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| **INTERNATIONAL TELECOMMUNICATION UNION** |  |
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| DRAFT NEW REPORT ITU-R M.[UAS-FSS] | |
| Technical and operational characteristics, interference and regulatory environments associated with the use of frequency bands allocated to  the fixed-satellite service not subject to Appendices 30, 30A and 30B  for the control and non-payload communication of unmanned  aircraft systems in non-segregated airspace | |

WRC-15 agenda item 1.5

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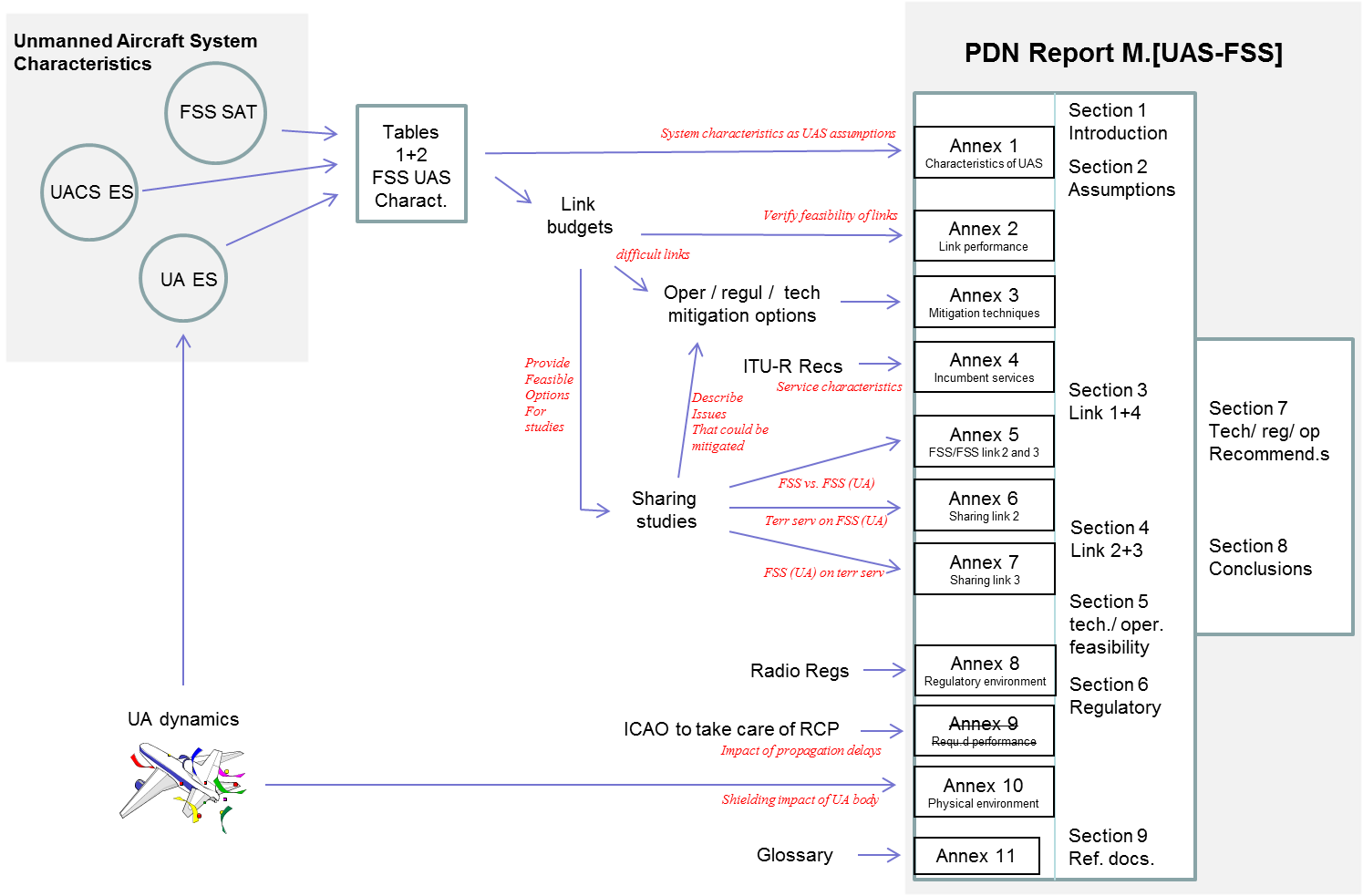
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**Executive summary**

This Report addresses the technical, operational, and regulatory including the necessary sharing and compatibility studies as required by WRC-15 agenda item 1.5 and described in Resolution **153 (WRC-12)** to enable the conference to decide on the usage of the fixed-satellite service (FSS) for the control and non-payload communication (CNPC) links for the operation of unmanned aircraft systems (UAS)[[1]](#footnote-1), as appropriate. There were several technical and operational assumptions made for these studies that are clearly identified in section 2 of the Report. Among them are two that are fundamental and affect the choice of studies that were necessary:

1) UAS operations, for the purpose of this agenda item, are within non-segregated airspace; and

2) the UAS control station (UACS) is at a fixed location consistent with the definition of the FSS

Therefore, studies of the operation of UAS CNPC earth stations within the FSS leading to technical, regulatory, and operational recommendations to WRC-15 as identified in *invites ITU-R 1 and 2* of Resolution **153 (WRC-12)** to accommodate these earth stations were required. These studies, only addressing the link between the UA and the FSS satellite, are summarized in the main body of this Report with further details provided in the annexes. In the development of this Report careful consideration was given to ensuring to the extent possible that only issues which are the responsibility of the ITU, in terms of impacts to the Radio Regulations (RR), were addressed.

Any aspects to be taken into account when certifying UAS for airworthiness are beyond the scope of this Report.

This report does not intend to cover means of effective and useful integration of UAS into non-segregated airspace. All aspect of using airspace with UA need to be defined by the International Civil Aviation Organization (ICAO) andotheraviation standardisation organizations (e.g. EUROCAE and RTCA). National civil aviation authorities requirements need also to be met to achieve certification for the operation of UAS.

# 1 Introduction and scope

Resolution **153 (WRC-12)** *invites ITU-R,*

“ *1 to conduct, in time for WRC 15, the necessary studies leading to technical, regulatory and operational Recommendations to the Conference, enabling that Conference to decide on the usage of FSS for the CNPC links for the operation of UAS;*

*2 to include, in the studies referred to in invites ITU-R 1, sharing and compatibility studies with services already having allocations in those bands;*

*3 to take into account information from operations referred to in considering e).*

*Considering e) takes note of the fact, that UAS already operate in fixed-satellite service (FSS) frequency bands for the UA-to-satellite CNPC links under* ***No. 4.4*** *of the Radio Regulations.”*

This Report provides the associated studies on technical and operational characteristics, interference and regulatory environments, corresponding to each of these invitations, when considering UAS CNPC links for earth stations on-board UAs and UACS on fixed point on the ground communication using FSS links in frequency bands allocated to the fixed-satellite service not subject to Appendices **30**, **30A** and **30B**.

It is a fundamental assumption made throughout this Report that to use the frequency bands allocated to the FSS the UAS CNPC link must operate within the same regulatory and performance limitations as any other FSS earth or space station and that, from an interference perspective, it must perform its function in exactly the same manner as any other FSS earth or space station. This means that, when compared to a non-UAS FSS system, the UA or the space station supporting the UA must neither cause additional interference to other incumbent services nor require additional protection from other incumbent services. Such incumbent services include the other co-frequency FSS networks.

Furthermore, it should be noted that successful coordination of assignments in the frequency coordination process is a fundamental prerequisite for UA CNPC operation. Such coordination ensures that FSS network interference levels are never higher than those that would occur under the maximum transmit levels allowed by Article **21** and maximum off-axis e.i.r.p. levels allowed in ITU‑R S.524, consequently by using these levels this Annex addresses the very worst case FSS network compatibility analyses.

It should be noted that RR No. **1.59** allows FSS to be used like any other radiocommunication service for the provision of safety service.

The ICAO is responsible for developing the technical standards and recommended practices (SARPs) for CNPC to ensure safe operation of UAS in non‑segregates airspace. UAS CPNC operations in non-segregated airspace need to satisfy ICAO SARPS requirements.

# 2 Terminology and assumptions

## 2.1 Terminology

As shown in Figure 1, a typical unmanned aircraft system (UAS)[[2]](#footnote-2) comprises

– **Unmanned aircraft (UA)**: UA designates all types of remotely controlled aircraft.

– **UA control station (UACS)**: Facility from which a UA is controlled remotely. The studies performed in this Report consider UACS earth stations using satellite communication located at a fixed point.

– **Geostationary satellite (GSO)**: 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 (RR No. **1.189**).

Figure 1

Typical beyond line of sight control and non-payload communication links in an unmanned aircraft system



As invited by Resolution **153 (WRC-12)**, all studies in this Report focus on radio regulatory conditions for UA CNPC applications operating in the FSS under regulatory of flight conditions applicable for non-segregated airspaces.

The definition of non-segregated airspace is adopted from ICAO as follows:

**– Segregated airspace** is defined as[[3]](#footnote-3):"Airspace of specified dimensions allocated for exclusive use to a specific user(s)".

**– Non-segregated airspace** is airspace other than those designated as segregated airspace.

Although the overall performance of forward and return links is driven by Links 2 and 3 between a UA and a satellite, the regulatory conditions for each of the four links shown in Figure 1 differ and will therefore be discussed individually.

Further assumptions for all studies in this Report are:

– an UAS comprises only system concepts that are based on geostationary FSS satellites which are typically characterized as shown in Annex 1;

– a UAS comprises UACS earth stations (UACS ES) that are mounted in fixed locations on the earth's surface;

– CNPC beyond line of sight (BLOS) (i.e. no payload data) communication via geostationary FSS satellite networks

– BLOS CNPC links should not include inter satellite links.

