~~WORKING DOCUMENT TOWARDS PRELIMINARY~~ 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

LIST OF CONTENT

List of Annexes

Annex 1: Typical characteristics of unmanned aircraft systems used for studies

Annex 2: Link performances analysis

Annex 3: Techniques to mitigate the impairments and failures affecting unmanned aircraft system command and non-payload communication links

Annex 4: Characteristics of incumbent terrestrial services used in sharing studies

Annex 5: 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.

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)

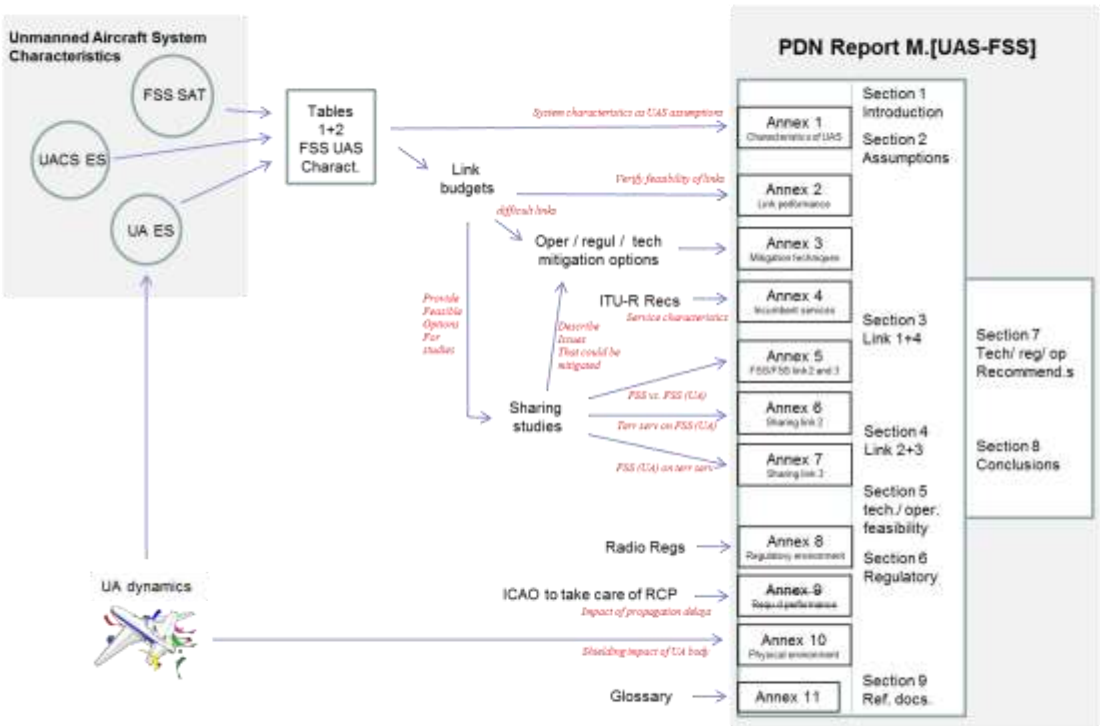
Annex 7: Sharing studies on emissions from earth stations on-board unmanned aircraft intended to communicate with a satellite network in frequency bands allocated to the fixed satellite service into incumbent terrestrial services for link #3

~~Annex 8: (incorporated in main text)~~

~~Annex 9: (deleted)~~

Annex 10: Physical environment of unmanned aircraft

Annex 11: Glossary and list of abbreviations.



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], 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

[1] All terms used in the Report, are described in Section 0. Abbreviations are provided in Annex 11.

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] comprises

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

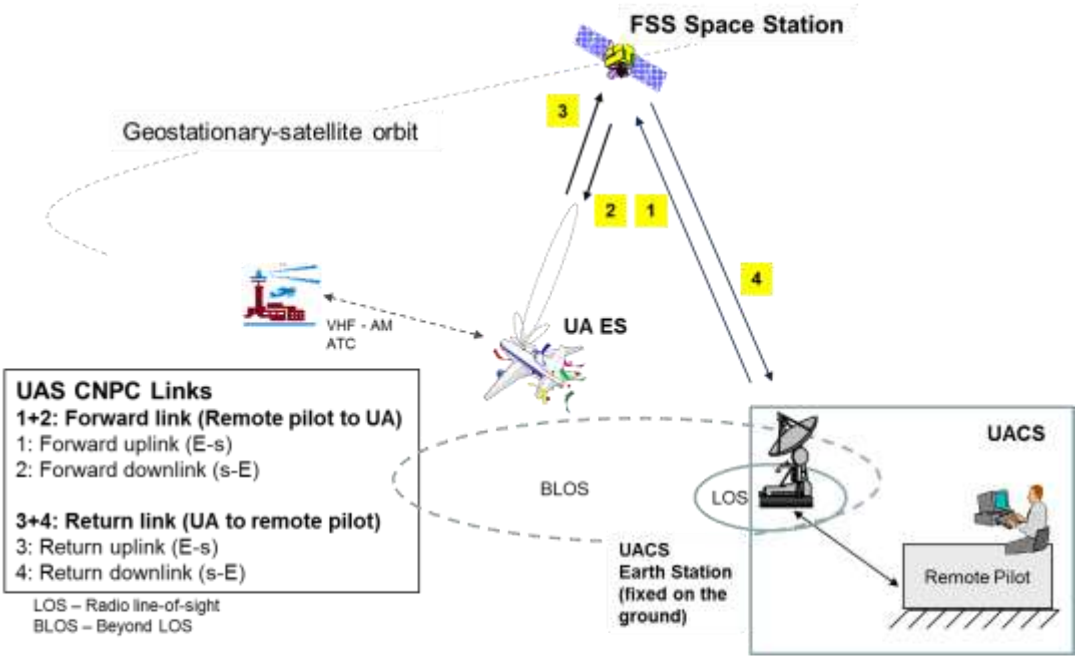
– **UA control station (UACS)**: Facility from which a UA is controlled remotely.
The studies performed in this Report consider UACS earth stations using satellite communication located at a fixed point.

– **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**).

[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.

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]:"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] 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

[3] Definition quoted from ICAO Circular 328 AN/190 “Unmanned Aircraft Systems (UAS)”, ISBN 978-92-9231-751-5.

– **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).

---

[4] Control and non-payload communication (CNPC) are referred to in ICAO as command and control (C2) or command, control and ATC communication (C3).

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)

Parameter	Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
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[1]	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)

1 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.

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, amss[1], FS[2], mmss[3]	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, amss[1], FS[2,4], mmss[3,]	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, mmss[3,] amss[1]	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, mmss[3,] amss[1]	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 GHz[5]	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, FS[6], ms[7], BSS[8]	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), fs[1], ms[1]	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-s[2])), fs[1], ms[1]	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, fs[3], ms[3]	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, FS[5], MS[5]	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, FS[5], MS[5]	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 $\geq$ 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] 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

---

[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;

– 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	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	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	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	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	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	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	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	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	Propagation data and prediction methods required for the design of Earth-space telecommunication systems
ITU-R P.676	Attenuation by atmospheric gases
ITU-R P.836	Water vapour: surface density and total columnar content
ITU-R P.839	Rain height model for prediction methods
ITU-R P.840	Attenuation due to clouds and fog
ITU-R P.1623	Prediction method of fade dynamics on Earth-space paths
ITU-R P.2041	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	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	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	Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites
ITU-R S.672	Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites
ITU-R S.733	Determination of the G/T ratio for Earth stations operating in the fixed-satellite service
ITU-R S.1064	Pointing accuracy as a design objective for earthward antennas on board geostationary satellites in the fixed-satellite service
ITU-R S.1255	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	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	Satellite system characteristics to be considered in frequency sharing analyses within the fixed-satellite service
ITU-R S.1432	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	Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service
ITU-R SF.1719	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	Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace
ITU-R M.2230	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	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

This annex provides typical parameters used for the analyses of this Report. These parameters are compatible with the applicable FSS Recommendations. No different parameters than the usual FSS parameters are identified.

A1.1 Unmanned aircraft system parameters compatible with fixed satellite service networks in the 11/14 GHz frequency ranges

TABLE A1-1

Characteristics of typical unmanned aircraft system for control and non-payload communication via space stations operating under an allocation to the fixed satellite service in the 11/14 GHz frequency ranges

Data rate, modulation and coding				
Parameters	**Units**	**Values**	**Remarks**	**Reference**
Telecommand, UACS-to-satellite-to-UA (links 1 and 2) information data rate	kbps	10		Report ITU-R M.2171 Report ITU-R M.2233
Telemetry, UA-to-satellite-to-UACS (links 3 and 4) information data rate	kbps	320		
Modulation & Coding & E_b/N_o (DVB-S2)			Including ~ 2 dB for implementation loss	DVB-S2 Standard: ETSI EN 302 307 v. 1.2.1
Modulation		BPSK		
Spectral Efficiency	bits/Hz/sec	0.33		
E_b/N_0 @ 1E-8 BER	dB	4		
Roll-off factor	%	35		
Reference bandwidths	kHz	40 1 300	For Telecommand, UACS-to-satellite-to-UA (links 1 and 2) Telemetry, UA-to-satellite-to-UACS (links 3 and 4)	

TABLE A1-2

Characteristics of typical fixed satellite service earth stations on-board unmanned aircraft operated under an allocation to fixed satellite service in the 11/14 GHz frequency ranges

<table>
<tr><th colspan="2">Parameters</th><th>Units</th><th>Values</th><th>Remarks</th><th>Reference</th></tr>
<tr><td colspan="6">Transmission parameters</td></tr>
<tr><td colspan="2">Frequency (GHz)</td><td>GHz</td><td>14</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="3">On-axis e.i.r.p. density including scan loss</td><td rowspan="3">dBW/40kHz</td><td>35.8</td><td>For 0.45 m dish</td><td rowspan="3"></td></tr>
<tr><td>46.8</td><td>For 0.8 m dish</td></tr>
<tr><td>50.7</td><td>For 1.25 m dish</td></tr>
<tr><td colspan="2">Maximum off-axis e.i.r.p density</td><td>dBW/Hz</td><td>See Note 1</td><td>e.i.r.p. refers to above mentioned wave forms</td><td>Recommendation ITU-R S.524-9 Section 3</td></tr>
<tr><td rowspan="3">Typical equivalent antenna diameter</td><td>Small</td><td rowspan="3">m</td><td>0.45</td><td rowspan="3">Gimbaled dish antennas, or phased array antennas or hybrid mechanically electrically steered phased array antennas can be used</td><td rowspan="3">Sizes derived from market survey on these antennas (2013)</td></tr>
<tr><td>Medium</td><td>0.8</td></tr>
<tr><td>Large</td><td>1.25</td></tr>
<tr><td colspan="2">Typical antenna efficiency</td><td>%</td><td>55</td><td></td><td>Recommendation ITU-R S.733-2 section 4.1</td></tr>
<tr><td colspan="2">Antenna patterns</td><td></td><td>See Note 2</td><td></td><td>Recommendation ITU-R S.580; RR AP 7/ AP 8</td></tr>
<tr><td colspan="2">Antenna pointing error</td><td>degrees</td><td>0.2</td><td></td><td></td></tr>
<tr><td colspan="2">Pointing method</td><td></td><td>open loop</td><td></td><td></td></tr>
<tr><td colspan="2">Power control</td><td></td><td>Yes</td><td></td><td>Recommendation ITU-R S.1255</td></tr>
<tr><td colspan="6">Receive parameters</td></tr>
<tr><td colspan="2">Frequency</td><td>GHz</td><td>11</td><td></td><td></td></tr>
<tr><td colspan="2">Temperature</td><td>K</td><td>200</td><td>elevation 10°</td><td>Recommendation ITU-R S.733-2</td></tr>
<tr><td rowspan="3">Equivalent antenna diameters</td><td>Small UA</td><td rowspan="3">m</td><td>0.45</td><td rowspan="3">Gimbaled dish antennas, or phased array antennas or hybrid mechanically electrically steered phased array antennas can be used</td><td rowspan="3">Sizes derived from market survey on these antennas (2013)</td></tr>
<tr><td>Medium UA</td><td>0.8</td></tr>
<tr><td>Large UA</td><td>1.25</td></tr>
<tr><td colspan="2">Typical antenna efficiency</td><td>%</td><td>55</td><td></td><td></td></tr>
<tr><td colspan="2">Antenna patterns</td><td></td><td>See Note 2</td><td></td><td>Recommendation ITU-R S.580; RR AP 7/ AP 8</td></tr>
<tr><td colspan="2">Antenna pointing error</td><td>degrees</td><td>0.2</td><td>UA relies on its IMU (Inertial Measurement Unit) and GNSS to determine its pointing error</td><td></td></tr>
</table>

Parameters	Units	Values	Remarks	Reference
NOTE 1 − Based on the Recommendation ITU-R S.524-9 Section 3, the earth station uplink off-axis e.i.r.p. density for the 14 GHz frequency band can be summarized as follows:				
Angle off-axis		*Maximum e.i.r.p. per 40 kHz*		
2.5° ≤ φ ≤ 7°		(39-25 log φ) dB(W/40 kHz)		
7° < φ ≤ 9.2°		18 dB(W/40 kHz)		
9.2° < φ ≤ 48°		(42-25 log φ) dB(W/40 kHz)		
48° < φ ≤ 180°		0 dB(W/40 kHz).		
NOTE 2 – UA and UACS antennas are assumed to meet the antenna patterns in accordance with RR Appendix 7, RR Appendix 8 or Recommendation ITU-R S.580.				
NOTE 3 – To compensate antenna pointing error, satellite/beam handover, or other link impairments additional 3 dB to the edge of coverage are taken into account.				

A1.2 Unmanned aircraft system parameter [compatible] with fixed satellite service networks in the 20/30 GHz frequency ranges

TABLE A1-3

Characteristics of typical unmanned aircraft system for control and non-payload communication via space stations operating under an allocation to the fixed satellite service in the 20/30 GHz frequency ranges

Data rate, modulation and coding				
Parameters	**Units**	**Values**	**Remarks**	**Reference**
Telecommand, UACS-to-satellite-to-UA (links 1 and 2) Information data rate	kbps	10		Report ITU-R M.2171 Report ITU-R M.2233
Telemetry, UA-to-satellite-to-UACS (links 3 and 4) information data rate	kbps	320 kbps		
Modulation & Coding & Eb/No (DVB-S2)			Including ~ 2 dB for implementation loss	[DVB-S2 Standard: ETSI EN 302 307 v. 1.2.1]
Modulation FEC E_b/N_0 @ 1E-8 BER	 bits/Hz/sec dB	BPSK ½ 0.5 4		
Roll-off factor	%	35		
Reference bandwidths	kHz	40 1 300	Telecommand, UACS-to-satellite-to-UA (links 1 and 2) Telemetry, UA-to-satellite-to-UACS (links 3 and 4)	

TABLE A1-4

Characteristics of typical fixed satellite service earth stations on-board unmanned aircraft operated under an allocation to fixed satellite service in the 20/30 GHz frequency ranges

Parameters		Units	Values	Remarks	Reference
Transmission parameters					
Frequency		GHz	30		
Equivalent antenna diameters	Small	m	0.45	Gimbaled dish antennas, or phased array antennas or hybrid mechanically electrically steered phased array antennas can be used	
	Medium		0.8		
	Large		1.25		
Typical antenna efficiency		%	55		Recommendation ITU-R S.733-2 section 4.1
Antenna patterns			See Note 1		Recommendation ITU-R S.580; RR AP 7/ AP 8
Antenna pointing error		degrees	0.2	UA relies on its IMU (Inertial Measurement Unit) and GPS to determine its pointing error	
On-axis e.i.r.p. density including scan loss		dBW/40 kHz	34.4	For 0.45 m dish	
			36.4	For 0.8 m dish	
			40.4	For 1.25 m dish	
Off axis e.i.r.p. density		dBW/40 kHz		See Note 1	Recommendation ITU-R S.524-9 Section 4
Pointing method			Open or closed loop		
Power control			Yes		Recommendation ITU-R S.1255
Receive parameters					
Frequency		GHz	20		
Temperature		K	220	Including the scan loss	Recommendation ITU-R S.733-2 section 4.1
Equivalent antenna diameter	Small UA	m	0.45	Gimballed dish antennas, or phased array antennas or hybrid mechanically electrically steered phased array antennas can be used	
	Medium UA		0.8		
	Large UA		1.25		
Typical antenna efficiency		%	55		Recommendation ITU-R S.733-2 section 4.1
Antenna patterns			See Note 1		Recommendation ITU-R S.580 RR AP 7/ AP 8
Antenna pointing error		degrees	0.2 (see Note 2)	UA relies on its IMU (Inertial Measurement Unit) and GNSS to determine its pointing error.	

Parameters	Units	Values	Remarks	Reference
NOTE 1 − UA and UACS antennas are assumed to meet the antenna patterns in accordance with RR Appendix 7, RR Appendix 8 or Recommendation ITU-R S.580.				
NOTE 2 – To compensate antenna pointing error, satellite/beam handover, or other link impairments additional 3 dB to the edge of coverage are taken into account.				

A1.3 Typical fixed satellite service network parameter in the 11/14 GHz frequency ranges

TABLE A1-5

Characteristics of typical fixed satellite service earth stations for the control of unmanned aircraft operated under an allocation to the fixed satellite service in the 11/14 GHz frequency ranges (links 1 and 4)

Parameters	Units	Values	Remarks	Reference
Transmission parameters				
Frequency	GHz	14		
Transmit power density	dBW/4 kHz	–14	In the 14 GHz band, uplink power density may be lower than -14 dBW/4 kHz due to large antennas	Derived from link budget calculation using ITU-R Recommendations of P-Series for location dependencies
Antenna size	m	13	Actual antenna size depends on the UACS earth station location, elevation angle, rain rate zone etc.	
Typical antenna efficiency	%	65		
Antenna patterns	dBi	29-25*log (Θ)		Recommendation ITU-R S.580; RR AP 7/ AP 8.
Antenna pointing error	degrees	0.025	25% of antenna 3 dB beamwidth	
Receive parameters				
Frequency	GHz	11		
G/T	dB/K	36.5 (26 to 36.5)	Maximum antenna size for ≥ 100 mm/h rain rate only	
Antenna size	m	13 (3.9 to 13)		
Typical antenna efficiency	%	65		Recommendation ITU-R S.733-2 section 4.1
Antenna patterns	dBi	29-25*log (Θ)		Recommendation ITU-R S.580; RR AP 7/ AP 8
Antenna pointing error	degrees	0.04	25% of antenna 3 dB beamwidth	

TABLE A1-6

Characteristics of typical fixed satellite service geo-stationary orbit space station operated under an allocation to the fixed satellite service in the 11/14 GHz frequency ranges

Parameters	**Units**	**Values**	**Remarks**	**Reference**
Transmission parameters				
Frequency	GHz	11		
3 dB beamwidth	degrees	4.0 0.7	low gain beam high gain beam	Derived from typical commercial satellite beam types and ITU-R filings
e.i.r.p. transmit density	dBW/4 kHz dBW/36 MHz	15 or 50		Basis: pfd limits according to RR Art. **21** section V (elevation equal to or greater than 10°)
Antenna pointing error	degrees	0.25	Note 3	Recommendation ITU-R S.1064-1
Receive parameters				
Frequency	GHz	14		
3 dB beamwidth	degrees	4.0 0.7		Derived from typical commercial satellite beam types
G/T	dB/K	1 8	low gain beam (EoC) high gain beam (EoC	G/T scaled from Recommendation ITU-R S.1328 Table 1 row 4.1 using Recommendation ITU-R S.672-4 section 2.1
Antenna pointing error	degrees	0.2	Note 3	Recommendation ITU-R S.1064
NOTE 3 – To compensate pointing error, satellite/beam handover, or other link impairments an additional 3 dB loss relative to the edge of coverage are taken into account.				

