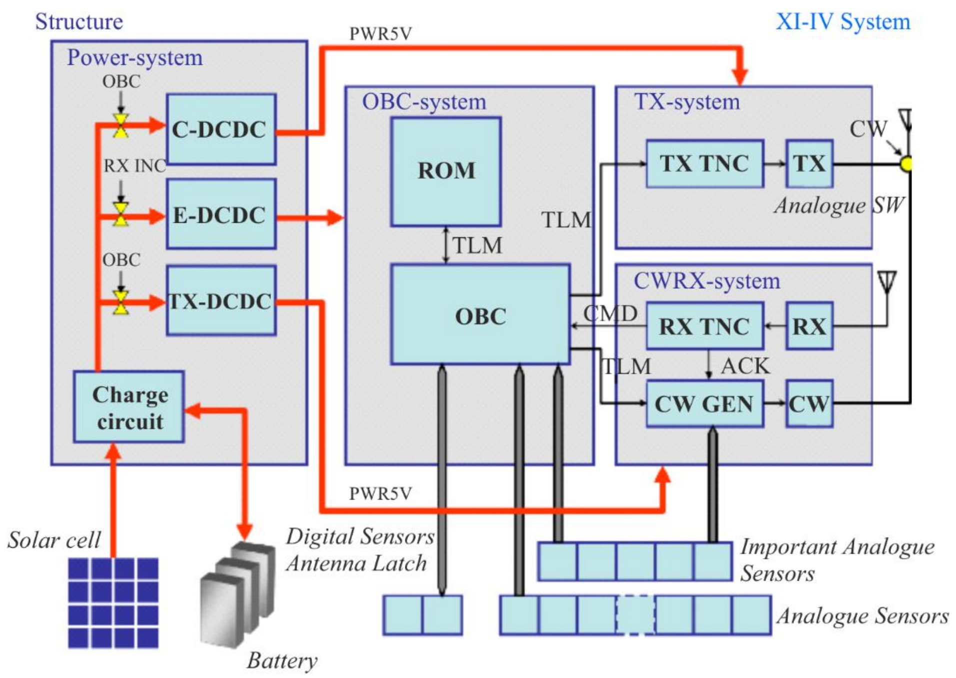
The University of Tokyo is looking into remote sensing as one effective mission that could be performed by micro/nano/pico-satellite. As the first step towards this goal, XI-IV was also assigned an advanced mission entailing obtaining and downlinking images of Earth using a miniature CMOS camera. Two flight models, called XI-IV and XI-V were developed together with the same design to select one for launch and the other for backup to be kept on the ground, which would be used for trouble shooting when some anomaly occurs in the flight model in orbit.

The specifications of CubeSat XI-IV, which was designed for the initial launch, are detailed in Fig. 43. Of all the satellites whose size and weight have been disclosed, it was the smallest and lightest in the world at that time. All of the parts are commercially available products except for solar cells, meaning that the whole satellite was developed at an exceedingly low cost.

Figure 44 shows the system block diagram of XI-IV and XI-V. Three central processing units (CPUs), PIC 16LF877, are implemented in different subsystems, OBC, TX, and CW/RX subsystems, which are watching the behaviour of the other CPUs mutually, and when some anomalies are detected, some CPUs will reset (power off-on) the power line to the specific CPU. Also, the excess current triggered by the radiation effect can be detected by the CPU of the other subsystem, and power off-on operation is quickly conducted.

FIGURE 44

System block diagram of CubeSat XI-IV (almost the same as XI-V)



Handbook on Small Satellites-44

For communication, it uses an amateur radio-frequency band. The transceiver was developed in collaboration with a private company, which has since been used by a large number of other universities. The beacons and downlink format were released to the public to enable cooperation with a reception from amateur radio operators around the world. The solar cells were single crystal silicon with 16% efficiency based on space specifications. Although active attitude control was initially considered, it was deemed to be difficult to equip a 10 × 10 × 10 cm satellite with an active attitude control system at that time. Consequently, passive attitude control was used, involving fitting a permanent magnet and a hysteresis damper designed to align the satellite with the geomagnetic direction. This is also why the solar cells were mounted on all the body surfaces rather than on wings. These decisions reflected the experiences of other countries, whereby micro-satellites weighing 50 kg or less based on a system of three-axis attitude control and solar paddles had frequently ended in failure in the past as a result of insufficient solar power generation due to anomalies of their three-axis attitude control system.

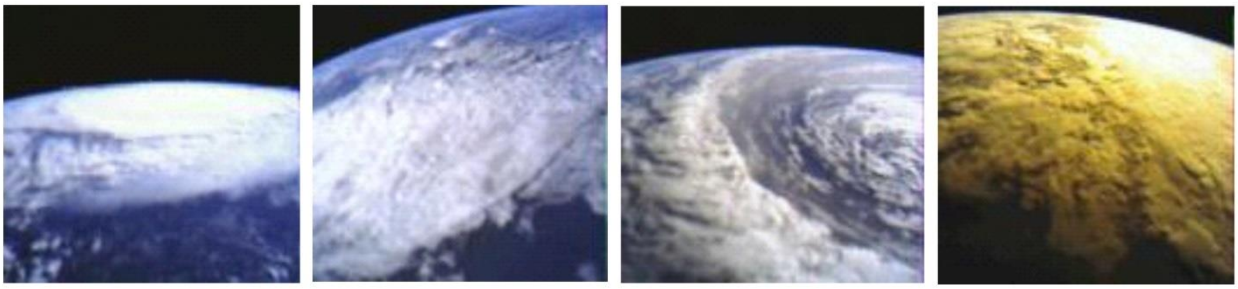
The decision was made to use and test lithium-ion batteries (to be used in mobile phones), which had hardly been used in space previously at that time, due to their high levels of efficiency. The antenna was coiled up on the side and held in place with fishing wire for the launch, using a system whereby the fishing wire would be cut using a nichrome line after separation. This is a method commonly used in the field of micro/nano/pico-satellites as it is simple, low impact, and relatively reliable.

CubeSat XI-IV was launched from Plesetsk in Russia at 11:15 pm (Japan time) on 30 June 2003, using a three-stage rocket called “ROCKOT” provided by a company “Eurockot”. At 0:48 am on the following day, on July 1, XI-IV was successfully delivered into a sun-synchronous orbit at an altitude of 824 km. In addition to the University of Tokyo’s CubeSat, the same rocket also carried CUTE-1 (the Tokyo Institute of Technology’s CubeSat), two 1U CubeSats from Denmark and one from Canada, a US satellite with the size of three CubeSat satellites (3U) called “QuakeSat” and two 60 kg-class satellites called “Mimosa” and “Most”. BREEZE-K, the upper stage of the rocket launched these satellites into their designated orbits in sequence. As it passed over Japan for the first time at 4:36 am on July 1, a CW beacon from XI-IV was received by wireless stations set up at the University of Tokyo and the Sugadaira ground station owned by the University of Electro-Communications, confirming that the satellite had been launched into orbit without any problems and was functioning normally. Since then, the commissioning phase was conducted, when a communication experiment using an amateur frequency band was also successfully conducted together with external amateur engineers.

The University of Tokyo’s CubeSat is equipped with a CMOS camera, which has successfully taken and downlinked more than 700 Earth images over 18 years as in Fig. 45.

FIGURE 45

Earth photos captured by XI-IV (from left, captured in 2005, 2006, 2007, and 2012)



Handbook on Small Satellites-45

XI-V was developed as a twin of XI-IV and was used as backup on the ground when XI-IV in orbit had some anomalies, i.e. XI-V was used to search for the true cause of anomalies of XI-IV in orbit. This method worked quite well, and several problems of XI-IV could be solved efficiently. During that time, an offer of a launch slot was obtained from the team of European student satellite “SSETI-EXPRESS”, which can deploy two 1U CubeSats in orbit. At the same time, a test opportunity in space of newly developed solar cells (CIGS thin-film cell, which is tolerant against radiation) and GaAs high-efficiency solar cells was requested by JAXA. These cells were implemented on one surface of XI-V, which finally has three types of solar cells, Si, GaAs, and CIGS. An onboard camera was also modified with a shorter interval to obtain better images.

XI-V was transported to the European Space Agency where it was loaded into a deployer of SSETI-EXPRESS, which was launched by a Russian COSMOS-3M rocket on 27 October 2005. On the same day, XI-V was deployed successfully, and the first beacon signals were obtained on the night of October 27. Since then, XI-V has been operated successfully for over ten years, including experiments of solar cell performance checks under radiation environment and the onboard camera.

9.2.2 KSU_CUBESAT

The KSU_CUBESAT satellite is the first 1-U launched by King Saud University in Saudi Arabia. The satellite was built and developed by the College of Engineering students with the aim of preparing and training engineering students at the university in the field of designing and programming satellites in line with the Kingdom's vision 2030. The specific objective of the CubeSat is sending telemetry and images by a small camera from space and repeating a received voice signal.

FIGURE 46

KSU_CUBESAT satellite

Handbook on Small Satellites-46

The satellite was launched on 22 March 2021 by the Soyuz Rocket from the Tyuratam Missile and Space Centre, Kazakhstan, in collaboration with Saudi Arabia and the Aerospace Capital (12U deployer). The KSU_CUBESAT is also known by its Norad ID 47954 or the international designation (CO SPAR) 2021-022Y. The satellite orbits with an altitude of 550 km and an inclination of 97.6 degrees, at a speed of 27 000-28 000 km/h and can easily pick up its signal in the Kingdom within 7 to 12 minutes. The lifespan for the KSU_CUBESAT is expected to be 24 months.

The design of the KSU_CUBESAT includes various Commercial Off the Shelf Components (COTS) and a custom Printed Circuit Board (PCB) for the camera and the transmitter as the payload. The CubeSat is equipped with a commercial ARM processor for the On-Board Computer. It measures 0.1 × 0.1 × 0.1 m and weighs 1 kg. The communication system has a UHF transmitter (Mode U – GMSK4k8 AX.25) operating on a downlink band of 437.130 MHz, at a speed of 4 800 bit/s. Moreover, the UHF Antenna System consists of RF Splitter and four monopole antennae, with a typical peak gain of 37 dB delivering a maximum RF power of 10 W. The camera in the system is a 0.3 pixel and weighs 0.4 kg (similar to other 1U CubeSats).

9.2.3 QB50 project

The QB50 project, funded by the European Commission, aimed to use the CubeSat concept to further facilitate access to space for future generations, to carry out novel science, to demonstrate new space technologies, and train young engineers. QB50 had the scientific objective to study *in situ* the temporal and spatial variations of a number of key constituents and parameters in the lower thermosphere with a network of about approximately 50 double CubeSats carrying identical sensors.

The project, coordinated by the von Karman Institute for Fluid Dynamics in Belgium, invited universities worldwide to contribute to the mission with their own CubeSats. Over 50 teams were initially selected and were supported by the QB50 consortium by receiving guidance and key technologies.

The objective “Facilitating access to space” was not solely achieved by procuring an affordable launch for the constellation but also by the unprecedented undertaking in terms of teamwork and the centralized coordination of the administration paperwork. The QB50 Consortium guided the CubeSat teams by facilitating their efforts to develop and ultimately to launch their satellites. For example, the Consortium provided technical guidance for CubeSat development through the definition of system requirements, advice and recommendations for design and milestone reviews. A typical review process (PDR/CDR/TRR/FRR) permitted to validate the developments and eventually the readiness for launch. To facilitate the reviews, templates for the technical documents were provided. They allow for an efficient and effective reporting of the technical design, the development status, and the identification of risks and non-compliances. The review process, conducted mainly by the Consortium itself, helped in mitigating potential flaws in the design and integration of the CubeSats.

The Consortium supported the participant teams also by coordinating all necessary international legal permission for launch. The satellites were registered by VKI with the state of Belgium. In addition, the majority of the CubeSats benefitted from the radio frequency coordination carried out by VKI in collaboration with AMSAT and IARU, the Belgian Institute for Post and Telecom (BIPT) and ITU. The frequency coordination for QB50 was performed together with IARU due to the usage of the radio amateur spectrum. VKI issued a customized IARU coordination letter template together with the radio amateur community to simplify the process for the teams. This template already included pre-filled launcher and orbit information for QB50. After the QB50 teams filled the request with the information of their satellite and the proposed used spectrum for uplink and downlink. IARU coordinated than the requested frequencies in the available radio amateur frequency bands. Due to the rare amount of available VHF frequencies, the downlink was restricted to the UHF band and the VHF tele-commanding frequencies had to be shared between different teams. The distribution has been performed with respect to geographical distribution of the teams with shared uplink frequency. IARU informed each team with a letter including the coordinated frequencies. After the coordination by IARU, VKI together with BIPT (Belgian national telecommunication administration) performed the ITU filing in according with the Radio Regulations by issuing the API (Advanced Publication Information) and afterwards the CR/NOTIF (Coordination/Notification notice) on behalf of the QB50 teams and their local telecommunication offices. For this, a fax had been sent to the local telecommunication offices to notify them of the process and the intention to coordinate the ITU request from Belgium. In case of objections by local offices or the QB50 teams and usage of non-amateur radio frequencies, the QB50 team was in charge to perform the ITU request for their CubeSat independently, interacting with their national administration.

This centralized coordination was very efficient, and it left the CubeSat teams caring only about their own national laws such as export/import regulations. Despite being registered in Belgium, each satellite remained the property of the organization that had developed it and it was operated by its own ground station.

All QB50 CubeSats were successfully coordinated and finally 36 CubeSats (1U to 2U CubeSat), with a common purpose, related to below 300-km altitude atmospheric science missions or related technologies demonstrations such as drag sails or re-entry surviving capsules, were launched in Spring 2017. The (technological and scientific) success level varied from a CubeSat to another, but no perturbations nor detrimental radio-interferences were reported. The QB50 project can be considered as a major success in terms of organization and coordination of what was the first (and is possibly still the only one to date) international collaboration aiming at developing a constellation of CubeSats manufactured by universities and research institutes. QB50 was the first step in Space for many universities and lead to the creation of several start-up companies. Many lessons learned were collected and are made available to the community.

9.3 Experimental missions

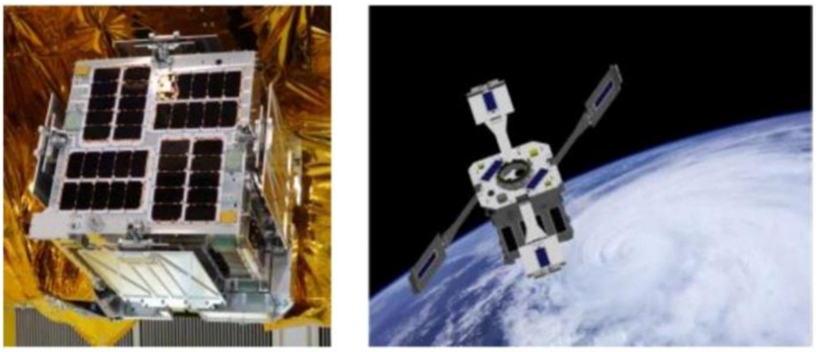
9.3.1 HIBARI, for variable shape attitude control demonstration

Laboratory for Space Systems at Tokyo Institute of Technology has developed a flight model of a 50 kg-class-microsatellite called HIBARI for advanced attitude control technology: variable shape attitude control (VSAC) (see Fig. 47). The satellite is planned to launch on after October 1, 2021 with JAXA’s rocket vehicle Epsiron-5.

A major external feature is the four movable solar panels that can be driven by motors, which are used for VSAC. VSAC enables the attitude of the satellite to be quickly directed in any direction. In addition, the atmospheric drag can be changed by opening and closing the paddles to realize orbit descending control without thrusters.

FIGURE 47

Flight model of HIBARI and on-orbit image illustration



Handbook on Small Satellites-47

TABLE 20

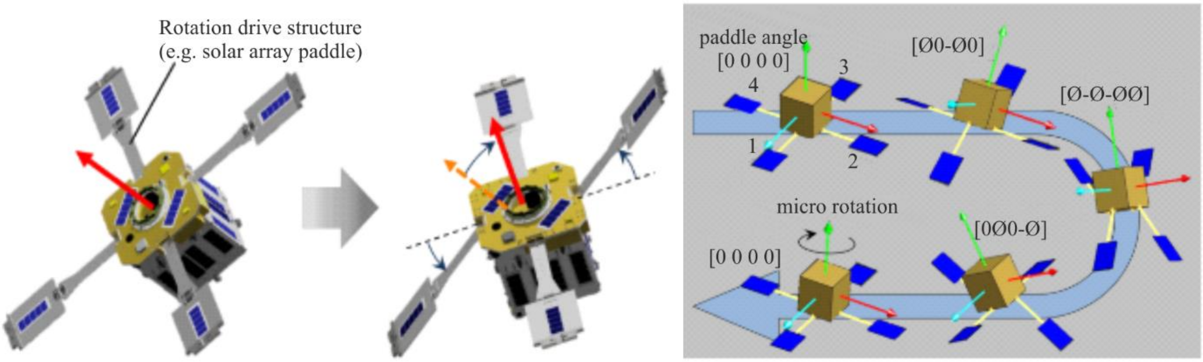
Specifications of HIBARI

Dimension	570 × 570 × 550 mm
Mass	55 kg (main part 45 kg; paddles 2.5 kg × 4)
Communication	S-band Tx/Rx (two antennas each) Globalstar Tx
Power	Li-ion battery, total 161 Wh Typical power generation = 40 W (sun pointing)
Orbit	Sun-synchronous orbit 565 × 547 km, local descending time 9:30)

By changing the system shape on orbit, three main things can be made possible as follows: (1) Attitude control using anti-torque generated by shape change; (2) orbit/attitude control by shifting to desired shapes and changing the external environmental forces such as atmospheric drag; (3) change of satellite function according to the mission. The attitude of the satellite body is controlled by using a part of the solar array paddle as a rotary drive actuator. It has better energy efficiency than conventional wheels. Also, by increasing the mass of the driving structure, the attitude change angle can be increased. This enables agile attitude control as the inertia of the system is increased, which makes stability control easier than previous methods. In addition, by using control under nonholonomic constraints, the satellite attitude can be changed while restoring the shape. By repeating such nonholonomic turns, it is possible to change to any 3-axis attitude, exceeding the limit of the attitude change angle due to the drivable range of the paddles.

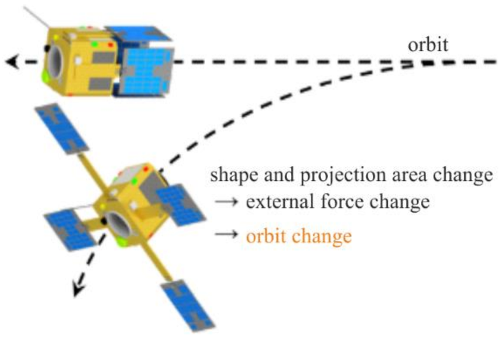
FIGURE 48

Attitude and orbit control by VSAC



a) concept of VSAC

b) example of non-holonomic attitude control



c) orbit control using external force

Level	Mission
Min.	• Confirm attitude change predicted by variable shape function of motor drive
Full	• VSAC ⌗ Agility: 20 degrees/10 sec ⌗ Pointing Accuracy: 5 degrees
Extra	• VSAC ⌗ Agility: 40 degrees/10 sec ⌗ Stability: 300 arcsec / 1 sec ⌗ Large-angle maneuver using non-holonomic control: 40 degrees • Cooperative control with RW ⌗ Stability: 300 arcsec /10 sec • Confirmation of orbit/attitude change with controlled atmospheric resistance

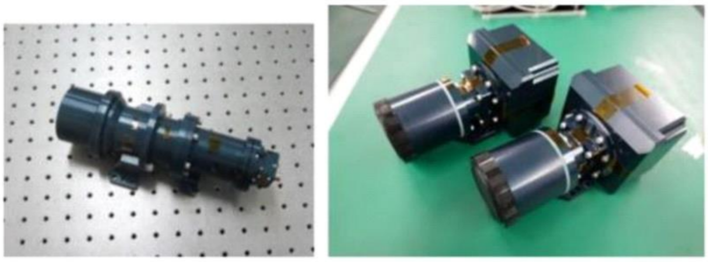
d) success criteria

Handbook on Small Satellites-48

HIBARI carries out the following sub-missions (see Fig. 49). By a newly developed ultraviolet camera UVCAM, it measures emission rays from the upper atmosphere and ultraviolet rays from the aurora over high latitudes. By a visible light main camera, 3-axis relative attitude determination experiment is conducted using continuous Earth and cloud images. Also, newly developed high-performance star tracker (STT) is demonstrated. In communication, the Globalstar Tx antenna STINGR originally designed for ground usage is installed to demonstrate real-time communication with the ground.