**Control and non-payload communication**[[4]](#footnote-4) is understood as the radio data links used to exchange information between the UA and UACS ensuring safe, reliable, and effective UA flight operation. A CNPC communication link comprises data for

– **Telecommand** (forward) control messages and **Telemetry** (return) data relevant to enable full remote control all UA functions;

– **Air Traffic Control** **relay** communication (to ensure at the remote pilot site the same situational awareness of VHF voice communication representative for the radio vicinity at the current location of the UA;

– **Sense and avoid data**: comprising target track data, airborne weather radar data corresponding to the piloting principle of “see and avoid” which is used in all airspace volumes where the pilot is responsible for ensuring separation from nearby aircraft, terrain and obstacles.

The communication between a remote pilot in charge of the flight and his/her associated aircraft needs a full-duplex communication comprising a forward- and a return link with the following definitions:

– **Forward link**: CNPC-link from the remote pilot (located at the UACS) to the UA through satellite links 1 and 2.

– **Return link**: CNPC-link from the UA to the UACS through satellite links 3 and 4.

In order to simplify the reference to frequency ranges and to avoid the use of non-ITU-R terms "Ku" and "Ka"-band, the following terms are used in this report:

– "14/11 GHz" frequency range: Identifies frequency bands allocated to the fixed-satellite service in the frequency range 10.7-14.8 GHz not subject to Appendices 30, 30A and 30B as shown in Table 2

– "30/20 GHz" frequency range: Identifies frequency bands allocated to the fixed-satellite service in the frequency range 17.3-30 GHz not subject to Appendices 30, 30A and 30B as shown in Table 3

## 2.2 Characteristics of unmanned aircraft systems

In line with *considering i)* of Resolution **153 (WRC-12)**, Annex 1 provides the characteristics of UAS in the 14/11 GHz and 30/20 GHz frequency bands, used for the analyses of this Report. These characteristics are in line with the current FSS technical environment and the relevant provisions of the Radio Regulations.

## 2.3 Definition of flight scenarios and flight phases

### 2.3.1 Typical unmanned aircraft flight scenarios

ICAO provided flight scenarios summarized in Table 1. Each scenario is further described in the following sections.

NOTE: For the first six scenarios, the requirements for flight before and after the specific scenario including take-off, climb to height, transit, land etc. are not included in Table 1. To construct a “gate-to-gate” operation the appropriate mix of scenario elements need to be considered. Alternatively it could be assumed that flight before and after the scenario is supported by a different CNPC link e.g. line-of-sight (LOS).

TABLE 1

Unmanned aircraft system (remotely piloted aircraft system) scenarios as provided by ICAO

| Parameter | Units | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | High altitude surveillance/ Aerial work  (search pattern) | Medium altitude surveillance/ Aerial work  (search pattern) | En Route Oceanic | Low level surveillance  Maritime patrol | Short en-route populated land | Medium range –Low altitude surveillance over land  Below 1 000 ft AGL  Linear feature and/ or search pattern | Departure  Descent above 3 000ft AGL | Take-off/ land, taxi | Urban Surveillance – Very low level, short range, very small fixed or rotary wing |
|  |  | (ATC radar /ADS-B control for separation) | (ATC radar control for separation) | Class A procedural ATC control | International (non Radar, Non ATC control )  Class G | Class A, B ,C (ATC radar control for separation) | Class G  (no ATC separation) | (ATC radar control for separation) |  | Class G (no ATC separation) |
| Max altitude AMSL | ft | 66 000 | 30 000 | 60 000 | 10 000 | 38 000 | 1000 AGL | 19 000 | 3000 AGL | 400 AGL |
| Max altitude AMSL | ft | 66 000 | 30 000 | 60 000 | 10 000 | 38 000 | 1000 AGL | 19 000 | 3000 AGL | 400 AGL |
| Min altitude AMSL | ft | 30 000 | 19 000 | 20 000 | 500 | 19 000 | 100 AGL | 3 000 AGL | 0 AGL | 0.5 AGL |
| Max latitude (°) | degrees | 90 | 90 | 90 | 90 | 70 | 90 | 70 | 70 | 70 |
| Max rain rate at aircraft*[[5]](#footnote-5)* | mm/hr | 0 | 5 | 20 | 10 | 20 | 5 | 20 | 20 | 3 |
| Max ground speed including wind | Kts | 50 | 300 | 550 | 250 | 550 | 150 | 250 | 200 | 50 |
| Min ground speed | Kts | 0 | 100 | 250 | 80 | 150 | 40 | 100 | 0 | 0 |
| Max roll | degrees | 10 | 20 | 10 | 30 | 10 | 30 | 20 | 30 | 20 |
| Max pitch | degrees | 5 | 5 | 5 | 10 | 5 | 5 | 10 | 10 | 5 |
| Max ATC voice/data round trip latency | s | 10 | 5 | 120 | Not relevant | 5 | Not relevant | 3 | 1 | Not relevant |
| Max aircraft response time over C2/C3 link e.g. for DAA | s | 5 | 2 | 30 | 2 | 2 | 1 | 1 | 1 | 0.5 |

ADS-B: Automatic dependent surveillance broadcast

AGL: Above ground level

AMSL: Above mean sea level

ATC: Air traffic control

DAA: Detect and avoid

kts: Knots (NM/hr)

#### 2.3.1.1 Scenario 1: High altitude surveillance / aerial work (search pattern)

In this scenario, the aircraft would typically be operating at very high altitudes while conducting operations such as maritime surface surveillance or acting as a communication relay and thus could be required to take place at any location globally. Typical flights would be of a long endurance, both due to the need to transit to the location and to achieve the required time on-station. Operations would be above most typical weather systems and also above the operating levels of other typical air traffic, thus requirements for manoeuvring would be routinely limited to positioning turns to remain on station and, therefore, only low rate turns are required. Although the aircraft’s airspeed may be relatively low in comparison to other aircraft types, the actual groundspeed value may be high due to high level atmospheric effects (Jetstream etc.). The airspace is controlled by air traffic control (ATC), but due to the altitudes, the density of other traffic is likely to be low and hence the ATC response timing is not critical.

#### 2.3.1.2 Scenario 2: Medium altitude surveillance / aerial work (search pattern)

Surveillance platform for monitoring international borders, forest fires, wild life (large scale migration), natural phenomena (ice, volcanoes). Operation in controlled airspace, requiring the ability to respond to ATC instructions in a timely manner. Missions will potentially require polar coverage with speeds up to 300 NM/h. Modest manoeuvre rates and attitudes are required (sufficient to maintain a tight surveillance grid). Generally missions will be pre-planned with low rate of instruction update (from ATC or pilot).

#### 2.3.1.3 Scenario 3: En route oceanic

This scenario replicates the long range transit (from “Point A” to “Point B”) flights that are carried out by intercontinental airliners, and may involve the transportation of cargo/passengers or simply the re-positioning of the aircraft for another tasking. The transit would be at a high altitude, but may be varied in order to take the best advantage of prevailing wind flows and would involve operation within a traffic flow of other aircraft following similar routes which could include transit over Polar Regions and over land or water. As such, the aircraft and its data link system would need to be able to withstand the same weather conditions as other aircraft. Airspace will be controlled by ATC and will be subject to the same communication latency requirements that apply to manned flights (which are low on oceanic flights). Manoeuvring rate requirements will be relatively low due to the “stable” nature of a transit flight (long periods on a specific heading and altitude without the need to manoeuver). Again, groundspeed may be expected to be relatively high due to high level atmospheric effects.

#### 2.3.1.4 Scenario 4: Low level surveillance maritime patrol

This is the typical mission for detection of smuggling or illegal immigration by boat. Operation will be at 5 000-10 000 ft for detection and at very low altitude, down to 500 ft, for identification. All weather operation is required (short of extreme conditions) with high manoeuvring capability to allow tracking of fast targets. Fast response command and control (C2) instructions from pilot /mission controller will be required, but no ATC communication as operation will typically be in international Class G airspace.

#### 2.3.1.5 Scenario 5: Short en-route over populated land

This scenario replicates a relatively short range transit overland flight from one location to another (‘A’ to ‘B’), (e.g. within a country), either for the transportation of cargo/passengers or the re‑positioning of the aircraft for a future tasking. Flight will include a climb portion, a period of level flight, and a descent portion, although depending on the distances involved and the type of aircraft, it is quite feasible that the route may consist of a climb (to a ‘mid-way’ point on the route) followed immediately by a descent to the destination.

The flight will be under ATC control, within controlled airspace throughout and the traffic density of the airspace is likely to be high; therefore there is a requirement for an effective two-way flow of RT communication with ATC in order to ensure that ATC instructions can be complied with. At altitudes above 19 000 ft, however, flights following this scenario are most likely to have already been properly established on their basic route, thus large, or rapid, heading changes are less likely to be required. Vertical manoeuvres will routinely be limited to simple ‘levelling off’ at the top of the climb, or the initiation of the descent prior to landing.

#### 2.3.1.6 Scenario 6: Medium range – low altitude surveillance over land, below 1 000 ft above ground level monitoring linear feature and / or executing search pattern

Typical mineral exploration survey with earth sensors (e.g. magnetometers) at low altitude but over wide areas and monitoring of long linear infrastructure, e.g. oil and gas pipelines or electricity pylons. Operation at very low altitude on pre-planned missions at moderate speed (up to 150 kts – often slower) and only in reasonable weather. (For magnetometer surveys, these can only take place in good space weather conditions – low sun spot activity). High turn rate ability required to maintain search patterns/track following and to avoid intruders (collision avoidance). Occasional low latency C2 communication required to allow remote pilot to manage unexpected events. Operation in Polar Regions is often required.