A1.4 Typical fixed satellite service network parameter in the 20/30 GHz frequency ranges

TABLE A1-7

Characteristics of typical fixed satellite service earth stations for the control of unmanned aircraft operated under an allocation to the fixed satellite service in the 20/30 GHz frequency ranges (links 1 and 4)

Parameters	Units	Values	Remarks	Reference
Transmission parameters				
Frequency	GHz	30		
e.i.r.p. density	dBW/40 kHz	11.47 + G_{Ant} (0) – G_{Ant} (off-axis@ 2°)	Significantly lower due to large antenna	Derived from link budget calculation using Recommendation ITU-R S.524; Sizes according to typical fixed stations
Antenna size	m	13 (3.9 to 13)	Actual antenna size depends on the UACS earth station location, elevation angle, rain rate zone etc. (maximum for rain rate ≥ 100 mm/h)	
Typical antenna efficiency	%	65		Recommendation ITU-R S.733-2 section 4.1
Antenna patterns	dBi	29-25*log (Ɵ)		Recommendation ITU-R S.580
Antenna pointing error	degrees	0,01	25% of antenna 3 dB beamwidth	RR AP 7/ AP8
Receive parameters				
Frequency	GHz	20		
G/T	dB/K	42 (30 to 42)		Recommendation ITU-R S.733-2
Antenna size	m	13 (3.9 to 13)	Actual antenna size depends on the UACS earth station location, elevation angle, rain rate zone etc. (maximum for rain rate ≥ 100 mm/h)	
Typical antenna efficiency	%	65		
Antenna patterns	dBi	29-25* log (Ɵ)		Recommendation ITU-R S.580; RR AP 7/ AP8
Antenna pointing error	degrees	0.02	25% of antenna 3 dB beamwidth	

TABLE A1-8

Characteristics of typical fixed satellite service geo-stationary orbit space station operated under an allocation to the fixed satellite service in the 20/30 GHz frequency ranges

Parameters	Units	Values	Remarks	Reference
Transmission parameters				
Frequency	GHz	20		
3 dB beamwidth	degrees	0.5 1.4	High gain Low gain	Derived from typical satellite beam types (depending on beam coverages)
Downlink power flux-density	$dBW/m^2/MHz$	–112.5	Applicable to the17.7-19.7 GHz range for elevation equal to or greater than 10°	RR Art. **21** section V
Antenna pointing Error	degrees	0.2	See Note 2	Recommendation ITU-R S.1064-1
Receive parameters				
Frequency	GHz	30		
3 dB beamwidth	degrees	0.5 1.4	High gain Low gain	Typical FSS satellite beams
G/T	dB/K	14 9	High gain Low gain	G/T scaled from Recommendation ITU-R S.1328 Table 1 row 4.1 using Recommendation ITU-R S.672-4 section 2.1
Antenna pointing error	degrees	0.2	See Note 1	
NOTE 1 – To compensate pointing error, satellite/beam handover, or other link impairments an additional 3 dB loss relative to the edge of coverage are taken into account.				

A1.5 Accompanying system parameters used for the analyses

TABLE A1-9

Accompanying parameters for link budgets (frequency independent)

Parameters	Units	Values	Remarks	Reference
Elevation	degrees	10		
FSS internal interference	% of noise temperature increase	25	Each in uplink and downlink	Derived from typical satellite systems and specifications
Cross-polar interference	dB	25	Each in uplink and downlink	

ANNEX 2
TO REPORT ITU-R M.[UAS-FSS]

Link performance analysis

The purpose of this Annex is to calculate the link budgets and, under the considered ICAO scenarios, the maximum atmospheric attenuation that can be encountered to derive and compare such fade values with the available link margins, under the conditions in Annex 1 for FSS CNPC links, in order to assess link availabilities.

One main set of results together with supplementing dependency analyses are presented.

The main study refers to both 14/11 GHz and 29/19 GHz frequency bands and uses – in order to show the general picture – conservative assumptions in both, the link budget and the atmospheric fade calculations. For example, fade calculations are made on a global scale, but always with the minimum elevation angle of 10 degrees, which can lead to very large atmospheric attenuation values when rain fade is considered.

Supplementing studies to the above study have been carried out for showing the dependency of the link availability on the climatic zones, elevations and MODCOD types for the 30/20 GHz frequency band only. Some of the identified mitigation techniques listed in Annex 3 but also the worst case interference level given in Annex 5 are applied. For instance, availability calculations are made for elevation angles ranging from 0 to 90 degrees, rather than only 10 degrees. Also, as an additional example, spread spectrum techniques are also used. Apart from this worst case assumptions are still used when dealing with aspects such as atmospheric fade and intra-system interference.

This Annex is structured in sections as follows:

- **Section A2-1 Summary of achievable availabilities per scenario:** link availabilities are summarized for the main study, while the minimum elevation angle required to achieve link availability close to 100% is shown in the supplementary study
    - **Link availabilities are shown for the main studies for 14/11 GHz and 29/19 GHz band strictly considering the input parameters from Annex 1,**
    - **Additional sensitivity analyses for link availability close to 100% with varying input parameters like elevation angle, satellite beam gain etc.**
- **Section A2-2 Unimpaired link performance – total link margins**: achievable link budget margins are calculated for FSS CNPC links for the different ICAO scenario, without considering propagation effects.
- **Section A2-3 Atmospheric link impairments**: the various contributions to the atmospheric fading are described.
- **Section A2-4 Estimation of propagation impairments and resulting link availability on chosen flight scenarios with reference to link budgets in section A2-1:** total maximum atmospheric fades are calculated using realistic worst case assumptions on a global scale and with an elevation angle of 10 degrees.
- **Section A2-5 Sensitivity analyses regarding the propagation impairments and resulting link availability on chosen flight scenarios, with reference to the link budgets in section A2-2.3:** total maximum atmospheric fades are calculated using, conservatively, worst case assumptions for three different climatic regions and various elevation angles.
- **Section A2-6 Conclusions:** conclusions are drawn.

A 2-1. Summary of achievable link availabilities per flight scenario

A 2-1.1. Link Availabilities for 14/11 GHz and 29/19 GHz frequency band

The minimum **link margins** for both frequency ranges and for three UA antenna types according to Annex 1 are

- 6.2 dB in 11 GHz band,
- 7.8 dB in 14 GHz band
- 16.4 dB in 20 GHz band
- 8.5 dB in 30 GHz band

Details for those link margins are given in Tables A2-5 through A2-8.

The main results from the derived **link availabilities** are summarized as follows:

- close to 100% for flight scenarios 1, 2, 3 (for all types of UA and satellite antennas);
- close to 100% for flight scenario 4 (also covering scenario 7) for all cases at flight altitudes above rain clouds and for the majority of cases at flight altitudes below rain clouds;
- close to 100% for flight scenario 5 in 14/11 GHz range, and
- close to 100% for flight scenario 6 (UA medium and large) in 14/11 GHz range.

Details for those link availabilities are given in Table A2-46.

All other cases might necessitate mitigation measures to maintain link availabilities close to 100%. Examples on the improvement by mitigations are shown Annex 2, whereas the full set of mitigation techniques is contained in Annex 3. They show methods to improve link availabilities and margins. Depending on the selected flight scenario, the increase of elevation reduces the atmospheric contribution to the link attenuations by up to 40 dB (compared to the conditions for 10 degrees elevation).

Scenarios 7-9 are not considered under this methodology, as these scenarios refer mainly to take-off and landing phases of the flight where alternative CNPC links may be realistically more likely to be used (e.g. line of sight).

A 2-1.2. Supplementary studies for Ka-30/20 GHz frequency band

Table A2-2

Minimum elevation angle in degrees required to achieve availability close to 100% for the downlink to the unmanned aircraft vehicle

	Dry climate	Temperate climate	Tropical climate
SCENARIO 4	10°	10°	10°
SCENARIO 6	10°	10°	10°
SCENARIO 7	10°	10°	12.5°
SCENARIO 8	10°	10°	14°

Table A2-3

Minimum elevation angle in degree required to achieve availability close to 100% for the uplink from the unmanned aircraft vehicle

	Dry climate	Temperate climate	Tropical climate
SCENARIO 4	10°	12.5°	26°
SCENARIO 6	10°	10°	15°
SCENARIO 7	13°	17°	48 °
SCENARIO 8	20°	25°	N/A

Minimum elevation angles of 10 degrees is deemed to be sufficient to achieve availabilities of 100% for both the downlink and the uplink in Scenarios 1, 2, 3 and 5 as the rain fade will be zero or very small, due to the very high minimum UAV altitude to be considered (5800 m, 6100 m). Results for Scenario 9 are expected to be similar to the ones for scenario 8.

A 2-2. Pure link performance – total link margins

A 2-2.1. Methodology description for 14/11 GHz and 29/19 GHz frequency band

The following methodology to determine the feasibility of FSS links is applied:

(1) Derive typical UA CNPC link conditions from UAS characteristics given in Annex 1. Determine feasibility of link budgets and the achievable total link margin under particular UA CNPC conditions for all cases determined in Figure A2-1.

(2) Analyze link impairments introduced by the atmosphere for CNPC links.

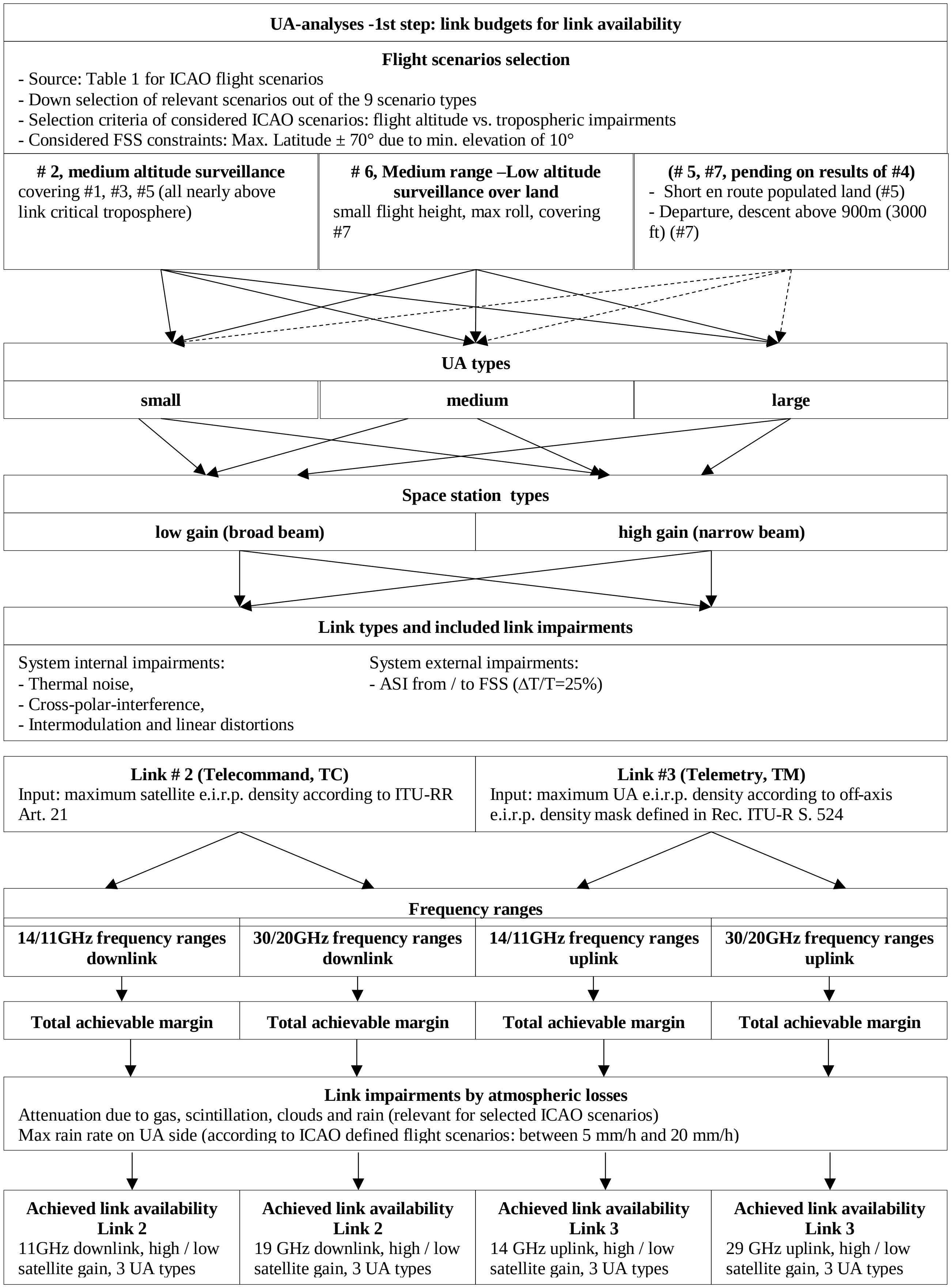
(3) Determine link availabilities under flight scenarios as defined in Figure A2-1.

(4) Refer to mitigation options for cases of critical link performances.

Because the pure link budgets and their total link margins for clear sky conditions are independent on the subsequent impairment based availability and sharing analyses they only need to get calculated once and independent on flight scenarios or subsequent sharing studies. The last two elements shown in the following figure are determining how and in which amount the achieved total margin will be used.

FIGURE A2-1

Determination of study cases for link budgets



A 2-2.1.1. Link performance in terms of fade margin estimation for user links

The following tables summarize the achieved total link margin for link #2 (CNPC towards UA as telecommand, TC) and link #3 (CNPC from UA as telemetry, TM).

These maximum achievable link margins – basis for the availability and continuity assessments by comparing with needed atmospheric link losses – are highlighted in bold and determined in such a manner that the excess margin for the respective link part becomes 0 dB.

The following tables summarize the link budgets results for the 24 link cases comprising:

- 14/11 and 29/19 GHz frequency ranges,
- Low / high satellite antenna gain per each frequency range,
- 3 x UAV types each,
- for Link #2 and #3 each.

On the first step the nominal link budgets – still without the atmospheric link impairments – have been calculated for UA on ground. Because of being independent on all atmospheric losses no additional calculations for higher altitudes are needed. The differentiation is only necessary afterwards for availability and sharing assessments.

On the second step all the atmospheric impairments on link #2 and #3 will be considered when deriving the availability due to atmospheric impairments based on the achieved link margins from step 1 (listed in rows 8 and 9 in each of the following four tables, see section A 2-4).

To consider a very conservative case it is assumed that the UACS locations in link#1 and #4 experience always 100 mm/h rain.

System external interferences: Typical FSS interference amount in terms of 25% increase of system noise temperature for both, uplink and downlink is also covered in the link budgets of step 1. This figure is based on Recommendations ITU-R S.1432 / ITU-R S.1323. Further impacts are subject for dedicated frequency coordination between neighbouring satellite networks as per RR Article **9**.

The worst case interference levels of non-participating adjacent FSS satellite networks towards the satellite receiver (link 3) and the receiver on board unmanned aircrafts are elaborated in Annex 5. This Annex shows that

- the derived interference levels towards satellite receiver are well below the above mentioned 25% increase of the system noise temperature.
- the derived worst case interference levels towards FSS receiver on-board unmanned aircraft for the non-coordinated case are below the achieved link margins given in the following subchapters; i. e. the link margin is high enough to meet any such degradation in the received C/N. Nevertheless it should be noted that lower – because coordinated – interference levels are more likely in real world scenarios (Successful coordination with the adjacent satellite system(s) is a prerequisite for applying UA CNPC).

Terrestrial interference is intensively analysed in Annex 6 showing full compatibility of UA reception of the satellite signal (link #2). All the other links do not face different interference situations as in typical FSS systems.

A summary of the accompanying system assumptions used for the analyses is in the table below:

TABLE A2-4

Accompanying parameters for link budgets (frequency independent)

Parameters	Units	Values	Remarks	Reference
Elevation	Degrees	10		
FSS internal interference	% of noise temperature increase	25	Each in uplink and downlink	Derived from typical satellite systems and specifications
Cross-polar interference	dB	25	Each in uplink and downlink	

A 2-2.1.2. Achievable link margin in 14/11 GHz frequency band fixed satellite service

TABLE A2-5

Typical link budgets for 14/11 GHz-frequency band unmanned aircraft system scenarios (beam type 1, low satellite antenna gain)

		Units	14/11 GHz frequency range low satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2
2	From (station type)		UA small	UA medium	UA large	UACS	UACS	UACS
3	To (station type)		UACS	UACS	UACS	UA small	UA medium	UA large
4	Net user bit rate	Kbps	320	320	320	10	10	10
5	Waveform (calculation example)		BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3
6	Uplink C/N_0	dBHz	67.3	77.3	81.2	67.4	67.4	67.4
7	Downlink C/N_0	dBHz	61.5	71.5	75.3	44.1	44.1	44.1
8	**Uplink margin** UACS: rain (100 mm/h) + tropo **UA: totally max. achievable** (clear sky)	dB	**7.8**	**16.0**	**18.0**	28.5	28.5	28.5
9	**Downlink margin** UACS: rain (100 mm/h) + tropo (G/T degr. covered) **UA: totally max. achievable** (clear sky)	dB	18.3	18.3	18.3	**6.2**	**10.9**	**14.8**
10	First limiting parameter (hardware capability for e.i.r.p. or ITU-R S.524 or PFD limits of App. 21)		Rec. ITU-R S.524	Rec. ITU-R S.524	Rec. ITU-R S.524	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit

TABLE A2-6

Typical link budgets for 14/11 GHz frequency band unmanned aircraft system scenarios (beam type 2, high satellite antenna gain)

		Units	14/11 GHz frequency range high satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2

		Units	14/11 GHz frequency range high satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2
2	From (station type)		UA small	UA medium	UA large	UACS	UACS	UACS
3	To (station type)		UACS	UACS	UACS	UA small	UA medium	UA large
4	Net user bit rate	Kbps	320	320	320	10	10	10
5	Waveform (calculation example)		BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3
6	Uplink C/N_0	dBHz	74.3	84.3	87.5	72.4	72.4	72.4
7	Downlink C/N_0	dBHz	63.5	73.5	76.6	44.1	44.1	44.1
8	**Uplink margin** UACS: rain (100 mm/h) + tropo **UA: totally max. achievable** (clear sky)	dB	**13.7**	**19.0**	**19.7**	28.5	28.5	28.5
9	**Downlink margin** UACS: rain (100 mm/h) + tropo (G/T degr. covered) **UA: totally max. achievable** (clear sky)	dB	18.3	18.3	18.3	**6.2**	**10.9**	**14.8**
10	First limiting parameter (hardware capability for e.i.r.p. or ITU-R S.524 or PFD limits of App. 21)		Rec. ITU-R S.524	Rec. ITU-R S.524	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit

A 2-2.1.3. Achievable link margin in 29/19 GHz frequency band fixed satellite system

TABLE A2-7

Link budgets for 29/19 GHz frequency band unmanned aircraft command and non-payload communication applications (Beam type 1, low satellite antenna gain)

		Units	29/19 GHz frequency range low satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2
2	From (station type)		UA small	UA medium	UA large	UACS	UACS	UACS
3	To (station type)		UACS	UACS	UACS	UA small	UA medium	UA large
4	Net user bit rate	Kbps	320	320	320	10	10	10
5	Waveform (calculation example)		BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3
6	Uplink C/N_0	dBHz	67.9	70.0	73.6	66.0	66.0	65.9
7	Downlink C/N_0	dBHz	68.3	70.4	74.0	44.1	44.1	44.1
8	**Uplink margin** UACS: rain (100 mm/h) + tropo **UA: totally max. achievable** (clear sky)	dB	**8.5**	**10.4**	**13.5**	47.7	47.7	47.7

		Units	29/19 GHz frequency range low satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2
9	**Downlink margin** UACS: rain (100 mm/h) + tropo (G/T degr. covered) **UA: totally max. achievable** (clear sky)	dB	23.5	23.5	23.5	**16.4**	**19.5**	**23.2**
10	First limiting parameter (hardware capability for e.i.r.p. or ITU-R S.524 or PFD limits of App. 21)		Rec. ITU-R S.524; Note 12 exception needed!	Rec. ITU-R S.524	Rec. ITU-R S.524	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit

TABLE A2-8

Link budgets for 29/19 GHz frequency band unmanned aircraft command and non-payload communication applications (Beam type 2, high satellite antenna gain)

		Units	29/19 GHz frequency range high satellite antenna gain					
1	Link number		#3 --> #4	#3 --> #4	#3 --> #4	#1 --> #2	#1 --> #2	#1 --> #2
2	From (station type)		UA small	UA medium	UA large	UACS	UACS	UACS
3	To (station type)		UACS	UACS	UACS	UA small	UA medium	UA large
4	Net user bit rate	Kbps	320	320	320	10	10	10
5	Waveform (calculation example)		BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3	BPSK-1/3
6	Uplink C/N_0	dBHz	72.9	75.0	78.6	69.0	69.0	68.9
7	Downlink C/N_0	dBHz	70.3	72.4	76.0	44.1	44.1	44.1
8	**Uplink margin** UACS: rain (100 mm/h) + tropo **UA: totally max. achievable** (clear sky)	dB	**12.9**	**14.6**	**16.9**	47.7	47.7	47.7
9	**Downlink margin** UACS: rain (100 mm/h) + tropo (G/T degr. covered) **UA: totally max. achievable** (clear sky.)	dB	23.5	23.5	23.5	**16.4**	**19.5**	**23.2**
	First limiting parameter (hardware capability for e.i.r.p. or ITU-R S.524 or PFD limits of App. 21)		Rec. ITU-R S.524; Note 12 exception needed!	Rec. ITU-R S.524	Rec. ITU-R S.524	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit	Downlink e.i.r.p. density for PFD limit

A 2-2.2. Supplementing analyses for 30/20 GHz frequency band

Because of the higher atmospheric propagation attenuations additional sensitivity analyses have been carried out for the 30/20 GHz band w. r. t. achievable fade margins.