FIGURE 49

Variety of sub-mission instruments: left) Visible light main camera, right) high-performance star tracker

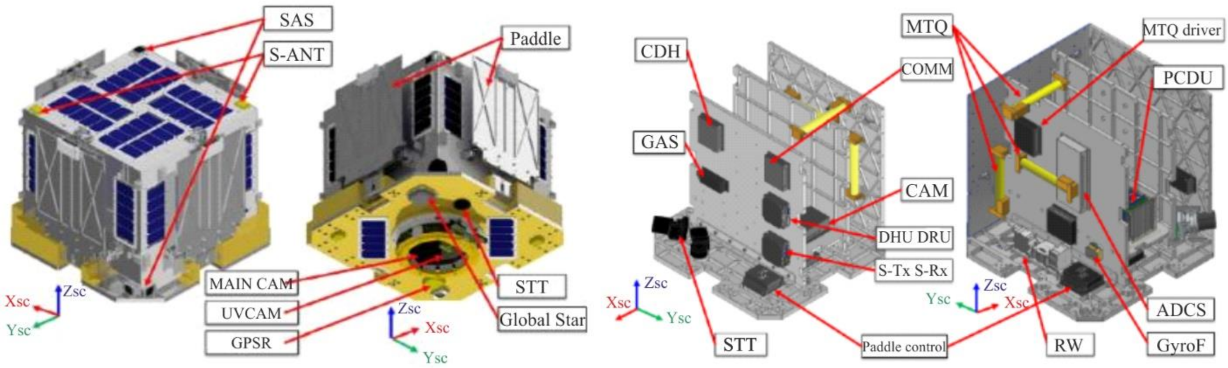


Handbook on Small Satellites-49

Satellite shipping was finished on 18 August 2021 after the additional vibration test caused by battery replacement and the final functional test. The handover and integration to the rocket interface was carried out at the JAXA Uchinoura Space Centre. This work finished in two days (20-21 August 2021) from opening the satellite container after truck transportation.

FIGURE 50

External view and internal structure



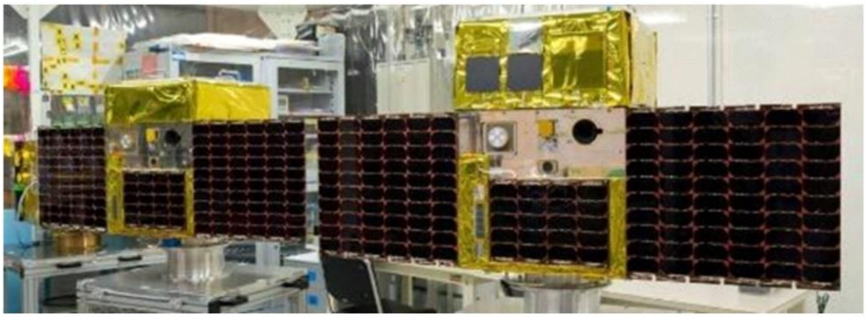
Handbook on Small Satellites-50

9.3.2 Hodoyoshi-3 and 4, for technology demonstration and Earth observation missions

Hodoyosh-3 and 4 were developed by The University of Tokyo together with several Japanese universities and small companies in the "Hodoyoshi Project" (2010-2014). The Hodoyoshi Project ("Hodoyoshi" stands for "just good") has been led by The University of Tokyo and funded by the Cabinet Office of Japan. The project aims to develop technologies and infrastructure for micro-satellites and to seek innovative utilizations. Hodoyoshi-3 and 4's primary missions include Earth observation with 40 m and 240 m GSD (Hodoyoshi-3) and 6.3 m GSD (Hodoyoshi-4) optical cameras. New components developed through the Hodoyoshi Project were implemented for space demonstrations, including a Silicon On Insulator, System On Chip (SOI-SOC) radiation-hardened onboard computer, X-band transmitter with maximum 500 Mbit/s speed, reaction wheels, and ion thruster. "Store and Forward (low-power RF signal collection)" experiment and "hosted payload" business experiment were also tried as additional missions. At the beginning of the Hodoyoshi Project, the University of Tokyo had already developed, launched, and operated successfully three satellites, but Hodoyoshi-3 and 4 were the first satellites for the University of Tokyo to attempt three-axis stabilization using a full set of attitude sensors and actuators, including gyros, magnetic sensors, sun sensors, magnetic torques and reaction wheels.

FIGURE 51

Flight models of Hodoyoshi-3 (left) and Hodoyoshi-4 (right)



Handbook on Small Satellites-51

Three-axis attitude control experiment: Attitude determination using magnetic sensors and sun sensors combined with gyros via Kalman Filtering worked well, and attitude control accuracy and stability required for Earth observation with 6 m resolution was successful. On the other hand, full performance of attitude control was not demonstrated because the star sensor cannot work sufficiently.

Earth observation mission: Hodoyoshi-3 and 4 each has six cameras with different resolutions, which captured Earth photos successfully. Figure 52 shows two example photos taken by Hodoyoshi-3 (left, 240 m GSD) and Hodoyoshi-4 (right, 6.3 m GSD).

"***Store and Forward (S&F)***" ***mission***: S&F mission means that the ground sensors send data to the sky with small power, which is to be captured by the satellite's onboard receiver. This mission was only possible from a certain place in Japan because of RF regulation, but the experiment itself was successful.

"***Hosted Payload***" ***mission***: Several small 10 cm cubic spaces were prepared within Hodoyoshi-3 and -4 into which electric power, an information line, and camera capturing functions are provided. Some experiments with companies using the spaces were successfully demonstrated.

Tests of new components: SOI-SOC radiation-hardened onboard computer, ion thruster, reaction wheels, fibre optics gyro sensors, and X-band transmitters were tested in space successfully. Based on the demonstration results, some of these components were used in many projects afterward.

Table 21 summarizes the specifications of Hodoyoshi-3 and Hodoyoshi-4.

TABLE 21

Specifications of Hodoyoshi-3 and Hodoyoshi-4

	Hodoyoshi-3 (H3) (2014-033-F) [40015]	**Hodoyoshi-4 (H4) (2014-033-B) [40011]**
Size	0.5 × 0.5 × 0.7 m	0.5 × 0.6 × 0.8 m
Mass	56 kg (including H_2O_2)	64 kg (including Xe gas)
Orbit	SSO: 612 × 665 km, e = 0.0037, and = 97.97 deg, LTAN 10:30 AM	SSO: 612 × 650 km, e = 0.0027, and = 97.97 deg, LTAN 10:30 am
Lifetime	3 years (planned)	
Communication System	H/K telemetry downlink: S-band, 32/64 kbit/s, 200 mW/ Command Uplink: S-band, 4 kbit/s Mission data downlink: X-band 10 Mbit/s, 2 W	
Ground Station	JAXA/ISAS Sagamihara Ground Station: 3.8 m, S/X antenna, Peak Gain 36 dBi (S-band)/47.5 dBi (X-band)	
EPS	Generation: max 130 W (GaInP2/GaGa/Ge SolarCell), Power Consumption: average 40-50 W, max 70 W, Battery: 5.8 Ah, Nominal 28 V (24-32V) (Li-Ion Battery)	
Attitude Modes	Initial, Spin-sun, 3 axis Sun pointing, 3 axis Earth pointing, Actuators: RW, MTQs Sensor: FOG, STT, SAS, GAS, Position is estimated by GPS.	
C&DH	OBC: two SOI-SOC On-board computers (OBCs) for Main Data Handing (MOBC) and Attitude Control (AOBC). Software: Developed in HILS with “Hodoyoshi-Satellite Tool Kit”	

FIGURE 52

Photos captured by Hodoyoshi-3 (left) and Hodoyoshi-4 (right)

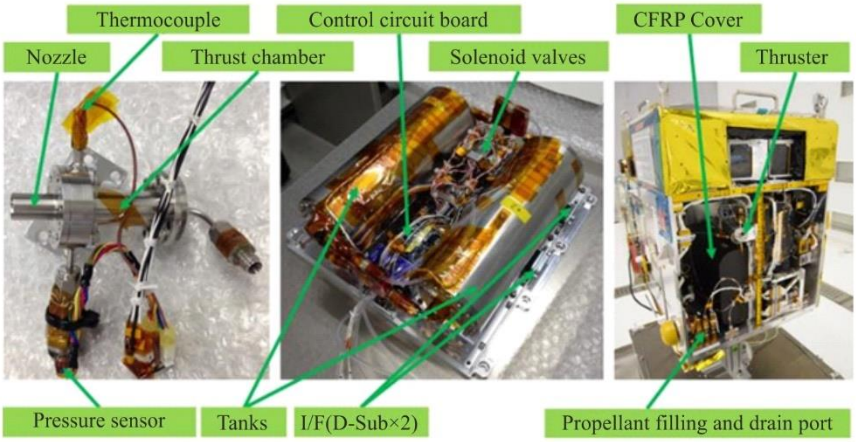
Handbook on Small Satellites-52

9.3.3 Hodoyoshi-1 and Hodoyoshi-3, for demonstration of propulsion system

A group of Tokyo Metropolitan University and National Institute of Technology, Oyama College, is conducting research and development of Microsatellite-Friendly Multi-Purpose Propulsion (MFMP-PROP) based on four policies of “Safety first, Border Free, Effective cost and Easy scalability” (see Fig. 53). With a view to further diversifying and deepening the missions of microsatellites, which can achieve relatively free orbit insertion, constellation construction with on-orbit phase adjustment, formation flight, and halo orbit maintenance around Lagrange points by installing a propulsion system. MFMP-PROPs were installed in two microsatellites and already demonstrated the mono-propellant mode in space.

FIGURE 53

MFMP-PROP installed on Hodoyoshi-3,
left) thruster, middle) entire system, right) installed in Hodoyoshi-3



Handbook on Small Satellites-53

Hydrazine propellant, which has been used for many years, is used for a satellite propulsion system, and its specific impulse can be obtained for 220 to 240 seconds as mono-propellant propulsion by using a preheated catalyst. However, due to its toxicity, legal restrictions, and safety concerns, its use in microsatellites is completely unrealistic. Here, less toxic propellants such as HAN[2)], AND[3,4)], and highly concentrated hydrogen peroxide, rather than hydrazine, is going to be adopted for microsatellites, and they can provide the same or higher specific impulse than hydrazine mono-propellant propulsion. The MFMP-PROP team have also been engaged in the research and development of a low-toxicity propulsion system. Although hydrogen peroxide systems are generally used with a high concentration of about 90%, a solution using 60 wt% hydrogen peroxide (60 wt% H2O2) was adopted for its higher safety, easier handling, and wider availability. Figure 54 shows the filling process of hydrazine and 60 wt% H2O2 (see Fig. 54). While hydrazine propellants require workers to wear scape suits and work in a clean room with explosion-proof equipment, 60 wt% H2O2 requires only simple gloves, protective glasses, and masks.

In mono-propellant mode of MFMP-PROP, oxygen and wet vapor are obtained by catalytic decomposition of 60 wt% H2O2 as shown in Fig. 54, and temperature in the thruster chamber is the boiling point under the internal pressure of the thruster chamber. A number of tests were carried out, and thrust is specified by thruster size and obtained as 350 mN to 500 mN with specific impulse of 80 to 90 seconds. Two MFMP-PROPs specified for mono-propellant system were installed onto Japanese microsatellites, Hodoyoshi-1 and Hodoyoshi-3, and already demonstrated in space.

In bi-propellant mode of MFMP-PROP, 60 wt% H2O2 is used as an oxidizer, and ethanol is mixed with it as fuel and combusted to produce high-temperature gases as shown in Fig. 55. Although the bi-propellant mode of MFMP-PROP has not yet been demonstrated in space, it has achieved a specific impulse of about 220 seconds in ground tests.

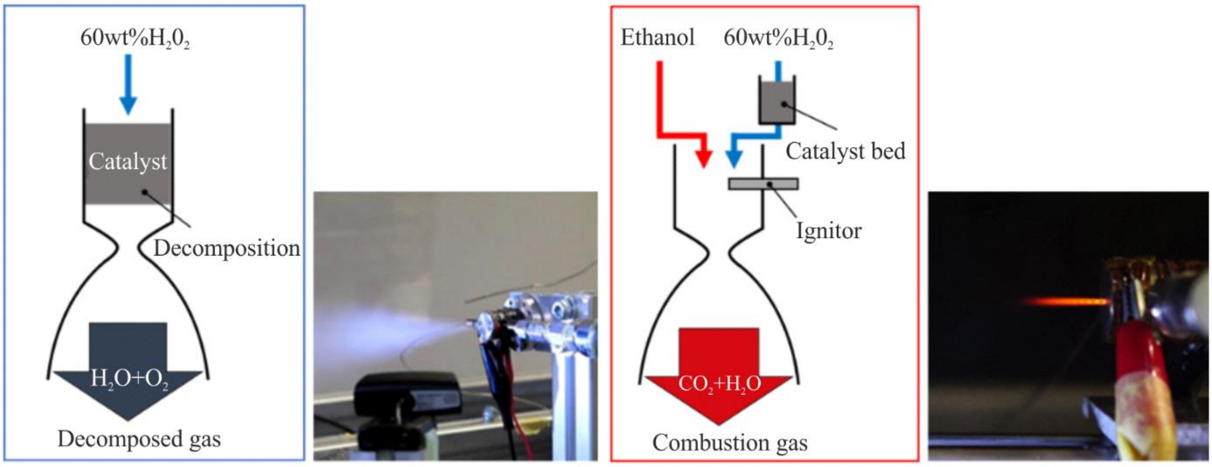
FIGURE 54

Filling process of left) hydrazine into NASA's SDO and right) 60 wt% H2O2 aboard Hodoyoshi-1

Handbook on Small Satellites-54

FIGURE 55

MFMP-PROP operation in mono-propellant mode (left) and in bi-propellant mode (right)



Mono-propellant mode **Bi-propellant mode**

Handbook on Small Satellites-55

The major advantage of MFMP-PROP is that its propellant is safer and far less expensive, although its specific impulse is slightly lower than other low-toxicity propellants. In addition, a thruster that operates on both mono-propellant mode and bi-propellant mode has been developed, so that both small impulse bit with mono-propellant mode and the relatively large thrust with bi-propellant mode, can be obtained in a single MFMP-PROP. Furthermore, modularity of MFMP-PROP ensures the freedom of combination and scalability according to the mission.

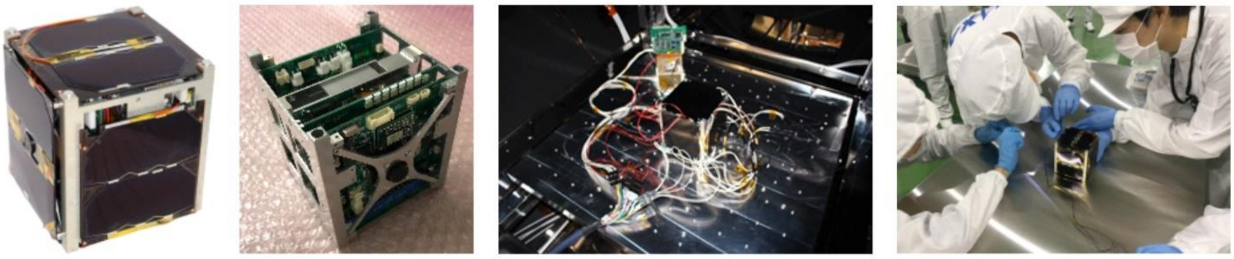
The first MFMP-PROPs were installed on Hodoyoshi-3 (launched in June 2014) and Hodoyoshi-1 (50 cm cubic, 60 kg, launched in November 2014), and injected several times in the mono-propellant mode. Hodoyoshi-1 conducted the injection also in 2020, and its healthy operation was confirmed.

9.3.4 NEXUS, for telecommunication

NEXUS is a 1U CubeSat developed by the joint team of Space Structure Systems Laboratory of Nihon University (SSS) and Japan AMSAT Association (JAMSAT). NEXUS was launched on 18 January 2019 by the Epsilon rocket #4 of JAXA. After two years mission operation, the team achieved the full success of the mission. Additional operations started during April 2021, which is the amateur radio operation using the linear transponder and other equipment and is scheduled and operated by amateur radio people of all over the world. NEXUS will decay in about five years after the launch by the effect of atmospheric drag.

FIGURE 56

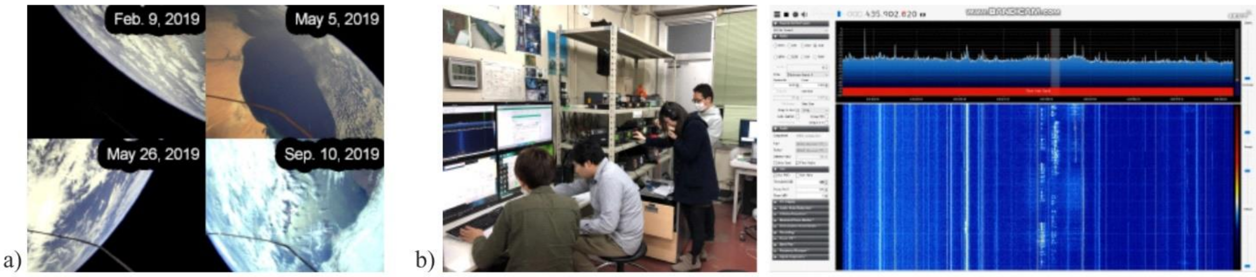
Flight model of NEXUS, flight operation started since January 2019



Handbook on Small Satellites-56

FIGURE 57

Operation results: a) examples of observed images, b) operation of linear transponder



Handbook on Small Satellites-57

The first objective of project is to verify the amateur radio transmitters and the linear transponder developed by JAMSAT. The communication speed of conventional transmitters for amateur radio CubeSat is quite slow, e.g. 1.2 or 9.6 kbit/s, which is not suitable for satellite mission with large amount of downlink data such as Earth observation. So, JAMSAT developed the transmitters of higher communication speed with low power consumption to meet the limited power resource of a CubeSat. Furthermore, many amateur radio people had awaited amateur radio linear transponder (TRP) because few TRPs are available, in particular, no TRP is available for a Japanese satellite. So, JAMSAT developed the TRP, too. The second objective of project is to cultivate university students capable of CubeSat development project management. The project started in June 2016, and the development of NEXUS completed in September 2018. The total duration from the project start to the initial operation after the launch was about two and a half years, which was an appropriate time span for students. SSS had developed three CubeSats, i.e. SEEDS (1U)/2006, SEEDS-2(1U)/2008, SPROUT(8U)/2014, and NEXUS was developed on the basis of their technical heritages.

The mass of NEXUS is 1.24 kg, and the dimensions are W105.0 × D105.0 × H113.5 mm. NEXUS was injected into Sun Synchronous orbit of an altitude of 500 km with 97.3-degree inclination along with other six satellites. NEXUS has four mission payloads: π/4 shift QPSK transmitter (QPSK), FSK transmitter (FSK), linear transponder (TRP), and a camera system (N-CAM). QPSK is a small technology (80 × 40 × 10 mm, 15.5 g) with the bit rate 38.4 kbit/s. FSK is a small transmitter (80 × 28 × 5mm, 6.5 g) with the variable bitrate between

1.2 to 19.2 kbit/s. N-CAM is a small camera system developed by SSS students, and its image size is up to 2544 × 1944 pixels. QPSK and FSK were verified in space by using photos and movies taken by N-CAM. TRP operation is scheduled and used by the amateur radio people.