#### 2.3.1.7 Scenario 7: Departure / descent above 3 000 ft above ground level

This scenario covers the “Terminal Manoeuvring Phase” of a flight, during which various heading and height adjustments are required, either from after take-off until the aircraft is fully established en-route, or from the point that the aircraft has started to descend towards its destination until the final approach to the runway has commenced. The flight will be required to integrate with other air traffic, under ATC control and hence will need to be able to respond in a timely fashion, both for ATC radio telephony (RT) communication and for heading and level changes. A variable mix of weather conditions are clearly going to be encountered, up to the design limits of the aircraft. Aircraft speeds are normally limited to 250 kts max.

#### 2.3.1.8 Scenario 8: Take-off, land and taxi

This covers final approach circuit and landing phases below 3 000 ft where the operation is automatic. High manoeuvring capability may be required (depending on the size of the UA) but speed will normally be limited to below 200 kts. Despite the landing/take-off phases being fully automated, there may be a requirement for the remote pilot to intervene rapidly in order to ensure safety. Even a short term loss of C2 could trigger a requirement for some sort of alternative action (e.g. a go around) which is not desirable because of the resultant disruption to the traffic flows. Operation in the taxi phase (assumed to be manual) may need to contend with radio line of sight screening and multipath effects due to buildings. Requirements for take-off are similar to landing.

#### 2.3.1.9 Scenario 9: Urban surveillance, very low level, short range, very small fixed or rotary wing

Typical of police operations (crime or crowd surveillance) or short range infrastructure surveys (bridges, chimneys). Low and very low speed operation typically with auto stabilized UA under manual control requiring a fast response to remote pilot inputs. Not usually required in Polar Regions but screening by buildings and multipath effects may be significant.

### 2.3.2 Selection of flight scenarios for sharing studies

Scenarios 2 and 4 of Table 1 are taken for analyses as they include the characteristics of all other scenarios describing typical dynamic flight cases for UA CNPC via satellite communication.

– Scenario 2 covers the conditions of scenarios 1, 3, and 5

– Scenario 4 covers the conditions of scenario 7

Scenarios 6, 8, and 9 describe local events that might be covered by LOS communication, thus they are not candidates for satellite CNPC communication.

Therefore, scenarios 2 and 4 are included in the study cases.

## 2.4 Fixed satellite service frequency bands studied for unmanned aircraft control and non-payload communication application

In consideration of *recognising b)* of Resolution **153 (WRC-12)**, this Report studies the regulatory, technical, and operational aspects of using UA CNPC in FSS geo-stationary orbit (GSO) networks operating in frequency bands allocated to the FSS as listed in Table 2 and Table 3, which are not subject to the provisions of RR Appendices **30**, **30A** and **30B**.

Incumbent services in each of these bands are taken from the Table of Frequency Allocations in RR Article **5**, taking table entries as well as entries by footnote into account for sharing analyses. Footnotes to Tables 2 and 3 provide additional information. Also listed are frequency bands allocated to the fixed-satellite service (FSS) which are shared with mobile satellite service (MSS) or aeronautical mobile satellite service (AMSS), however not in all ITU-Regions. The FSS direction in the “Direction” column is consistent with the “Link” direction (the first column) for the ITU-R Region(s) listed in the “Remarks” column.

Table 2

Frequency bands in 14/11 GHz allocated to the fixed satellite service not subject to Radio Regulations Appendices 30, 30A and 30B investigated for unmanned aircraft control and non-payload communication applications

| Link | Frequency band | Allocated to | Direction | Provisions | Remarks |
| --- | --- | --- | --- | --- | --- |
| L3  (UA to SAT)  (U/L) | 14.0-14.25 GHz | FSS, RNS, mss, srs, amss1, FS2, mmss3 | Earth to space | RR Nos. **5.457A, 5.457B, 5.484A, 5.504, 5.504A, 5.504B, 5.504C,5.505, 5.506, 5.506A, 5.506B** | R1, R2, R3 |
| 14.25-14.3 GHz | FSS, RNS, mss, srs, amss1, FS2,4 , mmss3, | Earth to space | RR Nos. **5.457A, 5.457B, 5.484A, 5.504, 5.504B, 5.505, 5.506, 5.506A, 5.506B, 5.508, 5.508A,** | R1, R2, R3 |
| 14.3-14.4 GHz | FSS, FS, MS, mss, rnss, mmss3, amss1 | Earth to space | RR Nos. **5.457A, 5.457B, 5.484A, 5.504A, 5.504B, 5.506, 5.506A, 5.506B, 5.509A,** | R1, R2, R3 |
| 14.4-14.47 GHz | FSS, FS, MS, mss, srs, mmss3, amss1 | Earth to space | RR Nos. **5.457A, 5.457B, 5.484A, 5.504A, 5.504B, 5.506, 5.506B, 5.509A,** | R1, R2, R3 |
|  |  |  |  |  |
|  |  |  |  |  |  |
| L2  (SAT to UA)  (D/L) | 10.7-11.7 GHz5 | FSS, FS, MS | Space-to-Earth; Earth-to-space (R1) | RR Nos. **5.441, , 5.484,5.484A** | R1, R2, R3 |
| 11.7-12.2 GHz | FSS, FS6, ms7, BSS8 | Space-to-Earth  (R2) | RR Nos. **5.484A, 5.485, 5.486, 5.488, 5.489** | R2 |
| 12.5-12.75 GHz | FSS, BSS, FS, MS | Space-to-Earth  (R1+R3)Earth-to-space  (R1+R2) | RR Nos. **5.484A**, **5.493**, **5.494,** **5.495,** **5.496** | R1, R3 |

1. The secondary allocation to the aeronautical mobile-satellite service is specifically mentioned in RR Nos. **5.504A**, **5.504B**, and **5.504C**.

2. The fixed service is allocated on a primary basis in 42 countries by RR No. **5.505**.

3. The maritime mobile-satellite service is allocated on a secondary basis in 19 countries by RR No. **5.457B**.

4. The fixed service is allocated on a primary basis in 6 countries by RR No. **5.508**.

5. The sub-bands 10.7-10.95 GHz (space-to-Earth) and 11.2-11.45 GHz (space-to-Earth) are subject to the provisions of Appendix **30B** per RR No. **5.441** and are therefore excluded from consideration for UA CNPC applications.

6. In Region 2, in two countries, the fixed service allocation is secondary in the band 11.7-12.1 GHz per RR No. **5.468** and the fixed service is allocated on a primary basis in 1 country in RR No. **5.489**.

7. In Region 2, the mobile service is allocated on a secondary basis in the band 11.7-12.1 GHz and there is no mobile service allocation in the band 12.1-12.2 GHz.

8. In Region 2, the broadcasting-satellite service is allocated by RR No. **5.485.**

Note – The frequency band 14.5-14.8 GHz is only for BSS feeder link and not authorized in Europe (see RR no. 5.510).

Table 3

Frequency bands in 30/20 GHz allocated to the fixed satellite service not subject to Appendices 30, 30A and 30B   
investigated for unmanned aircraft control and non-payload communication applications

| Link | Frequency band | Allocated to | Direction | Provisions | Remarks |
| --- | --- | --- | --- | --- | --- |
| L3  (UA to SAT)  (U/L) | 27.5-28.5 GHz | FSS, FS, MS | Earth-to-space | RR Nos. **5.484A**, **5.516B**, **5.537A**, **5.538**, **5.539**, **5.540** | R1, R2, R3 |
| 28.5-29.1 GHz | FSS, FS, MS, eess (E-s) | Earth-to-space | RR Nos. **5.484A**, **5.516B**, **5.523A**, **5.539**, **5.540**, **5.541** | R1, R2, R3 |
| 29.1-29.5 GHz | FSS, FS, MS, eess (E-s) | Earth-to-space | RR Nos. **5.516B**, **5.523C**, **5.523E**, **5.535A**, **5.539**, **5.540**, **5.541A** | R1, R2, R3 |
| 29.5-29.9 GHz | FSS, eess (E-s), MSS (R2)/mss (E-s), fs1, ms1 | Earth-to-space | RR Nos. **5.484A**, **5.516B**, **5.525, 5.526, 5.527, 5.529, 5.539, 5.540, 5.541, 5.542** | R1, R2, R3 |
| 29.9-30.0 GHz | FSS, MSS, eess (E-s, s-s2)), fs1, ms1 | Earth-to-space | RR Nos. **5.484A, 5.516B, 5.525, 5.526, 5.527, 5.538, 5.539, 5.540, 5.541, 5.542, 5.543** | R1, R2, R3 |
|  |  |  |  |  |  |
| L2  (SAT to UA)  (D/L) | 17.3 – 17.7 GHz | FSS, rls, fs3, ms3 | Earth-to-space (R1)  space-to-Earth | RR Nos. **5.514, 5.516, 5.516A, 5.516B,** | R1 |
| 18.1 – 18.4 GHz | FSS, FS, MS, Meteo.Sat Service (s-E)4 | space-to-Earth | RR Nos. **5.484A, 5.516B, 5.519, 5.520, 5.521** | R1, R2, R3 |
| 18.4-18.6 GHz | FSS, FS, MS | space-to-Earth | RR Nos. **5.484A**, **5.516B** | R1, R2, R3 |
| 18.6-18.8 GHz | FSS, EESS (passive), FS, MS, SRS/srs (passive) | space-to-Earth | RR Nos. **5.516B**, **5.522A**, **5.522B**, **5.522C** | R1, R2, R3 |
| 19.7-20.1 GHz | FSS, MSS/mss, FS5, MS5 | space-to-Earth | RR Nos. **5.484A, 5.516B, 5.524, 5.525, 5.526, 5.527, 5.528, 5.529** | R1, R2, R3 |
| 20.1-20.2 GHz | FSS, MSS, FS5, MS5 | space-to-Earth | RR Nos. **5.484A, 5.516B, 5.524, 5.525, 5.526, 5.527, 5.528** | R1, R2, R3 |

1. The fixed and mobile services are allocated on a secondary basis in 35 countries by RR No. **5.542**.

2. The Earth exploration-satellite service (space-to-space) is allocated on a secondary basis by RR No. **5.543**.

3. The fixed and mobile services are allocated on a secondary basis in 29 countries by RR No. **5.514**.

4. The meteorological-satellite service (space-to-Earth) is allocated on a primary basis by RR No. **5.519**.

5. The fixed and mobile services are allocated on a primary basis in 44 countries by RR No. **5.524**.

Note - The frequency range 17.3-17.7 GHz is ruled by the Appendix 30A in Region 2.

