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(09/2014)

Characteristics, definitions and spectrum requirements of nanosatellites and picosatellites, as well as systems composed of such satellites

SA Series
Space applications and meteorology



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(2014)

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1 Introduction

ITU-R approved Question ITU-R 254/7 – Characteristics and spectrum requirements of satellite systems using nano and picosatellites. In this Question, the Radiocommunication Assembly *decides* that the following Questions should be studied:

1 What are the distinctive characteristics of nano and picosatellites and satellite systems in terms of their use of the radio spectrum as defined by data rates, transmissions time and bandwidths?

2 Taking into account such distinctive characteristics, what are the spectrum requirements for nano and picosatellite systems?

3 Under which radiocommunication services can satellite systems using nano and picosatellites operate?

The space research, Earth exploration, amateur, and educational communities, like other communities focused on leveraging space-based radiocommunication technologies, have an interest in utilizing the potential benefits offered by small satellites, including those referred to as nanosatellites or picosatellites. These technologies allow many projects to be developed quickly and deployed with lower cost than with traditional, larger satellites. While even the most advanced nanosatellites are typically no more than a few million United States Dollars (USD), the smallest missions may have a total developmental and operational budget (excluding launch and ground infrastructure) of only a few tens of thousands of USD¹. Nanosatellites and picosatellites also provide a means for testing emerging technologies and economical commercial off-the-shelf (COTS) components that may be useful in future space missions, including those utilizing larger satellite platforms. They offer new opportunities for existing and new satellite operators, such as universities, educational institutes, governments, and private industry that might not otherwise have considered or been able to afford the use of satellite technologies. They have been demonstrated in a variety of practical applications, including Earth observation, space astronomy, space physics, and maritime communications. Recent proposals for the use of nanosatellites and picosatellites include solar system exploration, interplanetary and even outer solar system missions.

In this Report, the distinctive characteristics of nanosatellites and picosatellites are identified, in response to Question ITU-R 254/7. Furthermore, their spectrum requirements are studied. Finally, the radiocommunication services under which these satellites could operate are identified.

2 Characteristics of small satellites

To carry out the studies related to the Question the class of objects to which the studies apply, as opposed to all satellites, needs to be established. A convenient way to classify satellites is by their mass. Satellites that weigh less than ~ 500 kg are often referred to as small satellites; they can be further classified as shown in Table 1:

¹ Plus additional budgetary items for coordination of frequency assignments, ITU filing (cost recovery if applicable) and related expenses.

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			
Femtosatellite	< 0.1	1	< 50 k	0.01-0.1	1		< 1

Values provided here are typical for the listed satellite types when this report was prepared in 2014. They are not meant to represent fixed limits.

2.1 Mass

While mass may be a good way to easily characterize a satellite, the regulatory challenges associated with filing a picosatellite or a nanosatellite are not necessarily related to the physical characteristics of the satellite. 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.

2.2 CubeSat design specification

One of the most frequently cited nanosatellite and picosatellite design guidelines is the CubeSat specification, developed in 1999 by California Polytechnic State University (Cal Poly) and Stanford University engineers with the goal of easing access to space for the academic community. Since then, the specification has been widely adopted not only by the academic community but others as well, due to easy access to launch services and low cost.

A CubeSat is a miniaturized satellite in the shape of 10 cm cube, with a volume of exactly one litre, and a mass of no more than 1.33 kg. The design is modular; the basic unit is called a 1U CubeSat. A 0.5U module is also available. At present, up to three modules may be linked lengthwise, the base being always a 10 cm × 10 cm square. In the future other base configurations, e.g. 2U × 2U or 2U × 3U, may become possible. While CubeSats are generally characterized by a physical dimension of 10 cm × 10 cm × 10 cm, ancillary equipment such as antennas, solar panels, solar sails or drag chutes to facilitate de-orbiting may extend the overall dimensions.

Although CubeSats are in many cases synonymous with nanosatellites, they are in fact a subset. A number of organizations around the world now build and fly nanosatellite buses that do not conform to the CubeSat design specification, as designs have developed to suit specific mission requirements.