TABLE 22

System specifications of NEXUS

Size and Weight at Launch		**Mission Equipment**	
size	W105.0 × D105.0 × H113.5 mm	QPSK	$\pi/4$ shift QPSK transmitter
weight	1.24 kg		frequency: 435.900 MHz
Orbit			bit rate: 38.4 kbit/s
type	Circle (Sun Synchronous Orbit)		bandwidth: 24.89 kHz
lifetime	5 years until orbital decay (predicted)		output power: 0.3 W
altitude	500 km (94.6 min period, Beginning of life		protocol: CCSDS
inclination	97.3 degree	FSK	FSK transmitter
Attitude control			frequency: 435.900 MHz
N/A			bit rate: 1.2, 2.4, 4.8, 9.6, 14.4, 19.2 kbit/s
Power			bandwidth: 21.02 kHz
solar cells	triple junction GaAs cell (30% efficiency)		output power: 0.4 W
	2 series × 6 parallels (total)		protocol: Preamble + AX.25
	Vmp: 2.4 V, Imp: 502.9 mA	TRP	Linear Transponder
batteries	Li-ion, 1 series × 4 parallels		TX: 435.880 – 435.910 MHz
	3.7 V, 7.52 Ah, 27.8 Wh (total)		RX: 145.900 – 145.930 MHz
P. generation	3.3 W (avg. In sunshine)		bandwidth: 29.010 kHz
P. consumption	8.9 W (QPSK+N-Cam)		output power: 0.5W
	5.6 W (TRP)	N-CAM	Nihon University miniature camera system
	1.5 W (nominal)		size: 70 × 30 × 10mm (board)
Communication			30 × 30 × 23mm (camera module)
location	Funabashi station, Japan		weight: 23g
	2 × Yagi antenna (polarization diversity)		angle of view: H:63, V:49, D:75 deg
uplink	VHF, 1.2 kbit/s at Funabashi		image size: QVGA, VGA, SVGA, HD,
downlink	UHF, 0.8 W, 9.6 kbit/s (telemetry)		Full HD, MAX(2544 × 1944)

The power subsystem consists of solar cells with 30.0% efficiency and Li-ion batteries (3.7 V, 7.52 Ah, 27.8 Wh). Power generation is 3.3 W average during sunshine phase, and consuming power is 8.9 W at maximum in real time photo image downlink mode with QPSK and N-CAM. It is operated most of time with 1.5 W nominal mode, i.e. only CW output, to keep the battery full except for during the mission operation.

The ground station of NEXUS is located in Nihon University. It has a circularly polarized RX system (CP) and a polarization diversity RX system (PD). The latter system consists of a horizontal polarization system and a vertical one. The effective throughput of PD was compared with that of CP and the polarization diversity was proved to be quite effective in amateur radio operation for receiving large amounts of data.

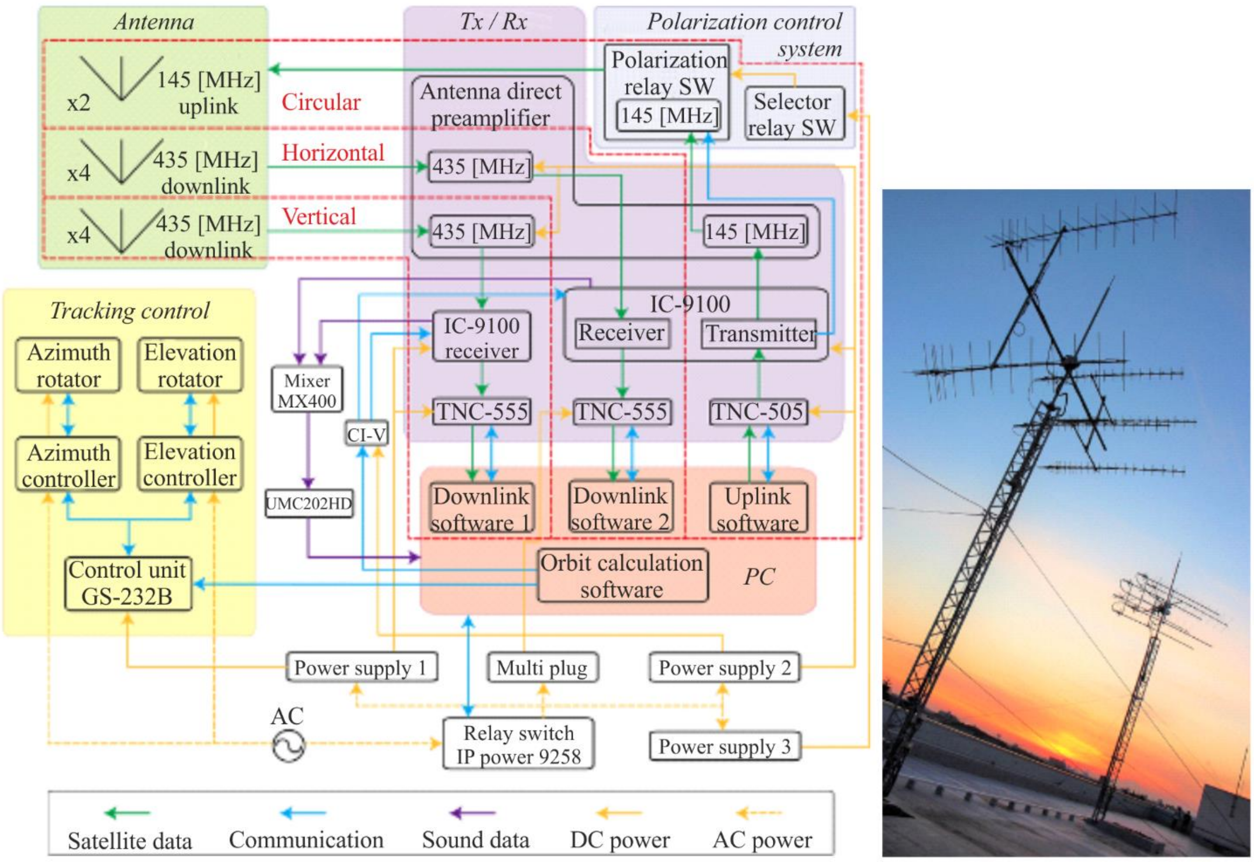
TRP has function to measure received signal strength indication, and the project team made a RSSI map of VHF at 500 km altitude, which clearly clarified the distribution of the VHF radio noise at that altitude.

The detail specification and CAD data of the printed circuit board as well as the structure components of NEXUS are opened at the official website to give the supportive information to new young developers of CubeSat in the world.

SSS in Nihon University moved to the Institute of Space and Astronautical Science (ISAS) of Japan Aerospace Exploration Agency (JAXA) in October 2020. Following the success of NEXUS, SSS is designing two satellite missions. One of them is a radio observation CubeSat mission with a deployable membrane antenna, and the other is an astronomy mission with the formation of two micro-satellites. ISAS/JAXA started CubeSat/micro-satellite missions for space science and will establish a nano/micro space exploration program based on the cooperation with universities in the near future. The above post-NEXUS satellites will be developed in that programme.

FIGURE 58

Ground stations for polarization diversity by Nihon University



Handbook on Small Satellites-58

9.3.5 HIROGARI (OPUSAT-II), 2U CubeSat with deployable mechanisms

The 2U CubeSat HIROGARI (OPUSAT-II) was developed by the joint team of Small Space Systems Research Center (SSSRC) of Osaka Prefecture University, Japan and Aerospace Plane Research Center (APReC) of Muroran Institute of Technology. This CubeSat was deployed in a 400-km circular orbit on 14 March 2021 by the support of Kibo Japanese Experiment Module on the ISS and is still in operation at the end of August 2021.

This satellite has two major experimental missions. One is a deployment of a thick plate with “Miura-ori” folding and the shape measurement of its three-dimensional shape with high accuracy by sampling Moiré method on orbit. This was developed by APRec of Muroran Institute of Technology. The other mission is a demonstration of a high-speed communication system to improve the transmission speed and error correction capability using amateur radio band communication system for amateur satellites that was developed by SSSRC of Osaka Prefecture University, as well as development of the complete bus system. The deployment method of HIROGARI is shown in Fig. 59, and the major specifications are listed in Table 23. The ground station built in Nakamozu Campus of Osaka Prefecture University has been used for communication.

FIGURE 59

Deployment method of HIROGARI (OPUSAT-II) and CG image on orbit

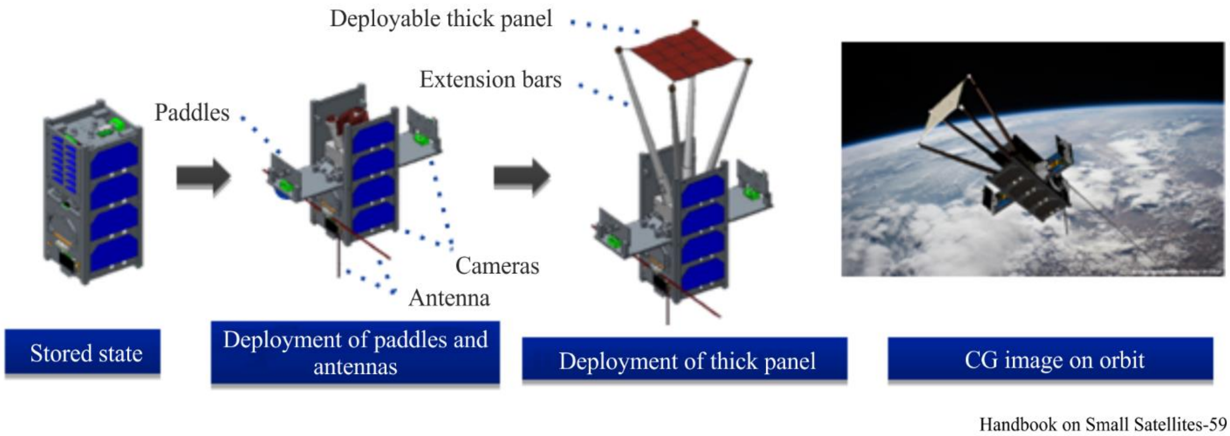


TABLE 23

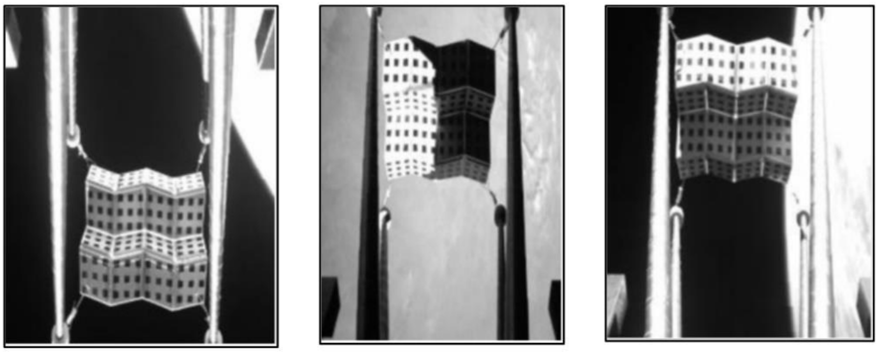
Specifications of HIROGARI

Dimensions (mm)	W100 × D100 × H227 (stored), W350 × D283 × H930 (deployed)
Mass	2.36 kg
Attitude	Passive magnetic attitude control using permanent magnet and hysteresis dumper
Communication	Uplink: FM 1.2 kbit/s (430MHz) Downlink: CW 40/80 wpm, FM 1.2 / 9.6 / 13.6 / 19.2 kbit/s (145MHz)
Power	Lithium-ion battery (1W)
Thermal control	Driven by heater for battery

The first pass was successfully received on March 21 after spending a week within a critical phase after the release on orbit. After a few days for the critical phase, the deployment of Miura-Ori thick panel was tried. It took one more week to confirm the deployment of the paddles on March 30 and more five days to confirm the successful deployment of the thick panel on April 3. The deployment image took on orbit is shown in Fig. 60. Then, the three-dimensional shape of the panel was successfully reproduced by the sampling Moiré method.

FIGURE 60

Images of deployed Muira-Ori thick panel with Earth in background

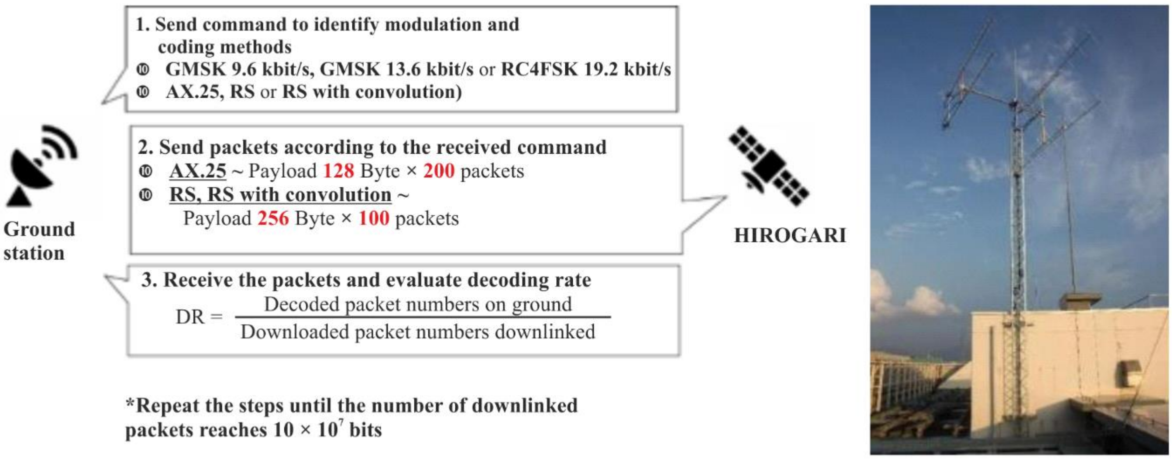


Handbook on Small Satellites-60

The second mission, the communication mission, was almost achieved in success at the end of August. The evaluation flow and the current results are summarized in Fig. 61, where the adopted modulation and the coding methods are summarized in Table 24. As the decoding rate and the effective speed and the decoding depend on the ground conditions including illegal usage of the amateur band, the results are summarized by dividing the daytime in busy traffic and the nighttime in light traffic. Results obtained until mid-August are summarized in Table 24.

FIGURE 61

Flow of high-speed communication mission: right) Ground station in Osaka Prefecture University



Handbook on Small Satellites-61

OPUSAT (CosMoz), predecessor satellite: OPUSAT(CosMoz) shown in Fig. 62, is the first CubeSat of 1U size developed by SSSRC. It was launched by H-II on 24 February 2014 as a piggy payload of the GPM satellite and ended its operation on 24 July 2014 by re-entering the atmosphere.

This CubeSat had two main missions. One is to verify a new power storage device that combines two power supplies, a lithium-ion battery and a lithium-ion capacitor. Charging and discharging on orbit missions were achieved successfully. The other mission was the solar paddle deployment as shown in Fig. 62, which was not completed in this mission but definitely led to the success of HIROGARI mission.

Based on the OPUSAT, the 1U bus kit called OPUSAT-kit as shown in Fig. 62 was developed. Since the bus system can work independently, the desired mission will be carried out by installing the mission board developed by users at the space shown by the red arrow in Fig. 63.

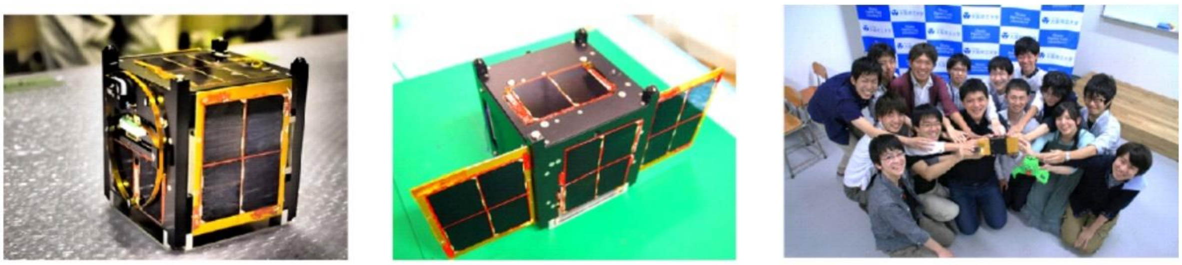
TABLE 24

Decoded rate (DR) and effective speed (ER)

Modulation	Trans. rate (kbit/s)	Coding	Daytime		Night time	
			DR [%]	ER (kbit/s)	DR [%]	ER (kbit/s)
GMSK	9.6	AX.25	54.867	4.20	62.062	4.70
GMSK	13.6	AX.25	48.568	5.22	52.021	5.59
GMSK	13.6	RS w conv.	72.810	3.86	77.979	4.13
RC4FSK	19.2	RS w conv.	42.774	3.20	47.615	3.57
GMSK	13.6	RS	69.053	7.51	72.782	7.92
RC4FSK	19.2	RS	11.807	1.81	18.327	2.82

FIGURE 62

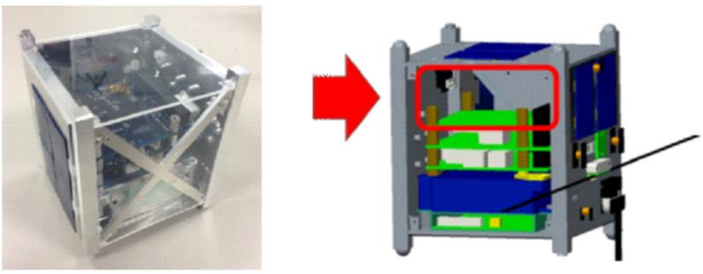
OPUSAT (CosMoz): left) Storage state, mid) Solar puddle deployed state and right) Team members



Handbook on Small Satellites-62

FIGURE 63

OPUSAT-kit



Handbook on Small Satellites-63

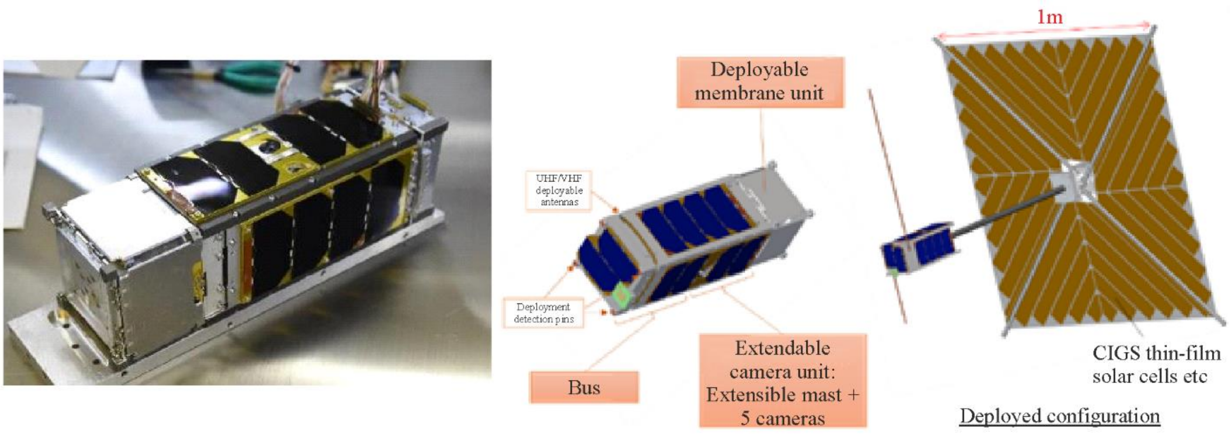
9.3.6 OrigamiSat-1 and succeeding satellites for deployable structure demonstrations

The 3U CubeSat OrigamiSat-1 (FO-98) was developed by the joint team of Tokyo Institute of Technology; Sakase Adtech Co., Ltd.; WEL Research Co., Ltd.; Tokyo Metropolitan University; and Nihon University. It was launched into orbit on January 18, 2019, by an Epsilon Rocket in Japan. The main objective is to demonstrate a “multifunctional” membrane deployable space structure technology in orbit. Thin-film devices attached throughout the membrane will enable innovative space systems, such as ultralightweight array antennas and solar arrays.