## 2.5 Protection criteria considered in this report for the unmanned aircraft receiver (link 2)

It is a basic assumption throughout this report that stations on-board UA communicating with satellites operating in the fixed-satellite service (FSS) will operate under the same technical and regulatory conditions as an FSS Earth station.

Accordingly, the protection criteria of the fixed-satellite service (FSS) are applicable for UAS CNPC links applications. Consequently, the long-term interference criterion, which is provided by Recommendation ITU-R S.1432, could be applied. However, because of the moving nature of the UA receiver this criterion alone is not sufficient to ensure the necessary protection. Therefore, a parametric approach was applied to provide information on the time-varying characteristics of the short-term interference and its impact on the UA receiver while the UA is flying through non-segregated airspace. This could provide the basis for short-term protection criteria definition.

# 3 Compatibility and sharing conditions for radio links between the unmanned aircraft control stations and the fixed satellite service space station (links 1 and 4)

These links provide connections between UACS Earth stations and satellites for which the current fixed satellite service (FSS) allocation as mentioned above would be used. Link 1 and Link 4 are operated as typical FSS links and their characteristics are identical to typical FSS applications. Therefore, there is no need for compatibility studies.

Technical and operational aspects are to be within the envelope of typical characteristics of the earth station as coordinated and recorded in the ITU MIFR under the relevant provisions of Articles **9** and **11** of the Radio Regulations that is analysed in section 6.

## 3.1 Compatibility analysis for link 1

Assuming that a conventional FSS link provides the necessary availability, then Link 1 can be considered as a typical Earth-to-space link between an FSS earth station fixed on the earth's surface and a geostationary satellite operated in the FSS. Any application of such a link, including UAS CNPC, follows the same coordination process as given by RR Article **9** and **11**.

## 3.2 Compatibility analysis for link 4

Assuming that a conventional FSS link provides the necessary availability, then Link 4 can be considered as a typical space-to-Earth link between a geostationary satellite and an FSS earth station fixed on the earth's surface. Any application of such a link, including UAS CNPC, follows the same coordination process as given by RR Article **9** and **11**.

# 4 Compatibility and sharing conditions for radio links between the unmanned aircraft and the fixed satellite service space station (links 2 and 3)

In line with *considering f)* of Resolution **153 (WRC-12)**, and based on the CNPC link characteristics defined in Annex 2, this section examines the sharing conditions of both links 2 and 3 with existing terrestrial services with a primary allocation as well as with other FSS networks.

Study cases are defined for each link by proper combinations of UAS characteristics as given by tables in Annex 1 such as frequency range, existing service, and the UA antenna size as well as the flight scenario 2 or 4 from Table 1. Studies are performed for scenarios 2 and 4 as these are assumed to be representatives of all other flight scenarios as defined in Table 1.

## 4.1 Characteristic of incumbent services

The characteristics of the only incumbent service, the fixed service, used in the studies are described in Annex 4.

## 4.2 Compatibility analysis for link 2

Because the space station supporting the UA operates with the same parameters as an FSS space station, the use of the satellite downlink (link 2) for UA CNPC will not change the sharing conditions with incumbent services, including the FSS applications.

Studies are provided in Annexes 5 and 6.

The incumbent services have been derived from entries in the allocation tables and corresponding footnotes of RR Article **5**, as listed in Tables 2 and 3 above.

Incumbent services considered in the studies were:

– For Link 2 in 11 GHz: FS, MS, EESS (passive), SRS

– For Link 2 in 20 GHz: FS, MS, EESS (passive), SRS

The characteristics of services applied for the impact analyses are summarized in Annex 4.

### 4.2.1 Compatibility with incumbent services for link 2 in the 11 GHz frequency range

#### 4.2.1.1 Impact from emission of fixed service stations

The impact of fixed service station emissions into the aircraft receiver was studied taking dynamic flight parameter into account as given by flight scenarios 2 and 4 as shown in Table 1. The methodology for analysing the exceedance of *I/N* under these dynamic conditions is based on link impairments

– for long-term effects into the earth station on-board the UA, presented as a cumulative distribution function (CDF);

– for short-term effects into the UA receiver by means of a parametric presentation in the time domain presented as fade / interfade durations for corresponding link availabilities as well as CDF;

Assumptions on technical characteristics were taken from

– Annex 1 for the satellite and the unmanned aircraft station

– Annex 2 for link performance

– Annex 4 for the fixed service.

Study results from long-term effects towards the Earth station on-board the UA

The *I/N* versus their probability of exceeding a given threshold are based on simulations comprising antenna characteristics as defined in Recommendation ITU-R S.580 but also, for comparison reasons, defined as a peak envelope Bessel characteristics taking into account different aircraft cruising speeds and altitudes in accordance with ICAO scenarios 2 and 4. The modelled FS station density distribution for the long-term analyses assuming a mix of low, rural, and urban FS station densities) as described in Appendix 1 of Annex 6.

Main results are:

– the probability of exceedance of an *I/N* threshold is lower when using a more realistic peak envelope Bessel antenna characteristic as compared to an antenna mask defined by Recommendation ITU-R S.580

– the probability of exceeding an *I/N* threshold decreases with growing UA speeds

– the probability of exceeding an *I/N* threshold decreases with lower latitudes of UA position

– for the FS station density distribution used – low in one study and mixed in the other (see Appendices 1 and 1A) – the resulting CDF shows that an aggregate *I/N* of –10 dB is met with a probability not exceeding more than 20% of the samples analysed.

Details are provided in Appendices 1 and 1A of Annex 6.

Study result from short-term effects towards the Earth station on-board the UA

Results show that the maximum possible peak *I/N* thresholds (derived from the link margin calculation for small / medium / large UA antennas):

– are not exceeded for the flight scenario 2 (also covering flight scenarios 1, 3, and 5) as specified in Table 1

– are not exceeded for all flight scenario 4 (also covering flight scenario 7) as specified in Table 1 for cruising altitudes above clouds

– are not exceeded for the majority of cases for the flight scenario 4 (also covering flight scenario 7) as specified in Table 1 for cruising altitudes below clouds.

The achievable link availabilities are presented for each frequency band and flight scenario showing availabilities very close to 100%. In addition, it was simulated, that for link 2, if the link is implemented on two uncorrelated frequencies no link interruption would be detected at all.

The analyses assuming a mixed FS station density distribution and different UA antenna sizes provide the following results by means of the probability of exceedance over a range of *I/N* thresholds (shown as a CDF) and fade and interfade durations with corresponding link availabilities.

– the interference levels into the Earth station receiver on board the UA depend on the density of FS operating co-frequency;

– the increase of the UA antenna elevation from 10° to 20° reduces the interference level at the UA receiver input by 8 dB;

– for each antenna diameter assumed, two different models describing the antenna pattern are applied. Varying the antenna size from 0.45 m to 1.25 m results in a reduction of the interference level by 6 dB;

– when taking a more realistic description of the antenna pattern the resulting interference level can be decreased by up to 10 dB;

– at high ground speed, the FS station causes shorter average fades compared to lower ground speeds of the UA;

– the various link availabilities for the maximum possible *I/N* thresholds, as provided in Tables A6-8 through A6-11 of Annex 6, are 99% or better for all cases studied. The link availabilities when assuming the peak envelope Bessel function antenna pattern are closed to 100%;

– the simulations for rural and remote areas as well as for the flight over sea scenarios show low *I/N* levels and low fading durations resulting in very high link availabilities even for small *I/N* thresholds.

– the time-variant assessments confirm the results of the time-invariant assessments presented in Appendices 1 and 1A.

Details are provided in Appendices 2 and 2A of Annex 6.Long and short-term interference assessments

The synthesis presents interference levels during a 24h flight of the UA under flight scenario 2 and flight scenario 4 considering all the samples of the whole simulations. Interference levels are calculated every second, which allows detecting rapid changes of the I/N ratio at the UA receiver input, corresponding to short term interference.

The analyses show that for all combination of parameters (frequency band, flight scenario, UA antenna size) considered:

− The aggregate I/N ratio exceeds -10 dB for less than 20% of the samples analysed, hence the long term protection criterion used for FSS is not exceeded.

− During short periods of time smaller than 1 second, the aggregate I/N ratio can exceed the maximum possible peak level derived from link budgets established in Annex 2.

Details are provided in Appendix 3 of Annex 6.

#### 4.2.1.2 Impact from the mobile service

No technical characteristics of land mobile systems in the land mobile service for the frequency bands 10.95-12.75 GHz have been identified.

#### 4.2.1. 3 Impact from the broadcasting satellite service

Portions of frequency bands allocated or frequency bands with regional allocations to the BSS are not considered for sharing as they fall under Appendix 30, 30A, and 30B.

### 4.2.2 Compatibility with incumbent services for Link 2 in the 20 GHz frequency range

#### 4.2.2.1 Impact from emissions of fixed service stations

Generally, the studies show much better results with those described in section 4.2.1.1 (11 GHz case), however, with the following exceptions due to slightly different propagation conditions in the 20 GHz frequency range:

– regarding the long-term effects, the probability of *I/N* exceedance for given thresholds is less for links in the frequency range 17.3 to 20.2 GHz

– regarding the short-term effects, the interference level in the 20 GHz frequency range are significantly lower than the level in the 11 GHz range, mainly due to higher gaseous attenuations and the lower spectral density emitted from FS stations compared to the 11 GHz range. On average, the interference level in the 20 GHz frequency range is 20 dB lower than that in the 11 GHz frequency range.