3 Comparison of technical characteristics between traditional satellite systems and those of nanosatellite and picosatellite systems

The technical and operational characterization of satellites in general has a number of perspectives. These include but are not limited to a specific community of operators, spectral usage including power, orbital characteristics, period of operation, and service or application type. Nanosatellite and picosatellite systems share both similarities and differences with more traditional satellites in terms of their technical and operational characteristics.

Table 2 presents a comparison of the technical and operational characteristics between traditional satellite systems and nanosatellite and picosatellite systems. For both systems, these should be considered as a characterization of the missions undertaken to date. Both traditional and nanosatellite and picosatellite systems have a wide variety of technical and operational characteristics, and there is a continuing developmental work (e.g. propulsion systems) to enhance the capabilities of nanosatellite and picosatellite systems.

TABLE 2

Comparison of satellite system characteristics

	Satellite system characteristic	Traditional satellite systems	Typical nanosatellite and picosatellite systems
Space-to-Earth emission considerations	Spectral usage	The frequency band and transmission parameters of these systems are subject to the ITU Radio Regulations	
	Transmission power	Low to high power systems	Low transmission power, but not necessarily low power spectral density (PSD)
	Transmission rates, modulation schemes	A few kbps to Gbps depending on the service, usually bandwidth efficient (Quaternary Phase Shift Keying or higher order)	A few kbps to a few Mbps, lower data rates, typically optimized for power efficiency (e.g. Frequency Modulation/Frequency Shift Keying) and without coding
	Antenna directionality	Many antenna types. Omni-directional antennas are often used, especially for critical operations (e.g. satellite recovery). Sometimes directional antennas are used	Typically only 1 or 2 active antennas per band, often omnidirectional (for example due to lack of attitude control and/or antenna pointing mechanisms)
	Transmission control (switching on and off)	Planned with known associated earth station(s) or service area(s)	

TABLE 2 (end)

	Satellite system characteristic	Traditional satellite systems	Typical nanosatellite and picosatellite systems
Orbit considerations	Type of orbit	All types	Mainly low Earth orbit (LEO)
	Launch arrangements	Established years in advance; however, some contractual adjustments are fairly common for commercial satellites	Mostly opportunistic; based on available space on scheduled launch vehicles. Possibility for dedicated launches
	Orbit	Dedicated launches provide greater control over the range of orbital parameters in mission planning	Non-dedicated launches (e.g. opportunistic secondary payloads) may require consideration of a greater range of potential orbital parameters in mission planning
	Station keeping	Usually, on board propulsion to maintain orbital parameters	Usually, no on board propulsion or limited manoeuvring capability. Some of these missions and future missions will have propulsion systems
	Operational timeline	Dependent on fuel capacity/consumption and/or mission timeline	Often dependent on battery life, orbital altitude, and other considerations
Physical characteristics	Mass	Typically > 500 kg	Typically < 10 kg
	Linear dimensions	Up to several metres in any linear dimension. Solar panels may increase physical size	As small as 10 cm. Simple antennas or other components may extend from the spacecraft bus and substantially increase the linear dimensions
Other considerations	Applicable radio service	Any space radio services could apply to traditional or nanosatellite or picosatellite systems depending on their mission requirements	
	Class of Station	Any class of station could apply to traditional or nanosatellite or picosatellite systems depending on their mission requirements	
	Development and launch timeline	Typically 3-5 years	Months to few years
	Authorization	Domestic and international filing and licensing requirements apply to both space systems. However, the desired development and deployment timelines for nanosatellite and picosatellite systems may be much shorter than those of the filing procedures in some space radiocommunication services	
	Hardware cost (excluding launch)	Hundreds of thousands to tens of millions of USD	Tens to hundreds of thousands USD
	Spectrum management cost	Low compared to cost of satellite	With the exception of the amateur-satellite service, for nanosatellite and picosatellite satellite systems, the cost for the filing, coordination and notification procedure may be relatively high compared to the hardware cost
	Interference considerations	Protection criteria and status as defined by ITU-R Recommendations and the Radio Regulations apply equally to both space systems	

4 Characteristics of nanosatellite and picosatellite systems

The following sections present characteristics of nanosatellite and picosatellite systems that may differ from traditional satellite systems. These characteristics include programmatic timeline, launches, deployment mechanisms, manoeuvring and propulsion, and command and control. These characteristics do not necessarily serve as a definition from a frequency management perspective, but they show some differences between nanosatellite and picosatellite systems and traditional satellite systems which may apply.