OrigamiSat-1’s main mission consists of three items. (M1) Membrane deployment mission: to contribute to the realization of future applications, a multifunctional membrane structure is deployed; and its deployment behaviour and deployed shapes are measured in orbit. (M2) Deployable structure experiment platform mission: to obtain a space demonstration scheme for researchers of space deployable structures, commercially available components are used. In addition, an on-orbit measurement system for deployable structures, using a stereo camera system, is developed. (M3) Amateur radio mission: to enhance radio communication skills, 5.6 GHz band high-speed transmission from space is used.

FIGURE 64

Flight model of OrigamiSat-1, and configuration before/after structure deployment



Handbook on Small Satellites-64

Table 25 shows the basic system specifications. The satellite does not have an active attitude control system. Instead, the neodymium (Nd) magnet was used to passively stabilize the attitude along geomagnetism. Moreover, two pieces of PC permalloy works as magnetic dampers to attenuate angular velocity.

TABLE 25

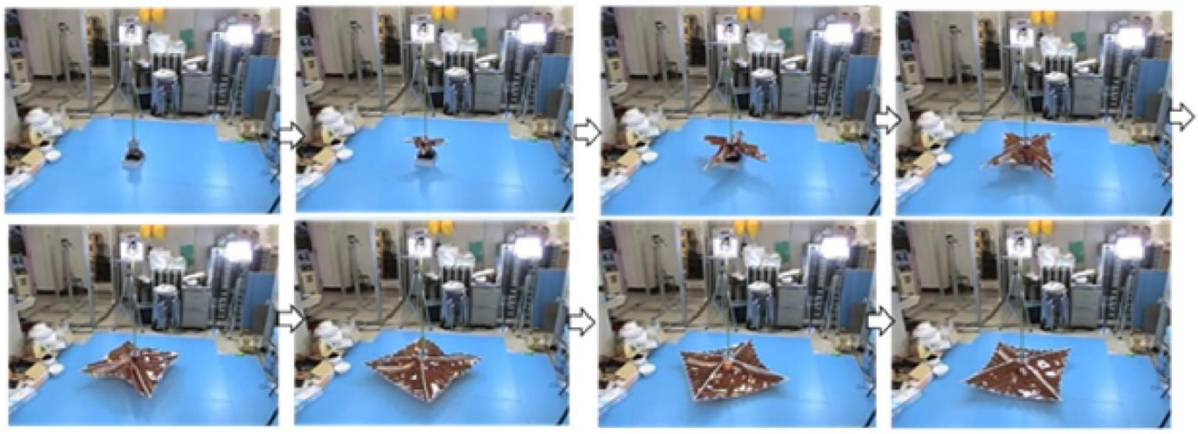
System specifications of OrigamiSat-1

Basic specifications		**Communication**	
Size	100 × 100 × 340.5	Location	Tokyo Tech station, Tokyo
Mass	4.1 kg		Yagi-antenna (UHF/VHF),
Launch	By Epsilon rocket on January 18, 2019		1.8 m-dish (5.6 GHz band)
Orbit	500 km altitude sun-synchronous orbit	Uplink	VHF 144 MHz band, 1 200 bit/s (Amateur Radio)
		Downlink	UHF 430 MHz band, 1 200 bit/s (Amateur Radio)
			SHF 5.6 GHz band, 115.2 kbit/s (Amateur Radio)

The membrane deployment system deploys a boom-membrane integrated structure, folded with a Flasher origami pattern. The membrane is made of plain-woven textile to accommodate the thickness of the on-membrane devices. This membrane enables the attachment of thin-film devices on the entire membrane, such as thin-film solar cells, thin shape memory alloy antennas, and dummy devices made of 50 mm-thick film. The membrane is deployed by four diagonal tubular CFRP (carbon fibre reinforced plastic) booms of 13 mm diameter. Two metal convex tapes are installed in the CFRP booms to increase the deployment forces. The deployment experiment on the ground is shown in Figs 65 and 66. The tips of the deployable booms are suspended from the ceiling for gravity compensation in these deployment tests. OrigamiSat-1 achieved this unique multifunctional deployable membrane design.

FIGURE 65

Deployment test of multifunctional membrane on ground



Handbook on Small Satellites-65

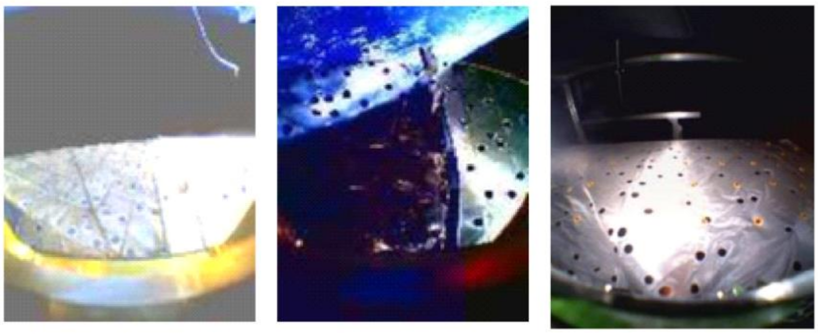
FIGURE 66

Deployment movie taken by onboard camera during ground deployment test

Handbook on Small Satellites-66

FIGURE 67

On-orbit pictures taken by two-sideview onboard cameras and picture taken on ground: left, mid) flight data, right) ground data



Handbook on Small Satellites-67

During the two years of operation until today (September 2021), the communication between the ground station and the satellite has been unstable due to an anomaly, presumably in the satellite communication and power systems. Thus far, the multifunctional membrane was already deployed in space, and its pictures have been taken by two side-view cameras onboard the satellite.

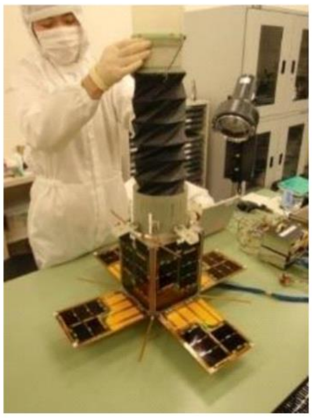
The multifunctional deployable membrane and experiment platform technologies demonstrated by OrigamiSat-1 are to be used in the following successive space demonstrations. First, the component HELIOS, to be flown in 2022 as one of “Innovative Satellite Technology Demonstration-3”, will demonstrate a 1 m-by-1 m multifunctional deployable membrane. Thin-film solar cells and array antennas are attached to the membrane and their functions are to be tested in orbit. Second, OrigamiSat-2 is now planned to demonstrate a membrane reflect array antenna technology.

9.3.7 PRISM with an extensible boom optical system for Earth Observation

Pico-satellite for Remote-sensing and Innovative Space Missions (PRISM) is an 8.5 kg remote sensing satellite for next-generation nano-satellites. The primary mission of PRISM is to obtain 30 m resolution Earth images. In order to acquire high-resolution Earth images, conventional remote sensing satellites have to be equipped with an optical system with multiple lenses or reflection mirrors to realize long focal lengths within their limited size. Such a system requires stiffness of the structure, which induces the increase of mass. In order to reduce the total mass of the telescope, PRISM adopted “an extensible boom” for the optical system. In order to meet the requirement for Earth observation, PRISM should be stabilized by less than 0.7 degree/s during observation, and the optical system should be directed towards a certain point on the Earth. Therefore, an active attitude control system including gyros, magnetic sensors, and magnetic torquers is implemented. In addition, several new ideas for attitude control, including estimation and compensation for the residual magnetic momentum were tested in orbit, providing new data and valued experience.

FIGURE 68

PRISM flight model and specifications

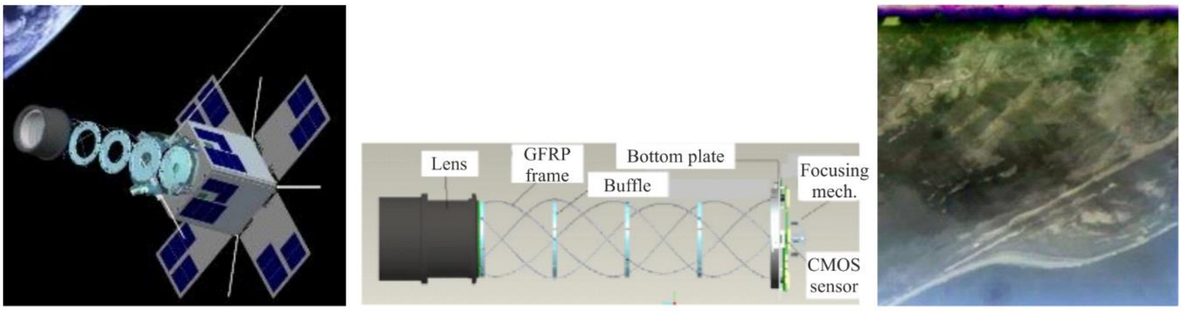


Size and mass	192 × 192 × 400 [mm] (stowed) 8.5 [kg]
Orbit	SSO, LTAN 13 pm Altitude 660 [km]
Attitude Sensors, Actuators	3-axis magnetic sensor, Sun sensor × 5, 3-axis magnetic torquer
OBCs	SH7145 (Renesas technology) H8-3048 (Renesas technology) PIC-16F877 (Microchip)
Communication	Up: 145 MHz AFSK 1 200 bit/s Down: 435 MHz AFSK 1 200 bit/s 435 MHz GMSK 9 600 bit/s
Optical System	Fluorite apochronmat Lens f90 mm, Focal length 500 mm IBIS-5A CMOS 1.3M pixel

Handbook on Small Satellites-68

FIGURE 69

In-orbit image of boom structure for optical system and example of captured image (GSD 30m)



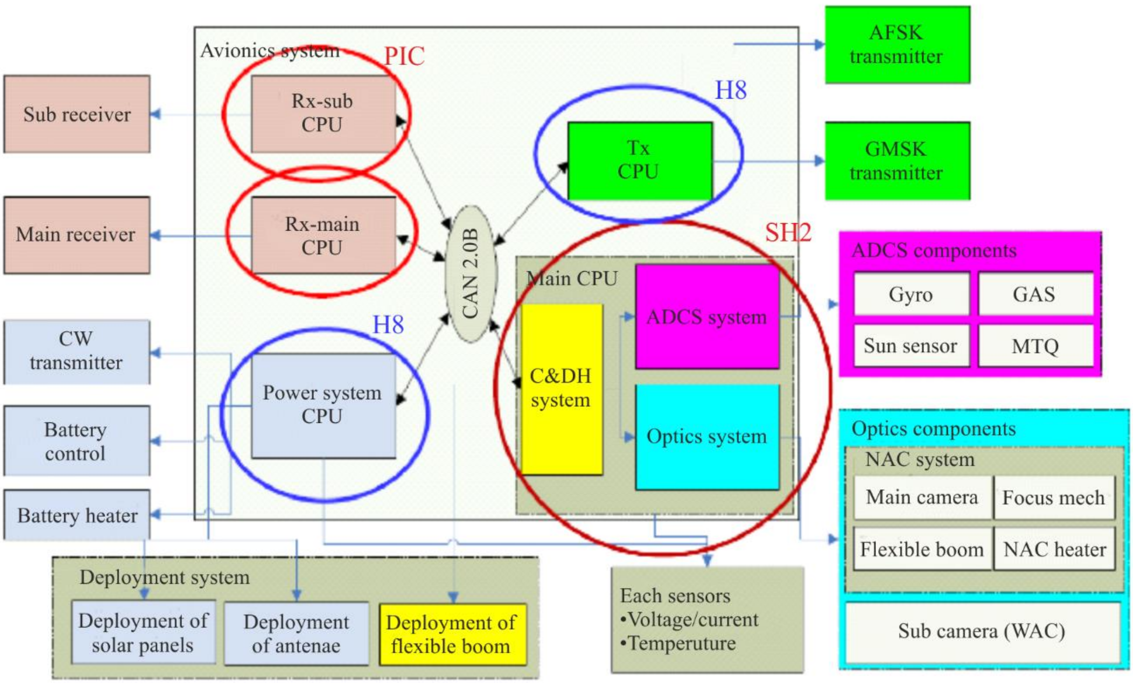
Handbook on Small Satellites-69

The structure of the extensible optical system consists of flexible materials which can extend by only the internal elastic force. Any mechanical actuators are not employed for the extension of the boom. These features of flexible extensible boom enabled the design a very compact, light-weight optical system. In this structure, the glass fibre reinforced polymer (GFRP) frame plays the role of a coiled spring, which pushes the lens and baffle plates out when the structure is unfolded and extended. Some threads connect baffle plates to each other, constraining each distance. These plates determine the total length of the boom and also determine the relative position and the tilt angle of the lens toward the image sensor. Compensation of structural error of the boom is the most distinctive technology for the project. The image sensor board is pushed by a stepping motor while it is pulled by springs. The board is guided by a linear rail and can move straight forward. Thus, the relative position of the image sensor with respect to the lens can be dynamically controlled to keep focusing.

Figure 70 shows the system diagram. As to Command and Data-handling Systems (C&DH), three microprocessors are installed, SH7145F as the main processor, H8-3048 for transmitter and power subsystems, and PIC16F877 for two redundant communication receivers. These processors are connected with each other using Can-Bus, which has high reliability in the severe space environment. PRISM communication subsystem consists of a Tx module and two Rx modules. The Tx module has two radio modules, AFSK1200bps / GMSK9600bps. The AFSK module is mainly used for the downlink of housekeeping data, such as a history of the temperature sensors or current sensors. Furthermore, the GMSK module is used for the downlink of image data. The GMSK module has a communication rate eight times better than the AFSK module, which was first time this was tested in the space environment.

FIGURE 70

System block diagram of PRISM



Handbook on Small Satellites-70

PRISM was launched by Japanese H-IIA as a piggy-back on 27 January 2009, successfully together with the main payload "GOSAT" (JAXA's greenhouse gases observing satellite). Initial checkout was performed, and after two weeks, the extensible boom was deployed by cutting the nylon wire with nichrome heaters. The attitude control experiment was also performed. The magnetic disturbance was much larger than expected and the Earth-oriented attitude by gravity gradient was difficult to keep, due to the unpredicted residual magnetic momentum of PRISM. Residual magnetic momentum estimation was conducted, and attitude control was enhanced with the estimation results. Earth photographs with 30 m resolution were successfully captured in April 2009, three months after the launch.

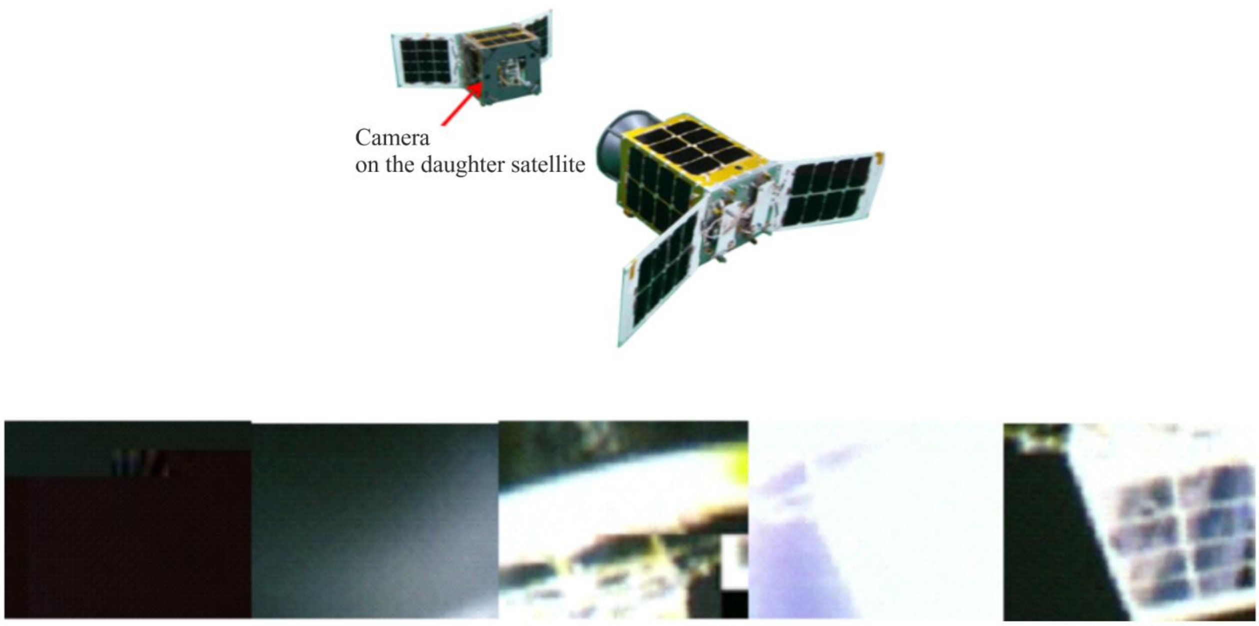
9.3.8 STARS, nano/micro satellite series with tethered deployment mechanism

The STARS (Space Tethered Autonomous Robotic Satellite) is a nano/micro satellite series that deploys mother / daughter / elevator satellites by the original tethered deployment mechanism. Since the first STARS was launched in 2009, successor satellites of STARS-II (2014), STARS-C (2016), STARS-Me (2018) and STARS-EC (2021) were launched by upgrading the system and the missions. The platforms were changed from an initial 10 kg nano-satellites to a 2U CubeSat, and the next STARS-X (2022, scheduled) will be a 50 kg class microsatellite.

Figure 71 shows the flight model of STARS, which was the first satellite in the STARS project, and whose nickname is "KUKAI". The left and the right Fig. 71 show the daughter satellite (3.8 kg, 160 × 160 × 158 mm) which is a tethered space robot, and the mother satellite (4.2 kg, 160 × 160 × 253 mm) which has a tether deployment mechanism, respectively, and they are connected by 5 m Kevlar tether. Each satellite has two paddles for mounting solar cells, and also antennas named "Solar Paddle Antenna (SPA)", which is attached on the paddle edge.

FIGURE 71

STARS flight model (up) and observation images (low, mother sat. taken by daughter sat.)



Handbook on Small Satellites-71

STARS was successfully launched at 12:54 JST (Japan Standard Time) on 23 January 2009. The orbit is sun synchronous (Altitude: 666 km, Inclination: 98 degrees). The CW beacon transmitted from STARS was received by the ground station at 14:34 (mother) and 14:36 (daughter) on time. Hence, the paddle (with antenna) deployment succeeded. Flight models packet uplink and downlink, taking camera photographs and their downlink, and inter satellite communication through Bluetooth, were confirmed successfully for the first ten days.

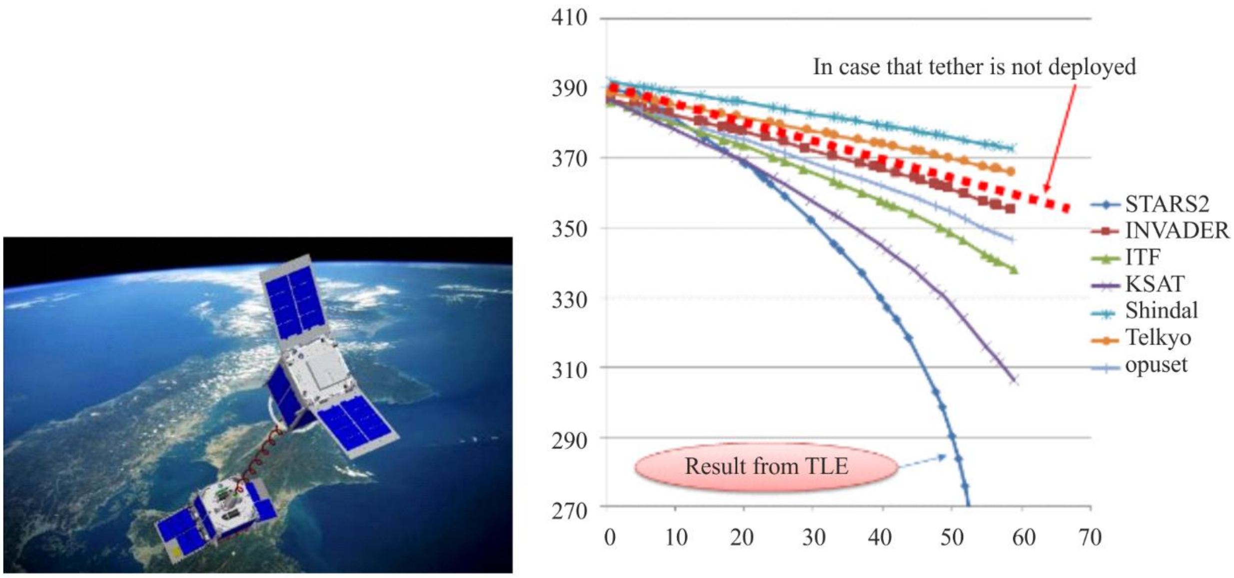
After the initial check, the first trial for tether deployment was performed. As a result of several launch lock release commands, the launch lock was released. Finally, the tether was deployed for several centimetres only. The reason is considered that the compression mechanism (the pulley mechanism) for the deployment springs, was troubled during the reel launch lock release.