Details of the compatibility studies are provided in Annex 6.

#### 4.2.2.2 Impact from the mobile service

No technical characteristics of land mobile systems in the land mobile service for the frequency bands 17.3-20.2 GHz have been identified.

#### 4.2.2.3 Impact from the Earth exploration-satellite service (passive)

In the band 18.6-18.8 GHz, the EESS allocation is for passive reception. Since this analysis considers interference into the UAS reception of satellite transmissions, the EESS (passive) will not contribute to that interference. Therefore, the EESS (passive) was not considered in the analysis of the 18.6-18.8 GHz band.

#### 4.2.2.4 Impact from the space research service

In the band 18.6-18.8 GHz, the Space Research Service allocation is for passive reception. Since this analysis considers interference into the UAS reception of satellite transmissions, the Space Research Service will not contribute to that interference. Therefore, the Space Research Service was not considered in the analysis of the 18.6-18.8 GHz band.

## 4.3 Compatibility analyses for link 3

In line with c*onsidering f)* of Resolution **153** **(WRC-12)** on the protection of incumbent services, and based on CNPC links characteristics defined in Annex 2, this section analyses the sharing conditions of a transmitting (FSS) earth station located on-board a flying UA.

The affected incumbent terrestrial services have been derived from entries in the allocation tables and corresponding footnotes of RR Article **5**, as listed in Tables 2 and 3 above.

Incumbent services considered in the studies were:

– For Link 3 in 14 GHz: RNS, mss, srs, amss, FS, MS

– For Link 3 in 30 GHz: FS, MS, EESS (E-s), MSS (E-s)

The characteristics of services applied for the impact analyses are summarized in Annex 4.

Studies are provided in Annex 7.

### 4.3.1 Compatibility with incumbent services for link 3 in the 14 GHz frequency range

#### 4.3.1.1 Impact on the radionavigation service

There are no records in the ITU master international frequency register (MIFR) indicating use of the radionavigation allocation in the 14.0-14.3 GHz band by any administration. No additional information was obtained on radionavigation use of the band as a result of inquiries by former ITU‑R Study Groups.

#### 4.3.1.2 Impact on the fixed service

This section provides concise results from the potential impact from emissions of the transmitter on board an UA into a fixed service (FS) receiver operating in the frequency range of 14 GHz.

The analyses show: the long-term protection criterion of Rec. ITU-R F.758-5 is met in all cases. The short-term protection criterion of Recommendation ITU-R F.1494 is met for all cases with UA operating at altitudes of ≥ 9 000 ft.

To assure short-term protection criteria are met, a power flux density mask is derived in Appendix 5 of Annex 7.

Details of the compatibility studies are shown in Annex 7.

#### 4.3.1.3 Impact on the mobile service

No technical characteristics of land mobile systems in the land mobile service for the frequency bands 14.0-14.47 GHz have been identified.

#### 4.3.1.4 Impact on the radioastronomy service

In order to ensure protection of the radioastronomy allocation in the band 14.47-14.5 GHz, it is proposed not to consider the use of this FSS band for UAS CNPC links.

### 4.3.2 Compatibility with incumbent services for link 3 in the 30 GHz frequency range

#### 4.3.2.1 Impact on the fixed service

The analyses show: the long-term protection criterion of Rec. ITU-R F.758-5 is met in all cases studied. The short-term protection criteria of Recommendation ITU-R F.1495-2 are met for all cases. The short-term protection criterion of Rec. ITU-R F.1494 is met for all cases.

To assure short-term protection criteria are met, a power flux density mask is derived in Appendix 5 of Annex 7.

Details of the compatibility studies are shown in Annex 7.

#### 4.3.2.2 Impact on the mobile service

No technical characteristics of land mobile systems operating in the mobile service for the frequency bands 27.5-30.0 GHz have been identified.

#### 4.3.2.3 Impact on the Earth exploration-satellite service

In the band 28.5-30.0 GHz, the Earth exploration satellite service (EESS) allocation supports Earth-to-space transmissions from Earth stations in the EESS to satellites of the EESS. The EESS operation in the band 28.5-30.0 GHz is limited to the transfer of data between stations and not to the primary collection of information by means of active or passive sensors (RR No.**5.541**) and in the 29.5-30.0 GHz band is limited to space-to-space links between EESS on a secondary basis (RR No.**5.543**). Therefore, the EESS operations in this band represent another satellite uplink that is included in the coordination of FSS assignments.

#### 4.3.2.4 Impact on the mobile-satellite service

No technical characteristics of land mobile systems in the land mobile service for the frequency bands 27.5-30.0 GHz have been identified.

## 4.4 Interference received by earth stations on board unmanned aircraft (link #2) and received by their supporting space stations (link #3) from other fixed satellite service systems

This section considers the compatibility conditions for cases of inter-system interference, i.e. between GSO FSS systems, that may be experienced by earth station on-board the UA and the supporting space stations when operating in the frequency bands 14/11 GHz and 30/20 GHz.

Studies performed provide realistic worst-case interference conditions potentially caused by other FSS networks when operating in FSS allocations in the 14/11 GHz and 30/20 GHz bands.

Furthermore, it is assumed that the coordination procedures under RR Article 9 provide the concerned administrations and satellite operators with the tools for calculating and limiting the magnitude of inter-system interference for FSS systems. Such coordination ensures that FSS network interference levels are never higher than those that would occur under the maximum transmit levels allowed by RR Article **21** and maximum off-axis e.i.r.p. levels allowed in Recommendation ITU-R S.524, consequently by using these levels.

Based on typical link budget computations (as per Annex 2) for assessment of the UAS CNPC link performance in the FSS, it can be noted that the interference apportionment due to adjacent FSS satellites is not limiting the achievable availability performance of UAS CNPC link.

When comparing the degradation in C/N caused by interference from other satellite systems with the minimum allowance in the link budget presented in this report, it can be concluded that such allowances are sufficient for compensating the interference degradation, taking into account clear sky conditions and even assuming the UA on ground.

It should also be noted that, in the analysis no improvements of the achieved link performance due to the implementation of the different mitigation techniques described in this report are taken into account.

More details on the performed compatibility studies are provided in Annex 5.

# 5 Technical and operational feasibility

## 5.1 Achievable link performances

*Considerings c)* and *d)* of Resolution **153 (WRC-12)** reflect that the safe flight operation of UA needs reliable communication links. This section analyses the end-to-end link performances under conditions given by cases defined in sections 3 and 4.

Detailed link budgets, achievable margins, and corresponding link availabilities have been analysed for links 1 and 2 as well as for links 3 and 4 (Figure 1) for the frequency ranges 14/11 GHz and 30/20 GHz, for low and high satellite-antenna gains, for each frequency range, as well as for each type of small, medium, and large UA antenna.

As a first step, the nominal link budgets – taking into account system internal impairments and typical interference of 25% of system noise but no atmospheric link impairments for links 2 and 3 – were calculated for all UA located on the Earth's surface and considering worst case conditions of 10° elevation to the satellite. The calculated ranges of link margins vary between 6.2 dB and 19.7 dB in the 14/11 GHz frequency range and between 8.5 dB and 23.2 dB in the 30/20 GHz range.

As a second step, those link margins were used for compensating all atmospheric impairments on links 2 and 3 to derive link availabilities under defined atmospheric impairments and for representative flight scenarios in accordance with flight scenario definitions in Table 1.

Achieved link availabilities for latitudes between ±70° are:

For altitudes above rain height:

– close to 100% for flight altitudes of the UA for all frequency bands and all types of antennas (UA and satellite)

For altitudes below rain height:

– close to 100% for flight altitudes of the UA for 14/11 GHz frequency range and all types of antennas (UA and satellite)

– close to 100% for flight altitudes of the UA for 30/20 GHz frequency range and for medium and large types of UA antennas

All other cases might necessitate mitigation measures to maintain link availabilities close to 100%. Examples on the achievable improvement by mitigations are shown Annex 2. Depending on the selected flight scenario, the increase of elevation above 10° reduces the atmospheric attenuation by up to 40 dB in the 30/20 GHz frequency range.

Link performances and budgets, margins and derived link availabilities are provided in Annex 2.

## 5.2 Required communication performance

ICAO has informed ITU-R that it is currently developing SARPs and other relevant provisions in support of insertion of remotely piloted aircraft systems (RPAS) (ICAO terminology for UAS) into civil (including non-segregated) airspace. This task includes the determination of the required communication performance (RCP) for the C2 (ICAO terminology for CNPC) link between the pilot and the aircraft.

## 5.3 Operational performance

The physical environment of UA relevant for the CNPC assessments is mainly determined by the antenna pointing error on one side (mainly affecting the link budgets) and the losses due to the fuselage shielding (mainly affecting the interference to / from stations operating in the fixed service).

Studies are provided in Annex 10.

## 5.4 Mitigation measures

C*onsidering g)* of Resolution **153** **(WRC-12)**[[6]](#footnote-6) raises the need for introducing mitigation options.

If need arises, various mitigation techniques can be considered when specifying, designing, or planning UAS operations.

Mitigation measures are identified that would ensure maintaining compliance with applicable link availability requirements. It is however to be noted that these finally required link availabilities are currently under development in ICAO.

Potential link impairments that might necessitate mitigation are:

– atmospheric attenuations

– higher interference noise from non-participating FSS systems (beyond a 25% noise increase, which is already taken into account);

– interference from incumbent radio services (Annex 6).

System failures like satellite transponder outage or hardware failures on-board the UA are usually mitigated by UA System design and mission planning taking appropriate redundancies into account and can be compensated by

– Redundancy-based mitigation techniques on link level, UACS site diversity, system inherent redundancies

– Signal-based mitigation techniques (adaptive coding/modulation, spreading, uplink power control, interference detection/mitigation, automatic re-acquisition, handshake protocols, a.o.)

– Antenna pattern improvements (front-back gain ratio, sidelobe gain reduction)

– Operational measures (flight planning).