A number of assumptions were made in estimating the maximum link margin. The main ones are the following:

In the forward link (satellite-to-UAV or downlink):

– A maximum satellite edge of coverage e.i.r.p. of 41 dBW for the CNPC carrier is assumed. This level is based on the maximum power that is likely to be agreed during frequency coordination between operators of around 44 dBW in any 1 MHz (which itself is related to a maximum pfd regulatory level in 1 MHz set by some administrations for licensing of 30/20 GHz frequency band satellite networks over their territory). A reduction of 3dB is made on the maximum e.i.r.p. at beam centre to account for potential operation at the beam edge of coverage.

  It is also assumed that the carrier power can be operated in a bandwidth much smaller than 1 MHz and that such operation will be acceptable in coordination with adjacent satellite services. This is considered to be reasonable since, typically, adjacent satellite operators are likely to deploy carriers with a much wider carrier bandwidth than 1 MHz at 30/20 GHz frequency band. While in cases where narrow band carriers are deployed on adjacent satellites then these may be coordinated on case by case basis.

  It is noted that the operation of higher carrier powers than assumed may be feasible particularly within the frequency band 19.7-20.2 GHz which is not subject to Article **21** limits. However this is not considered further in the scope of this study since even in this band, the maximum regulatory pfd licencing requirement in 1 MHz referenced above would typically apply.

  It is also noted that spread spectrum techniques may be used to increase the maximum link margin available while maintaining the transmitted e.i.r.p. spectral density coordinated with adjacent satellite networks and the compliance with any regulatory requirements.

– A simplified link budget analysis is adopted that examines the maximum margin that is likely to be available for the downlink. It is assumed that large gateway antennas employing site diversity for the links 1 and 4 of Figure 1 in section 2 of the main body of this report are used. This also means that any intra-system link degradation (e.g. to account for frequency reuse considerations, receipt of adjacent channel intra-system interference, intermodulation degradation, cross polarisation effects, antenna miss-pointing, and like) can be accounted for through a general single provision (expressed in dB) within the estimate of the link margin.

– To maximise the available fade-margin it is assumed that the modulation and coding for the carrier is ¼-rate QPSK carrier defined within the DVB-S2 standard (Table 13 ETSI EN 302 307 V1.2.1 (2009-08)). This carrier is used for the link assessment since it has the lowest C/(N+I) requirement listed within the DVB-S2 standard (approximately -2.1dB (including a 1dB modem implementation allowance) for a quasi error free PER = 10^{-7} (AWGN channel)). Commercially available modems typically support the operation of this type of carrier.

  It should be noted that the choice of this carrier and modulation-coding rate is illustrative and operational conditions might recommend the use of more robust channel coding and modulation schemes resulting in slightly better modem performance (of perhaps 1dB lower requirement) than assumed.

– An interference margin provision of 1 dB is included within the simplified link budget approach to account for the potential for intra-system degradation effects discussed above, together with a 0.5 dB margin to account for inter-system interference.

Additionally, the simplified link budget accommodates potential interference resulting from adjacent satellite networks at a 2 degrees orbital separation to the wanted system (based on Annex 5 analyses), and having an interference power of -16 dBW/Hz (3 dB higher than the wanted power) on the forward link (link 2, satellite-to-UAV). This approach was adopted to take into account of a higher potential of interference from adjacent satellite systems operating in the FSS due to the use of small size UAV antenna, than the permissible allowance of 20 to 25% of total system noise specified in Recommendations (e.g. Recommendation ITU-R S.1323).

In the return link (link 3, UAV-to-satellite or uplink):

– For the operation of small terminals, the maximum transmitted e.i.r.p. is limited by the need to comply with the maximum off-axis e.i.r.p. density levels contained in Recommendation ITU-R S.524-9. For 30/20 GHz band frequencies, the off-axis e.i.r.p. density limit is equal to 19-25*log(theta) dB(W/40 kHz) for 2 deg < theta < 7 deg, theta being the off-axis angle. Even the worst case operation of a 45cm antenna having a 29-25*log(theta) sidelobe gain pattern in 30/20 GHz band will result in relatively modest margins on the link. To increase those margins mitigation measures as explained in Annex 3 can be applied.

  It is noted that, similarly to the forward link, the choice of this carrier and modulation-coding rate is illustrative. Although a higher order code may also be deployed, a spreading factor of 8 is thought to be a good compromise between the wanted link margin and the available bandwidth requirements over a satellite link. Furthermore, as in the forward link case, the use of an antenna with a diameter larger than 45cm can increase the link margin.

– As in the case of the forward link, a simplified link budget analysis is adopted for the return link, which allows both inter and intra system degradation effects to be accounted for through a single provision within the link design.

A 2-2.2.1. Impairments due to the interference from other fixed satellite service systems

An analysis based on worst-case assumptions and based on limitations agreed in the coordination agreements between operators and administrations is carried out in Annex 5 for calculating the maximum interference levels that FSS networks operating UAS CNPC links could experience. Such levels are included in the link budget calculations which follow. It should also be noted that lower interference levels are more likely in real world scenarios because the successful coordination of the respective satellite system is a prerequisite for applying UA CNPC.

A 2-2.2.2. Impairments due to the interference from non-fixed satellite systems

Annexes 6 and 7 of this Report provide an analysis of the interference received by and caused to services sharing the same band as that used by the UAS CNPC links in frequency bands allocated to the FSS. Nevertheless, a provisional margin of 0.5 dB has been included in the link budgets calculations which follow as an additional precautionary measure.

A 2-2.2.3. Achievable link margins

The following Table shows a summary of the maximum margins for the forward link that can be made available for 30/20 GHz frequency band systems (under the assumptions listed above). A detailed calculation is made available in Table A2-12. It should be noted that the estimated margins do not account for any propagation impairments on the link. Instead, they represent the maximum propagation impairment that may be accounted for 30/20 GHz frequency band links.

TABLE A2-9

Maximum potential margin on the forward link (Satellite-to-unmanned aircraft vehicle or downlink) in the 30/20 GHz frequency range

User terminal type	Unit	Typ-45 cm	Typ-80 cm	Typ-125 cm
Satellite e.i.r.p. (EOC)	dBW	41	41	41
Maximum available link fade margin (excl. propagation losses)	dB	**19.9**	**29.2**	**33.1**

It is further noted that fading of the wanted and adjacent satellite interference paths are likely to be correlated in the operation of UAV due to the similar path geometries. It means that the interference signal path from the adjacent satellites is likely to be received at the UAV antenna through the same rain cloud as the wanted signal path, resulting in similar impairment on the two links.

Table A2-13 presents the assessment of the margin in the return link. A summary of the results is indicated in Table A2-10 below which presents the maximum link margin that may be available with 45 cm, 80 cm and 125 cm antenna to a 1.3 degrees satellite receive beam (at 30 GHz and under the assumed link operation). For comparison, Table A2-11 shows the increase in margin that would be available through the use of higher gain satellite beams with beam widths of 1.0, 0.7 and 0.3 degrees, respectively. To limit number of combinations, results are only shown for the 125 cm antenna.

In summary, very high fade margins (around 30 dB) can be available for the operation of UAV antennas on both, the uplink and the downlink.

TABLE A2-10

Maximum potential margin on the return link (unmanned aircraft vehicle-to-satellite or uplink) in the 30/20 GHz frequency ranges

User terminal type	Unit	Typ-45 cm	Typ-80 cm	Typ-125 cm
Terminal e.i.r.p.	dBW	53.3	58.2	62.1
Receive beam size	deg	1.3	1.3	1.3
Maximum available link fade margin (excl. propagation losses)	dB	**14.6**	**19.5**	**23.4**

TABLE A2-11

Increase in margin as a function of the size (gain) of the satellite beam on the return link (unmanned aircraft vehicle-to-satellite or uplink)

User terminal type	Unit	Typ-125 cm	Typ-125 cm	Typ-125 cm
Terminal e.i.r.p.	dBW	62.1	62.1	62.1
Receive beam size	deg	1.0	0.7	0.3
Maximum available link fade margin (excl. propagation losses)	dB	**24.8**	**26.3**	**27.4**

TABLE A2-12

Estimate of a likely maximum link margin that could be available to support a user data rate of 10kbps for different terminal sizes and link allowances in the downlink direction

Parameter	**Unit**	**Satellite eirpd = -19 dB(W/Hz) EoC averaged 1 MHz**	**Satellite eirpd = -19 dB(W/Hz) EoC averaged 1 MHz**	**Satellite eirpd = -19 dB(W/Hz) EoC averaged 1 MHz**
User terminal type	-	Small - 45 cm	Medium - 80 cm	Large - 125 cm
Antenna Diameter	m	0.45	0.80	1.25
Antenna Efficiency	-	0.55	0.55	0.55
lambda	m	0.015	0.015	0.015
Target bit rate	kbps	10.00	10.00	10.00
Modulation	symbols	4.00	4.00	4.00
FEC Rate	-	0.25	0.25	0.25
Filter Roll off	%	20.00	20.00	20.00
Satellite EIRP (EOC)	dB(W/MHz)	41.0	41.0	41.0
Downlink Frequency	GHz	20.00	20.00	20.00
Elevation (EOC)	deg	10.0	10.0	10.0
Carrier occupied bandwidth	kHz	**24.0**	**24.0**	**24.0**
Downlink Range (EOC)	km	**40586.0**	**40586.0**	**40586.0**
Path loss	dB	**210.6**	**210.6**	**210.6**
Terminal Max gain	dBi	36.9	41.9	45.8
E/S Noise (clear sky, including 1 dB Radome Loss)	K	215.0	215.0	215.0
Intra-system degradation allowance	dB	1.0	1.0	1.0
Inter-system interference allowance (in add to adjacent inter.)	dB	0.5	0.5	0.5
Received C (minus degradation allowances) (clear sky EOC)	dB(W)	**-134.2**	**-129.3**	**-125.4**
Received I (clear sky)	dB(W)	**-157.9**	**-157.9**	**-157.9**
System noise temperature N (clear sky)	dB(W)	**-161.5**	**-161.5**	**-161.5**
C/N	dB	**27.2**	**32.2**	**36.1**
I/N	dB	**3.6**	**3.6**	**3.6**
Total C/(N+I)	dB	**22.1**	**27.1**	**30.9**
Min Target C/(N+I) (DVB-S2 -> 1/4 rate QPSK, incl. 1dB implementation loss)	dB	-2.14	-2.14	-2.14
Maximum available link margin (exclusive propagation losses). I.e., based on C/(N+I) exclusively	dB	**24.2**	**29.2**	**33.1**

TABLE A2-13

Estimate of a likely maximum link margin that could be available to support a user data rate of 320 kbps for different terminal sizes and link allowances in the uplink direction

Parameter	**Unit**	**1.3 degrees beam**	**1.3 degrees beam**	**1.3 degrees beam**	**1.0 degrees beam**	**0.7 degrees beam**	**0.3 degrees beam**

Parameter	Unit	1.3 degrees beam	1.3 degrees beam	1.3 degrees beam	1.0 degrees beam	0.7 degrees beam	0.3 degrees beam
User terminal type	-	Typ-45 cm	Typ-80 cm	Typ-125 cm	Typ-125 cm	Typ-125 cm	Typ-125 cm
Modulation		1/2 rate BPSK with SF=8	1/2 rate BPSK with SF=8	1/2 rate BPSK with SF=8	1/2 rate BPSK with SF=8	1/2 rate BPSK with SF=8	1/2 rate BPSK with SF=8
Target bit rate	kbps	320.00	320.00	320.00	320.00	320.00	320.00
Modulation	bit/symbol	1.00	1.00	1.00	1.00	1.00	1.00
Coding Rate	-	0.50	0.50	0.50	0.50	0.50	0.50
Code spreading factor		8.00	8.00	8.00	8.00	8.00	8.00
Filter Roll off	%	25.00	25.00	25.00	25.00	25.00	25.00
Uplink Frequency	GHz	30.0	30.0	30.0	30.0	30.0	30.0
Elevation (EOC)	deg	10.0	10.0	10.0	10.0	10.0	10.0
Adjacent interference uplink off-axis eirpd	dB(W/Hz)	-31.0	-31.0	-31.0	-31.0	-31.0	-31.0
Antenna diameter	m	0.45	0.8	1.25	1.25	1.25	1.25
Antenna efficiency	numerical	0.55	0.55	0.55	0.55	0.55	0.55
lambda	m	0.010	0.010	0.010	0.010	0.010	0.010
D/lambda	numerical	45.0	80.0	125.0	125.0	125.0	125.0
Carrier occupied bandwidth	kHz	6400.0	6400.0	6400.0	6400.0	6400.0	6400.0
Uplink range (EOC)	km	40586.0	40586.0	40586.0	40586.0	40586.0	40586.0
Path loss	dB	214.2	214.2	214.2	214.2	214.2	214.2
Terminal max gain	dBi	40.4	45.4	49.3	49.3	49.3	49.3
Terminal Sidelobe gain (at 2 degree offset, including pointing error)		20.9	21.0	21.0	21.0	21.0	21.0
max psd to comply with oa eirp density of -35dBW/Hz @ 2 deg offset	dB(W/Hz)	-55.9	-56.0	-56.0	-56.0	-56.0	-56.0
Terminal EIRP (clear sky)	dBW	52.6	57.5	61.4	61.4	61.4	61.4
Satellite antenna gain (BP)	dBi	42.1	42.1	42.1	44.6	48.1	54.2
Satellite antenna gain (EoC)	dBi	39.1	39.1	39.1	41.6	45.1	51.2
Satellite G/T	dB	14.0	14.0	14.0	16.5	20.0	26.1
Sat noise temperature	K	645.7	645.7	645.7	645.7	645.7	645.7
Intra-system degradation allowance	dB	1.0	1.0	1.0	1.0	1.0	1.0
Inter-system interference allowance (in addition to adjacent interference)	dB	0.5	0.5	0.5	0.5	0.5	0.5
Antenna misspointing loss	dBi	0.5	0.5	0.5	0.5	0.5	0.5
Received C (minus degradation allowances) (EOC)	dB(W)	**-124.5**	**-119.6**	**-115.7**	**-113.2**	**-109.7**	**-103.6**
Received I (BP)	dB(W)	**-135.0**	**-135.0**	**-135.0**	**-132.5**	**-129.0**	**-122.9**
System noise temperature N (clear sky)	dB(W)	**-132.4**	**-132.4**	**-132.4**	**-132.4**	**-132.4**	**-132.4**
C/N	dB	**8.0**	**12.9**	**16.7**	**19.2**	**22.7**	**28.8**
I/N	dB	**-2.6**	**-2.6**	**-2.6**	**-0.1**	**3.4**	**9.5**

Parameter	Unit	1.3 degrees beam	1.3 degrees beam	1.3 degrees beam	1.0 degrees beam	0.7 degrees beam	0.3 degrees beam
Total C/(N+I)	dB	**6.0**	**10.9**	**14.8**	**16.2**	**17.7**	**18.8**
Min Target C/(N+I) (predicted based on packetized frame transmissions)	dB	-8.60	-8.60	-8.60	-8.60	-8.60	-8.60
Maximum available link margin (excl. propagation losses). I.e., based on C/(N+I)	dB	**14.6**	**19.5**	**23.4**	**24.8**	**26.3**	**27.4**

A 2-3. Atmospheric link impairments

A 2-3.1. Link impairments due to propagation phenomena

The link budgets under Section A2-2 are taking into account the free space loss only. The derived link margins of Tables A2-5 through A2-13 can be used for determining the achievable link availability against scenario dependent impact of atmospheric gas, tropospheric scintillations, clouds and rain.

If the maximum margin available is higher than those atmospheric fades the operation of UA CNPC via satellite is possible without any constraint, if it is lower than the atmospheric fade, adequate mitigation techniques will have to be implemented for avoiding the loss of the command and control link of the unmanned aircraft (see Annex 3).

A 2-3.2. Impairments due to rain

Rain attenuation is predicted by paragraph 2.2.1.1 of Recommendation ITU-R P.618 with equation (1) computing the slant-path length, L_S, from h_S, the height of the Earth station above mean sea level. For a path between an airborne platform and space, h_S is replaced by the altitude of the airborne platform above mean sea level based on the chosen flight scenario. In case h_S is greater than or equal to h_R (rain height per ITU-R P.839), the rain attenuation is 0 dB.

The procedure of paragraph 2.2.1.1 of Recommendation ITU-R P.618 considers the rain attenuation to be exceeded for 0.01% for an average year (based on the rainfall rate, R0.01, exceeded for 0.01% of an average year). Nevertheless, the same procedure can be applied to compute the maximum fade experienced by a radio link between an UAV and a satellite, if the maximum rain rate is known. In the case of UAS CNPC links, the maximum rain rate, conservatively considered as constant through the flight, is provided for each ICAO scenario.

Additional to the rain path attenuation itself, noise increase at the receiver effecting a degradation of the G/T at the UA receiver in downlink (link 2) has to be considered. Recommendation ITU-R P.618 provides in section 3 the procedure how the noise increase can be estimated.

$$T_S = T_M\left(1 - 10^{-A/10}\right) \quad (4)$$

Where:

T_S = sky-noise temperature (K) as seen by the antenna;

A: path attenuation (dB);

T_M: effective temperature (K) of the medium (260 K).

This effect occurs only in flight scenarios where the minimum flight altitude is below the rain height (e.g. flight scenario 4 and 6). Therefore G/T degradation due to noise increase at the receiver has no effect on the on the link performance of link 3 (uplink). Additional the G/T degradation has no effect on the feasibility decisions in Table A2-1 based on the extrapolated link availabilities summarized in Table A2-46.

A 2-3.3. Impairments due to gaseous attenuation

The gaseous attenuation for an Earth-space path is predicted by equation (29) of Recommendation ITU-R P.676:

For a path between an airborne platform and space, the corresponding gaseous attenuation is:

$$A_G^{AS}(p) = \frac{A_o^{AS} + A_w^{AS}(p)}{sin\phi} \quad (5)$$ [1]

A_o^{AS} is predicted as follows:

$$A_o^{AS} = A_o e^{-altitude/h_o} \quad (6)$$

where $altitude$ is the UA altitude above the surface of the Earth, and h_o is obtained from equation (25a) of Recommendation ITU-R P.676 and r_p at the surface of the Earth.

$A_w^{AS}(p)$ is predicted from equation (37) of Recommendation ITU-R P.676, where $V_t(p)$ is obtained from Annex 2 of Recommendation ITU-R P.836, and alt is the altitude of the airborne platform above mean sea level specified in Annex 2 paragraph 1e) of Recommendation ITU-R P.836.

A 2-3.4. Impairments due to cloud attenuation

For calculating the impairments due to cloud attenuation three different situations have to be considered:

1) Airborne platform is flying below rain height.

2) Airborne platform is flying above rain height but still below cloud top.

3) Airborne platform is flying above cloud top

For the airborne platform flying below rain height as specified in Recommendation ITU-R P.839 the cloud attenuation is calculated according to Recommendation ITU-R P.840.

For an airborne platform flying above rain height a different approach has to be used: Predicting the cloud attenuation from an airborne platform to space needs to consider different cloud types at different altitudes with different vertical extents. For this purpose a conservative approach is applied assuming that the cloud base is at the rain height per Recommendation ITU-R P.839 and the cloud top, h_c, is at 6.36[2] km. The cloud attenuation can then be computed according to Recommendation ITU-R P.840 as follows:

---

[1] Equation numbers are taken from the referenced original document Rec ITU-R P.676-9 for easier navigation.