Figure 72 shows pictures of the mother satellite taken by the camera mounted on the daughter satellite. Pictures (a) and (b) were taken under the docking condition when the tether was not deployed. It is noted from pictures (c) and (d) that the daughter satellite separated from the mother satellite, that is, the tether was extended. Also, picture and shows the solar paddle of the mother satellite. As a result, it can be said that the tether deployment of several centimetres succeeded.

STARS-II, Electro Dynamic Tether experiment: STARS-II, whose nickname is "GENNAI", was launched on 28 February 2014, as one of piggy-back satellites by the H-IIA rocket. STARS-II consists of a mother satellite and a daughter satellite connected by Electro Dynamic Tether (EDT). The mother satellite deploys an EDT having the daughter satellite at its end. The daughter satellite is a tethered space robot, and it has one arm whose end is attached to the EDT.

FIGURE 72

STARS-II CG image and flight height history (km-days)



Handbook on Small Satellites-72

STARS-II was successfully launched at 3:37 am (JST) on 28 February 2014. The orbital altitude is 390 km, and inclination is 65 degrees. During the 1st pass of 5:13 am – 5:23 am (JST) on the launch day, the CW beacon from the daughter satellite was received at the Kagawa University ground station (JR5YDP). During the pass of 18:36 – 18:47 am (JST) on the launch day, the CW beacon from the mother satellite was received at another amateur radio station (JD1GDE) in Japan. From the CW beacon data, STARS-II successfully separated from the rocket, and the satellite system started.

Figure 72 shows the orbital altitude of seven piggy-back satellites on H-IIA #25, derived from Two Line Element (TLE) delivered on Space Track Home Page. The seven piggy-back satellites are two 50 kg satellites, four CubeSats, and 10kg STARS-II. Theoretically, the orbital lifetime of a 50 kg satellite is longer, and that of a CubeSat (10 cm cubic and 1kg mass) is shorter than that of STARS-II. Their results in Fig. 72 shows proper lifetimes except STARS-II. The orbital lifetime of STARS-II was 52 days, the shortest of all seven satellites. This meant that the tether was successfully deployed. The detailed data of the tether deployment and EDT mission could not be obtained because the main computer malfunctioned.

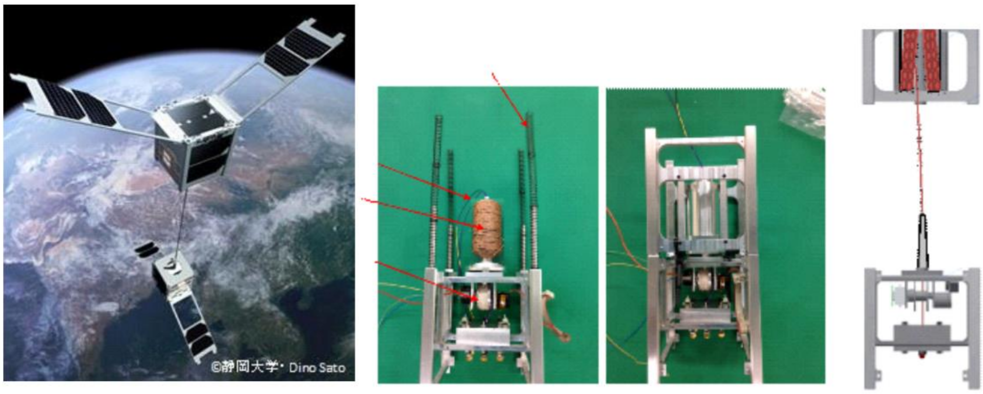
STARS-C, CubeSat for deployment 100m Kevlar tether: The third satellite STARS-C was deployed into orbit from the ISS in 2016. It is a 2U CubeSat, consisting of a mother satellite and a daughter satellite, respectively. They are connected by 100 m long Kevlar tether. The primary purpose is to obtain basic tether deployment dynamics data.

Figure 73 shows the engineering model of STARS-C. The tether is stowed on the spool mounted on the mother satellite (see the left figure). Under docking condition, the tether is covered by the tether box attached on the daughter satellite. Initial velocities of the mother and the daughter satellites for tether extension can be obtained from the spring force. Then, the spool of the mother satellite is pulled away from the tether covered with the tether box. And then, the tether is extended as if a wool ball comes loose. Finally, the tether extension is terminated by breaking force of the tether reel.

By the orbital height history, the tether seemed to be extended shorter than expected which was evaluated by the same method of STARS-II. Telemetry data could not be received well again.

FIGURE 73

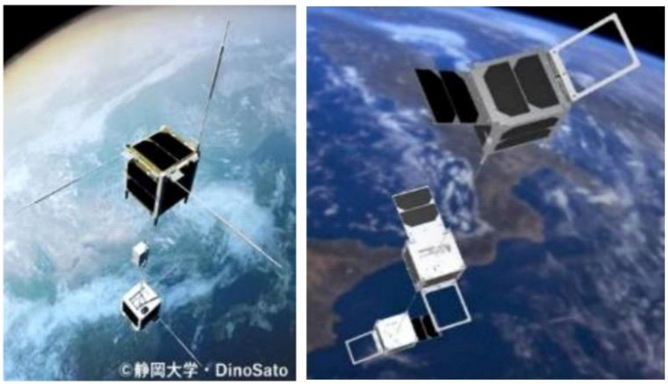
STARS-C flight image and engineering model



Handbook on Small Satellites-73

FIGURE 74

STARS-Me and STARS-EC flight images



Handbook on Small Satellites-74

STARS-Me, Demonstration of mini space elevator: STARS-Me is an extremely small orbital elevator. It consists of two CubeSats having basic functions independently, and each satellite communicates with the ground station independently. The two CubeSats are connected by a steel convex tape tether. One (CV) has a climber and approximately 3 m long tether, and the other (HT) has the tether deployment mechanism consisting of approximately 11 m long tether. The mission sequences are divided into three sections: (i) Two satellites are first secured together and put into orbit. Thereafter, they will be unlocked. Each satellite will simultaneously deploy their antenna. (ii) By the command from the ground station, two satellites will deploy the tether using motors. After acquiring detailed data of each, the separation distance and the stability are analysed. (iii) The climber will traverse on the tether after being unlocked. The climber has a Bluetooth communication with the main satellite. From the data of the climber and each satellite, we analyse the behaviour of the mini elevator.

STARS-Me was launched by the H-IIB rocket on 23 September 2018, and then the HTV vehicle carried it to the International Space Station (ISS). On 6 October 2018, STARS-Me was released from the ISS with other two CubeSats, SPATIUM-I and RSP-00. The CW beacon from STARS-Me, which is automatically transmitted after releasing, was received by many amateur ground stations over the world. The CW beacon from the HT satellite (Call Sign: JJ2YPL) were clear signals, and HT could receive the FM packet command. On the other hand, the CW beacon and FM telemetry signals from the CV satellite (Call Sign: JJ2YPM) could not be received well due to the antenna mechanism. As a result, the first orbital mini elevator was developed, but could not be verified sufficiently. The satellites decayed in June 2021.

STARS-EC, Demonstration of mini space elevator: STARS-EC is also an extremely small orbital elevator, consisting of three CubeSats connected by a steel convex tape tether. The two CubeSats at the ends are same as one CubeSat of STARS-Me, which has the 11 m long tether deployment mechanism. The middle CubeSat is a climber. The mission sequence is follows. First, the one end CubeSat extends the 11 m tether, and then the other end CubeSat also extends an 11 m tether. Then, a 22 m orbital elevator is constructed on orbit. And then, the middle CubeSat moves on the extended tether.

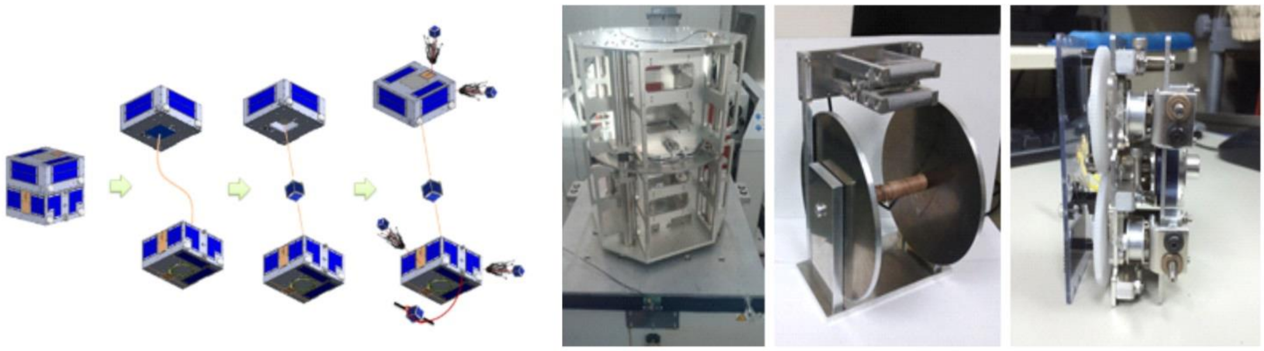
STARS-EC was launched on 21 February 2021, and then released from the ISS on 14 March 2021. The CW beacons from all three CubeSats, those are automatically transmitted after releasing, were received by many amateur grand stations over the world. After initial checking out, in the beginning of May 2021, tether extension and retrieving succeeded. Now in August, the mini elevator is under construction by extending the long tether.

STARS-X, Long tether deployment and space debris removal experiments: The next satellite in the STARS project is STARS-X, which is currently under development. STARS-X is planned to be launched in 2022 by the epsilon rocket. The weight will be around 65 kg, and the size is 540 × 540 × 580 mm. Its primary objective is to perform a 1 km orbital elevator and debris removal demonstrations on orbit. First, a Kevlar tether is planned to be extended for 1 km, and a climber translates on the extended tether. After the elevator demonstration, a dummy debris is deployed from the main satellite which is then captured by a net. Also, another method is planned to wind a dummy by a short tether.

The breadboard models of the mother and daughter satellites, reel mechanism, and climber have been developed as shown in Fig. 75. The reel mechanism for the tether deployment has been developed in order to control tether extension actively using the gravity gradient force, rather than passive control by a spool mechanism as in STARS-II. Also, Kevlar is employed for the tether, and its radius is less than 1 mm in order to stow the 1 km long tether. A wheel mechanism has been employed for a climber based on the technologies accumulated in the space elevator challenges in Japan. Separation and vibration tests for the mother and the daughter are being e conducted.

FIGURE 75

STARS-X mission sequence and breadboard model



Handbook on Small Satellites-75

9.3.9 MYSAT-1 – Earth Exploration Satellite

MYSAT-1 is the first nanosatellite of Yahsat Space Lab, funded by Yahsat in partnership with Khalifa University and Northrop Grumman. It is a 1U size CubeSat that was developed, built, and tested by graduate students from the Yahsat Space Lab. It provides a demonstration of Earth observation by taking images of Earth and transmitting them to the ground station. In addition, it demonstrates the performance of a new type of Lithium-Ion battery in the space environment, developed at Khalifa University's laboratories.

FIGURE 76

MYSAT-1 nanosatellite

Handbook on Small Satellites-76

The satellite was launched back on 17 November 2018 from Wallops Island, Virginia, USA and it was carried out by Northrop Grumman as part of a contract with NASA. Based on the orbital analysis that was conducted by the team, the satellite was agreed to be deployed in the lower Earth orbit (LEO), with an altitude of 471 km, an inclination of 51.7 degrees, and a mission lifetime expectancy of five years.

FIGURE 77

Design of MYSAT-1

Handbook on Small Satellites-77

The design of MYSAT-1 includes various commercial off-the-shelf (COTS) components for the bus and a custom-made printed circuit board (PCB) for the camera and the experimental battery of the payload. The CubeSat bus is equipped with an ARM A9 32-bit core CPU for the on-board computer (OBC), its Attitude, Determination and Control System (ADCS) includes a magnetometer and three magnetorquers for detumbling and pointing capabilities, the communication system has a UHF/VHF transceiver operating between 1 200 to 9 600 bit/s and finally the electrical power subsystem (EPS) it has two batteries with a max output of 8.4 V. The camera chosen was 0.3 megapixels with 16 mm lens due to the low communication speed and the lithium-ion battery was solely developed in the laboratories of Khalifa University. These Li-ion batteries for space applications are lightweight, low-cost, perform well at low temperature and are safer than conventional batteries. These batteries were developed using carbon nanomaterial-based composites electrodes.

9.4 Amateur-satellite missions

The history of amateur satellites can be traced back to the early days of the space age. The first amateur radio satellites, also known as "ham satellites", were launched in the 1960s and 1970s. These early satellites were primarily used by amateur radio operators to communicate with each other and to conduct experiments in space technology.

Over the years, the number of amateur satellites in orbit has increased, and the technology used in their design and construction has advanced significantly. Today, amateur satellites play a vital role in the field of amateur radio, providing opportunities for amateur radio operators to communicate with each other from around the world and to participate in various space-related experiments and projects.

9.4.1 OSCAR (Orbiting Satellite Carrying Amateur Radio) series

Ever since the launch of OSCAR I in 1961, it has been traditional for amateur radio satellites to carry the name OSCAR. The OSCAR series of satellites continues to play an important role in amateur satellite communication today. Well over 100 OSCARs have been launched. The full list of OSCARs is available at https://www.amsat.org/orbiting-satellites-carrying-amateur-radio/.

9.4.2 CubeSats operating in frequency bands allocated to the amateur satellite service

CubeSats are a type of miniaturized satellite that are popular among amateur satellite enthusiasts and educational organizations, due to their low cost and ease of construction. Many radio amateurs and educational organizations have built and launched CubeSats to test new technologies or conduct experiments. These missions demonstrate the creativity, resourcefulness, and passion of the amateur satellite community and their commitment to advancing the field of space technology. A list of CubeSats with their frequencies coordinated by IARU can be found at:

https://iaru.amsat-uk.org/finished.php

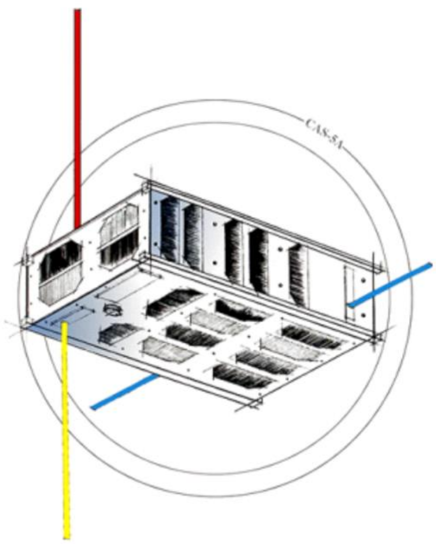
9.4.3 CAS-5A satellite (Fengtai-OSCAR 118 (FO-118))

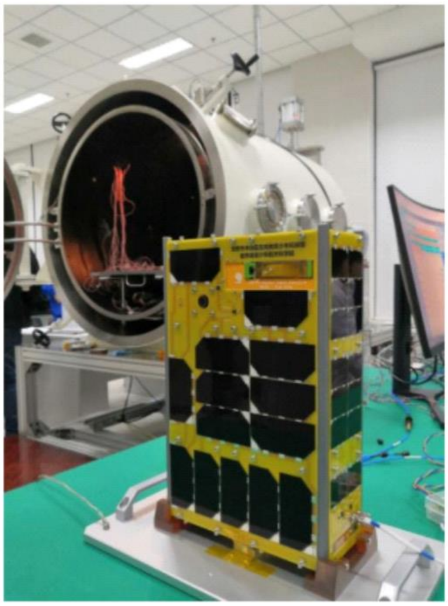
The amateur radio satellite CAS-5A was developed by Chinese Amateur Satellite Group (CAMSAT), and in cooperation with local education authorities. CAS-5A satellite has been designated as Fengtai-OSCAR 118 (FO-118) by Amateur Satellite Group (AMSAT). Thirty-one students from ten high schools learned satellite design, manufacturing, and applications through educational courses initiated by CAMSAT and the Fengtai educational institution.

CAS-5A adopts a 6U CubeSat structure with a mass of about 7 kg and has been launched by the Smart Dragon-3 Y1 launch vehicle from the Chinese sea launch platform in the Yellow Sea on December 9, 2022. The orbit of CAS-5A satellite is a circular sun-synchronous orbit with an altitude of 543 km and an inclination of 97.53 degrees, the orbit cycle is 95.575 minutes.

FIGURE 78

CAS-5A satellite





Handbook on Small Satellites-78

CAS-5A include UHF CW telemetry beacon, GMSK telemetry data transmission, V/U mode linear transponder, V/U mode FM transponder, H/U mode linear transponder, three visible light band space cameras.

FIGURE 79

Photos captured by CAS-5A satellite

Handbook on Small Satellites-79

9.4.4 CAS-7B (BP-1B) satellite (BIT Progress-OSCAR 102 (BO-102))

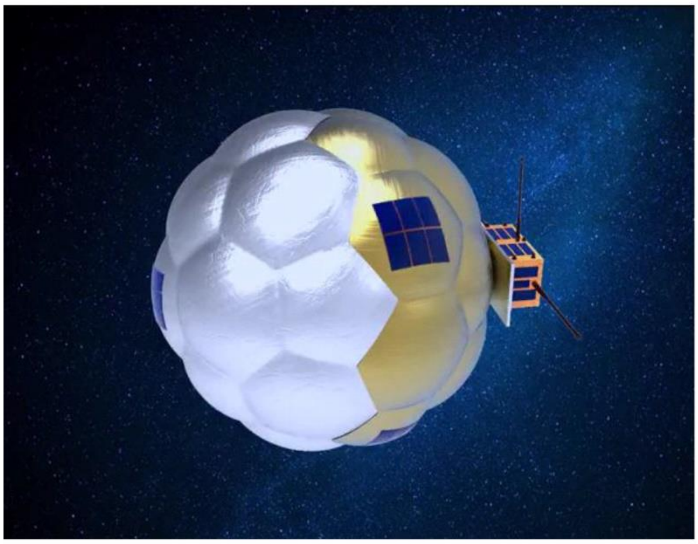
The amateur radio satellite CAS-7B (BP-1B) was developed by CAMSAT, and in cooperation with the Beijing Institute of Technology (BIT). CAMSAT completed the project planning, design, build, and testing, and manages the on-orbit operation of the satellite. BIT provided the satellite environmental testing, launch support, and financial support. Many students from BIT were involved with the project, learning about satellite technology and amateur radio. CAS-7B (BP-1B) has been designated as BIT Progress-OSCAR 102 (BO-102) by AMSAT.

CAS-7B (BP-1B), which adopts a 1.5U CubeSat structure, is a spheriform spacecraft of 500 mm diameter with a mass of 3. 95 kg and has been launched on Hyperbola-1 launch vehicle from the Jiuquan Space Center, China on July 25, 2019. The orbit of CAS-7B (BP-1B) satellite is a circular orbit with an altitude of 300 km and an inclination of 42.7 degrees.

CAS-7B (BP-1B) include UHF CW telemetry beacon, V/U mode FM transponder.