More detailed considerations of mitigation measures are provided in Annex 3.

# 6 Regulatory environment

This section provides studies on regulatory aspects regarding

– the appropriate Article **11** notification status of a FSS network which is required for use in UAS CNPC links as addressed in *considering j)* of Resolution **153 (WRC-12)**

– The impact of RR No. **4.10** (safety) as addressed in *recognising a)* and *e)* of Resolution **153 (WRC-12)**

– Experience of flights performed under RR No. **4.4** conditions as addressed in *considering e)* of Resolution **153 (WRC-12)**

– The need for globally harmonized spectrum in line with *considering b)* of Resolution **153 (WRC-12)**

– Mutual acceptance of license for CNPC equipment on-board UA and its radio operation.

– Consideration on the earth station on-board an unmanned aircraft

Among other things, the resolves of Resolution **153 (WRC-12)** call for studies of the regulatory actions to support the deployment of UAS CNPC links operating in bands allocated to the fixed-satellite service (FSS) not subject to Appendices **30**, **30A** and **30B**.

This Annex contains the description of the current regulatory framework in force for the bands above. Furthermore, it takes into account the seven conditions that the ICAO requires be fulfilled to guarantee the safe operation to be met for CNPC of UAS in bands allocated to the FSS in non‑segregated airspace. This Annex also lists suggested approaches to address the conditions and, gives some examples of regulatory implementations.

## 6.1 Regulatory regime currently governing the fixed satellite service

### 6.1.1 Regulatory status in the 14.0-14.5 GHz frequency band

The Fixed satellite service (FSS) is a primary service in the 14.0-14.5 GHz band. No. **5.504A** of the Radio Regulations indicates that aircraft earth stations may communicate with FSS space stations on a secondary basis. This provision is not applicable to agenda item 1.5 (WRC-15). There may be a new footnote to the allocation table which make a reference to a resolution indicating that UAS CNPC links can operate in this band under the resolves of an associated Resolution. Other communications different than UAS CNPC links can continue operating under RR No. **5.504A**.

### 6.1.2 Regulatory environment in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz

The FSS is allocated as a primary service in the bands 17.7-19.7 GHz and 27.5-29.5 GHz on a worldwide basis. It should be noted that there is a view that UAS systems might operate in FSS bands in the ranges 17.8-20.2 GHz and 27.5-30 GHz, subject to the positive results of the appropriate studies in this report.

### 6.1.3 Regulatory environment in the frequency bands 19.7-20.2 GHz and 29.5-30.0 GHz

In addition to FSS, which is a Primary service in the bands, 19.7-20.2 GHz and 29.5-30 GHz are allocated to the mobile-satellite service:

– In Region 2: on a primary basis.

– In Region 1 and Region 3: on a primary basis for the top 100 MHz, and on a secondary basis for the remaining 400 MHz.

These ranges seem therefore particularly appropriate from a regulatory standpoint to host UA/satellite mobile links. RR No. **5.527** states that “in the bands 19.7-20.2 GHz and 29.5‑30 GHz, the provisions of RR No. **4.10** do not apply with respect to the mobile-satellite-service”.

### 6.1.4 Requirement for allocations to be worldwide

Resolution **153 (WRC-12)** *considering b)* states that unmanned aircraft (UA) need to the extent practicable to use globally harmonized spectrum. Furthermore, use of harmonised FSS spectrum on a worldwide basis has the added advantage of simplifying the deployment of equipment on-board UA.

In the 10.95-12.75 GHz range, worldwide FSS (space-to-Earth) allocations not subject to Appendices **30**, **30A** and **30B** are in the bands **10.95-11.2 GHz** and **11.45-11.7 GHz**. Other parts of this range are either subject to Appendices **30** or **30B** in at least one Region, or not allocated to FSS (space-to-Earth) (case of 12.7-12.75 GHz in Region 2). In the 12.75-13.25 and 13.75-14.8 GHz range, worldwide FSS (Earth-to-space) allocations not subject to Appendices **30**, **30A** and **30B** are in the band 14.0-14.5 GHz.

Worldwide allocations to the FSS in the 30/20 GHz not subject to RR Appendix **30**, **30A** or **30B** are in the frequency ranges 17.8-20.2 GHz (space-to-Earth) and 27.5-30 GHz (Earth-to-space)*.*

### 6.1.5 Regulatory regime governing the notification of satellite frequency assignments

FSS satellites in the geostationary-satellite orbit are internationally regulated under Articles **9** and **11** of the Radio Regulations together with the relevant Appendices. Through the data available in the ITU MIFR, it is indicated that there is a large number of FSS assignments that have the potential to offer services to UAS CNPC links.

To obtain international recognition on the use of frequencies, Administrations responsible for the notification of a satellite network, follow the provisions of Articles **9**, **11** and **13** of the Radio Regulations. Following these regulations leads to registration of the satellite network into the ITU MIFR. This process ensures that the corresponding satellite network and its associated FSS frequency assignments are duly registered in the MIFR and consequently, they enjoy international recognition and the associated protection against harmful interference.

All geostationary satellites operating in the frequency bands allocated to the FSS not subject to RR Appendices **30**, **30A** and **30B** are subject to coordination as required pursuant to RR No. **9.7**. In addition to the above coordination, specific or other types of earth stations in the FSS need to carry out the required coordination under RR No. **9.17** or **9.17A** with respect to terrestrial services (the territory of the notifying administration of these terrestrial services are located inside the coordination contour of the earth station, established by the relevant provisions of the Radio Regulations, e.g. Appendix **7**) by the administration on the territory of which the earth station is located. From the submission of the Advance Information Publication under RR No. **9.1**, administrations need to submit the first notification under RR Article **11** and bring the satellite network into use within the maximum regulatory time limit of 7 years.

Coordination of satellite networks under Article **9** of the Radio Regulations is a regulatory obligation. Coordinated arrangements are set out in bilateral agreements between operators and the details of these are seldom released to ITU and are normally not publicly available. However, the details of the agreements reached are a matter to be discussed in bilateral or multilateral negotiations.

However, the result of that coordination agreement needs to be notified under Article 11 to the Bureau as appropriate. At the time of notification, when the Bureau examines the notified assignment it also examines the status of coordination to determine its finding under RR No. **11.32** and, if requested, RR No. **11.32A**. The coordination agreements will contain agreements on technical parameters and other measures to obtain compatibility between the two networks.

### 6.1.6 Assignments under RR No. 11.41

The outcome of the process described in 6.3.4 is that about half of all networks frequency assignments may have completed international frequency coordination process (in the ITU reported statistics, about 15415 FSS frequency assignments).

There are also FSS assignments with associated technical parameters for which coordination has not been completed and their coordination processes are extended over time. In this case, however, administrations may ask the Bureau to carry out *C/I* calculations to determine whether incoming assignments could cause interference to the existing assignments. Should the result of that examination be unfavourable, the notifying administration may request the Bureau to enter the assignment into the MIFR under RR No. **11.41**, with a note that coordination will continue.

Although FSS assignments registered under RR No. **11.41** (as per ITU statistics 20 July 2012, there are about 16933 assignments in this category), are not getting international recognition from those administrations with which coordination was not completed, the carriers proposing to use them can still operate and provide services, including UAS CNPC links. However, due to the nature of the safe operation of UAS CNPC links, it is understood that these types of assignments could support UAS CNPC links only in cases of redundant carriers or similar operational architectures.

It should be noted that many satellite networks are brought into use without completion of all the required coordination with other satellite networks due to lack of time before the BIU (Bring into Use) date; that is, these networks do not have favourable findings in the MIFR with respect to RR No. **11.32**. This means that both the operational limitations (in terms of protecting other networks) and interference scenario (in terms of being protected against interference from other networks) are not fully determined.

The Radiocommunication Bureau provided a summary of the status of frequency assignments recorded in the MIFR (status 50) in the bands 14-14.5 GHz, 10-95-12.75 GHz, 17.7-20.2 GHz and 27.5-30 GHz. The total number of groups of FSS assignments in the MIFR as at 20 July 2012, in all the bands listed above, is 32348 and a break-up of the number of groups recorded with and without the need for application of RR No. **11.41** are shown below:

|  |  |
| --- | --- |
| No. of Groups without application of RR No. **11.41** (coordination complete): | 15415 |
| No. of Groups for which RR No. **11.41** has been applied: | 16933 |
| No. of Groups considered definitive (recorded on or before 20.09.2005): | 9419 |
| No. of Groups considered definitive (recorded with CR/C on or before 20.09.2005): | 4916 |
| No. of groups which may not yet be considered definitive: | 2598 |

It was noted that the above survey reveals that more than 50% of the assignments for FSS are recorded in the MIFR under RR **11.41**.

## 6.2 Safety considerations

A number of references to safety requirements are noted. Safety issues are important and they are addressed by the Resolution **153 (RWC-12)**,as well as in the ICAO requirements and the Radio Regulations provision RR No. **4.10**:

a) Resolution **153 (WRC-12)**:

*Recognising a)* of Resolution **153 (WRC-12)** states that with the introduction of UA in   
non-segregated airspace, continued safety of other airspace users as well as life and property on the ground needs to be maintained.

b) ICAO Conditions related to safety:

– ICAO Condition 1: That the technical and regulatory actions should be limited to the case of UAS using satellites, as studied, and not set a precedent that puts other aeronautical safety services at risk

– ICAO Condition 2: That all frequency bands which carry aeronautical safety communications need to be clearly identified in the Radio Regulations.

– ICAO Condition 3 .That the assignments and use of the relevant frequency bands have to be consistent with Article **4.10** of the Radio Regulations which recognizes that safety services require special measures to ensure their freedom from harmful interference.

– ICAO Condition 6: That realistic worst case condition with inclusion of a safety margin can be applied during compatibility studies

c) RR No. **4.10**:

Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies.