[2] Although according to Recommendation ITU-R P.2041 the cloud top is assumed at 6 km, according to Rec. ITU-R P.839 the maximum rain height on a global scale is above 6 km (up to 6.36 km in a few locations in the Himalayan region). Therefore, also to make a conservative assumption, the cloud top is also assumed to be equal to 6.36 km.

- 100% of the total columnar content of cloud liquid water is used for altitudes below the rain height,
- 0% of the total columnar content of cloud liquid water is used for altitudes above the cloud top, and
- a linear transition of total columnar content of cloud liquid water can be assumed between the cloud base and the cloud top.

As a consequence, impairments due to cloud attenuation can (and will) be ignored for an UA flying above the height of the cloud top.

A 2-3.5. Impairments due to tropospheric scintillation

Fading due to tropospheric scintillation is predicted by paragraph 2.4.1 of the Annex 1 of Recommendation ITU-R P.618. If the airborne platform is at an altitude below the above specified rain height tropospheric scintillation is conservatively calculated assuming the airborne platform is located at the surface of the Earth.

A 2-3.6. Estimation of total attenuation due to multiple sources of simultaneously occurring atmospheric attenuation

For airborne platforms different parts of propagation losses have to be taken into account depending on the flight altitude of the airborne platform relative to the rain height specified in Recommendation ITU-R P.839.

The following table summarizes the parts of propagation losses to be considered at the different flight altitudes of the airborne platform.

TABLE 2-14

Definition of individual impairment effects

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Gaseous attenuation
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes

A 2-3.7. Below rain height

Below the rain height the total attenuation, A_T, due to propagation attenuations is calculated according to Recommendation ITU-R P.618 section 2.5:

Equations (53) and (54) take account of the fact that a large part of the cloud attenuation and gaseous attenuation is already included in the rain attenuation prediction for time percentages below 1%.

A 2-3.8. Above rain height, below cloud top

At altitudes above rain but below cloud top the total attenuation, A_T, due to propagation attenuations is calculated according to Sec. 5 of the Recommendation ITU-R P.2041-0.

The Recommendation ITU-R P.2041 indicates that this method is valid for $p \geq 0.1\%$.

For time percentages $\leq 0.1\%$, Working Party 3M suggests that the total columnar content of cloud liquid water and the total columnar water vapour content can be extrapolated using the values of the total columnar content of cloud liquid water and the total columnar water vapour content for time percentages ≥ 0.1% (see section A 2-3.10).

A 2-3.9. Above cloud top

At altitudes above cloud top the total attenuation, A_T, due to propagation attenuations is calculated according to Recommendation ITU-R P.2041.

The Recommendation ITU-R P.2041 indicates that this method is value for $p \geq 0.1\%$.

For time percentages ≤ 0.1%, Working Party 3M suggests that the total columnar water vapour content can be extrapolated using the values of the total columnar water vapour content for time percentages ≥ 0.1%.

A 2-3.10. Extrapolation of attenuation due to clouds and atmosphere for p ≤ 0.1%

As recommended by study group 3M the attenuation can be extrapolated for time percentages p<0.1% using the values of the total columnar content of cloud liquid water and the total columnar water vapour content for time percentages of p ≥ 0.1%.

To cope with the specific behaviour between the total columnar content of liquid water and the total columnar water vapour content, a polynomial curve fitting and extrapolation based on the polynomial is done. The used curve fitting with least squares minimizes the sum of the squares of the errors between the determined polynomial for the desired parameter and the given ITU data. This is done by setting the first derivation of the error function to zero and solving the set of equations by applying the Gaussian elimination.

The derived polynomial is used to calculate the wanted total columnar content of liquid water and the total columnar water vapour content for a fixed probability of p < 0.1%.

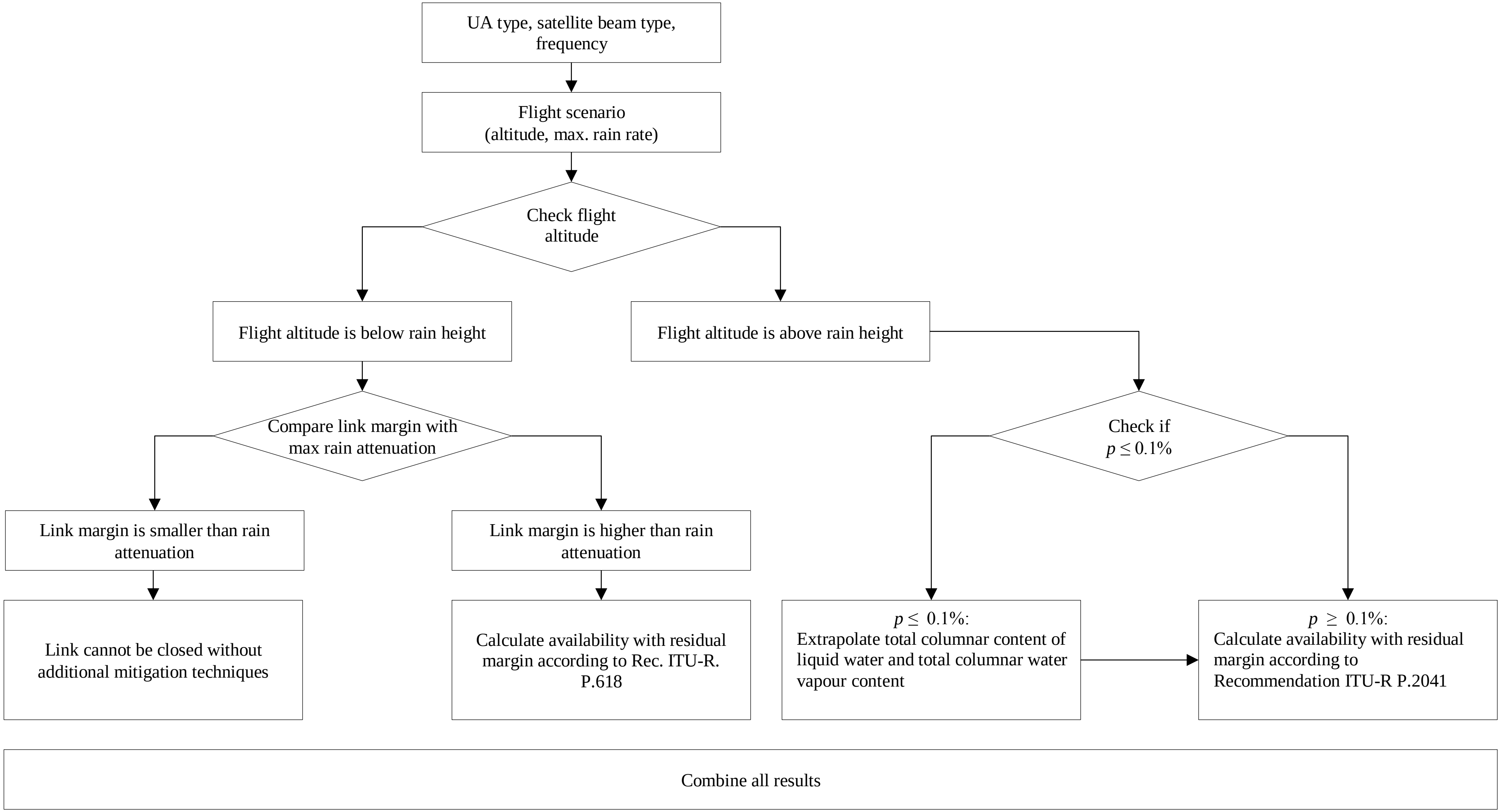
Whereas the simulations calculated all unavailabilities down to 10^{-13} the results are shown with three digits only. Link availabilities significantly higher than 99.999% (i. e. unavailability significantly smaller than 0.001%) are marked with “>>”.

A 2-4. Estimation of propagation impairments and resulting link availability on chosen flight scenarios with reference to link budgets in Sec. A2-2.1 for 14/11 GHz and 29/19 GHz band

To derive the performance of each flight scenario with every single UA type and satellite beam type the procedure shown in the following figure is used.

FIGURE A2-2

Structure of the availability analyses



The **results of the availability analysis** listed in the following Sections comprise:

- A map for each UA type showing the unavailability for each location on earth. The results are focused on the areas where the link margin is not sufficient to reach an availability as close to 100% as possible, i. e. for this simulation a value of p = 1e-13% as the computational limit of the used simulation hardware. I.e. the white areas in the maps are either not considered in the Flight scenario or the achievable unavailability is lower than 1e-13%. The unavailability is calculated by the relation:

  $$\text{Unavailabiliy} = 100\% - \text{Availability}$$

  Unavailability is chosen to provide maps in logarithmic scale for better presentation of the results.

- A diagram showing the cumulative distribution functions (CDFs) of the percentage of time, *p*, where the link margin is exceeded, for each UA type.

  On the abscissa the percentage of time, *p*, where the link margin is exceeded is plotted whereas the ordinate shows the cumulative probability this percentage of time occurs.

  Baseline assumption for the atmospheric attenuation is the elevation of 10 degrees for each considered location on the Earth's surface.

A 2-4.1. Performance analysis flight scenario 1

Flight scenario 1 is used according to the scenario description for high altitude surveillance / aerial work (search pattern). The application of this scenario is globally so there is no restriction in the geographical locations. The minimum altitude is 9150 m (30,000 ft) above mean sea level. Out of Figure A2-3 it can be seen that the minimum flight altitude is always above rain height and even above cloud top. Therefore UAs operating in this flight scenario do only experience impairments due to gaseous attenuation.

FIGURE A2-3

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight scenario 1

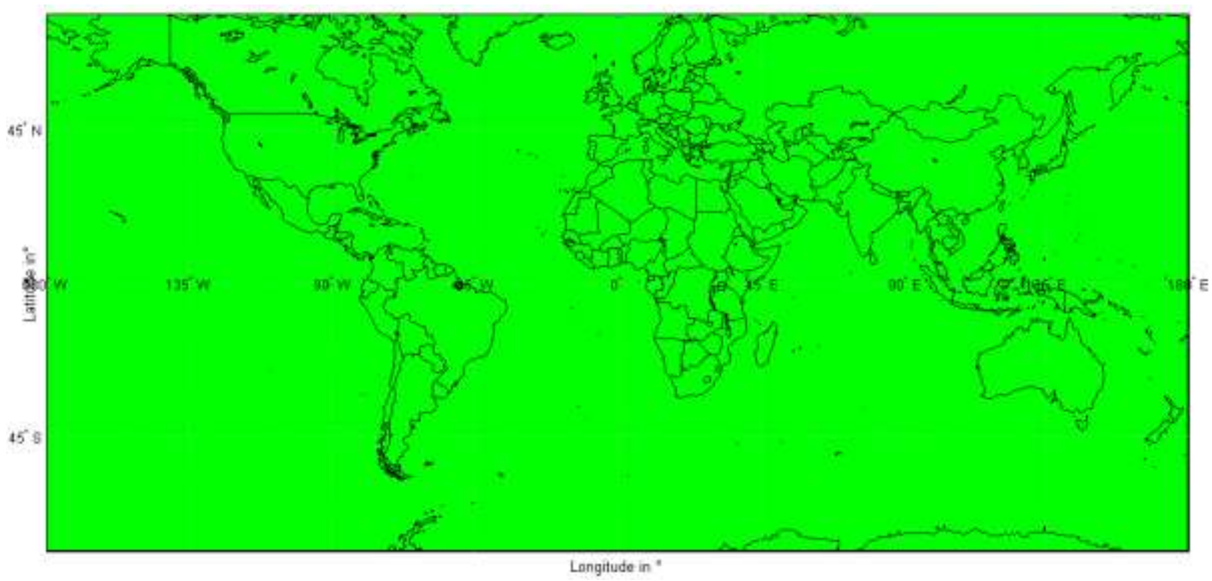


TABLE A2-15

Characterization of flight scenario 1

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Gaseous attenuation
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes
4	(White) Areas are not considered in the flight scenario				

Only the gaseous attenuation degrades the available link margin. Therefore all UA types in each frequency band operating with all types of space stations have availability significantly larger than 99.999%[3].

TABLE A2-16

Link availabilities for flight scenario 1

UA type	Link availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

A 2-4.2. Performance analysis flight scenario 2

Scenario 2 is described to globally use UAs for medium altitude surveillance / aerial work. The minimum flight altitude is 5,800 m (19,000 ft). According to Recommendation ITU-R P.839 the rain height is higher than the flight altitude only for a small portion of the considered locations on the Earth's surface, hence attenuation due to rain and scintillation has to be considered. For the rest of the considered locations the UA is flying between the rain height and cloud top. Figure A2-4 shows the appropriate propagation scenario of ICAO flight Scenario 2.

[3] Applying the extrapolation described in section A 2-4.1, it can be concluded that the availability of all UA types in all satellite beams and frequency bands is always larger than 99.9999999999999%.

FIGURE A2-3

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight Scenario 2

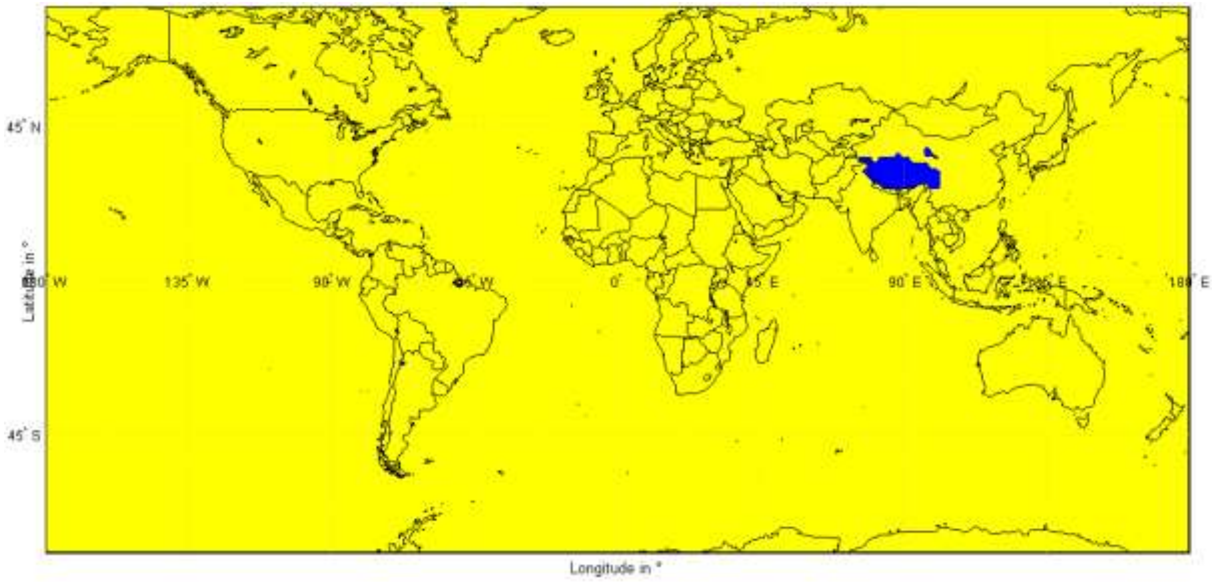


TABLE A2-17

Characterization of flight Scenario 2

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Gaseous attenuation
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes
4	(White) Areas are not considered in the flight scenario				

The analysis of the rain attenuation for 100% of the time compared to the available link margins in all considered frequency bands and for all UA types and satellite beams do not show any areas where the available link margin is less than the rain attenuation. Therefore this scenario can be supported with closed link budgets at any location on the Earth surface and additional excess margin.

A 2-4.2.1. 14 GHz frequency range uplink, low-gain satellite antenna

The link availabilities have been computed for each point on the Earth's surface in a 1° raster, taking into account the respective atmospheric attenuations for the chosen flight height. All link availabilities for the complete geographical area (including the blue one in Figure A2-4) are higher than 99.999%.

TABLE A2-18

Link availabilities in 14/11 GHz frequency range Earth-to-space, low-gain satellite antenna for flight Scenario 2

UA type	Availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

A 2-4.2.2. Uplinks in the 14 GHz frequency ranges, high-gain satellite antenna

Because of the high-gain satellite antenna the resulting link availabilities will become higher than in Chapter A 2-4.2.1 computed for the low gain case.

TABLE A2-19

Link availabilities in the 14/11 GHz frequency ranges Earth-to-space, high gain satellite antenna for flight Scenario 2

UA type	Availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

A 2-4.2.3. Downlinks in the 11 GHz frequency ranges, low- / high-gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 11 GHz frequency ranges downlinks the following table shows a link availability for all locations on the Earth’s surface significantly better than 99.999%.

The downlink is defined by the pfd limits according to Article **21** therefore the available margin for high antenna satellite gain is equal to the available link margin of the low gain satellite antenna.

TABLE A2-20

Link availabilities in the 11 GHz frequency range space-to-Earth, high / low gain satellite antenna for flight Scenario 2

UA type	Availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

A 2-4.2.4. Uplinks in the 29 GHz frequency ranges, low-gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 30 GHz frequency ranges uplink with low gain satellite antenna, the following table shows the achievable link availabilities for the different UA types.

For 99.1% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%. The residual 0.9% of the flight scenario locations has UA type dependent minimum availabilities of as shown in the table.

TABLE A2-21

Link availabilities in 29 GHz frequency range Earth-to-space, low-gain satellite antenna for flight Scenario 2

UA type	Availability for 99.1% of the considered geographical area	Availability the remaining 0.9% area
UA small	>>99.999%	≥ 88 %
UA medium		≥ 95 %

UA type	Availability for 99.1% of the considered geographical area	Availability the remaining 0.9% area
UA large		> 99.999 %

The geographic distribution of the areas with availabilities lower than 99.999% is shown in Figures A2-18 and A2-19.