FIGURE 80

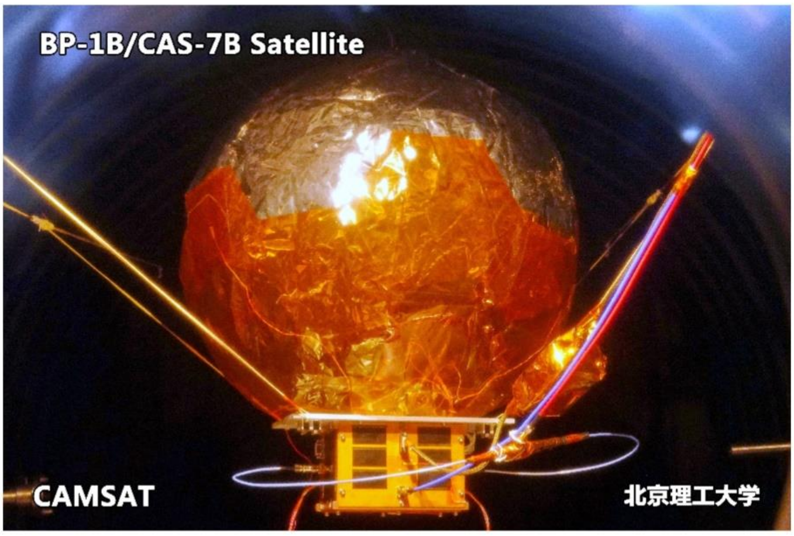
CAS-7B (BP-1B) satellite in orbit schematic diagram



Handbook on Small Satellites-80

FIGURE 81

CAS-7B (BP-1B) was undergoing thermal vacuum test



Handbook on Small Satellites-81

9.5 Commercial missions – small satellites in GEO

Small satellites in GEO stationary orbit can offer unique advantages over traditional, large, expensive GEO satellites. Small satellites can be built and launched quickly, in as little as 18 months, in comparison to large spacecraft which can take as many as five years to procure and build. Small satellites can also achieve a lower cost through simplicity of manufacturing, lower costs of testing and facility requirements, and through manufacturing many satellites as batches or on an assembly line. These advantages can make small satellites the ideal solution for coverage of small or medium-sized countries, or other customers who otherwise would never be able to afford their own dedicated on-orbit satellite asset.

Most technological development for small satellites has been confined to Low Earth Orbit, and for good reason, building small, high-powered satellites for the harsh environment of Geostationary Orbit is a significant technical challenge.

Satellite communications services have been identified as one of the primary application areas of small satellites as continuous and ubiquitous coverage that is highly desired requires a large number of satellites. Small, cost-efficient satellites may be the only way to close the business case and provide for a competitive offering. At least this is currently the approach for providing broadband communications globally through mega constellations such as OneWeb and Starlink. Typically, these constellations operate in the Ku-band or Ka-band to have sufficient bandwidth available for supplying high data rates.

There is also an increasing interest in using small satellites in the commercial applications, like Internet of Things (IoT) and Machine to Machine (M2M). The IoT and M2M deployments are within the Fixed-satellite service (FSS) and Mobile-satellite service (MSS). The number of small satellites IoT missions around the world is high.

Monitoring small (smart) sensors, stationary or moving, all over the globe and mostly in remote areas is foreseen as a significant growth market for the space industry. Using frequencies in the L-band and S-Band or possibly also in the UHF-bands, even allowing commonality with terrestrial bands for IoT applications is even possible for picosats and nanosats to enable massive machine to machine (M2M) connectivity in remote and rural areas beyond the availability of terrestrial cell towers. Currently, a large number of ambitious small satellite IoT constellation projects have been initiated some with ¼U satellites having a mass of less than 0.5 kg.

9.5.1 Astranis small satellites in the GSO

Astranis is building small, low-cost telecommunications satellites to connect the four billion people who currently do not have access to the Internet.

Each Astranis spacecraft operates from geostationary orbit (GEO) with a next-generation design of only 400 kg and Astranis's proprietary software-defined radio payload. This unique digital payload technology allows frequency and coverage flexibility, as well as maximum use of valuable spectrum. By owning and operating its satellites and offering them to customers as a turnkey solution, Astranis is able to provide bandwidth-as-a-service and unlock previously unreachable markets. This allows Astranis to launch small, dedicated satellites for small and medium-sized countries, Fortune 500 companies, existing satellite operators, and other customers.

Astranis has successfully launched a test satellite into orbit and is now underway with its first commercial programme – a satellite to provide broadband internet for Alaska that will more than triple the available bandwidth across the state. The operating satellite is now built, tested, and set for a launch in 2022.

9.5.1.1 Challenges for small satellite in GSO

9.5.1.1.1 Thermal challenges

Providing high-performance telecommunications service in geostationary orbit (GEO) requires high power – and generating and using power means a byproduct: heat. All power generated by the satellite's solar panels must either be emitted from the spacecraft as radio frequency (RF) energy or radiated as heat. And, because the vacuum of space makes thermal rejection difficult, the electronics in a satellite can often be at risk of overheating or failing entirely if steps are not taken to thermally balance the spacecraft.

Traditional, large GEO spacecraft has a relatively easier path to solving thermal challenges: their large size – and lower power density, as a result – gives both larger radiative surface area and allows more spacing between components to isolate hot and cold components from each other. This large size is enabled by using an entire dedicated rocket, like the Falcon 9 or Atlas V, which allows massive spacecraft to make it to orbit.

Building a small satellite for GEO telecommunications has all of the same fundamental thermal concerns as a large GEO, but has an added layer of difficulty: in order to fit within the EELV Secondary Payload Adapter

(ESPA) ring form factor, and thereby be able to fly more cheaply, flexibly, and responsively as a secondary payload to orbit, the satellite must weigh less than ~450 kg and fit within a roughly 1-metre cubed box. This small form factor means that high-powered, hot electrical components are tightly packed together, radiative surface area is more limited, and therefore the ability to manage the heat generated is more difficult.

Types of Thermal Effects

(a) Heat Dissipation without Convection

Dissipating heat for spacecraft is particularly challenging given the vacuum of space: without air, convection (e.g. cooling fans) will not work to keep the components from overheating. As such, all heat that is generated by the spacecraft (or otherwise absorbed by the spacecraft from the sun) must be radiated from the exterior surfaces of the spacecraft. Large GEO satellites have plenty of radiative space, but adding radiators or increasing the size profile quickly defeats the benefits of developing an otherwise small satellite.

(b) New Structural Concerns

Traditional, large GEO satellites separate the primary structure and thermal structures of the satellite – the former usually is a stiff, strong cylinder in the middle of the spacecraft that bears loads during launch, and the latter are flexible, radiative panels that can expand and contract with hot and cold temperatures. (Note that these two functions are directly contradictory, as one wants to be stiff where the other wants to be flexible.) In a small satellite form factor, there is not enough room for such a bifurcation, which means the primary structures also have to serve radiative purposes. Creating structures that are stiff and strong enough to survive launch, and flexible enough to withstand thermal contraction and expansion is challenging, and there are no examples from legacy large GEOs to guide that design tradeoff.

(c) Warming a Radiative Satellite When Necessary

Building a satellite to address the thermal rejection concerns above will mean that the satellite is naturally good at radiating heat quickly. In some off-nominal conditions like safe modes and immediately after tipoff from the launch vehicle, however, this may mean that some components get too cold. This poses a “worst case cold” risk for some components and must be addressed to keep critical components warm and safe while not consuming high amounts of power.

Strategies for solving thermal challenges

(a) Passive Design Strategies

One newer approach that has not been widely used in most traditional spacecraft designs is zoning: physically grouping components and systems that operate (and can withstand) higher temperatures together, doing the same for colder components, and isolating the two as much as possible. Some elements run extremely hot, others must run as cold as possible, and still more require a relatively tight temperature range to operate effectively. This makes thermal a primary driver to spacecraft architecture and layout.

Traditional material surface finish solutions for thermal control include using white and black paint or Optical Solar Reflectors (OSRs) with the desired emissivity and absorptivities in order to keep components warm or cool. Additional materials such as MLI (Multi-Layer Insulation) may also be utilized primarily to retain heat, but also create additional insulation between areas that occupy different hot and cold zones.

Component selection also takes on increased importance, since finding components that can both survive in the radiation environment of GEO and survive high temperatures for a long lifetime is challenging. State of the art satellite electronics have progressed significantly over the past 10 to 15 years, making it so that solving these challenges is uniquely possible today when it was not even ten years ago – but these components are still challenging to identify, purchase, and test.

(b) Active Design Strategies

Active strategies – like using Thermoelectric Coolers (TECs) – are critically important to distribute heat against the temperature gradient in cases where components need to be especially cool. As they have efficiencies of less than 100%, however, they increase the total amount of heat that the spacecraft needs to reject, and are therefore used sparingly. Active strategies transfer heat to other physical locations rather than improving the overall thermal rejection of the spacecraft. As a result, small GEO spacecraft generally avoid active heat control strategies, but may find that some components require active heat management to stay within their operational temperature range.

9.5.1.1.2 Radiation challenges

The Earth has two "radiation belts" formed by the planet's magnetic field interacting with charged particles in space. Planet Earth is constantly inundated with high energy particles, and many of these particles end up trapped by the Earth's magnetic fields. The resulting torus-shaped bands of particles are called the Van Allen belts.

The net effect is that LEO satellites are protected by the belts, while GEO satellites must operate at the far edge of the outer belt – meaning, while receiving a heavy dose of high energy particles that originate from outside of the Earth's sphere of influence, namely from stars, both from the sun and from supernovae and other interstellar sources. The flux of these higher energy particles (generally called heavy ions) is much lower, but the potential for damage or disruption by a single strike is much higher.

To solve the radiation challenge, large geostationary spacecraft typically use "rad hard" electronics that can withstand the harsh radiation environment of geostationary orbit. These electronics typically utilize components that are expensive, have long lead times, and perform poorly compared to state-of-the-art electronics for terrestrial applications. Using these components may be technically feasible for small satellite programmes, but break the business case – they can quickly dominate both cost and delivery timelines if used without critically assessing their need and can defeat the advantages of small satellites (e.g. low cost, fast delivery).

Traditionally, telecommunications satellites in geostationary orbit are built with flight heritage "rad hard" electrical components, designed to survive for fifteen-plus years of radiation bombardment. These components tend to come with extreme costs and lead times, as they have been designed and tested for very high radiation levels, often to such high radiation levels as to allow them to survive a nuclear attack. In addition to the high programmatic costs associated with use of these parts, they often have limited functionality: they use decades-old technology, draw higher power, are physically larger, and require the use of secondary processes like leadforming to install on a spacecraft. Further, despite being designed and screened to extreme levels, these short runs of components necessarily do not obtain the benefit of manufacturing at-scale and the inherent quality and defect detection that has become commonplace in the modern electronics industry.

Manufacturers of small satellites for LEO avoid the harsh radiation environment altogether. The Earth's magnetic field shields LEO satellites from the majority of radiation effects. This, combined with a higher risk tolerance, means that LEO operators now make extensive use of unscreened Commercial Off-the-shelf (COTS) components in their electronics. Some of these COTS components may incidentally be radiation tolerant, but they often are not.

Note: Some small satellites for GEO, mostly for defence-related experimental missions, are intended for just a one to two-year useful life, enough for a short technical demonstration. The strategies for developing radiation tolerance for such short missions are significantly different from those for a spacecraft that must last for seven to ten years.

In most cases, then, many operators do not have to take novel approaches to account for radiation. Traditional aerospace companies found business models where the impacts of using rad hard components were justified. LEO satellites escape the worst of radiation, and both LEO satellites and experimental missions have short lifetimes. As a result, solving these radiation challenges, particularly with less expensive, faster turn, and more flexible spacecraft is a rare knowledge base even within the aerospace industry. There are many misconceptions and myths in how many think of radiation in GEO, which makes it important to understand radiation effects on electronics from first principles.

Types of radiation effects

There are many types of radiation effects. The following represent the most important types for the purposes of radiation-hardening electronic systems.

(a) Total Ionizing Dose (TID)

TID occurs when charged particles deposit charge into materials. This charge builds up over time, eventually changing the electrical behaviour of a device or material. In a MOS (metal-oxide semiconductor) device, for example, charge can build up across the oxide layer, resulting in what used to be an insulator turning into a conductor.

There are three TID effects worth analysing: high dose rate, low dose rate, and annealing effects. The most critical effect is the total dose capability of materials used in electronics, namely of Silicon, since the sensitivity of Silicon tends to be the dominating factor and most electronics utilize Silicon. Some electronics use Gallium Arsenide (GaAs) or Gallium Nitride (GaN) due to their higher bandgap, allowing them to be much more resilient to both TID and SEE radiation effects. Other process types, such as Silicon on Insulator (SoI) and bipolar tend to have higher radiation tolerance (noting the ELDRs caveat below). The need to evaluate components for TID is not just limited to electronics: many other types of materials, such as plastics, can also degrade when subjected to very high levels of TID. This is rarely an issue behind the full shielding of an electronics box, but can easily become a problem for harnesses or other materials that are on the exterior of the spacecraft or even on the interior, but behind a smaller amount of shielding.

(b) Single Event Effects (SEE)

Single Event Effects are any measurable impact to a system due to a charged particle event. These come from high energy protons or heavy ions striking and imparting energy to a device. This usually results in an undesired change of state to the system. They are mostly caused by the Galactic Cosmic Rays (GCRs), but can also be caused by high energy trapped particles (usually protons). There are many types of SEEs, depending on the impact that is caused. These can range from the (relatively) benign, like SETs (Single Event Transients) or SEUs (Single Event Upsets) commonly known as “bit flips”, but can also range to more catastrophic effects that tend to happen in MOSFETs, such as SEB (Single Event Burnout) and SEGR (Single Event Gate Rupture), which can cause catastrophic failures.

(c) Displacement Damage (DD)

DD effects are observed in diodes and optical devices (such as optocouplers, opto-isolators, lenses, coverglasses). Displacement damage is caused primarily by protons, which enter a crystalline matrix and relocate individual atoms, changing the properties of the material (darkening glass, altering semiconductor bandgaps).

Types of radiation testing

(a) Total Ionizing Dose (TID)

When TID testing, it is important to look for the effects of high dose rate irradiation, low dose rate irradiation, and the impacts of annealing.

High dose rate testing is the most common type of radiation testing that is performed, and it is also the easiest and least expensive. It generally involves putting some number of components that you want to test under bias and subjecting them to a gamma source (often Cobalt-60) for as long as necessary to achieve the desired dose, generally up to 80 krad. At 50-300 rad/s, this can go relatively quickly. After dose, the part is removed from irradiation and tested. It should be noted that it is not sufficient to simply see if the device “turns on” since TID will often adjust the parameters of devices in entirely unpredictable ways, so it is necessary to characterize any parameters of the device that matter to the circuits of interest.

High dose rate testing, however, does not accurately simulate the environment that is seen in GEO since it tests what happens in ten years in as little as three minutes. For the most part, this is conservative in that most devices will actually outperform TID testing when subjected to the lower dose rate of a normal environment. Also, letting a device operate (and doing so at elevated temperature) enables “annealing”, which is the physical process by which damage to the semiconductor lattice is slowly repaired over time. As such, it is possible that a part may anneal back into an acceptable range and therefore still be acceptable for use in a GEO environment.

High dose rate testing, however, is not always conservative. For some types of devices, namely bipolar devices (such as those used in transistors, but also various types of ICs), the sensitivity is actually greater at lower dose rates than at higher dose rates. These are called Enhanced Low Dose Rate Effects (ELDRs) and require a very different type of test. For these effects, parts are tested in a similar way, but at rates of 0.01 to 0.1 rad/s, resulting in timeframes of several months to achieve 80 krad of total dose. ELDRs testing is therefore time consuming and requires both advanced planning and the resources to support such a long development cycle.

One additional challenge with TID testing is that total dose sensitivity is sensitive to process variation. As such, it is possible for parts from one lot of the same design to pass a TID test, but from a different lot (even at the same fab) to fail TID testing. Fortunately, more modern electronic fabs are becoming more controlled with their lot variation, but this cannot be assumed and parts must be "lot controlled", meaning purchased from the same Single Lot Date Code (SLDC) and pulled from that set to be tested. When this lot is expended, another sample of parts from the new lot must be tested.

(b) Heavy Ion Testing

Heavy ion testing is the most difficult and expensive of the radiation test types discussed here, and notably is generally unnecessary for LEO missions, where simpler proton testing can be sufficient. Heavy ions are primarily responsible for finding single-event effects, as described above. These tests generally tend to be a combination of characterizing two types of events: 1) the rate of upsets caused by ions of a given energy level; and 2) the predisposition of a component towards destructive effects. Heavy ion testing is much more difficult since it requires renting time at a Cyclotron (such as the one located at Texas A&M University) or Synchrotron (such as the one at Brookhaven National Labs), at which it is possible to produce "spills" of very high energy particles. The particle type to be fired at electronics under heavy ion test is tuned in order to simulate the Linear Energy Transfer (LET) of different types of particles that would be expected in the space environment. LET calculation is a function of the energy of the inbound particles, the substrate of the device in question, and the angle of incidence of the particles. For a destructive test (as would generally be done for something like a MOSFET), it is often permissible to test at a single (most destructive) LET to determine whether the part is acceptable or not. For a digital COTS device, however, one might expect many upsets, so it is necessary to test at multiple energy levels, or LETs, in order to construct what is known as a Weibull curve, allowing the full characterization of upset rates. It is noteworthy that proton testing is often also used in order to test for SEEs. It is generally more accessible and less expensive than heavy ion tests, so it can be used as a first screen before heavy ion testing, but it is not a replacement for proper cyclotron-based or synchrotron-based heavy ion testing, which is uniquely true outside of the Van Allen belts.

Strategies for solving radiation challenges

As discussed above, the approach of using solely traditional flight heritage, rad hard components to achieve a radiation-tolerant design has significant downsides in cost, lead time, and performance. The use of these components often makes such approaches uneconomical for smaller and lower-cost spacecraft missions.

To achieve cost-effective electronics that are still radiation-hardened for the GEO environment or beyond, other strategies must be deployed. Astranis has considered and implemented many such strategies: from upscreening COTS components, to improving circuit designs, to developing custom software that can detect and correct errors induced by radiation.

One particular strategy worth mentioning is shielding: additional shielding to protect electronics for the GEO environment can provide some, but not complete, mitigation against radiation effects. There are significant diminishing returns when adding shielding to protect against harsher radiation environments. The effectiveness of shielding is roughly logarithmic and the gains to be had at much thicker shielding thicknesses have much lower marginal benefit. For example, to protect a LEO satellite against the GEO environment with shielding alone, by reducing TID levels seen by the electronics from 60 krad to the level necessary to support COTS electronics would require multiple centimetres of aluminium shielding surrounding all electronics on the spacecraft. This much heavier shield would be massive, and therefore limit spacecraft lifetime, making it a suboptimal choice.

9.5.2 Jilin-1 satellite constellation

Chang Guang Satellite Technology Co., Ltd. (CGSTL), founded on 1 December 2014, it is the first commercial remote sensing satellite company in China. With the total registered capital of RMB 1.97 billion, the company is composed of the Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Jilin provincial government and social capital.

On the basis of “the integration of satellite-borne”, “the integration of airborne” and other core technologies, the company has set up the commercial business dealing with the development and operation of satellite and unmanned aircraft, as well as remote sensing information processing all in one. The main business covers satellite development, satellite in-orbit delivery, satellite component development, UAV development, UAV component development, mapping services, remote sensing advanced products, industry application solutions, ground application systems, large data application services, etc.

Strictly adhering to the spirit of unity, innovation, hard-work, and pragmatic, adopting the development concept of mass development and broad innovation, with the mission of “serving 7 billion people on the globe with the remote sensing information product integrating sky, space and ground”, aiming for building internet-based remote sensing information platform, and constantly introduce innovative products, the company goes all out to promote the industrial transformation and upgrading of Jilin Province, to drive the revitalization of the old industrial base in northeast China, and to strive to compose the brilliant chapter of the Chinese commercial remote sensing satellite.

9.5.2.1 Constellation Introduction

Jilin-1 satellite constellation is the core project under construction by CGSTL. It is composed of 138 high performance optical remote sensing satellites covering high resolution, large width, video and multi-spectrum. At present, CGSTL has successfully sent 75 jilin-1 satellites into space through 18 times launches. Jilin-1 constellation can visit any place in the world 25 to 27 times a day, with the ability to update a global map twice a year and a national map six times a year. Jilin-1 satellite constellation can provide high-quality remote sensing information and product services for agricultural and forestry production, environmental monitoring, smart city, geographical mapping, land planning and other fields.