### 6.2.1 Interpretation of the Safety Considerations applicable for unmanned aircraft command and non-payload communication links

The above requirements of safety should be interpreted as:

– That the UAS CNPC links should be robust enough to ensure they can serve to maintain safe command and control of the unmanned aircraft. This may include sufficient link margin and other technical and operational provisions.

– Safe operation should be achieved by identifying the frequencies in which FSS CNPC link should operate, through appropriate regulatory provisions.

– In 2014, ICAO is planning the development of associated standards and recommended practices (SARPs) taking into account the above as well as conclusions from the WRC 2015 relevant for this agenda item.

– In case administrations wish to use FSS frequency assignments for UAS CNPC links, they should use measures in order to be consistent with Article **4.10**.

The following points highlight operational safety:

a) In the coordination and notification procedures under Articles 9 and 11 satellite operators carry out their duties under the responsibility of their respective administrations;

b) the degree of safe and predictable operation of the UAS depends amongst others on the detailed arrangements made in the coordination of the used satellite network;

c) the licensing conditions of the various countries involved in the operation;

d) the contractual arrangements of the used satellite network with their end users and measures to ensure the protection obtained through the conditions agreed in the coordination procedures.

## 6.3 Regulatory aspects related to ICAO’s Position on WRC-15 AI 1.5

The ICAO Position on WRC-15 AI 1.5 contains three conditions to be met by any regulatory framework put in place for UAS CNPC links operating in FSS bands. Such conditions are listed here, together with a possible regulatory implementation, supported by specific examples when possible.

### 6.3.1 ICAO Condition 1

*“That the technical and regulatory actions be limited to the case of UAS using satellites, as studied, and not set a precedent that puts other aeronautical safety services at risk”.*

Regulatory consideration:

Provisions of Article **5** of the Radio Regulations are expected to be considered by WRC-15 and amendments may be made to support use of the FSS for UAS CNPC applications. Regulatory provisions to support UAS CNPC applications should be specific and would not apply indiscriminately to other services or scenarios.

### 6.3.2 ICAO Condition 2

*“That all frequency bands which carry aeronautical safety communications be clearly identified in the ITU Radio Regulations.”*

Regulatory consideration:

The FSS frequency bands identified to support UAS CNPC should be clearly identified in Article **5** of the Radio Regulations subject to the outcome of the studies contained in this Report. This could be via specific provisions (e.g., a new footnote and an associate Resolution) in the existing FSS allocations

### 6.3.3 ICAO Condition 3

*“That the assignments and use of the relevant frequency bands be consistent with article 4.10 of the ITU Radio Regulations which recognizes that safety services require special measures to ensure their freedom from harmful interference.“*

**Regulatory consideration:**

The FSS frequency bands identified to support UAS CNPC should be clearly identified in Article **5** of the Radio Regulations subject to the outcome of the studies contained in this Report. Any identification in Article **5** of the Radio Regulations should include specific measures to ensure consistency with RR No. **4.10**.

Specific examples of implementation:

Aviation authorities (including ICAO) may mandate a specific set of UAS CNPC operating and regulatory requirements, taking into account those FSS frequency bands identified in Article **5** of the Radio Regulations consistent with RR No. **4.10**. Satellite operators would not seek additional protection to ensure consistency with RR No. **4.10** during frequency coordination processes, as the current regulatory procedures would continue to apply When the coordination process is completed, the Bureau will be notified (according to the provisions of RR Article **11**) by the administration proposing the new system and the frequency assignments recorded in the Master Register.

## 6.4 Experience gained with unmanned aircraft flights under RR No. 4.4

Considering e) of Resolution **153 (WRC-12)** stated that UAS already operate in FSS frequency bands for UA-to-satellite CNPC links under RR No. **4.4**. However, there is no formal documentation on those UA-to-satellite CNPC links deployment history and there is no public announcement of such information in any form in the ITU-R publications because there is no obligation for Administrations to make notification under RR No. **4.4** in the FSS frequency bands. Examples of such deployment have not been quoted as there is no information up to the completion of this report.

## 6.5 The need for global harmonized spectrum for fixed satellite service unmanned aircraft command and non-payload communication

The frequency bands allocated to the FSS not subject to Appendices **30**, **30A** and **30B** have been supporting a multitude of UAS applications operating CNPC links in segregated airspace for several years. To date, these UAS CNPC links, operating under No. **4.4** of the Radio Regulations, have been supported with no complications. As these FSS bands currently support UAS CNPC, it is necessary to utilize the globally harmonized portions of these bands to prevent an impractical amount radio equipment on-board UA.

Resolution **153 (WRC-12)** *considering b)* states that UA need, to the extent practicable, to use globally harmonized spectrum.

In the 10.95-12.75 GHz range, worldwide FSS (space-to-Earth) allocations not subject to Appendices **30**, **30A** and **30B** are in the bands **10.95-11.2 GHz** and **11.45-11.7 GHz**. Other parts of this range are either subject to Appendices **30** or **30B** in at least one Region, or not allocated to FSS (space-to-Earth) (case of 12.7-12.75 GHz in Region 2).

## 6.6 Regulatory considerations about the status of an earth station on board an aircraft

It should be noted that for part of the Forward link (CNPC-link from the remote pilot (located at the UACS) to the unmanned aircraft (UA) through a satellite, i.e. link 1, the operation of earth stations UACS is assumed to be located on fixed point on the ground whereas for link 2 the operation of earth station on board aircraft is not at the fixed point as the earth station on the board aircraft is of aeronautical mobile type and thus cannot be considered as an earth station on fixed point. Nevertheless, in order to carry out compatibility studies it can be assumed that an earth station on board aircraft operates with characteristics and parameters (excluding its protection criteria) that are the same to those of the FSS even if it is not at a fixed point.

RR Article **1** is an essential element of international regulatory environment. Definitions of radio services and associated stations contained in RR Article 1 form a basis for the allocation concept of RR Article **5**. This concept consists in dividing spectrum into frequency blocks and allocating them to radio services defined in RR Article 1. Allocations to services sharing the same band are usually made taking into account their interference potential and topology, for example mobility of stations.

From a regulatory point of view, a footnote in RR Article 5 allowing earth stations on board aircraft to operate with space stations in FSS could be interpreted in the way that UAS are assimilated as earth stations belonging to the FSS: this would be inconsistent with Article 1 definitions, in particular of the fixed-satellite service (RR No. **1.21**) and aircraft station (RR No. **1.84**). In regulatory terms the class of the Earth station on-board an UA and that of the space station (FSS) does not match as the class of the station on-board an UA is ”TJ” and the class of station of the space station is “EC”.

A definition in RR Article **1** is not necessary to have an appropriate class of station designation. As indicated by the BR below a WRC is the highest authority regarding the Radio Regulations (RR). There is already precedent for indicating a class of station without a definition in the RR. Such can be provided through a class of station definition which makes reference to the regulatory provision which makes reference to the type of station of interest. In this case it is an earth station on board an UA operating in the FSS. A definition for such an earth station can be included in an associated Resolution.

A question on whether the FSS definition requires earth stations to be at fixed points was raised. It was also asked whether, in case RR provisions, e.g., a footnote, were added to allow UAS to communicate with space stations operating in the FSS, that UAS would be considered operating on a non-interference/non-protection basis as not conforming to the definitions contained in RR Article **1**.

Taking into account that a world radiocommunication conference (WRC) is the highest decision-making body on international regulations about radiocommunications, a straightforward reply from the BR to the question formulated above would be: if a WRC approves a provision, e.g. a footnote, allowing UA earth stations to communicate with FSS stations under some sharing conditions aimed at ensuring compatibility and this provision provides the status of earth stations on board UA equal to others services in the allocated band, then such UAS would **not** be considered as operating on a non-interference/non-protection basis (provisions can be included in a Resolution referenced in a footnote).

# 7 Technical, regulatory and operational results

In line with the *resolves and invites ITU-R 1-3* of Resolution **153 (WRC-12),** the following technical, regulatory and operational results can be derived from the analyses carried out in this Report:

General result

The report shows that FSS can be used for CNPC links for the operation of UAS under the technical, operational, and regulatory conditions given in this report.

## 7.1 Technical results

– Characteristics of UA systems using geostationary satellite networks operating in the FSS bands have been defined

– Adequate link margins can be provided under the condition that earth stations operating on-board UA and their supporting space stations use characteristics in line with the current FSS technical environment and relevant provisions of the Radio Regulations

– The UA can operate without creating harmful interference to incumbent services under the conditions given in this report

– The UA can operate with a sufficient link margin to compensate for interference received from incumbent services, if necessary

– Technical mitigations are available to improve the CNPC link performance and/or to reduce the effects of interference

## 7.2 Regulatory results

– The regulatory regime governing the notification of satellite assignments and coordination procedure does not require changes to apply CNPC links in FSS frequency bands

– In case administrations wish to use FSS frequency assignments for UAS CNPC links, they should use measures in order to be consistent with Article **4.10**

– Globally harmonized spectrum is available to support CNPC links

– This report concludes that there is no need for new types or definitions for earth stations in Article 1. This has been confirmed by the Bureau of Radiocommunication (BR)

– There are a sufficient number of fully coordinated FSS assignments which have the potential to be used for UAS CNPC link applications

– Compatibility of FSS supporting UAS CNPC links with respect to other FSS satellites (carrying regular FSS traffic) is feasible without any restriction to the FSS regular operations.

– The implementation of a UA CNPC link in FSS frequency bands does not impose constraints to assignments recorded in the MIFR

## 7.3 Operational results

– Minimum elevation angles for CNPC links to geostationary satellite show that these links can only be used for UA flights between latitudes of ±70°

– This report proves the feasibility of UA CNPC links operated in flight scenarios as given in Table 1

– Operational mitigations are available to improve the CNPC link performance and/or to reduce the effects of interference

– Further operational aspects, such as the required communication performance, are assumed to be further developed by ICAO, including certification, validation, and airworthiness of the UAS

# 8 Results

This report provides studies that have been prepared in compliance with the *invites ITU-R* of Resolution **153 (WRC-12)**.