FIGURE A2-4

Unavailability of the uplinks in the 30 GHz frequency range, unmanned aircraft small, low-gain satellite antenna

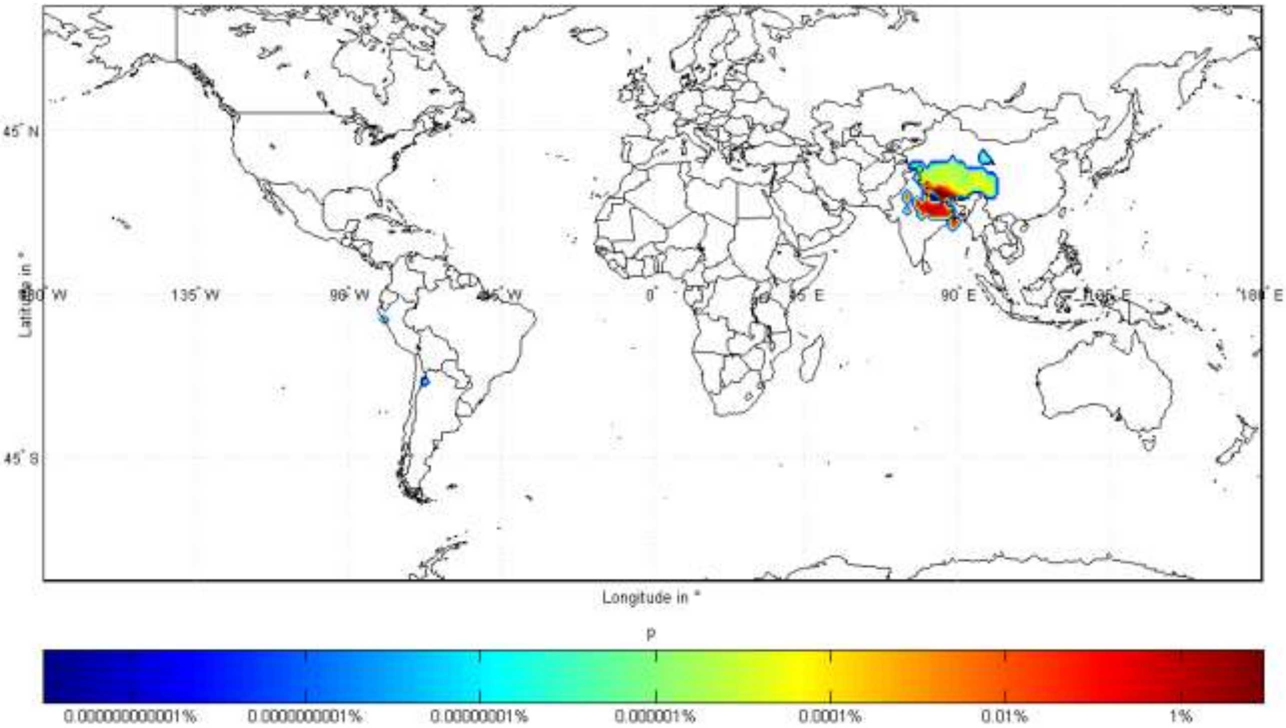
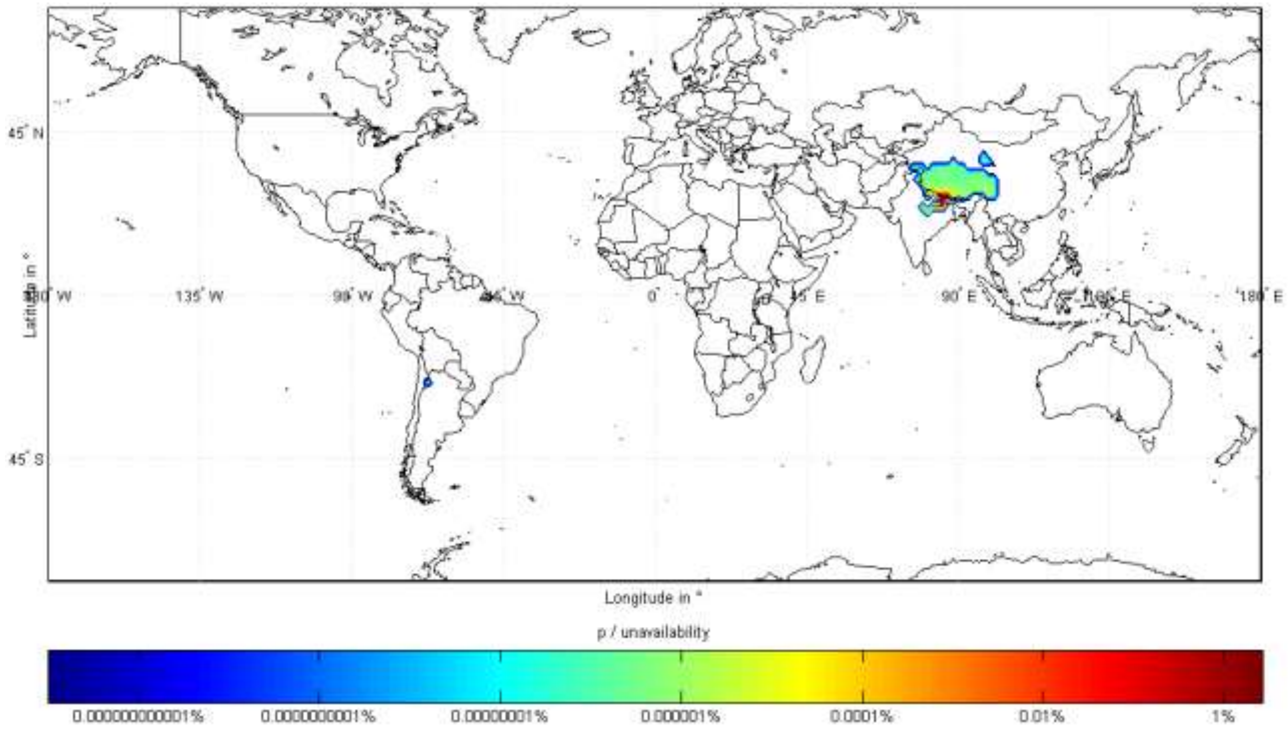


FIGURE A2-5

Unavailability of the uplinks in the 30 GHz frequency range, unmanned aircraft medium, low-gain satellite antenna



A 2-4.2.5. Uplinks in the 30 GHz frequency ranges, high-gain satellite antenna

Based on the calculation of the resulting unavailabilities, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 30 GHz frequency range uplink with high gain satellite antenna, the following table shows the achievable link availabilities for the different UA types.

For 99.4% of the considered geographical locations the availability of all three UA types is significantly larger than 99.999%. The residual 0.6% of the area has UA type dependent minimum availabilities as shown in the table:

TABLE A2-22

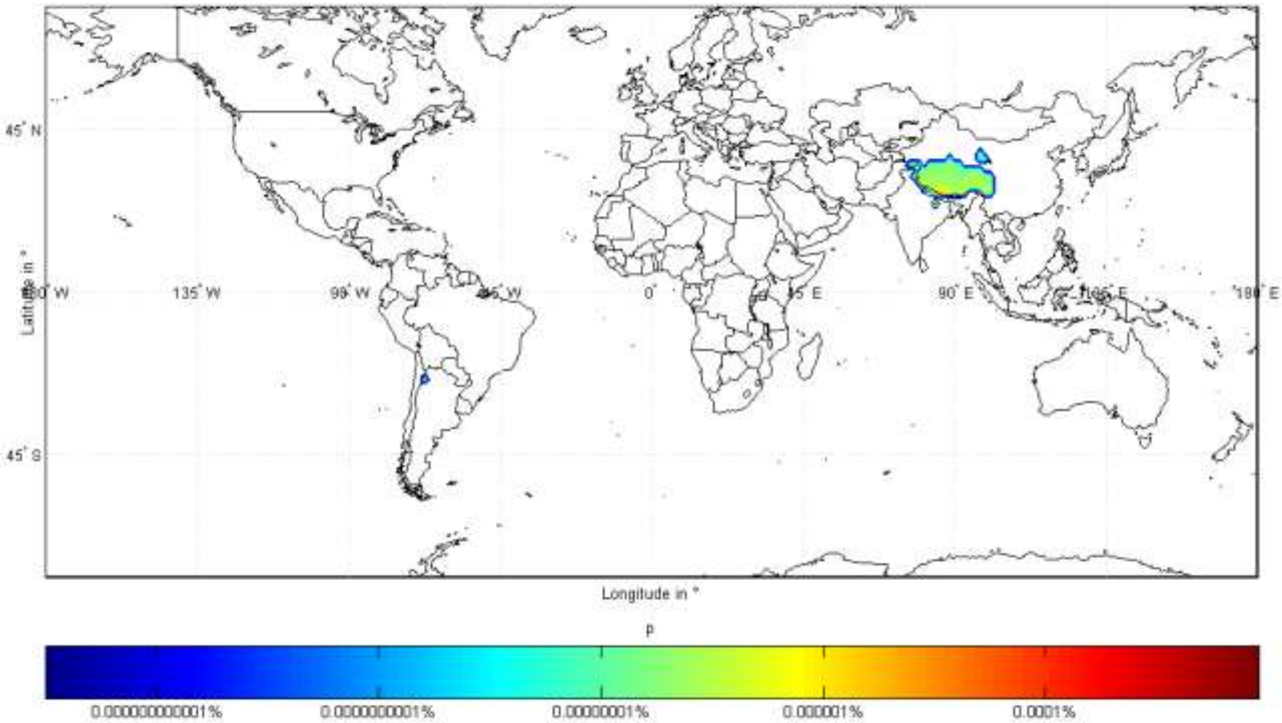
Link availabilities in the 30 GHz frequency range Earth-to-space, high-gain satellite antenna for flight Scenario 2

UA type	Availability for 99.4% of the considered geographical area	Availability for the remaining area
UA small	>>99.999%	≥ 99.99 %
UA medium		> 99.999 %
UA large		

The geographic distribution of areas with availabilities lower than 99.999% is shown in Figure A2-22 for the UA type small. The link availabilities of UA type medium and large are larger than 99.999% for the complete geographic area.

FIGURE A2-6

Unavailability of the uplinks in the 30 GHz frequency range, unmanned aircraft small, high-gain satellite antenna



A 2-4.2.6. 20 GHz frequency range downlink, low- / high-gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 20 GHz frequency range downlink, the achievable link availabilities for the different UA types are given below.

The downlink is defined by the pfd limits according to Article **21** therefore the available margin for high gain satellite antenna is equal to the available link margin of the low gain satellite antenna.

The link availability larger than 99.999% can be achieved for the complete geographical area for all types of UA antennas. No atmospheric constraints are to be expected.

TABLE A2-23

Link availabilities in 20 GHz frequency range space-to-Earth, flight Scenario 2

UA type	Availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

A 2-4.3. Performance analysis flight Scenario 3

Flight Scenario 3 considers en route oceanic usage of the UAs at high altitude of 6 100 m (20 000 ft) above mean sea level. The scenario excludes the land and has a maximum rain rate defined by

ICAO of 20 mm/h. The flight altitude in the considered areas is always above the rain height of Recommendation ITU-R P.839 and below the cloud top of 6.360 km. Therefore only gaseous and cloud attenuation applies as shown in Figure A 2-29.

This scenario is comparable with Scenario 2 in that manner that the flight altitude is above rain height as defined in Recommendation ITU-R P.839. Additional to the higher altitude the flight scenario defines maximum rain rate of 20 mm/h for 10% of the time. This value does not have an effect on the performance of the scenario as rain does have no impact if the UAS is flying above the rain height.

FIGURE A2-7

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight Scenario 3

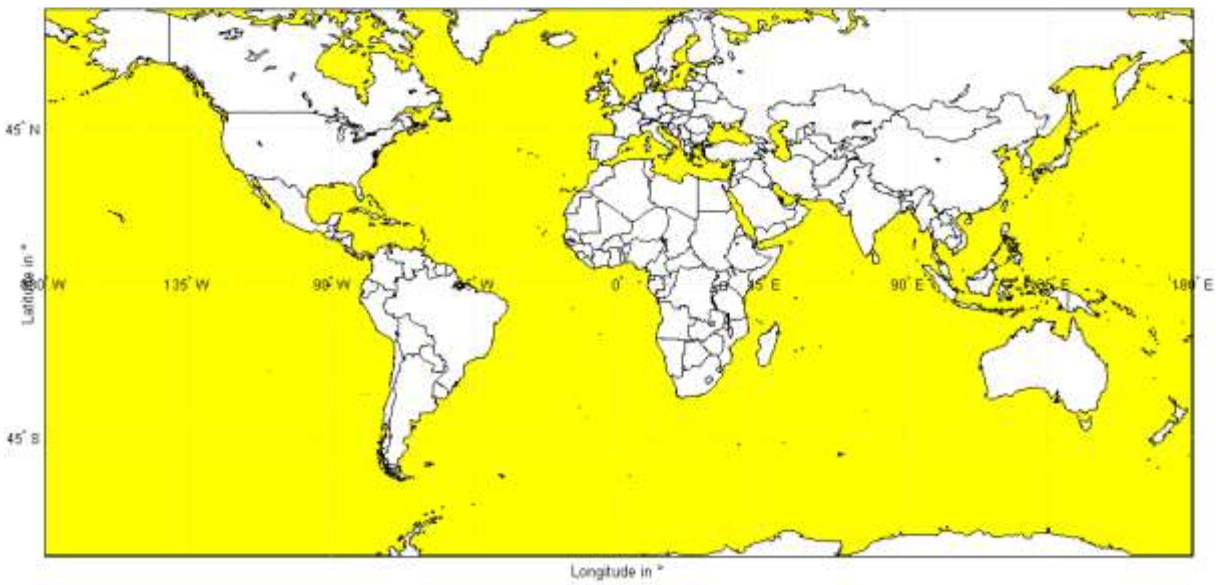


TABLE A2-24

Characteristics of flight Scenario 3

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Gaseous attenuation
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes
4	(White) Areas are not considered in the flight scenario				

For flight scenario 3 all the critical locations with a decrease of the availability are over land, only. Therefore it can be concluded that the achievable performance of this scenario is always significantly better than the 99.999% for the whole considered area on Earth's surface.

A 2-4.4. Performance analysis flight Scenario 4

The flight Scenario 4 as low level surveillance and maritime patrol is – from the SATCOM perspective – a demanding scenario with low flight altitudes for maritime operations of the UA. The maximum flight altitude is 150 m, above mean sea level. Therefore all atmospheric impairments are considered in the analysis as shown in Figure A 2-14.

FIGURE A2-8

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight Scenario 4

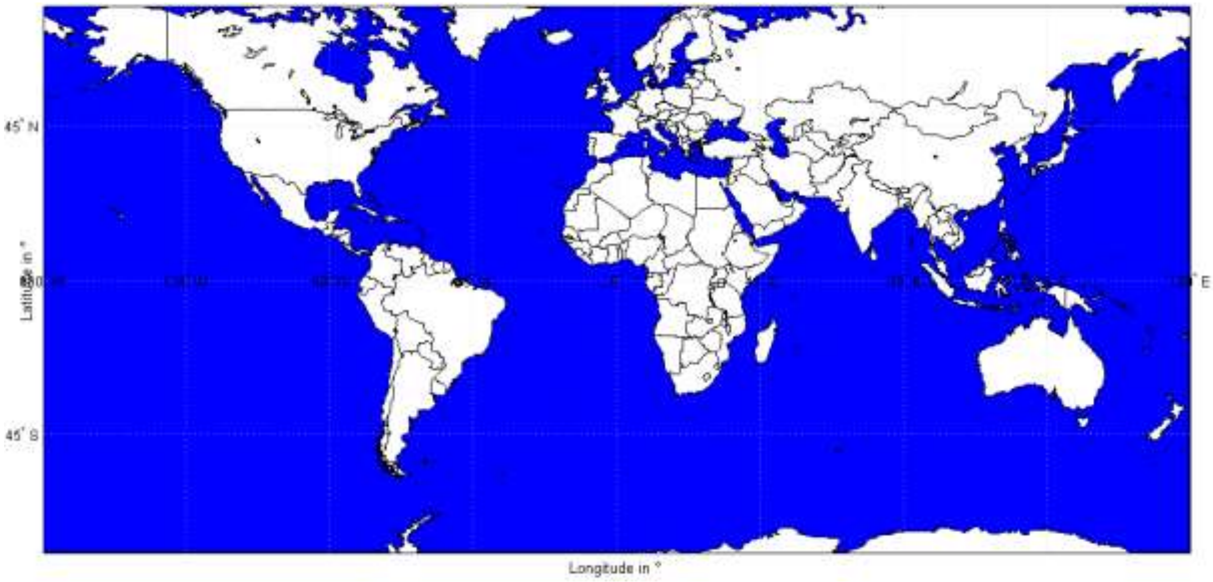


TABLE A2-25

Characteristics of flight Scenario 4

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Gaseous attenuation
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes
4	(White) Areas are not considered in the flight scenario				

A 2-4.4.1. Areas where rain attenuation exceeds available link margin

A 2-4.4.1.1. 14 GHz frequency range uplink

A flight altitude of 150 m above mean sea level results in a maximum attenuation of 12.9 dB to be covered by the link margin of link #3.

As the subsequent Chapters A 2-4.4.2 and A 2-4.4.3 show the high rain attenuation will result in degraded link availabilities for UA types small and – partly – medium.

A 2-4.4.1.2. 11 GHz frequency range downlink

A flight altitude of 150 m (500ft) above mean sea level results in a maximum attenuation of 7.7 dB to be covered by the link margin of link #2.

As the subsequent Chapter A 2-4.4.4 shows the high rain attenuation will result in degraded link availabilities for UA type small.

A 2-4.4.1.3. 30 GHz frequency range uplink

A flight altitude of 150 m results in a minimum of 42 dB link margin needed to overcome the rain attenuation in all locations considered in this scenario. Apart from this additional margin is needed to achieve high availabilities and to cover the impairments due to scintillation, clouds and gas.

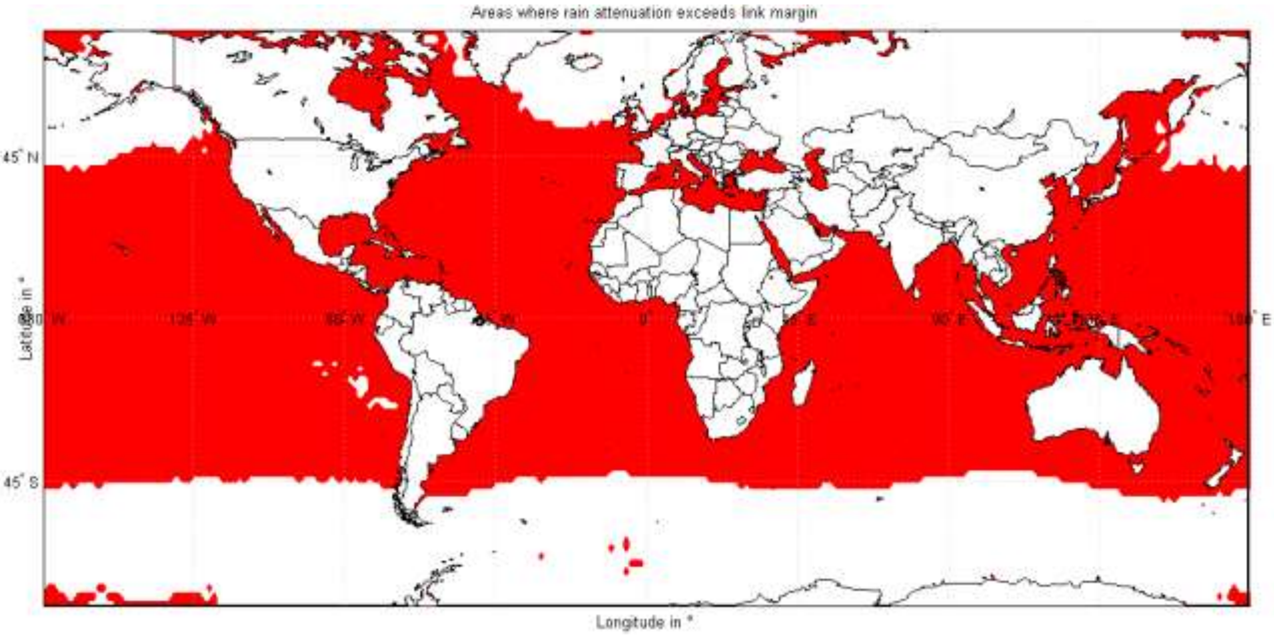
For this combination of UA type and satellite antenna gains, nearly no area can provide sufficient or even more margin than needed to cope with the rain attenuation in such low flight altitudes. Hence link availabilities lower than the 99.999% can only be achieved.

In fact the complete geographical area is affected from those high rain attenuations with the only exception of the southern parts close to the Antarctic for the UA type large. Hence only this diagram for the high satellite gain is shown, implicitly meaning worse conditions for the other cases (UA small, medium via both satellite antenna types).

The respective geographic unavailability results are shown in the subsequent Chapters A 2-4.4.5 and A 2-4.4.6.

FIGURE A2-9

Areas where rain attenuation exceeds link margin 30 GHz uplink; unmanned aircraft large, high gain satellite antenna



A 2-4.4.1.4. 20 GHz frequency range downlink

A flight altitude of 150 m results in a maximum attenuation to be compensated by the link margin of about 23 dB. If the rain attenuation is applied to each UA type the areas with insufficient link margins are shown for UA small and UA medium in 20 GHz frequency range downlink in Figures A2-20 and A2-21. The achieved link margin for UA large is sufficient to cover the maximum attenuation.

The respective geographic unavailability results are shown in the subsequent Chapter A 2-4.4.7.