Detailed information about some of the satellites in the constellation is shown in the Table 26 and illustrated in Fig. 82.

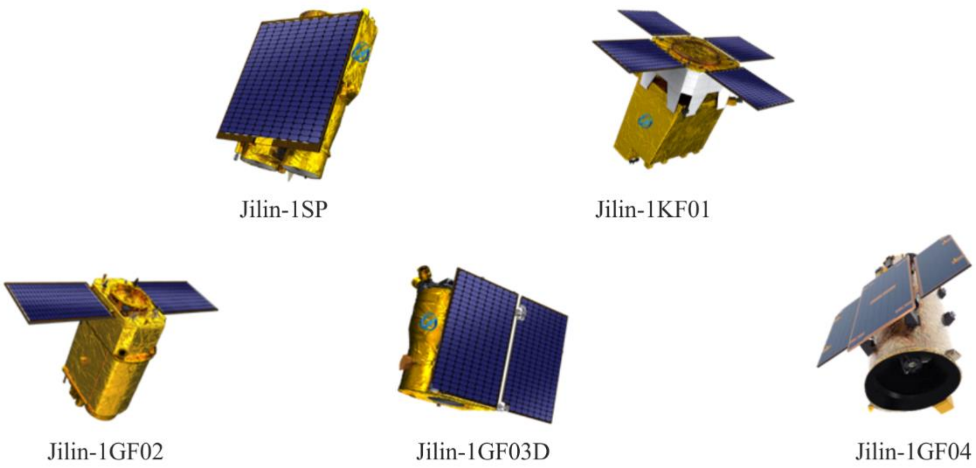
TABLE 26

Details of some of the satellites in the constellation

Satellite ID	Resolution	Width	Size
Jilin-1GF04	0.5 m	15 km	φ890 * 1 650 mm (folded)
Jilin-1KF01	0.5 m	150 km	4 600 * 4 700 * 3 200 mm
Jilin-1GF02	0.75 m	40 km	1 150 * 790 * 1 800 mm
Jilin-1GF03	0.75 m	17 km	460 * 610 * 850 mm
Jilin-1SP	0.92 m	19 km	1 300 * 650 * 1 700 mm

FIGURE 82

Illustration of some of the satellites in the constellation

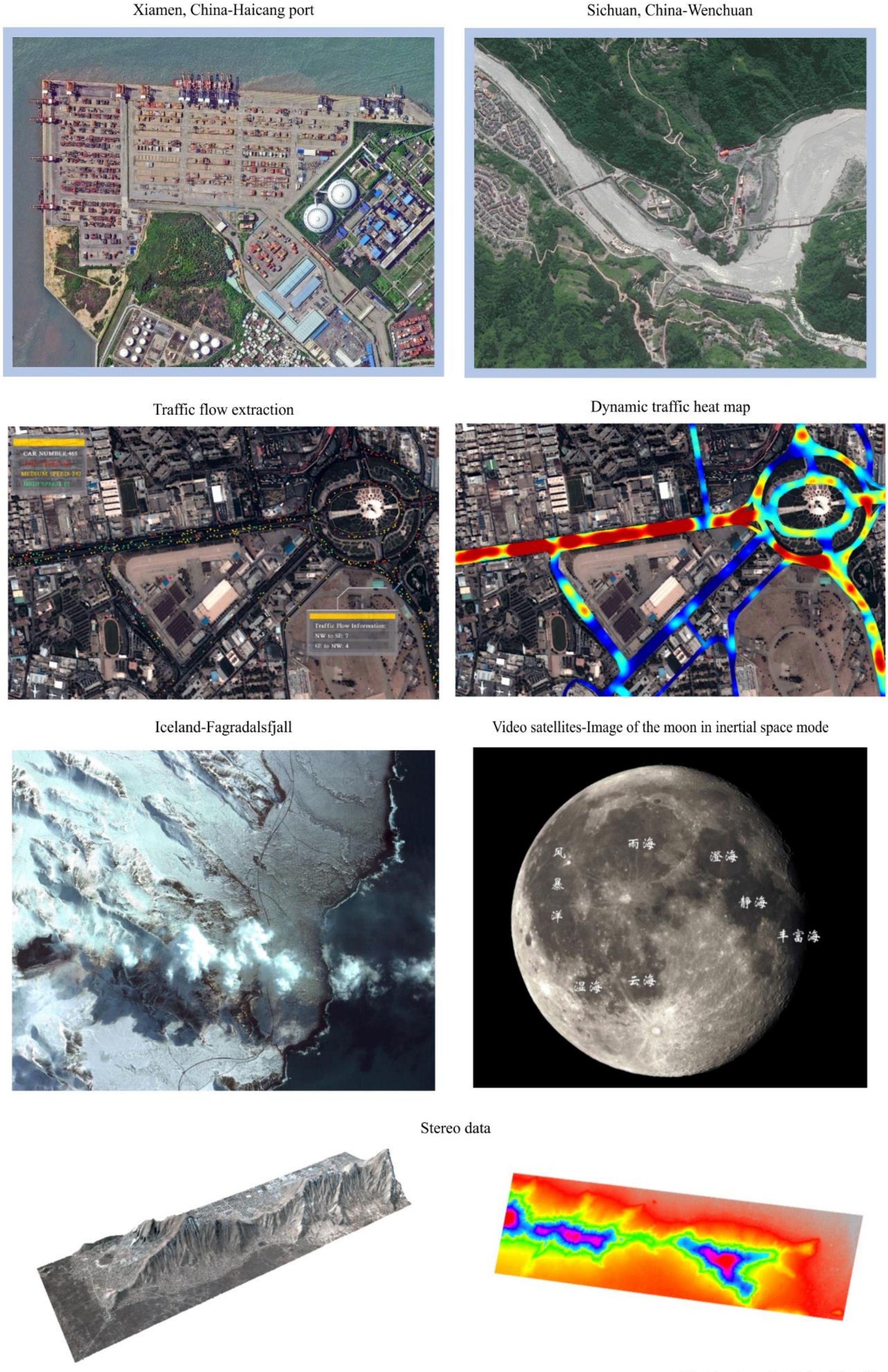


Handbook on Small Satellites-82

Jilin-1 satellite constellation has many kinds of data products, including high-resolution push-broom data, video data, multispectral data, night-time data, stereo imaging and inertial space imaging. At present, relying on the technical strength of aerospace mass production, CGSTL has built the world's largest sub-meter remote sensing satellite constellation, which can realize the rapid networking of the constellation. Relying on the advantages of satellites' number of Jilin-1 satellite constellation and the support of the company's strong ground processing system, CGSTL's satellite data products have the characteristics of strong coverage, high-cost performance, abundant amount of archived data, customizable shooting demand, flexible programming service and short delivery time, etc., which can achieve monthly coverage in the city and quarterly coverage in the province. See Fig. 83.

FIGURE 83

Sample data



Handbook on Small Satellites-83

9.5.2.1 Data service mode

The archived data service refers to providing users with archive remote sensing data query and download services. Users can query the archived data of Jilin-1 satellite constellation at all levels through the online distribution platform or API interface calling, and then users can submit the data requirements as needed. The data will be delivered to users through the public cloud platform within the specified time.

Task programming refers to providing users photography service with the ability of Jilin-1 satellite constellation. Users can submit future-oriented point/area shooting requirements. After responding to the requirements, Jilin No.1 Measurement and Operation Control Centre plans shooting task and data production within a specified period. Users will receive the entity data through the public cloud platform within the specified time.

BaseMap basic data service refers to publishing the data of a specific area and a specific time range into an online map service after mosaic and slicing, which is provided to users or various business systems for direct reference. The basic data of a map is tile data with three spectra and 8 bits.

ARD online application service refers to the information of data that can be directly used for remote sensing application analysis after orthophoto and atmospheric correction on the basis of standard sensor corrected images and provides online direct reference through API. ARD data is provided externally in the form of datasets. Users can retrieve and view data sets that can be analysed by online applications and their data indicators and refer to them online through specific API. ARD data service mainly solves the needs of users for online and real-time drawing.

9.5.2.3 Satellite remote sensing application products

Environmental protection has become a global concern. In order to effectively support the improvement of environmental quality such as atmosphere, water and ecology, the State Council of the PRC has sustainedly issued a number of medium and long-term ecological and environmental protection policy documents, including “the action plan for the prevention and control of air pollution”, “the action plan for the prevention and control of water pollution” and “the opinions on accelerating the construction of ecological civilization”. Relying on satellite remote sensing technology, CGSTL has established a set of product system covering environmental protection remote sensing monitoring service. The product has the characteristics of wide coverage and various monitoring types, also with the advantages of long-term, continuous and dynamic monitoring. The product combines with artificial intelligence algorithm, thus it can analyse and deal with problems at early stage, so as to improve efficiency of work. This product has provided stable services in Jilin Province, Shandong Province, Shanxi Province and other regions for a long period.

CGSTL’s forestry remote sensing monitoring service products are committed to carry out forestry monitoring services such as forest resource distribution, forest fire early warning and monitoring, forest pest monitoring, etc. by using the means such as satellite remote sensing, big data, artificial intelligence technology and space-ground integration, and so on. The products aim at achieving accurate supervision of forestry resources, accurate warning and prevention of forest fires and fine pest controlling by providing remote sensing big data services for all governments, emergency management departments, forestry and grass departments, etc. The products have provided stable services in Beijing, Jilin Province, Shandong Province, Shanxi Province, Zhejiang Province and other regions.

CGSTL is committed to help the development of precision agriculture by using satellite remote sensing, big data and artificial intelligence technologies. The company has developed remote sensing products such as the distribution of cultivated land resources as well as agricultural facilities, crop planting structure, crop growth monitoring, cultivated land soil moisture and crop drought monitoring, agricultural disaster monitoring and crop yield prediction. Through providing the remote sensing and big data service to various governments, agricultural insurance company, large agricultural enterprises, agricultural cooperative and professional farmers, it is realized the transformation of agricultural planting from the traditional experience mode of “influenced by nature conditions” to the modern mode of “utilizing the nature” and make agricultural planting truly “adjust measures to local conditions” by means of science and technology.

High-resolution remote sensing change monitoring service products of CGSTL are based on the high-resolution and wide area high-frequency remote sensing data of Jilin-1 constellation. The products have the capabilities of updating the monitoring area weekly / monthly with high-frequency coverage and finding the detailed changes in key areas quickly in combination with artificial intelligence analysis methods. It can provide a series of change monitoring products with the characteristics of dynamic, efficient, scientific and high-precision, which can be used for urban planning, natural resources supervision, ecological environment protection and other fields. The product forms include change monitoring thematic map, change monitoring analysis report, change monitoring integrated management platform and others. It also can provide users with customized services.

9.5.2.4 Satellite ground systems

Image processing system is the core of satellite data pre-processing after landing. The system decrypts and decompresses the received original code stream data, completes the analysis and processing of auxiliary data, and then catalogues the data. For push-broom images, the system completes the radiation correction and sensor correction processing of the images according to the laboratory calibration data or on-orbit calibration data, solves the RPC model corresponding to the images according to the orbit, attitude and time data, and completes the production of push-broom L1 imagery products. For video images, the system conducts orientation, registration and reacquisition between single-frame images to generate video L1 products after image stabilization processing.

The data management system is the centre of the storage, management and application service of satellite data products. It is mainly responsible for the storage, organization, application, management and maintenance of Jilin-1 push-broom imagery products, Jilin-1 video products, other types of remote sensing image data, basic geographic information products, control point data, auxiliary data, thematic value-added products and other data. The data management system can integrate heterogeneous storage devices, provide hierarchical storage strategy and unified access interface. Its main functions include:

1 It has the full life cycle management of data and realizes the full link management from data creation, production, storage, access, migration and offline backup.

2 It can automatically receive data and realize the archiving and extraction of massive multi-source image data, auxiliary data and product data at all levels.

3 It supports flexible retrieval of multi-dimensional and multi-data types and fast browsing of satellite images and video images.

4 It has a variety of rich statistical and analysis capabilities such as inventory data, data archiving records, data retrieval records and data extraction records.

5 It can be combined with third-party software to realize three-level storage management of satellite data online, near-line and offline. It has multi-level backup capability and can be recovered correctly and completely in case of data damage.

6 It has flexible data management object scalability and data storage capacity scalability.

The constellation mission planning system can accept the shooting needs of users, track the completion of shooting needs, simulate the scheduling of on-orbit satellites' resources, and conduct visibility analysis of target areas or target points required by users. Users can view the operation track of Jilin-1 satellites through the constellation mission planning system. The system mainly includes the following functions:

1 It receives, analyses and maps the user's shooting requirements into target points or target areas.

2 It conducts storage management, shooting management and demand satisfaction tracking of target points and target areas.

3 It conducts storage management of orbital elements of on-orbit satellites, orbital calculation and recurrence, visibility prediction of multiple on-orbit satellites to multiple targets.

4 It judges and resolves the resource conflict of on-orbit satellites, and conducts joint planning of on-orbit satellites for target points or target areas.

5 It supports the addition of other satellites except Jilin-1 satellites, and can simulate and analyse the operation trajectories of these satellites.

Jilin-1 emergency access and service equipment is a portable remote sensing satellite control and remote sensing information processing system. It mainly deals with the scene that the emergency events urgently need to obtain remote sensing data at the first time. It can realize the functions of on-site scheduling, task planning, instruction annotation, real shooting and real transmission, on-site interpretation, comprehensive analysis and so on. The system has complete functions and is easy to carry to another place. It can mobilize Jilin-1 satellites to promote services all over the world. The product has the following characteristics:

1 Easy to carry: The product is composed of 1 m aperture antenna, measurement and control data transmission terminal host and portable processing system. The product has small volume and light weight, thus it can be transported by vehicles, trains and aircrafts.

2 Live shooting and transmission: It takes no more than 15 minutes from satellite shooting to information processing.

3 On-site interpretation: It conducts format analysis, decryption, decompression, cataloguing and other processing of the original code stream data on the spot, and it quickly processes the push-broom data and video data to generate standard products.

4 Comprehensive analysis: It provides general and special analysis tools, target expert knowledge base and preloaded multi-source remote sensing data, which can realize target detection, target recognition, automatic detection and tracking of point/plane moving targets, and quickly generate intelligence information.

9.5.3 Starlink non-GSO satellite systems

Starlink non-GSO satellite system consists of a constellation of 4 408 satellites at altitudes ranging from 540 km to 570 km, as well as associated ground control facilities, gateway earth stations and end user earth stations. The overall constellation will be configured as shown in Table 27.

TABLE 27

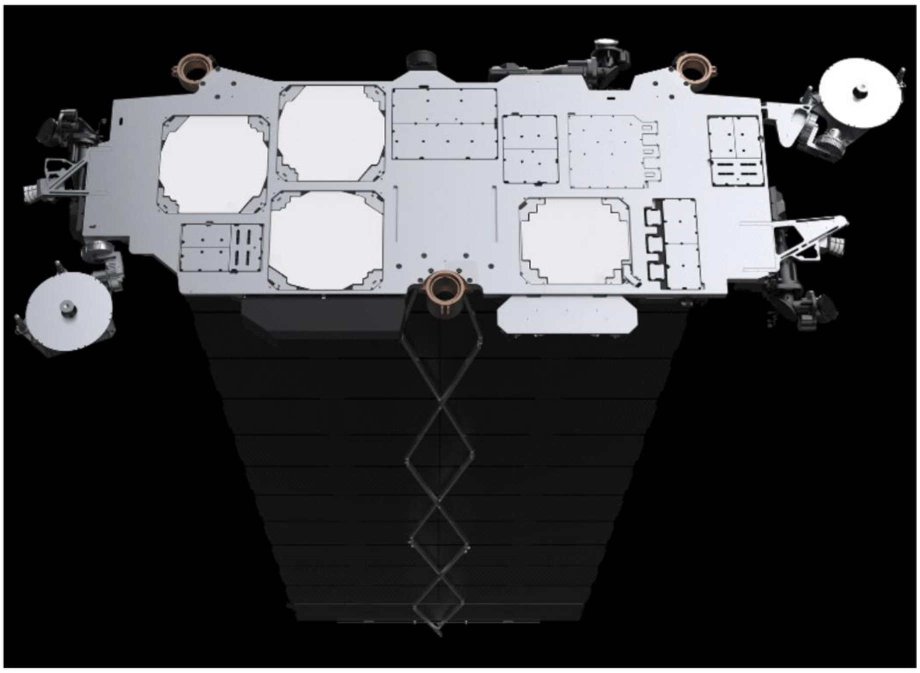
Overall constellation of Starlink non-GSO satellite systems

Starlink constellation					
Orbital planes	72	72	36	6	4
Satellites per plane	22	22	20	58	43
Altitude (km)	550	540	570	560	560
Inclination (degree)	53	53.2	70	97.6	97.6

Starlink is designed to provide a wide range of broadband and communications services for residential, commercial, institutional, governmental and professional users worldwide with low-latency connectivity. Advanced phased array beam-forming and digital processing technologies within the satellite payload give the system the ability to make highly efficient use of Ku- and Ka-band spectrum resources and the flexibility to share that spectrum with other licensed users. User terminals operating with the SpaceX System will use similar phased array technologies to allow for highly directive, steered antenna beams that track the system’s low-Earth orbit satellites. Gateway earth stations also apply advanced phased array technologies to generate high gain steered beams to communicate with multiple non-GSO satellites from a single gateway site.

FIGURE 84

Starlink Satellite and its payload



Handbook on Small Satellites-84

Starlink satellites, shown in Fig. 84, autonomously manoeuvre to avoid collisions with orbital debris and other spacecraft. They are also equipped with navigation sensors to survey the stars and determine each satellite's location, altitude, and orientation enabling precise placement of broadband throughput. The system also employs optical inter-satellite links (ISLs) for seamless network management and continuity of service without local ground stations providing truly global coverage. ISLs also aid in complying with emissions constraints designed to facilitate spectrum sharing with other systems. Efficient ion thrusters, powered by krypton, enable Starlink satellites to orbit raise, manoeuvre in space, and deorbit at the end of their useful life.

Starlink network has global reach broadband services with live in 50 markets across all seven continents as of October 2022. Starlink offers high-speed, low-latency broadband internet services to residential and enterprise users in remote and rural locations across the globe. Beyond consumer broadband, Starlink provides internet services in-motion within active coverage in land, maritime and aviation markets. It also enables cellular backhaul, connectivity for IoT devices and internet services for schools.

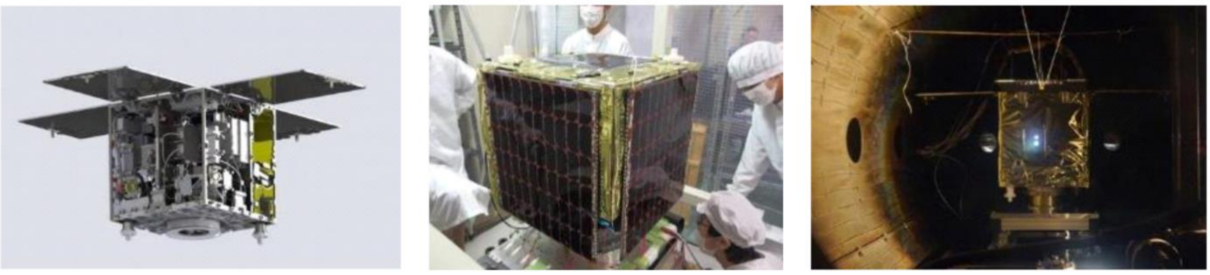
9.6 Earth-based, moon-based, inter-planetary or deep space missions

9.6.1 PROCYON for deep space exploration

The 50-kg-class deep space exploration micro-spacecraft PROCYON (Proximate Object Close flyby with Optical Navigation) was jointly developed by the Intelligent Space Systems Laboratory (ISSL) at the University of Tokyo and the Japan Aerospace Exploration Agency (JAXA). PROCYON was launched together with the Japanese second asteroid sample return spacecraft Hayabusa-2 on December 3, 2014, and it became the world's first 50 kg-class full-scale deep space probe which has the long-distance communication capability and trajectory control capability in deep space.