4.1 Programmatic timeline

The technologies that have enabled the development of nanosatellites and picosatellites have the potential to facilitate satellite missions for science, education, government and industry more quickly and at lower cost than missions relying on larger and more complicated satellites that may involve more complex developmental processes.

Nanosatellites and picosatellites have been used for a number of new, innovative and unique payloads and missions. Currently, many nanosatellite and picosatellite developers are pursuing project timelines as short as 9-24 months from inception to bringing into use. Table 3, below, shows, for example, the time-line, in days elapsed, from the preliminary design review to de-orbit for one project.

A key driver for this capability is the availability of pre-qualified components on the commercial market, and the high degree of re-use of qualified or heritage designs. Entire satellite buses can be kept on the shelf and be integrated with one or more payloads in a very short time. As the satellite can thus be accepted for flight in a short timeframe, a key timeline constraint within these programs is to determine or assume frequencies of operation early.

TABLE 3

Example of a picosatellite mission lifetime

Milestone	Day
Preliminary design review	0
Critical design review	53
Launch	206
Complete in orbit tests	277
Begin in orbit mission	287
De-orbit	392

4.2 Launches

Depending on specific mission objectives, nanosatellite and picosatellite missions may or may not have particular orbital requirements. Within these mission constraints, nanosatellite and picosatellite operators may have a number of potential launch opportunities available, and may thus not have knowledge of specific orbital characteristics until a launch vehicle is selected. This can occur as little as a few months before the actual launch and well into the development timeline of the satellite.

Nanosatellites and picosatellites have, to date, been launched mostly as secondary payloads, meaning that the primary mission for the launch vehicle involves the launch of one or more larger satellites. Because the launch vehicle often has sufficient excess lift capacity to permit the addition

of the lightweight nanosatellites and picosatellites to the launch mission, those satellites can “piggyback” on a primary payload, so long as the mission requirements for the nanosatellite or picosatellite are consistent with the mission profile for the launch vehicle. Because of the interest in nanosatellites and picosatellites, mission developers are now considering whether dedicated launches and/or launch vehicles would be useful.

Currently, most nanosatellites and picosatellites are launched using separation systems that require minimal interfaces with the launch vehicle. Many separation systems exist with flight heritage on a variety of launch vehicles, including several different manufacturers from around the world providing CubeSat-standard compatible systems, allowing satellite developers to design to a common form factor and encouraging the use of off-the-shelf subsystems from a variety of vendors. These characteristics allow for rapid launch arrangements and accommodation on the launch vehicle, often shared with several other nanosatellites or picosatellites from different organizations.

4.3 Manoeuvring and propulsion

Due to size and weight constraints, most nanosatellites and picosatellites to date have not included propellant or manoeuvring capability, and, once injected in orbit, have limited or no autonomous manoeuvring or station keeping capabilities. However, propulsion and attitude control systems are available to be incorporated into nanosatellites and picosatellites. These propulsion systems include mono propellant systems with a stored propellant, reactive chemical systems using multiple stored chemicals, and electrical or plasma propulsion systems. Also, spacecraft attitude may be maintained using propulsion methods that supplement reaction wheel control systems or magnetic torque coils. Nanosatellites and picosatellites may also have deployable aerodynamic devices to increase drag to promote orbit decay or other orbit manoeuvring. All of these devices and systems are also available for standard satellites, just in a smaller form factor. Though constrained by small physical and mass requirements, the control provided by these manoeuvring and attitude control systems are sufficient due to the mass of the satellite to meet mission needs. However, due to particular mission needs, such attitude or orbit control systems might not be incorporated into some nanosatellites and picosatellites.

As with larger satellites, the orbits of nanosatellites and picosatellites that lack manoeuvring capabilities will decay naturally over time and cannot be intentionally changed. The time that will elapse before any satellite decays from orbit is highly dependent on orbital characteristics and spacecraft design and may be as little as a few months or as long as a few decades. Just like larger satellites, nanosatellites or picosatellites that operate for only a matter of months can present a risk of collision with operational satellites and other orbital debris for decades. Even though many nanosatellite and picosatellite systems have no autonomous manoeuvring, the decay can be determined using up-to-date orbital element data.