FIGURE A2-10

Areas where rain attenuation exceeds link margin for 19 GHz downlink unmanned aircraft small

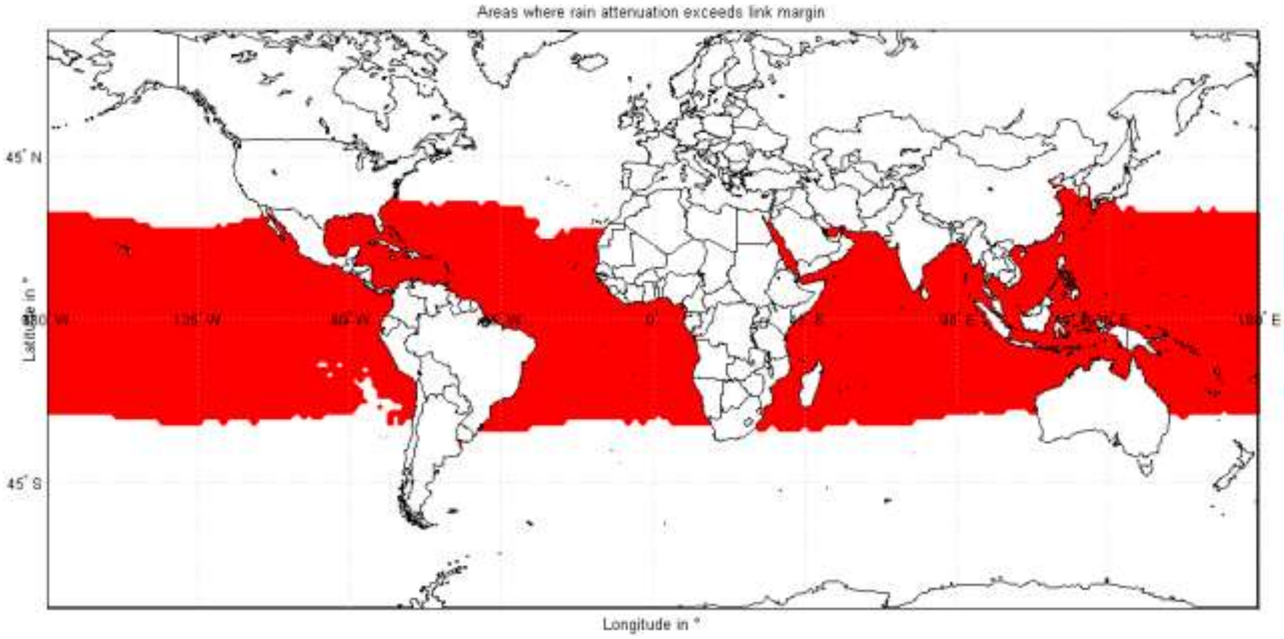
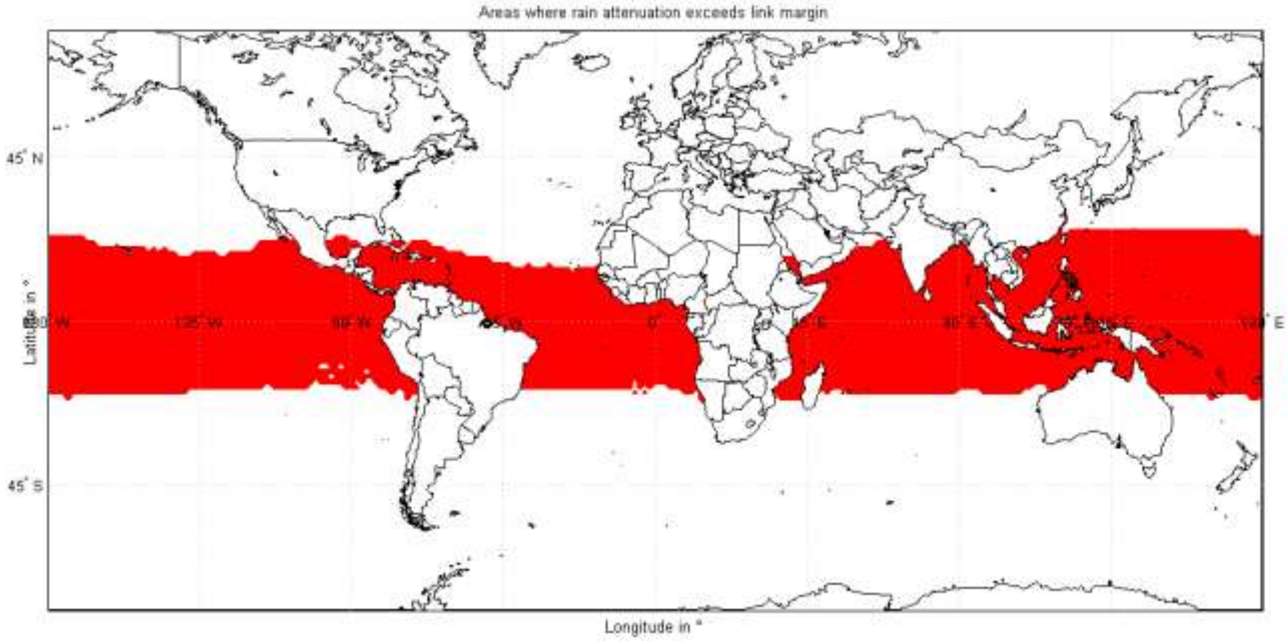


FIGURE A2-11

Areas where rain attenuation exceeds link margin 19 GHz downlink unmanned aircraft medium



A 2-4.4.2. Performance of 14 GHz frequency range uplink via low gain satellite antenna

Based on the calculation of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 14/11 GHz frequency range uplink with low gain satellite antenna, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed maximum rain are:

TABLE A2-26

Link availabilities in 14 GHz frequency range Earth-to-space, low satellite gain for flight Scenario 4

UA type	Availability threshold compliance
UA small	> 0 % for 100% of the area > 99.999% for 30% of the area
UA medium	≥ 88.0 % for 100% of the area >99.999% for 70% of the area
UA large	≥ 98.96 % for 100% of the area >99.999% for 99% of the area

The following Figures A2-23 to A2-25 are showing the geographic distribution of locations with the resulting unavailability.

FIGURE A2-12

Unavailability of the uplinks in the 14 GHz frequency range, unmanned aircraft small, low gain satellite antenna

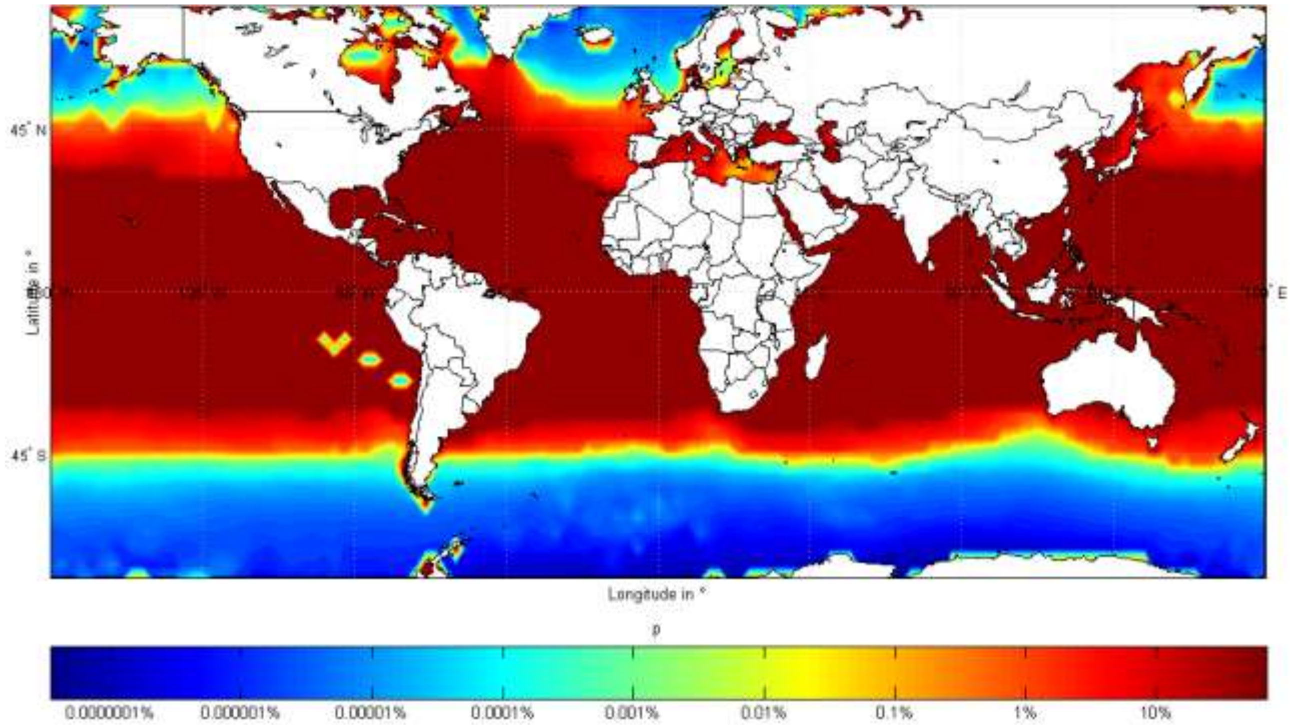


FIGURE A2-13

Unavailability of the uplinks in the 14 GHz frequency range, unmanned aircraft medium, low gain satellite antenna

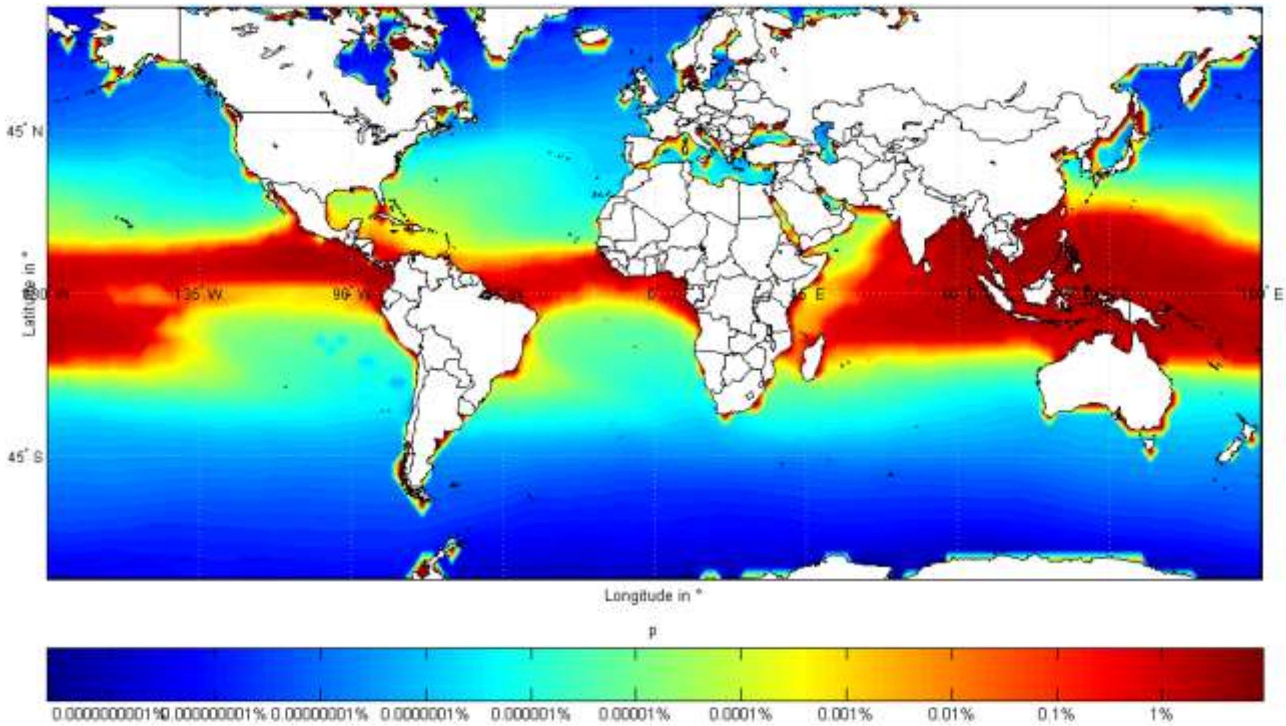
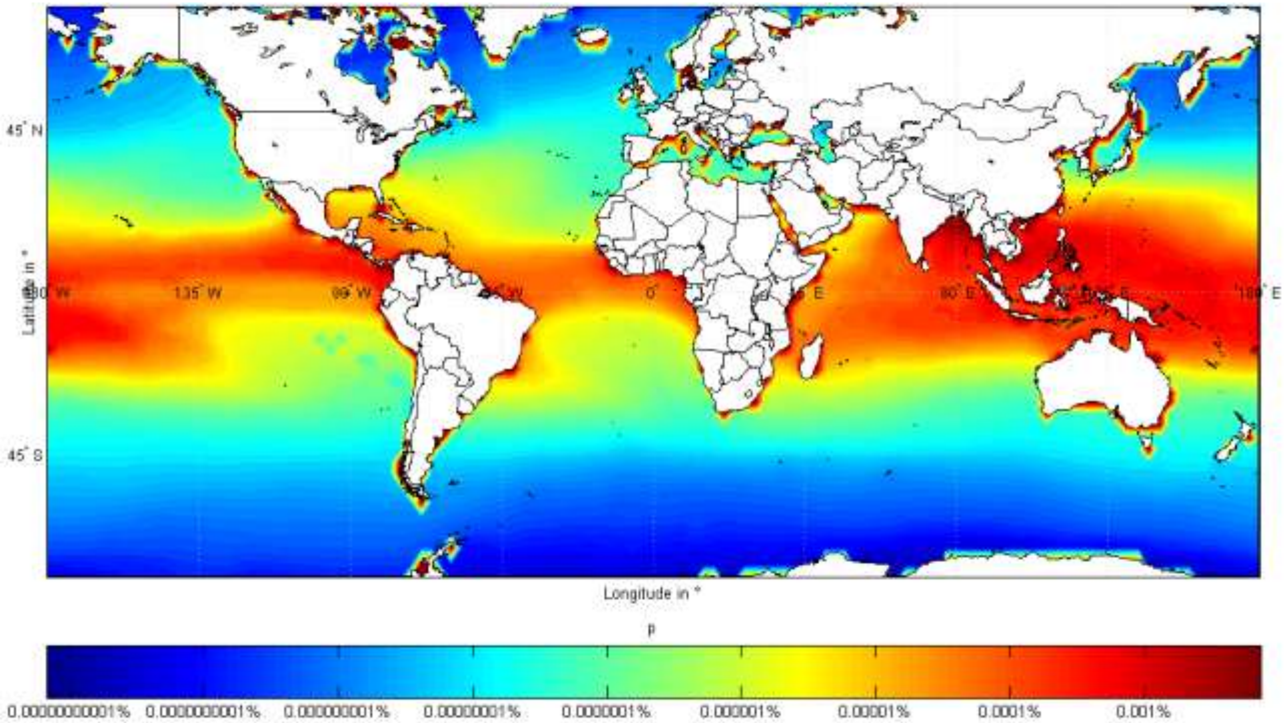


FIGURE A2-14

Unavailability of the uplinks in the 14 GHz frequency range;
unmanned aircraft large, low gain satellite antenna



A 2-4.4.3. Performance of 14 GHz frequency range uplink via high-gain satellite antenna

Based on the calculations of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 14 GHz frequency range uplink with the high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed rain impact are:

TABLE A2-27

Link availabilities in 14 GHz frequency ranges Earth-to-space, high-gain satellite antenna for flight Scenario 4

UA type	Availability threshold compliance	Link availability per extrapolation
UA small	> 57.9 % for 100% of the area > 99.999% for 65% of the area	> 57.9 %
UA medium	> 99.999 % for 100% of the area	≥ 99.9997 %
UA large	> 99.999 % for 100% of the area	≥ 99.99992 %

The following Figures A2-27 to A2-29 are showing the geographic distribution of the locations with the resulting unavailability.

FIGURE A2-15

Unavailability of the uplinks operating in the 14 GHz frequency range,
flight Scenario 4, unmanned aircraft small antenna and high-gain satellite antenna

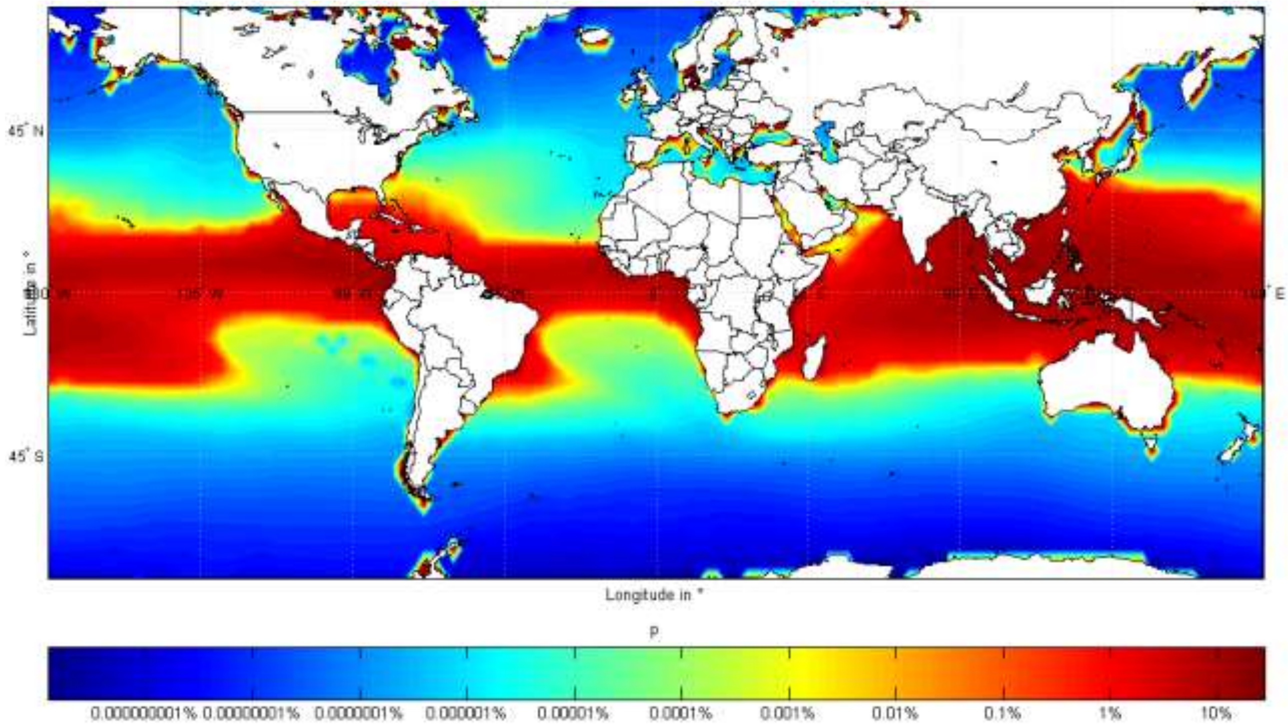


FIGURE A2-16

Unavailability of the uplinks operating in the 14 GHz frequency range,
flight Scenario 4, unmanned aircraft medium, high gain antenna satellite