# 9 Supporting documents

ITU-R Recommendations mentioned in this Report

|  |  |
| --- | --- |
| [ITU-R F.758](http://www.itu.int/rec/R-REC-F.758/en) | System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference |
| [ITU-R F.1094](http://www.itu.int/rec/R-REC-F.1094/en) | Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources |
| [ITU-R F.1245](http://www.itu.int/rec/R-REC-F.1245/en) | Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz |
| [ITU-R F.1336](http://www.itu.int/rec/R-REC-F.1336/en) | Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz |
| [ITU-R F.1494](http://www.itu.int/rec/R-REC-F.1494/en) | Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 10.7-12.75 GHz band on a co-primary basis |
| [ITU-R F.1495](http://www.itu.int/rec/R-REC-F.1495/en) | Interference criteria to protect the fixed service from time varying aggregate interference from other radiocommunication services sharing the 17.7-19.3 GHz band on a co-primary basis |
| [ITU-R F.1565](http://www.itu.int/rec/R-REC-F.1565/en) | Performance degradation due to interference from other services sharing the same frequency bands on a co-primary basis with real digital fixed wireless systems used in the international and national portions of a 27 500 km hypothetical reference path at or above the primary rate |
| [ITU-R M.1643](http://www.itu.int/rec/R-REC-M.1643/en) | Technical and operational requirements for aircraft earth stations of aeronautical mobile-satellite service including those using fixed-satellite service network transponders in the band 14-14.5 GHz (Earth-to-space) |
| [ITU-R P.618](http://www.itu.int/rec/R-REC-P.618/en) | Propagation data and prediction methods required for the design of Earth-space telecommunication systems |
| [ITU-R P.676](http://www.itu.int/rec/R-REC-P.676/en) | Attenuation by atmospheric gases |
| [ITU-R P.836](http://www.itu.int/rec/R-REC-P.836/en) | Water vapour: surface density and total columnar content |
| [ITU-R P.839](http://www.itu.int/rec/R-REC-P.839/en) | Rain height model for prediction methods |
| [ITU-R P.840](http://www.itu.int/rec/R-REC-P.840/en) | Attenuation due to clouds and fog |
| [ITU-R P.1623](http://www.itu.int/rec/R-REC-P.1623/en) | Prediction method of fade dynamics on Earth-space paths |
| [ITU-R P.2041](http://www.itu.int/rec/R-REC-P.2041/en) | Prediction of path attenuation on links between an airborne platform and Space and between an airborne platform and the surface of the Earth |
| [ITU-R S.465](http://www.itu.int/rec/R-REC-S.465/en) | Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz |
| [ITU-R S.524](http://www.itu.int/rec/R-REC-S.524/en) | Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands |
| [ITU-R S.580](http://www.itu.int/rec/R-REC-S.580/en) | Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites |
| [ITU-R S.672](http://www.itu.int/rec/R-REC-S.672/en) | Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites |
| [ITU-R S.733](http://www.itu.int/rec/R-REC-S.733/en) | Determination of the G/T ratio for Earth stations operating in the fixed-satellite service |
| [ITU-R S.1064](http://www.itu.int/rec/R-REC-S.1064/en) | Pointing accuracy as a design objective for earthward antennas on board geostationary satellites in the fixed-satellite service |
| [ITU-R S.1255](http://www.itu.int/rec/R-REC-S.1255/en) | Use of adaptive uplink power control to mitigate codirectional interference between geostationary satellite orbit/fixed-satellite service (GSO/FSS) networks and feeder links of non-geostationary satellite orbit/mobile satellite service (non-GSO/MSS) networks and between GSO/FSS networks and non-GSO/FSS networks |
| [ITU-R S.1323](http://www.itu.int/rec/R-REC-S.1323/en) | Maximum permissible levels of interference in a satellite network (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) in the fixed-satellite service caused by other codirectional FSS networks below 30 GHz |
| [ITU-R S.1328](http://www.itu.int/rec/R-REC-S.1328/en) | Satellite system characteristics to be considered in frequency sharing analyses within the fixed-satellite service |
| [ITU-R S.1432](http://www.itu.int/rec/R-REC-S.1432/en) | Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz |
| [ITU-R SF.1006](http://www.itu.int/rec/R-REC-SF.1006/en) | Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service |
| [ITU-R SF.1719](http://www.itu.int/rec/R-REC-SF.1719/en) | Sharing between point-to-point and point-to-multipoint fixed service and transmitting earth stations of GSO and non-GSO FSS systems in the 27.5-29.5 GHz band |
| PDN Rec ITU-R S.[UAS-FSS]  Doc. 4A/468 Annex 1 | Technical and operational characteristics of Unmanned Aircraft Control and Non-Payload satellite communication links operated in certain frequency bands allocated to the fixed-satellite service not subject to RR Appendices **30**, **30A** and **30B** |

ITU-R Reports mentioned in this Report

|  |  |
| --- | --- |
| [ITU-R M.2171](http://www.itu.int/pub/R-REP-M.2171/en) | Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace |
| [ITU-R M.2230](http://www.itu.int/pub/R-REP-M.2230/en) | Frequency sharing between unmanned aircraft systems for beyond line of sight control and non-payload communication links and other existing and planned services in the frequency bands 13.25-13.40 GHz, 15.4-15.7 GHz, 22.5-22.55 GHz and 23.55-23.60 GHz |
| [ITU-R M.2233](http://www.itu.int/pub/R-REP-M.2233/en) | Examples of technical characteristics for unmanned aircraft control and non-payload communication links |

annex 1

Typical characteristics of unmanned aircraft systems used for studies   
in this Report



Annex 2

Link performances analysis



Annex 3

Techniques to mitigate the impairments and failures affecting unmanned aircraft system control and non-payload communication links



Annex 4

Characteristics of incumbent terrestrial services used in sharing studies



Annex 5

Baseline interference assessment for fixed satellite service earth stations on board unmanned aircraft with non-participating fixed satellite service systems (links #2 and #3)



Annex 6

Effects on emissions from incumbent services into earth stations onboard unmanned aircraft intended to communicate with a satellite network in  
frequency bands allocated to the fixed satellite service (link 2)



Annex 7

Sharing studies on emissions from fixed satellite service earth station transmitters on-board unmanned aircraft into incumbent   
terrestrial services for link 3



~~Annex 8~~

~~(incorporated in Section 6)~~

~~Annex 9~~

~~(not used)~~

Annex 10

Physical environment of unmanned aircraft



annex 11

Glossary and list of abbreviations

ACP: Aeronautical Communication Panel (ICAO)

ADS-B: Automatic dependent surveillance broadcast

AES: Airborne earth station

AMSL: Above minimum sea level

AMSS: Aeronautical mobile satellite service

ATC: Air traffic control

BER: Bit error ratio

BLOS: Beyond line-of-sight

CNPC: Control and non-payload communication

DAA: Detect and avoid

DL: Downlink

DQPSK: Differential quadrature phase-shift keying

e.i.r.p.: Equivalent isotropic radiated power

E/S: Earth station

EESS: Earth exploration satellite service

EoC: Edge of coverage

EUROCAE: European Organization for Civil Aviation Equipment

FDD: Frequency-division duplex

FDR: Frequency-dependent rejection

FS: Fixed service

FL: Forward link

G/T: Ratio of receiving-antenna gain to receiver thermal noise temperature in Kelvin

GEO: Geo-stationary orbit

HPA: High-power amplifier

ICAO: International Civil Aviation Organization

IEEE: Institute of Electrical and Electronics Engineers

*I/N*: Interference-to-noise ratio

Kts: Knots (NM/hr)

LEO: Low Earth orbit (or a satellite in that orbit)

LOS: Line-of-sight

MIFR: Master international frequency register

MLS: Microwave landing system

MS: Mobile service

MSS: Mobile-satellite service

OFDM: Orthogonal frequency-division multiplexing

OFDMA: Orthogonal frequency-division multiple access

PFD: Power flux density

QPSK: Quadrature phase-shift keying

RF: Radio frequency

RL: Return link

RPA: Remotely Piloted Aircraft (ICAO)

RPAS: Remotely Piloted Aircraft System (ICAO)

RTCA: Radio Technical Commission for Aeronautics (US)

S&A: Sense and avoid

S/N: Signal-to-noise ratio

TDD: Time-division duplex

UA: Unmanned aircraft

UACS ES: UA control station Earth station

UAS: UA system

UL: Uplink

\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. All terms used in the Report, are described in Section ‎0. Abbreviations are provided in Annex 11. [↑](#footnote-ref-1)
2. In ICAO, an “Unmanned aircraft system” (UAS)is referred to as a “Remotely Piloted Aircraft System” (RPAS**)** to indicate that there is still a pilot responsible for the entire flight. Studies in this Report assume that this definition is equivalent with UAS. Nevertheless, to maintain consistency with existing ITU-R documentation, the term “UAS” is used. [↑](#footnote-ref-2)
3. Definition quoted from ICAO Circular 328 AN/190 “Unmanned Aircraft Systems (UAS)”, ISBN 978-92-9231-751-5. [↑](#footnote-ref-3)
4. Control and non-payload communication (CNPC) are referred to in ICAO as command and control (C2) or command, control and ATC communication (C3). [↑](#footnote-ref-4)
5. For operational reasons, aircraft need to avoid heavy rain. The aircraft would not be operated in areas experiencing higher rain rates than those specified in the table. [↑](#footnote-ref-5)
6. *Considering g)* that CNPC links will need the ability to operationally mitigate interference in order to ensure appropriate overall link integrity and availability that are consistent with UAS operations in non-segregated airspace;

   *Considering h*) that multi-frequency CNPC architectures provide a means of improving link availabilities, and have the potential to mitigate interference; [↑](#footnote-ref-6)