FIGURE 85

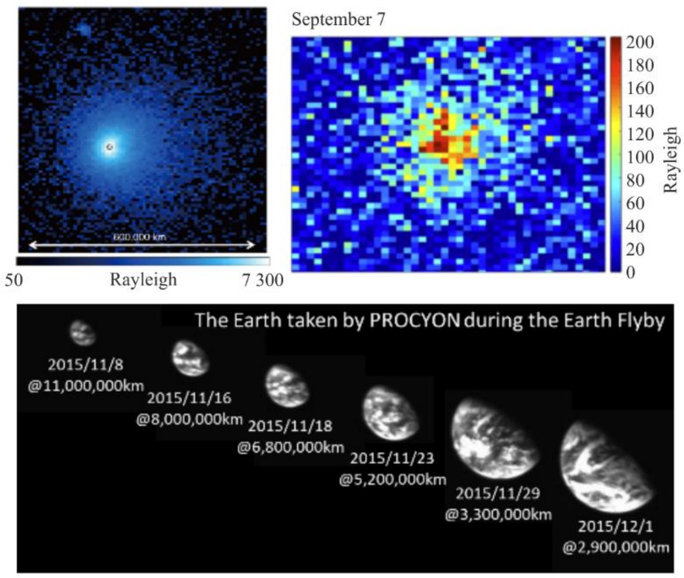
Flight model of PROCYON
left: internal configuration (CG); centre: actual spacecraft;
right: ion-thruster operation test in a vacuum chamber



Handbook on Small Satellites-85

FIGURE 86

Observations by PROCYON: left) Wide-view Earth corona by onboard UV telescope "LAICA" from deep space, canter) Emitted Hydrogen around 67P/Churyumov–Gerasimenko observed by LAICA, right) The view of the Earth when PROCYON came back after its one-year deep space flight



Handbook on Small Satellites-86

A low-cost miniaturized X-band onboard deep-space telecommunication system was newly developed for PROCYON. The development focused on adopting only commercially off-the-shelf (COTS) products and a GaN-based Solid State Power Amplifier (SSPA) with the world's highest RF efficiency, X-band Transponder (XTRP) and other components were newly developed, which achieved almost the same performance as a conventional large spacecraft (e.g. Hayabusa 2) while the mass of the communication system achieved almost 1/3 of the conventional deep space probes. A micro propulsion system named I-COUPS (Ion thruster and Cold-gas thruster Unified Propulsion System) was also newly developed for PROCYON. The propulsion system unified an ion thruster and cold-gas thrusters by sharing a single gas system to provide these propulsive capabilities with a limited mass and volume. The ion thruster provides 300 µN of thrust with a specific impulse of about 1000 s, which is used for a deep space manoeuvre (DSM). The cold-gas thrusters, which provide about 20 mN of thrust with a specific impulse of 24 s, are used for both reaction wheel desaturation and the asteroid flyby trajectory correction manoeuvre. The weight of the propulsion system is less than 10 kg including about 2.5 kg of propellant (Xenon).

Operation of PROCYON was performed through JAXA's deep space stations USC (Uchinoura Space Center) and UDSC (Usuda Deep Space Center). NASA's DSN (Deep Space Network) was also used when DDOR (Delta-Differential One-way Range) experiment was jointly performed with NASA. During its one-year flight in deep space, PROCYON succeeded in its primary mission (the demonstration of a 50-kg-class deep space exploration bus system). The normal operation of the spacecraft was verified, including deep space communication from a sixty-million-kilometre Earth distance, and trajectory guidance/navigation/control in deep space. PROCYON also achieved some of its optional missions, which are the demonstration of advanced deep space exploration technologies (e.g. demonstration of a novel DDOR orbit determination method) and scientific observations (e.g. geocorona observation). These successes demonstrated the capability of the ultra-small spacecraft for performing a deep space mission by itself and also demonstrated that it can be a useful tool for deep space exploration.

TABLE 28

System specifications of PROCYON

Structure	Size Weight	0.55 m × 0.55 m × 0.67 m + 4 SAPs (Solar Array Panels) <70 kg (wet)
Power	SAP (single attosecond pulse) Battery	Triple Junction gallium arsenide (GaAs), >240 W (at 1 AU, θs = 0, BOL) Lithium-ion (Li-ion), 5.3 Ahr (Ampere Hours)
AOCS	Actuator Sensor Performance	Reaction Wheels (RW) ×4, Three-axis Fiber Optic Gyro (FOG) ×1 Star Tracker (STT) ×1, Non-spin Sun Aspect Sensor (NSAS) ×5 Telescope (for optical navigation relative to the asteroid) <0.002 [deg/s], <0.01 [deg] (pointing stability)
Propulsion	RCS (reaction control system) Ion propulsion Propellant	Xenon cold-gas jet thrusters ×8, ~22mN thrust, 24s Isp Xenon microwave discharge ion propulsion system 0.3 mN thrust, 1000s Isp, ~400m/s ΔV capability (for 65 kg s/c) 2.5 kg Xenon (shared by RCS and ion propulsion)
Communication	Frequency Antenna Output power Orbit determination	X-band (for deep space mission) HGA ×1, MGA ×1, LGA ×2 (for uplink), LGA ×2 (for downlink) >15 W (RF output), >30 % (GaN XSSPA) Range, Range Rate, DDOR (Delta Differential One-way Range)
Payload	Weight	~10 kg (asteroid observation camera+Lyman alpha imager)

9.7 Practices for short-duration missions

Since the SDM concept is adopted by the ITU WRC-19, there is no trends for SDM submissions when this Handbook finalized. However, as of 12 May 2023, the ITU Bureau received 61 satellite networks for APIs and 7 satellite networks for Notification indicated as short-duration missions. All 7 notified networks had been launched by the time of the notification received.

In addition, 9 API contains the band 137.175-137.825 MHz and 24 API notices contain the band 148-149.9 MHz for space operation service, thereby not required to go through coordination procedures under Section II of RR Article **9**. It should be noted that for those containing the band 148-149.9 MHz, the examination of the PFD required in RR No. **5.218A** will be carried out only when the notification will be submitted, and if the examination results in an unfavourable finding, either the power will have to be reduced, or a separate request for coordination will have to be submitted to the BR.

9.8 Other multiple missions and national cases

9.8.1 Brazil

The efforts to create a specialized culture for space technology in Brazil started in the 1950s with the creation of Technical Institute of Aeronautics (ITA – *Instituto Técnico da Aeronáutica*). Soon after, in 1960s, the Brazilian Space Program was created and is nowadays coordinated by the Brazilian Space Agency (AEB – *Agência Espacial Brasileira*), involving several governmental, military, and civil organizations, with National Institute for Space Research (INPE – *Instituto Nacional de Pesquisas Espaciais*) playing special support in satellite projects.

Timeline

The first satellite operated by a Brazilian company was **Brasilsat A1**, active from 1985 to 1996 for telecommunications purposes by Embratel (*Empresa Brasileira de Telecomunicações*).

The first Brazilian small satellite was **Dove-OSCAR 17**, an amateur radio satellite launched in 1990. It was a microsatellite (almost 13 kg) carrying a Digital Orbiting Voice Recorder (DOVE) for synthesized voice messages transmitted in FM and digital telemetry for educational purposes.

The first satellites projected, developed and tested in Brazil was **SCD-1**, **SCD-2A** and **SCD-2**. The Data Collection Satellite (SCD – *Satélite de Coleta de Dados*) is the pioneer satellite program for Earth Observation of the Brazilian Complete Space Mission (MECB – *Missão Espacial Completa Brasileira*), created in 1979 to promote national space technology in Brazil in 3 segments: satellites (including the installations for development, integration and test of the satellite subsystems), launch vehicles and launcher sites. The satellite part was under responsibility of INPE. SCD-1 was launched in 1993 and SCD-2 in 1998. Both are minisatellites with mass around 155 kg and still partially active (several years ahead of the life expectancy) as relay of ground environmental data collections made by automatic Data Collection Platforms (DCPs) spread in remote areas of the country. Between 1998 and 2003, some missions were developed with several lessons learned.

In 2014, a new Brazilian small satellite project was developed, the **NanoSatC-BR1**, a cubesat operated by INPE and the Federal University of Santa Maria (UFSM – *Universidade Federal de Santa Maria*) carrying sensors to monitor the particle precipitation and disturbances at Earth magnetosphere over Brazil. It included a magnetometer to measure the intensity of the Earth Magnetic Field at the South Atlantic Magnetic Anomaly (SAA/SAMA) region and on the Brazilian sector of the Ionosphere Equatorial Electrojet (EEJ), as well a particle precipitation chip dosimeter. The communications were performed on the VHF and UHF with amateur radio operators integrated in the project monitoring and sharing telemetry and payload data in a collaborative network with INPE.

One year later, in 2015, **AESP-14** was part of the Capacity Building Integrated Program of ITA and INPE on space science, engineering and computing sciences with the objective of space technologies development through a CubeSat satellite, involving the students and professors in aerospace engineering. The technological mission consisted of the validation of first CubeSat platform developed in Brazil. AESP-14 also carried an amateur radio and educational mission with special digital messages that could be uploaded and stored on the satellite for scheduled transmissions to be received by amateur radio operators working with schools and students on STEM projects (Science, Technology, Engineering and Mathematics). Due to malfunction, the satellite was inoperative after been released by the ISS and re-entered in the Earth atmosphere in May 2015.

In the same year **SERPENS-1** (*Sistema Espacial para Realização de Pesquisa e Experimentos com Nanossatélites*) was developed by a consortium of Brazilian universities and coordinated by AEB. The universities involved were Federal University of Minas Gerais (UFMG – *Universidade Federal de Minas Gerais*), Federal University of Santa Catarina (UFSC – *Universidade Federal de Santa Catarina*), Federal University of ABC (UFABC – *Universidade Federal do ABC*) and University of Brasília (UnB – *Universidade de Brasília*). It was a 3U CubeSat that evaluated the use of nanosatellites for data collection of environmental sensors. The mission also planned a store-forward function for amateur radio. The CubeSat was deployed in September 2015 and re-entered in March 2016.

After SERPENS-1, several Brazilian small satellites were launched between 2017 and 2022. The first of this sequence was **Tancredo-1,** an elementary school project involving students in the age between 10 to 14, aiming youngers to pursue careers on STEM. The project received support of AEB, INPE and UNESCO. It was the first picosatellite operated by Brazil with 0.57 kg in TubeSat configuration. Tancredo-1 had as its payload an on-board voice recorder that transmitted a message chosen by a contest among students from schools in Ubatuba, São Paulo (for this reason the satellite was also knew as UbatubaSat). The ground segment had support of Amateur Radio stations that assisted the project.

The second is **ITASAT-1**, launched in 2018. It was a 6U CubeSat to train students for space-related projects, specially develop and demonstrate a platform to test in orbit different payloads like a national GPS receiver, sensors, as well perform a store and forward digital communication with the amateur radio community. The satellite is still partly functioning due power budget issues.

The third was **FloripaSat-1**, launched in 2019. The satellite was developed by UFSC as part of the Brazilian Space Program, UNIESPACO, sponsored by the AEB. FloripaSat-1 was an 1U CubeSat with main objective is to engage the students in a full space mission developing all the subsystems of a nanosatellite. The payloads were designed to validate a new approach to reconfiguring single event upsets due to solar radiation in reconfigurable logic circuits, as well test FGPA resistance to radiation. A planned amateur radio mission involved digital repeater and design of a ground station.

In 2021 the **NanoSatC-BR2** was launched as successor of first version of the satellite developed in 2014 by INPE. The 2U CubeSat kept the scientific mission to monitor the Earth's Ionosphere and Magnetic Field and particle precipitation, and the ionospheric composition disturbance in the SAMA region. The project involved VHF/UHF transceivers with 1k2 BPSK modulation.

Finally, in 2022, two small satellites were deployed. The first one is the **Pion-BR1**, that is a picosatellite in a pocketcube format developed by Brazilian start-up PION Labs in partnership with Federal University of São Carlos (UFSCar – *Universidade Federal de São Carlos*) and educational programs like the Latin American Space Challenge (LASC) and OBSAT (Brazilian Satellite Olympiad, promoted by the Ministry of Science, Technology, and Innovation of Brazil). It is an amateur radio mission combined with educational purposes aimed to access space technologies with the interaction of amateur radio community and students and using teaching tools in OBSAT program. The mission included a digital and store and forward communications in NGHam (Next Generation Ham Radio, a set of protocols for amateur packet radio communication), evaluate the attitude, collect data of the magnetorquer and other parameters of the satellite.

The second one is **AlfaCrux**, that was developed by UnB as an educational mission covering a complete process of developing and operating a space mission, including test of in orbit software defined radio to perform ionospheric scintillation analysis and involvement of the students to radio electronics, antennas, and digital communications. The spacecraft planned a digipeater for amateur radio using AFSK/FM modulation at 1 200 baud, payload downlink and GMSK telemetry. It was launched in April 2022.

Since 2014, all nine small satellites worked with amateur satellite segment. Useful downlink data is usually received by amateur radio operators in the country and abroad, shared with the community and mission control in a high collaborative technical level. In five of them (ITASAT-1, Tancredo-1, SERPENS-1, NanoSatC-BR2 and AlfaCrux), the very first telemetries were received by amateur radio operators and, during all satellite lifetime, monitoring is kept and shared through open amateur radio digital databases.

Partnership was also observed between research institutes and amateur radio society in the development of software, hardware, ground stations, operational guidelines, educational and public science activities, including amateur radio missions. Examples of this kind partnership happened in ITASAT-1 and NanoSatC-BR and Pion-BR programs between INPE and LABRE (the national amateur radio association).

Brazil is an active member of the IARU Satellite Frequency Coordination since 2016 and all Brazilian satellites that used these frequencies were coordinated. After September 2015 they also carried amateur radio callsigns issued by the Brazilian National Telecommunications Agency (Anatel – *Agência Nacional de Telecomunicações*). To support and guide small satellite activities in the country, Anatel produced, in 2020, the Spectrum and Orbit Resources Guide for Educational and Amateur Radio Small Satellites (*Manual de Espectro e Órbita para Pequenos Satélites Radioamadores e Educacionais*), in collaboration with the space, educational and amateur radio sectors.[11]

Next projects: Among the projects in development to be launched in the next years there are: VCUB1 (Visiona Space Technology), a joint venture between Embraer and Telebras; SPORT-1, a partnership among NASA, AEB, INPE and ITA); Aldebaran 1 of the Federal University of Maranhão (UFMA – Universidade Federal de Maranhão); PdQSat (UFMG); Consat (INPE); GOLDS-UFSC (UFSC); e Catarina Constelation (SENAI and UFSC).

11 The guide is available at https://www.gov.br/anatel/pt-br/regulado/satelite/pequenos-satelites

ANNEX A

List of Abbreviations

ADCS	Attitude, determination and control system
ADR	Assisted disposal and removal
ADS-B	Automatic dependent surveillance – Broadcast
AFSK	Audio frequency-shift keying
AI	Artificial intelligence
AIS	Automatic identification systems
AIT	Assembly, integration and testing
AOCS	Attitude and orbital control system
API	Advance publication information
APReC	Aerospace Plane Research Centre
ASAP	Automated structures analysis programme
BR	Radiocommunication Bureau of ITU
BR IFIC	BR International Frequency Information
BSS	Broadcasting-satellite service
C&DH	Command and data-handling systems
CALT	China Academy of Launch Vehicle Technology
CalPoly	California Polytechnic State University
CCV	Coordination Committee for Vocabulary
CMEs	Corona mass ejections
CGWIC	China Great Wall Industry Corporation
CLTC	China Satellite Launch & Tracking Control General
COTS	Commercial off-the-shelf
CPU	Central processing unit
CR	Coordination request
CS	Constitution
CTITU	ITU-R circular telegram
CV	Convention
CW	Carrier wave, or Continuous wave
DART	Double asteroid redirection test
DDOR	Delta-differential one-way range
DBIU	Date of bringing into use
DRO	Distant retrograde orbit
DSN	Deep space network
DSM	Deep space manoeuvre

EDT	Electro dynamic tether
EDL	Entry, descent and landing
E-to-s	Earth-to-space
EEE	Electrical, Electronic and Electromechanical
EESS	Earth exploration-satellite service
e.i.r.p.	Equivalent isotropic radiated power
EPS	Electrical power supply
EUV	Extreme ultraviolet
FCC	Federal Communications Commission
FDP	Fractional degradation in performance
FDS	Flight dynamics system
FM	Frequency modulation
FOS	Frequency overlap software
FOG	Fiber optic gyro
FSS	Fixed-satellite service
GFRP	Glass fibre reinforced polymer
GIBC	Graphical interface for batch calculations
GOSAT	Greenhouse gases observing satellite
GMSK	Gaussian minimum shift keying
GNSS	Global navigation satellite system
GSO	Geostationary/Geosynchronous Earth orbit
GTO	Geosynchronous transfer orbit
HEO	Highly elliptical orbit
HR	High resolution
HYP	Hyper spectral camera
I-COUPS	Ion thruster and Cold-gas thruster Unified Propulsion System
IADC	Inter-Agency Space Debris Coordination Committee
IARU	International Amateur Radio Union
ICT	Information and communication technology
IEEE	Electrical and Electronics Engineers
IoT	Internet of Things
ISS	International Space Station (ISS)
ISSL	Intelligent space systems laboratory
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
JSLC	Jiuquan Satellite Launch Centre
JST	Japan Standard Time

LEO	Low-Earth orbit
LEOP	Launch and early orbit phase
LF	Low frequency
LICIA	Light Italian CubeSat for Imaging of Asteroids
LM	Long march
M2M	Machine to machine
MarCO	Mars Cube One
MEMS	Micro-electromechanical system
MEO	Medium Earth orbit
MF	Medium frequency
MIFR	Master International Frequency Register
MLS	Multi-launch service
MSS	Mobile-satellite service
NASA	National Aeronautics and Space Administration of the U.S. federal government
NEO	Near Earth Objects
non-GSO	Non-geostationary satellite networks
OBC	On-board computer
OLFAR	Orbiting low frequency array
PCB	Printed circuit board
PLA	Payload adapter
PMO	Programme Management Office
PRISM	Pico-satellite for Remote-sensing and Innovative Space Missions
PROCYON	Proximate object close flyby with optical navigation
QKD	Quantum key distribution
QUESS	Quantum experiments at space scale
RCS	Reaction control system
RDSS	Radiodetermination-satellite services
RF	Radio frequency
RISESAT	Rapid International Scientific Experiment Satellite
RNSS	Radionavigation-satellite service
RoP	Rules of Procedure
RR	Radio Regulations
RRB	Radio Regulations Board
SAP	Single attosecond pulse
SAR	Synthetic aperture radar
SAST	Shanghai Academy of Spaceflight Technology
s-to-E	space-to-Earth

SDG	Sustainable development goal
SDM	Short-duration missions
SLS	Space launch system
SME	Small and medium enterprises
SOM	Satellite operation management
SOS	Space operations service
SPA	Solar paddle antenna
SSA	Space situational awareness
SSMS	Small Spacecraft Mission Service
SSO	Sun-synchronous orbit
SSPA	Solid state power amplifier
SSSRC	Small Space Systems Research Centre
SSTV	Slow scan tele-vision
STARS	Space tethered autonomous robotic satellite
STM	Space traffic management
TEC	Total electron content
TLE	Two line elements
TLI	Translunar injection orbit
TNSC	Tanegashima Space Centre
TSLC	Taiyuan Satellite Launch Centre
TT&C	Telemetry, tracking and command
UDSC	Usuda deep space centre
UHF	Ultra high frequency
USC	Uchinoura Space Centre
UV	Ultraviolet
VHF	Very high frequency
VIS	Visible
vLEO	very Low Earth Orbits
VSAC	Variable shape attitude control
VSOTA	Very small transmitter for component validation
WRC	ITU World Radiocommunication Conferences
WSIS	World Summit on the Information Society
WSLC	Wenchang Satellite Launch Centres
XSLC	Xichang Satellite Launch Centres
XTRP	X-band Transponder

ANNEX B

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