4.4 TT&C and communication links

Under No. **15.1** of the Radio Regulations (RR), transmissions, which are unnecessary or superfluous, are prohibited. Further, under No. **22.1** of the RR, 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 the Radio Regulations.

In order to comply with requirements to control and have the ability to cease transmissions, some nanosatellite and picosatellite missions have implemented a passively-safe system whereby the satellite is actively commanded to transmit when in view of an associated earth station.

Some nanosatellite and picosatellites use multiple frequencies for telemetry and data downlinks, as such they are no different than traditional satellites.

4.5 Ground segment

Historically, most nanosatellite and picosatellite missions have utilized a single earth station. These stations are typically small, comprising one or more directional antennas.

Recent developments in networks of cooperative earth stations have enabled satellite operators to receive telemetry throughout large proportions of the orbit. This means that the coverage area can be global. Thus, many of these nanosatellite and picosatellite missions would have to notify based on near-global coverage.

Some nanosatellite and picosatellite operators envisage using telecommand links from the earth station to the satellite, using output powers of up to 50 W in the bands allocated to the meteorological-satellite service, Earth exploration-satellite service and mobile-satellite service frequency allocations bands below 1 GHz. Antenna having maximum gains up to 10 dBi are planned. Therefore, the corresponding e.i.r.p. is up to 27 dBW. This has the potential to cause harmful interference. Generally, the Earth-to-space transmission only occurs when the nanosatellite is in visibility of the corresponding earth station(s).

4.6 Radiocommunication services in which nanosatellites and picosatellites typically operate

Based on filings received by the BR in 2013, most nanosatellites and picosatellites use the very high frequency (VHF) and ultra-high frequency (UHF) amateur-satellite service bands, while especially for the higher bands, the application is often for the space research service or the Earth exploration-satellite service. The nature of service is mostly operational traffic only or public correspondence. Some operators registered their systems to be private correspondence only or at least limited public, especially for uplink transmissions.

4.7 Operational lifetime

As mentioned in Table 2, the operational lifetime of nanosatellites and picosatellites is typically much shorter than for traditional satellites. Normally it is limited to the lifetime of the batteries, the electronic components and for some low altitude orbits, the orbital decay. Since the components are mostly COTS and not developed for space applications, the limit to their survival is about 1-5 years.

4.8 Satellite transmission power

Transmitters on board nanosatellites and picosatellites normally are only low power devices with small antennas. The radio frequency (RF) output power is typically around 1 Watt and typically not higher than 5 Watt. Also, the bandwidth, antenna gain and the e.i.r.p. highly depend on the frequency band. Table 4 shows typical values for different frequency bands. Since the occupied bandwidths involved are generally low, the resulting power spectral density can still be high. Depending on the mission, orbit and power generation capability, the transmission duty cycle of nanosatellites and picosatellites can vary from 10-15 minutes to continuous transmission over the entire orbital period. Some satellites operate a higher power transmitter for a shorter portion of the orbit. In this regard, nanosatellites and picosatellites cannot be distinguished from traditional satellites.

TABLE 4

Typical nanosatellite and picosatellite RF characteristics for different frequency bands

Frequency band	RF output power (W)	Antenna gain (dBi)	Bandwidth (MHz)
< 1 GHz	1	< 3	< 0.1
1-3 GHz	< 1	< 10	< 7.5

4.9 Orbital parameters

So far, most picosatellite and nanosatellite systems operate in NGSO, mainly LEO. The orbital parameters of nanosatellite and picosatellite systems are mostly not different from those of traditional satellites, and are typically not known with a high degree of precision until late in the satellite system design due to launch opportunities as secondary payloads. Since the mission objective of many nanosatellites and picosatellites is some form of technology demonstration like attitude control, tether manoeuvres or simply on orbit verification of materials or electrical components, these satellites are not restricted to special orbits, as long as the communication between the earth station and spacecraft is ensured on a regular basis. Accordingly, small satellite operators are generally open to different launch possibilities and flexible in both orbit altitude and inclination.

4.10 Frequency stability

Doppler shift induced frequency variations occur as for traditional NGSO satellites. Frequency stability with respect to temperature and aging effects depends on the used COTS components, the low available on board power does not allow the use of highly stable oscillators, and therefore, the frequency stability is generally not as good as traditional satellites.