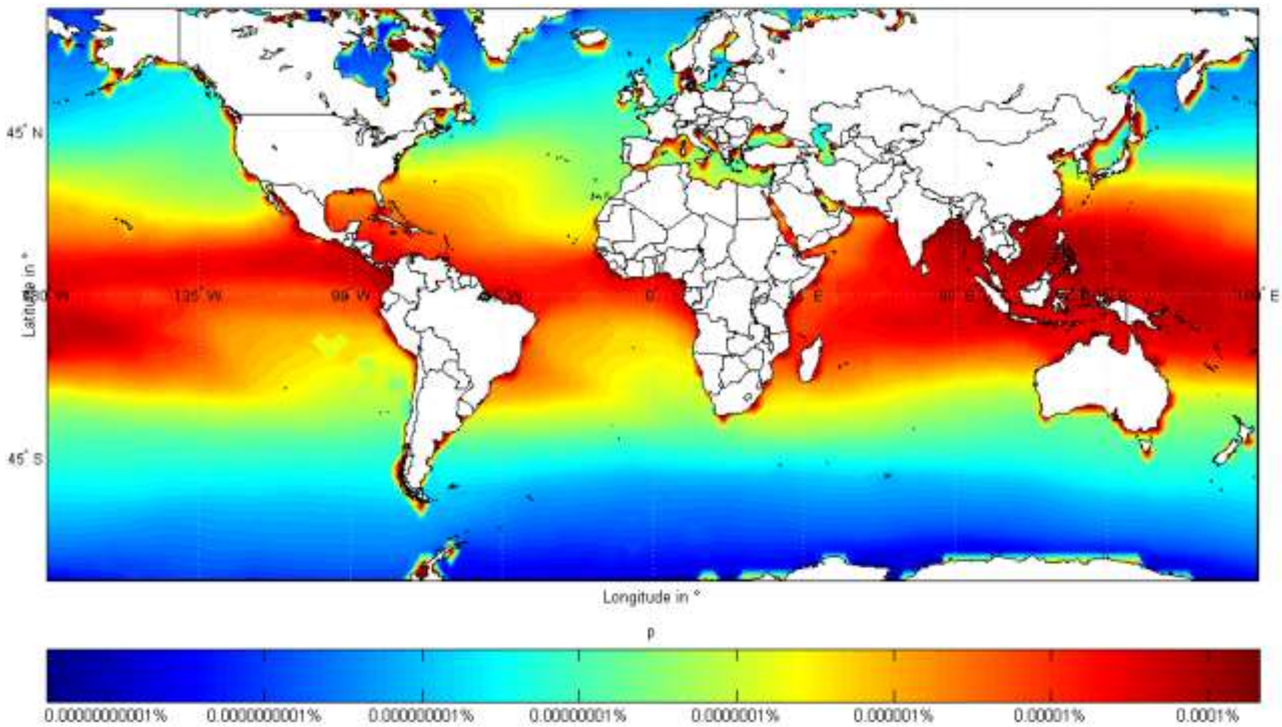
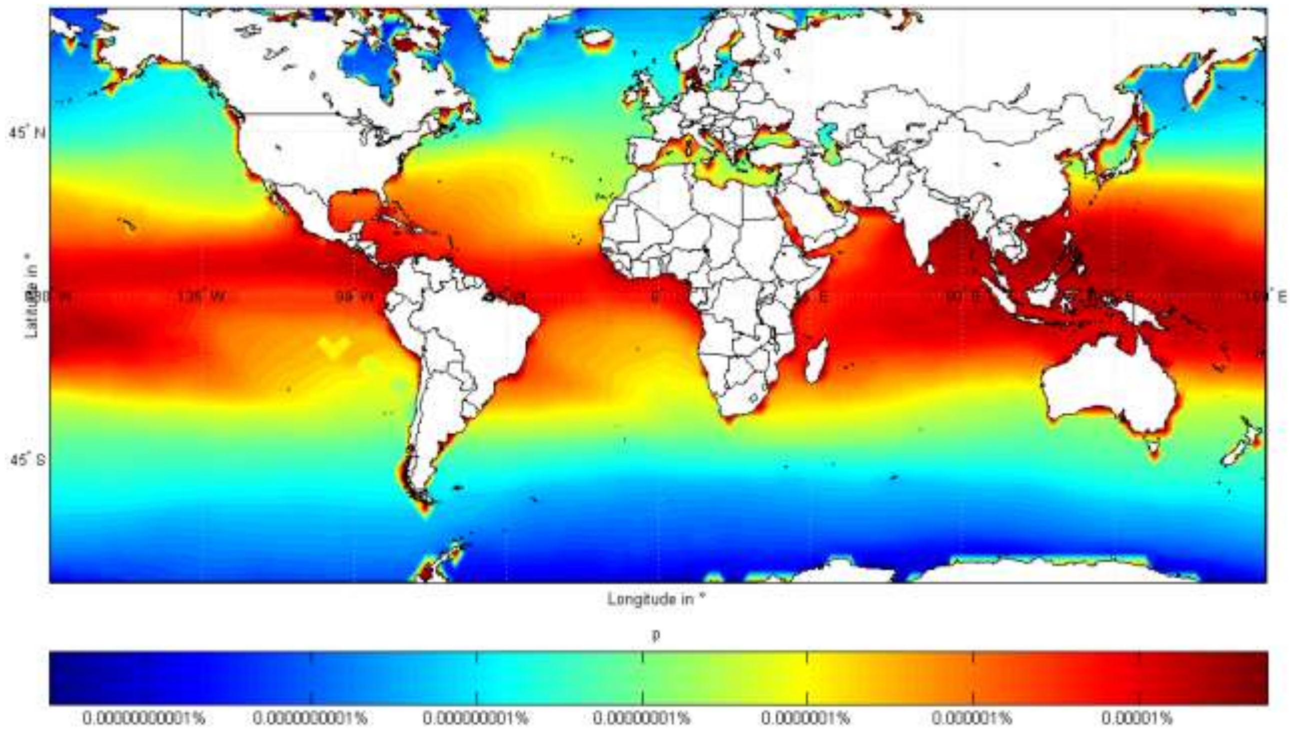


FIGURE A2-17

Unavailability of the uplinks operating in the 14 GHz frequency range, flight Scenario 4, unmanned aircraft large, high gain satellite antenna



A 2-4.4.4. Performance of the downlinks operating in the 11 GHz frequency ranges, low / high gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 11 GHz frequency range downlink, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed maximum rain are:

TABLE A2-28

Link availabilities in 11 GHz frequency range space-to-Earth, flight Scenario 4

UA type	Availability threshold compliance	Link availability per extrapolation
UA small	> 0 % for 100% of the area > 99.999% for 30% of the area	> 0 %
UA medium	≥ 99.92 % for 100% of the area > 99.999% for 85% of the area	≥ 99.92 %
UA large	≥ 99.999 % for 100% of the area	≥ 99.99998 %

The following Figures A2-4.31 to A2-4.33 are showing the geographic distribution of the achievable unavailability.

FIGURE A2-18

Unavailability of the downlinks operating in the 11 GHz frequency range, unmanned aircraft small, low / high gain satellite antenna

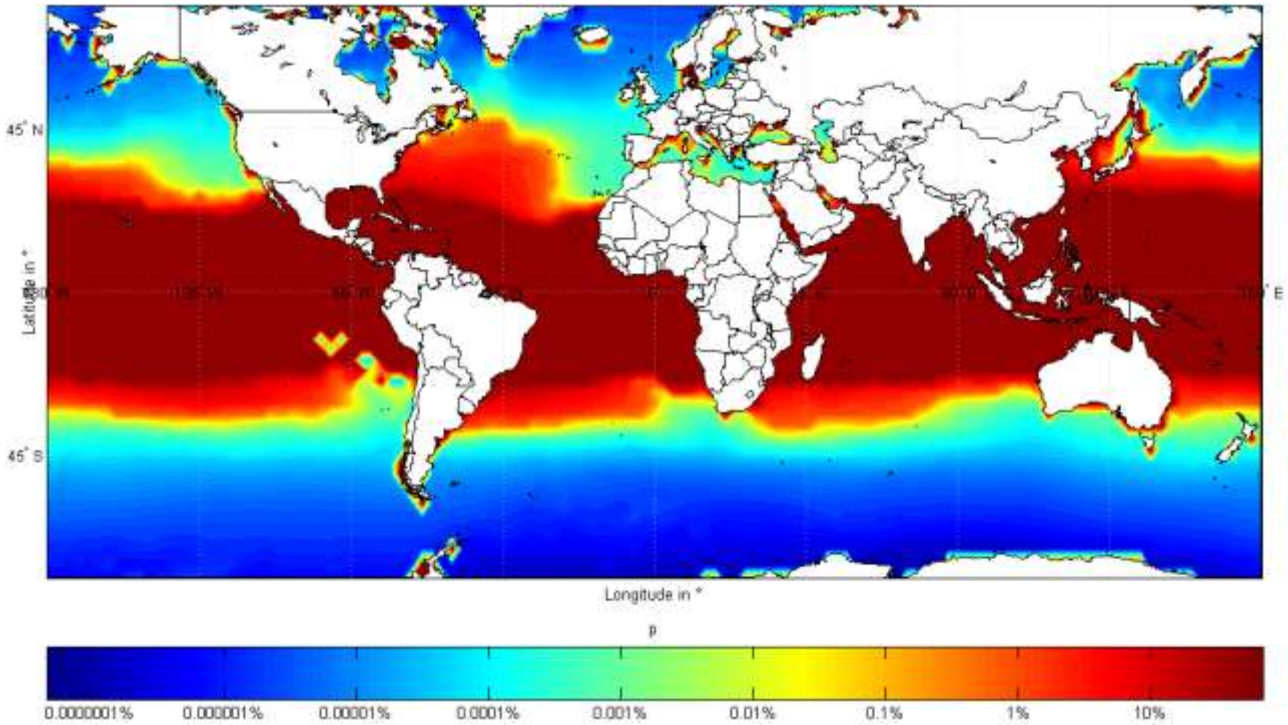


FIGURE A2-19

Unavailability of the downlinks operating in the 11 GHz frequency range, unmanned aircraft medium, low / high gain satellite antenna

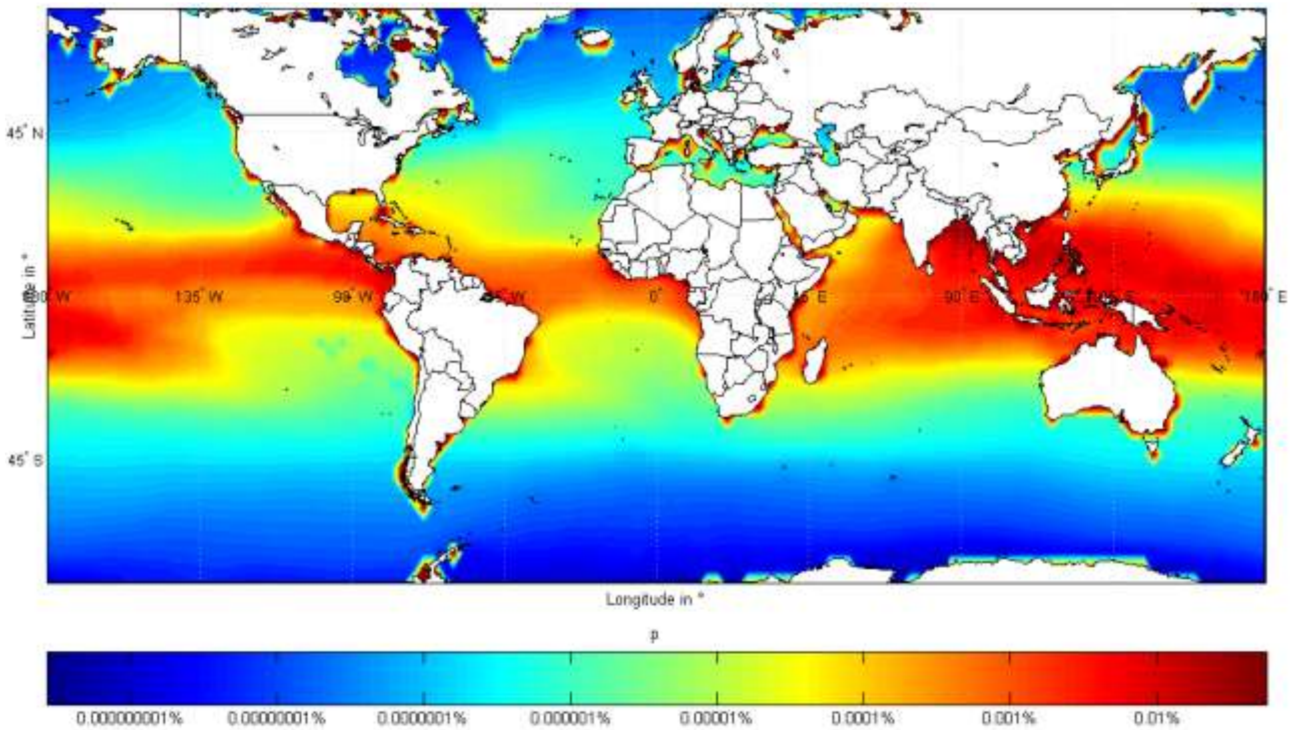
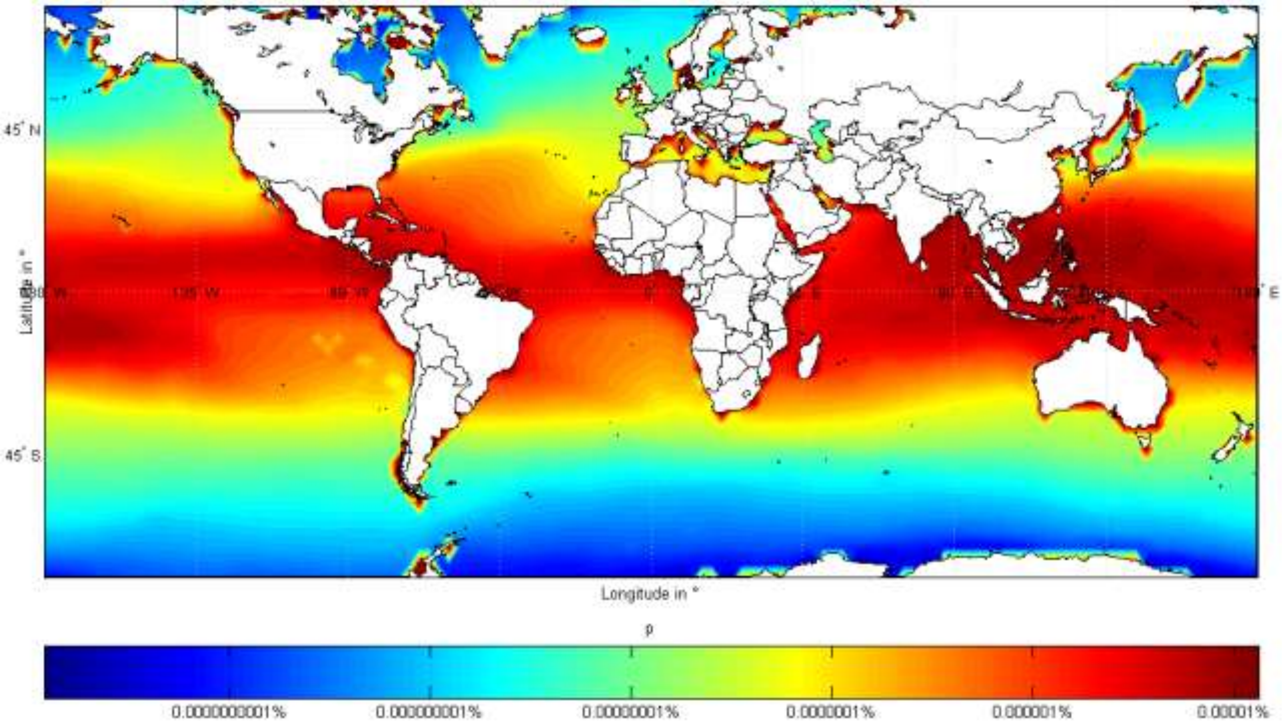


FIGURE A2-20

Unavailability of the downlinks operating in the 11 GHz frequency range, unmanned aircraft large, low / high gain satellite antenna



A 2-4.4.5. Performance of the uplinks operating in the 30 GHz frequency ranges, low gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 30 GHz frequency range uplink with low gain satellite antenna, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed maximum rain are:

TABLE A2-29

Link availabilities in 30 GHz frequency range Earth-to-space, low satellite gain for flight Scenario 4

UA type	Availability threshold compliance
UA small	> 0 % for 100% of the area > 99.999% for 2% of the area
UA medium	≥ 0 % for 100% of the area > 99.999% for 4% of the area
UA large	≥ 0 % for 100% of the area > 99.999% for 6% of the area

The achievable link margins are insufficient to support the anticipated link availability of 99.999% for nearly the complete Earth surface. Further mitigation measures according to Annex 3 are needed.

A 2-4.4.6. Performance of the uplinks operating in the 30 GHz frequency range, high gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 30 GHz frequency range uplink with high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed maximum rain are:

TABLE A2-30

Link availabilities in 30 GHz frequency range Earth-to-space, high satellite gain for flight Scenario 4

UA type	Availability threshold compliance
UA small	> 0 % for 100% of the area > 99.999% for 3% of the area
UA medium	> 0 % for 100% of the area > 99.999% for 6% of the area
UA large	> 0 % for 100% of the area > 99.999% for 12% of the area

The achievable link margins are insufficient to support the anticipated link availability of 99.999% for nearly the complete Earth surface. Further mitigation measures according to Annex 3 are needed. Compared to the low gain satellite antenna type the improvement in terms of usable geographic areas are small, CNPC operation is possible in southern parts close to the Antarctic only.

A 2-4.4.7. Performance of the downlinks operating in the 20 GHz frequency ranges, low / high gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 20 GHz frequency range downlink, the achievable link availabilities for the different UA types are given below.

The minimum achievable UA type dependent availabilities under the assumed maximum rain are:

TABLE A2-31

Link availabilities in 20 GHz frequency range space-to-Earth, Scenario 4

UA type	Availability threshold compliance
UA small	> 0 % for 100% of the area > 99.999% for 30% of the area
UA medium	> 0 % for 100% of the area > 99.999% for 45% of the area
UA large	> 0 % for 100% of the area > 99.999% for 55% of the area

The following Figures A2-37 to A2-39 are showing the geographic distribution of the achievable unavailability.

FIGURE A2-21

Unavailability of the downlinks operating in the 20 GHz frequency range, unmanned aircraft small, low / high gain satellite antenna

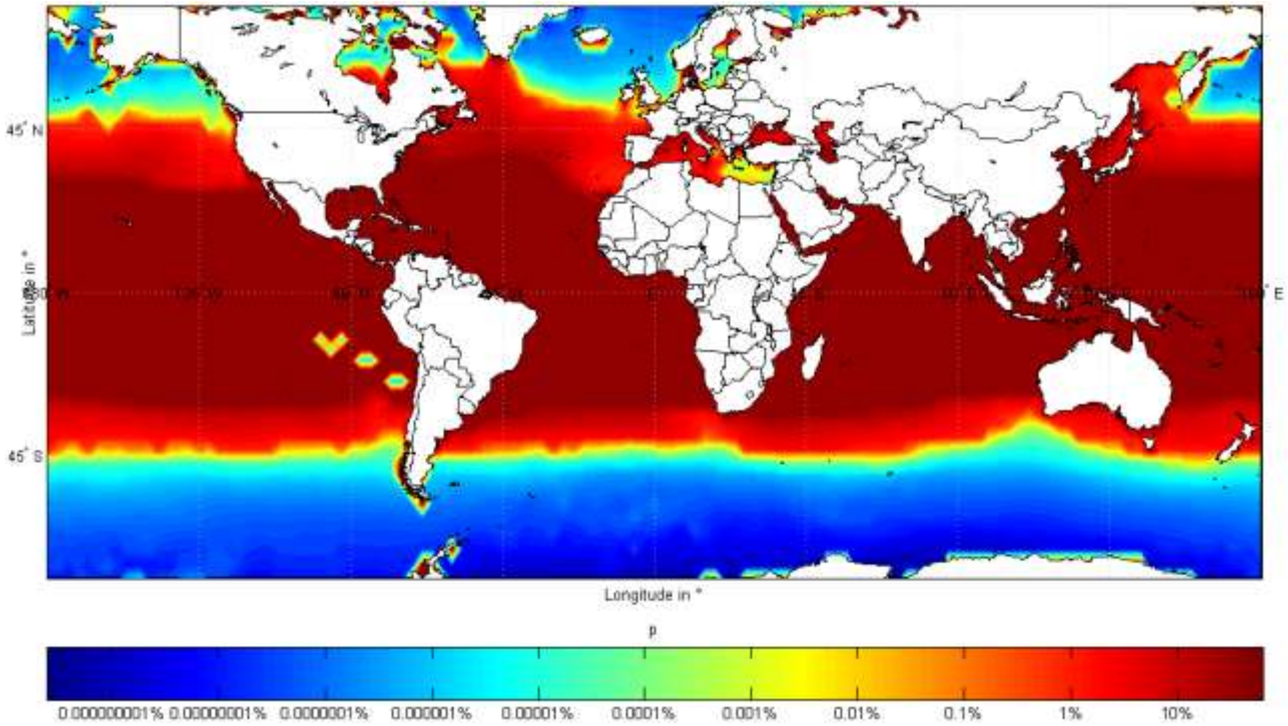


FIGURE A2-22

Unavailability of the downlinks operating in the 20 GHz frequency range, unmanned aircraft medium, low / high gain satellite antenna