4.11 Filtering (reduction of adjacent and out of band emissions)

Typically, nanosatellites and picosatellites have had limited physical volume available to carry common high performance RF filters, therefore, it is harder to achieve low levels of unwanted emissions. However, advances in miniaturization may enable improved performance in the future.

5 Types of missions and their spectrum use**5.1 Nanosatellite and picosatellite mission categories**

When examining radiocommunication service and spectrum use, nanosatellite and picosatellite missions can generally be arranged into three categories:

- Educational and amateur radio missions
- Experimental and research missions
- Commercial missions

5.1.1 Educational and amateur radio missions

These are satellite missions with the sole aim of educating people about space, electronics and all aspects of physics involved in space; as well as satellites used for amateur radio “self-training and communication”, with no pecuniary interest, as defined in Article 1 of the RR.

5.1.2 Experimental and research missions

Experimental and research missions are missions with one or more of the following purposes:

- To demonstrate a novel space technology in the space environment
- To perform a proof-of-concept for a certain application involving one or more nanosatellites and picosatellites
- To perform space research (primarily earth-orbiting, but also lunar and deep space applications).

Given the fact that satellites performing a proof-of-concept for a certain application can be used as pre-cursors to operational satellite missions there can potentially be a pecuniary (commercial) interest in these satellites which of course is most prevalent in the commercial operational phase which typically follows after such missions.

5.1.3 Commercial missions

The remaining category of nanosatellites and picosatellites consists of the satellites used for commercial missions, i.e. delivering a certain service in certain areas of applications with a clear pecuniary interest. Examples include commercial nanosatellite and picosatellite missions for Earth observation and telecommunication. Table 5 provides an overview of the typical applicable radiocommunication services per category and their coordination requirements.

TABLE 5

**Typical applicable radiocommunication services per category
and their coordination requirements**

Mission category	Typical applicable radiocommunication service	Typical coordination requirement under Radio Regulations section II of Article 9* (for NGSO)
Educational and amateur radio	Amateur-satellite	Not subject to coordination
Experimental, research	Space operation, space research, Earth exploration-satellite	Not subject to coordination
Commercial	Any radiocommunication service	May be subject to coordination

* All mission categories require advance publication and notification.

5.2 Evolution of nanosatellite and picosatellite missions and their applicable radio services

Starting from around 2003, when the CubeSat concept was introduced, many nanosatellites and picosatellites have operated in the amateur-satellite service, and some have operated in the space operation, space research or Earth exploration-satellite service. More and more missions operating in frequency bands allocated to the amateur-satellite service are not strictly compliant with the definition of the amateur-satellite service as defined in the RR, and it is expected that an increasing number of nanosatellite and picosatellite missions will also operate in other services. Even though these frequency bands are typically not subject to coordination, the RR (Section IA of Article 9) require that administrations do their best to resolve any difficulties in case an administration expects interference based on the published data in the API/A.

During recent years (since 2011), there has been a significant growth in the amount of commercial nanosatellite and picosatellite missions, and the first constellations of nanosatellites and picosatellites for commercial Earth observation are being put into orbit. Some developers are

working on commercial telecommunications applications using nanosatellites and picosatellites as well. Typically, for these applications, bands subject to coordination (Section IIA of Article 9) have been allocated to the applicable services.

As with any traditional satellite, irrespective of the operating frequency band and service at least some form of correspondence is always necessary. This can be either full coordination under Section IIA of Article 9, or under Section IA of Article 9. Both forms of correspondence require the Appendix 4 data to be correct and complete, and furthermore, would require the orbital parameters to be known with sufficient specificity to facilitate meaningful coordination. Since most nanosatellite and picosatellite systems operate in a limited range of orbits, the lack of knowledge of specific orbital parameters due to opportunistic launches should not be a barrier for submission of the API/A or CR/C (if applicable), although such filings may cover a range of orbits broader than necessary to operate. Submission of filings at the earliest possible date will facilitate compliance with the radio regulations, which is necessary to eliminate the potential of harmful interference to systems operating in the same frequency bands.

Communications equipment used in nanosatellites and picosatellites is generally COTS, with the ability to either set the frequency on build or set it prior to acceptance testing of the unit. The time within which this can and must be completed requires means that the frequencies for the operation of the satellite must be known quite early in the program. Changing frequencies late in the program can have significant cost and schedule impacts.

Due to limitations in the availability of low cost technologies the vast majority of nanosatellites utilize frequency bands ranging from 100 MHz to 10 GHz.

Many nanosatellite and picosatellite operations to date have been non-conforming to the Radio Regulations and were thus operating on an unprotected basis and subject to not causing harmful interference (RR No. 4.4). As an example, some administrations have used frequency bands allocated to the amateur or amateur-satellite service. However, the use of amateur or amateur-satellite service spectrum, under the amateur service, is only appropriate if the definition of the amateur service (RR No. 1.56) is 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.” A number of applications and operations in these frequency bands may not comply with all the requirements for amateur use and have therefore been authorized only for experimental operation.

Space research and space operation service bands have also been used by nanosatellites and picosatellites. Frequency bands allocated to the Earth exploration-satellite service, meteorological-satellite service and mobile-satellite service have been used for Earth-to-space links for the purpose of telecommand links. Some nanosatellites and picosatellites have occasionally used bands which are designated under footnote No. 5.150 of the RR for use by industrial, scientific and medical (ISM) applications. It should be stressed that the definition of ISM does not include radiocommunication, and developers should be aware that nanosatellites and picosatellites do not fall under the definition of ISM applications. While they cannot operate on the same unlicensed basis as ISM equipment, they may be eligible for licensing on an experimental basis, depending on the provisions of the responsible administration. No matter what service a nanosatellite or picosatellite frequency assignment operates under, the characteristics of the ground stations used with it need to be documented and the compatibility of its frequency assignments with stations in other services needs to be assessed. It should be recognized that, when frequency assignments that are not in conformance with the RR are notified to the ITU, this should be done in accordance with Article 8.4 of the RR.

As use of nanosatellite and picosatellite systems expands to support other applications, developers may seek to use additional frequency bands allocated to the appropriate service of operation.

Interest in other frequency bands allocated to other services may result from mission specific requirements, availability of terrestrial infrastructure to support a particular mission, or other yet to be identified factors. As the relatively short development cycle and reduced cost offers easier access to space to new communities (e.g. educational institutes), either through partnerships with civil space agencies or as independent satellite operators, the range of applications as well as spectrum requirements will undoubtedly expand.

With the continuing miniaturization of technologies and the expansion of innovative applications for nanosatellite and picosatellite systems, bandwidth and data rate requirements are also anticipated to increase over time.

As for any other satellite, the allocation to the relevant space radiocommunication service should reflect the actual application.

6 Conclusion

This Report has been produced in response to Question ITU-R 254/7 by presenting a study of the distinctive characteristics of nanosatellites and picosatellites as opposed to traditional satellites, spectrum requirements, and services under which these satellites can operate.

Nanosatellite and picosatellite systems have provided unprecedented access to space by way of their reduced deployment timelines and costs. Further, standardization of certain physical aspects allows increased flexibility for their deployment as secondary payloads.

While nanosatellites and picosatellites are most often recognized by their small physical dimensions and mass, there are several other programmatic and technical aspects which make them different from more traditional satellite systems. These may include short development times and short operational life. It should be noted that most of these characteristics, as well as physical dimensions and mass, are not part of the information to be submitted under Appendix 4 of the RR. It is difficult under Appendix 4 of RR (edition 2012) to distinguish nanosatellites and picosatellites from others. Nevertheless, nanosatellites and picosatellites may be used for a variety of applications in a number of different satellite services. Currently, these applications are often, but not always, experiments, tests or technology demonstrations. As new concepts are continually being developed for nanosatellite and picosatellite applications, the differences between these satellites and traditional satellites may become less distinct.

Annex 1

List of abbreviations

API – Advance publication information

COTS – Commercial-off-the-shelf

GEO – Geostationary Earth orbit

HEO – High Earth orbit

ISM – Industrial, scientific and medical

LEO – Low Earth orbit

MEO – Medium Earth orbit

NGSO – Non-geostationary satellite orbit

PSD – Power spectral density

TT&C – Telemetry, tracking and telecommand

UHF – Ultra high frequency

VHF – Very high frequency