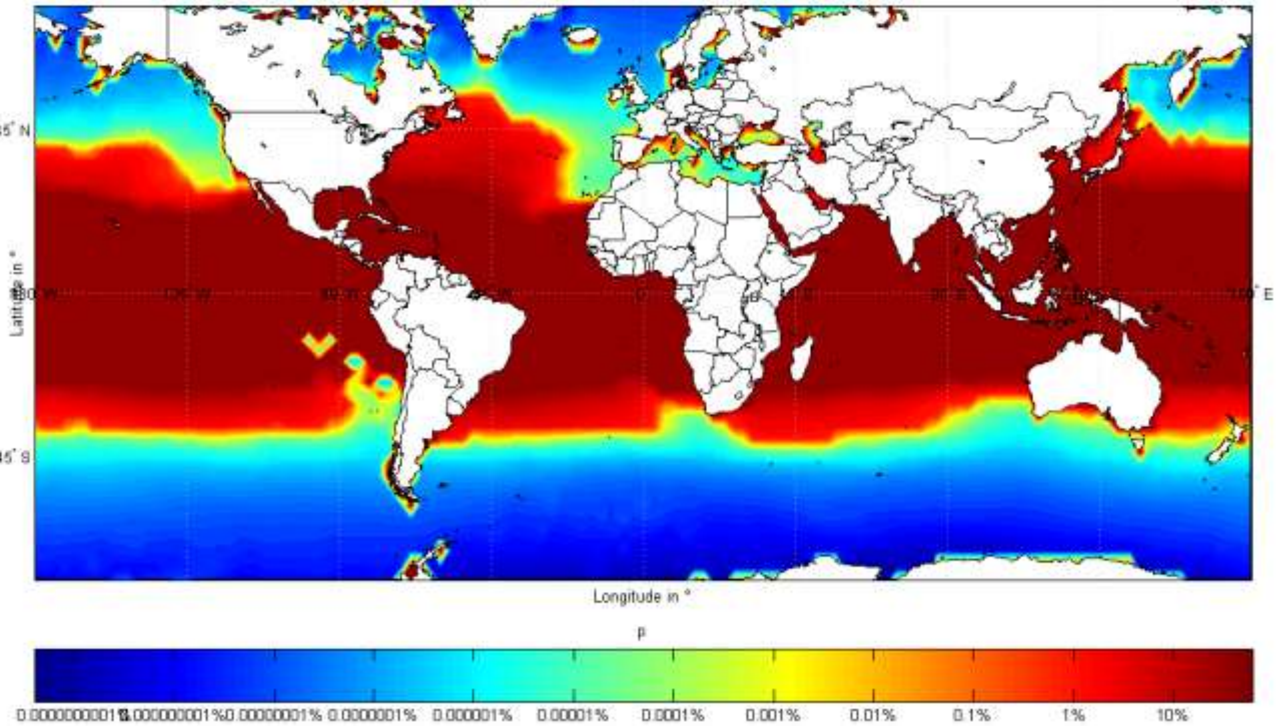
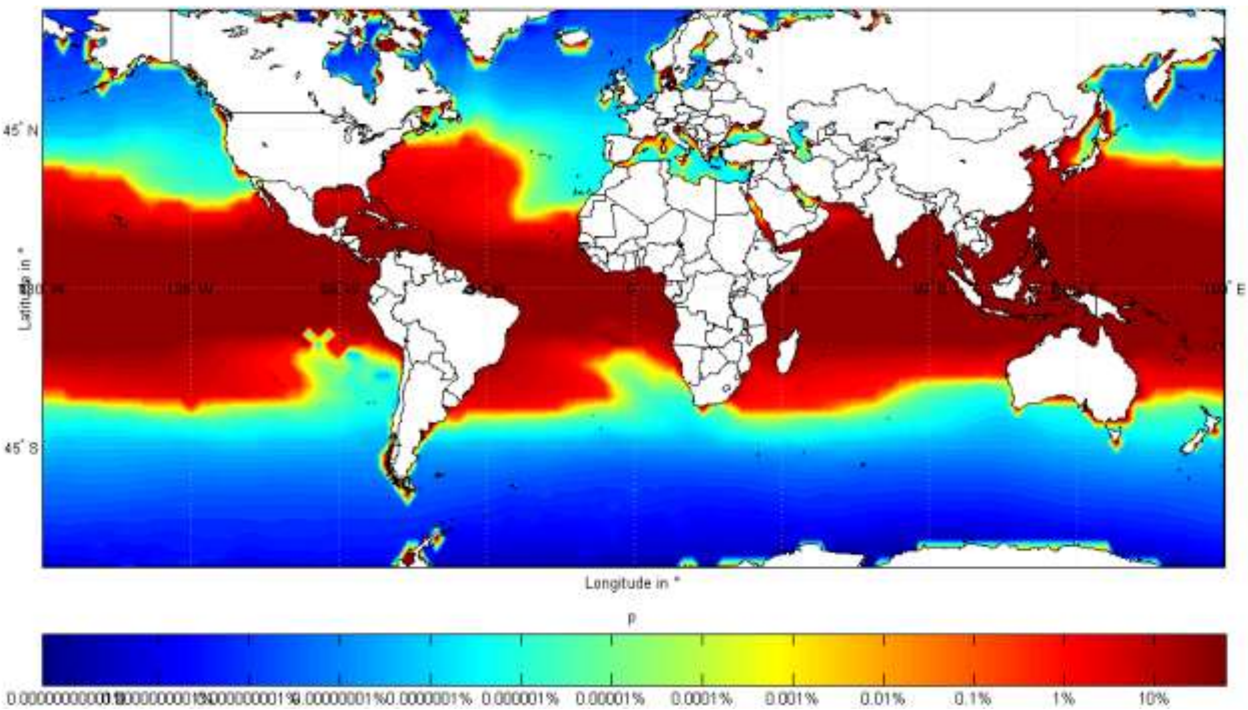


FIGURE A2-23

Unavailability of the downlinks operating in the 20 GHz frequency ranges, unmanned aircraft large, low / high gain satellite antenna



A 2-4.5. Performance analysis flight Scenario 5

Under flight Scenario 5 the UA operate as short en-route over populated land. The conditions are similar to flight Scenario 2 except the rain rate of 20 mm/h in this scenario. The minimum altitude is 5 800 m (19 000 ft). This height is for the most location above the rain height specified in Recommendation ITU-R P.839 but below cloud top. Only for small areas the UA is flying below the rain height, hence only there the full atmospheric impairments have to be applied, as shown in Figure A2-40.

FIGURE A2-24

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight Scenario 5

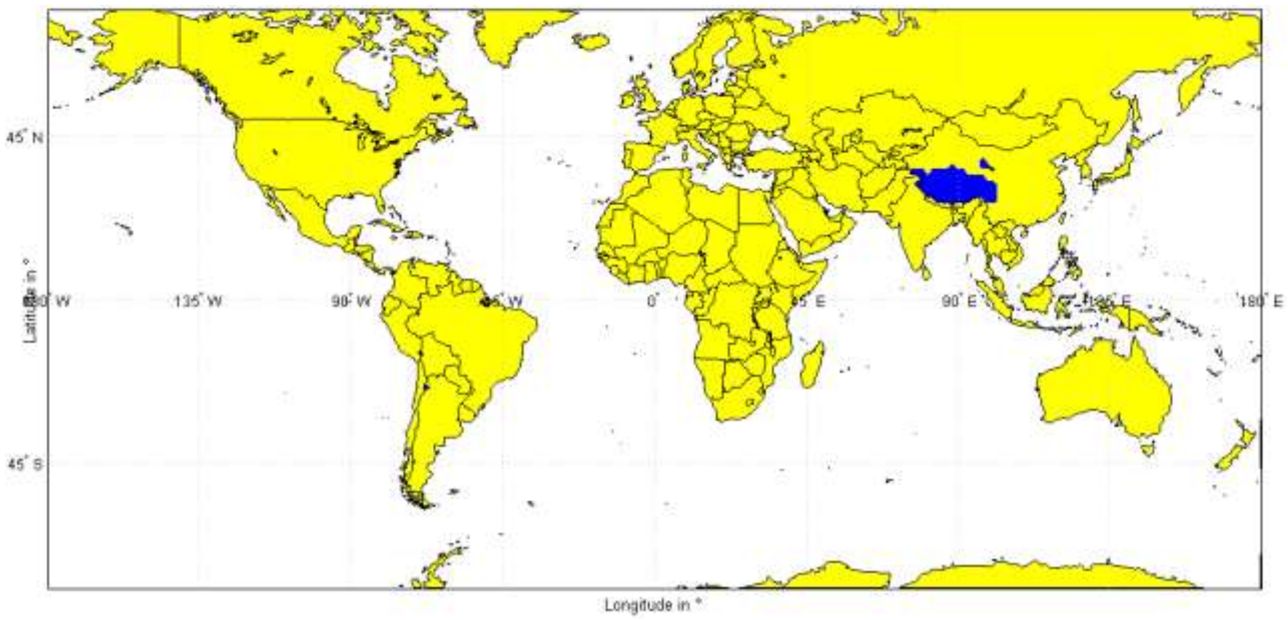


TABLE A2-32

Characteristics of flight Scenario 5

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Atmosphere
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes
4	(White) Areas are not considered in the flight scenario				

A 2-4.5.1. Areas where rain attenuation exceeds link margin

A 2-4.5.1.1. 14/11 GHz frequency ranges

The analysis of the rain attenuation for 100% of the time compared to the available link margins shows for all space station gain types and all UA types for both directions, Earth-to-space (link #3) and space-to-Earth (link #2), full compliance for all considered areas with achieved link margins exceeding the maximum signal attenuations Therefore this scenario does not include any locations where link #2 or #3 cannot be closed in 14/11 GHz frequency range.

A 2-4.5.1.2. 30/20 GHz frequency ranges

The analysis of the rain attenuation for 100% of the time compared to the available link margins shows for high space station gain and all UA types for both directions, Earth-to-space (link #3) and space-to-Earth (link #2), full compliance for all considered areas with achieved link margins exceeding the maximum signal attenuations For link budgets via a low gain antenna on board space station such areas with rain attenuation exceeding the link margin do rarely exist and are limited to the Himalaya area shown in the Figure A2-40 above.

A 2-4.5.2. Performance of the uplinks operating in the 14 GHz frequency ranges, low gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 14 GHz frequency range uplink with low gain satellite antenna, the achievable link availabilities for the different UA types are given below.

For 99.7% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%, but in any case the 99.999% link availability will be achieved for 100% of the geographic area

TABLE A2-33

Link availabilities in 14 GHz frequency range Earth-to-space, low satellite gain for flight Scenario 5

UA type	Availability threshold compliance
UA small	>> 99.999 % for 100% of the area
UA medium	
UA large	

The link availabilities of all uplinks are larger than 99.999% for the complete geographic area and for all UA types, hence no unavailability maps are shown.

A 2-4.5.3. Performance of the uplinks operating in the 14 GHz frequency ranges, high gain antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 14 GHz frequency range uplink with high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

For 99.7% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%, but in any case the 99.999% link availability will be achieved for 100% of the geographic area.

TABLE A2-34

Link availabilities in 14 GHz frequency range Earth-to-space, high satellite gain for flight Scenario 5

UA type	Availability threshold compliance
UA small	>> 99.999 % for 100% of the area
UA medium	
UA large	

The link availabilities of all uplinks are larger than 99.999% for the complete geographic area and for all UA types, hence no unavailability maps are shown.

A 2-4.5.4. Performance of the downlinks operating in the 11 GHz frequency range, low / high gain antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 11 GHz frequency range downlink with high and low gain satellite antenna.

For 99.7% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%, but in any case the 99.999% link availability will be achieved for 100% of the geographic area.

TABLE A2-35

Link availabilities in 11 GHz frequency range space-to-Earth, flight Scenario 5

UA type	Availability threshold compliance
UA small	>> 99.999 % for 100% of the area
UA medium	
UA large	

The link availabilities of all uplinks are larger than 99.999% for the complete geographic area and for all UA types, hence no unavailability maps are shown.

A 2-4.5.5. Performance of the uplinks operating in the 30 GHz frequency ranges, low gain satellite antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 30 GHz frequency range uplink with low gain satellite antenna, the achievable link availabilities for the different UA types are given below.

For 99.5% of the considered geographical area the availability of all three UA types is significantly larger than the 99.999%. The availability for the residual area parts in flight scenario 5 for 30 GHz frequency range uplink and low gain satellite antenna is in minimum:

TABLE A2-36

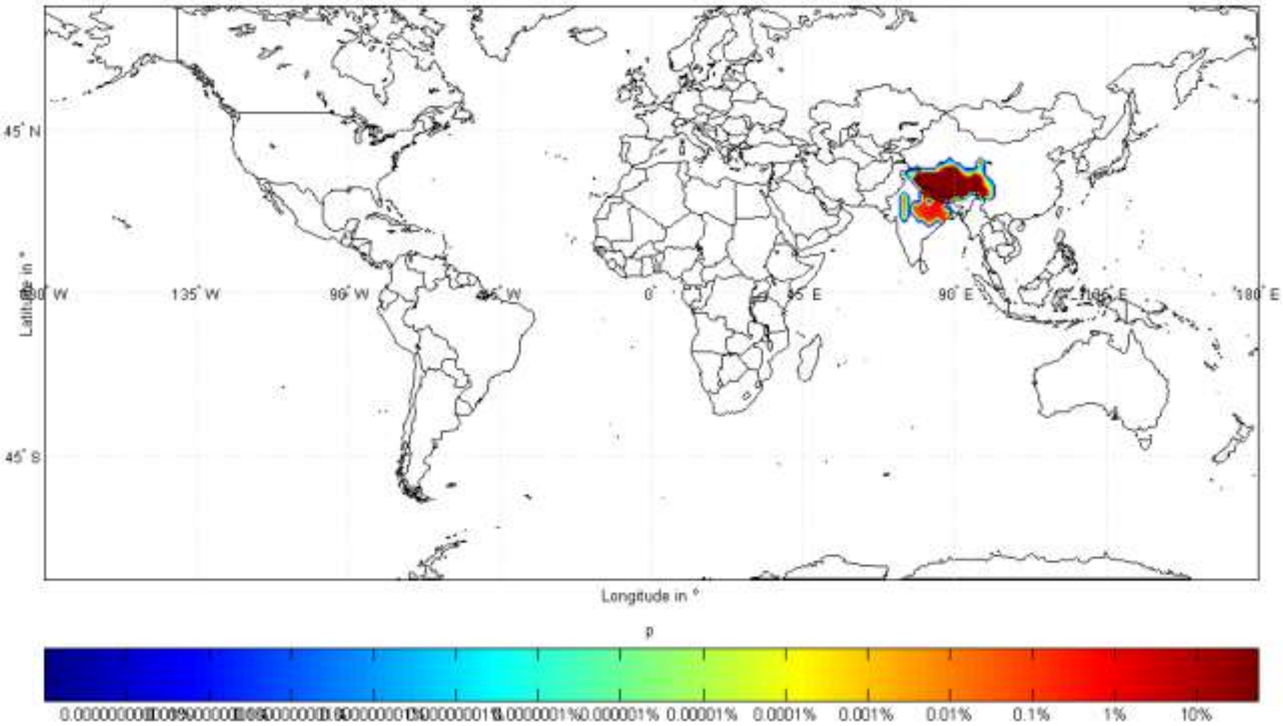
Link availabilities in 30 GHz frequency range Earth-to-space, low satellite gain for flight Scenario 5

UA type	Availability threshold compliance
UA small	> 0% for 100% of the area > 99.999% for 99.5% of the area
UA medium	> 0% for 100% of the area > 99.999% for 99.8% of the area
UA large	> 0% for 100% of the area > 99.999% for 99.85% of the area

UA CNPC via satellite is feasible nearly for the complete Earth surface. The following Figure A2-47 shows the geographic distribution of areas with availability lower than the computational limit of 1e-13% for UA type small. Those ones for the larger UA types are slightly smaller but of the same character.

FIGURE A2-25

Unavailability of the uplinks operating in the 30 GHz frequency range, flight Scenario 5, unmanned aircraft small, low gain satellite antenna



A 2-4.5.6. Performance of the uplinks operating in the 30 GHz frequency ranges, high gain antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 30 GHz frequency range uplink with high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

For min. 99.5% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%. The availability for the residual area parts in flight Scenario 5 for 30 GHz frequency range uplink and high gain satellite antenna is in minimum:

TABLE A2-37

Link availabilities in 30 GHz frequency range Earth-to-space, high satellite gain for flight Scenario 5

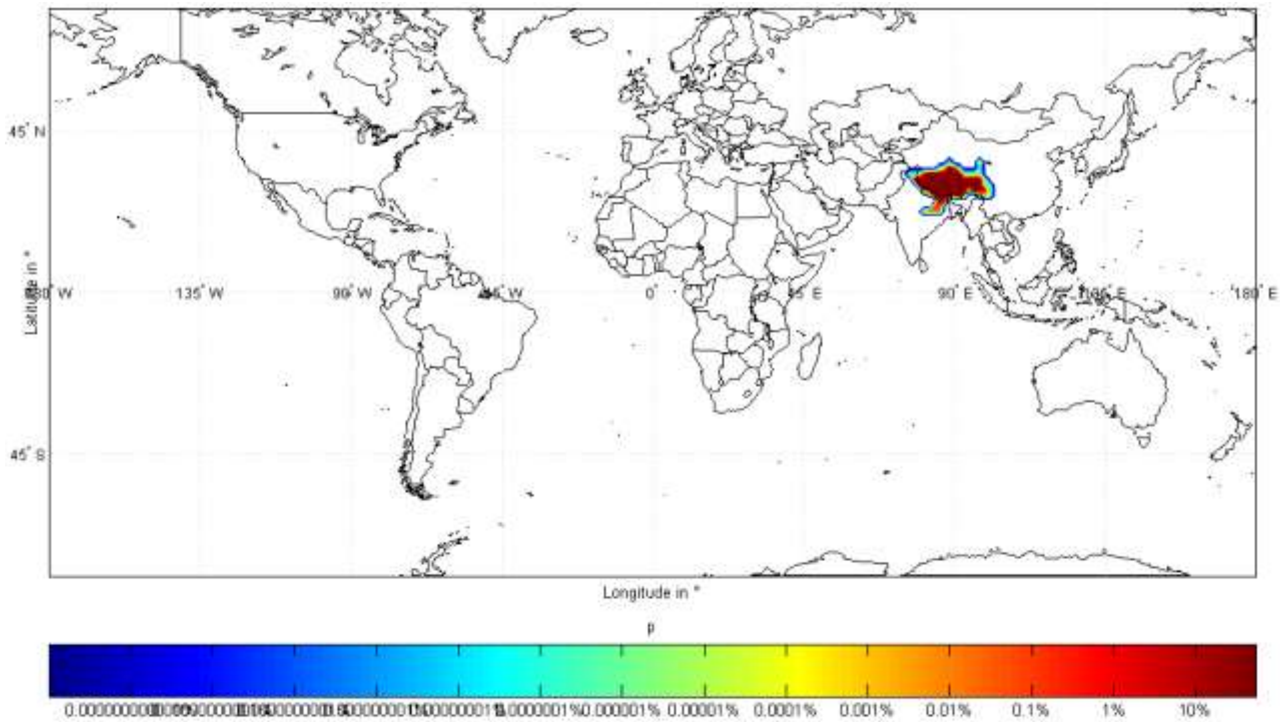
UA type	Availability threshold compliance
UA small	> 0 % for 100% of the area > 99.999% for 99.5% of the area

UA type	Availability threshold compliance
UA medium	> 0 % for 100% of the area > 99.999% for 99.7% of the area
UA large	> 0 % for 100% of the area > 99.999% for 99.98% of the area

UA CNPC via satellite is feasible nearly for the complete Earth surface. The following Figure A2-49 shows the geographic distribution of areas with availability lower than the computational limit of 1e-13% for UA type small. Those ones for the larger UA types are slightly smaller but of the same character.

FIGURE A2-26

Maps unavailability of the uplinks operating in the 30/20 GHz frequency ranges, unmanned aircraft small, high gain satellite antenna



A 2-4.5.7. Performance of the downlinks operating in the 20 GHz frequency ranges, low / high gain antenna

Based on the calculations of the resulting unavailability, i.e. the percentage of time when the total attenuation exceeds the available link margin for UA small, medium and large in 20 GHz frequency range downlink with low and high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

For 99.6% of the considered geographical area the availability of all three UA types is significantly larger than 99.999%, but in any case the link availability of 99.999% can be achieved for 100% of the geographical area.

TABLE A2-38

Link availabilities in 30/20 GHz frequency range space-to-Earth, flight Scenario 5

UA type	Availability threshold compliance
UA small	>> 99.999 %
UA medium	
UA large	

The link availabilities of all uplinks are larger than 99.999% for the complete geographic area and for all UA types, hence no unavailability maps are shown.

A 2-4.6. Performance analysis flight Scenario 6

The flight Scenario 6 is a scenario which is used for medium range – Low altitude surveillance over land and below 300 m (1 000 ft) above ground level. The minimum flight altitude used for the analysis is 30 m (100ft) above ground. Therefore the atmospheric impairments vary depending on the absolute height of the UA which is flight altitude plus geo height above sea level. In some areas the absolute UA height is below rain height, sometimes above rain height, but mainly below cloud top, and for small areas even above the cloud top. The precise analysis of the propagation impairments per analysed location is shown in Figure A2-51. For this scenario only locations over land are considered.

FIGURE A2-27

Applicable propagation impairments related to flight altitude of the unmanned aircraft in flight Scenario 6

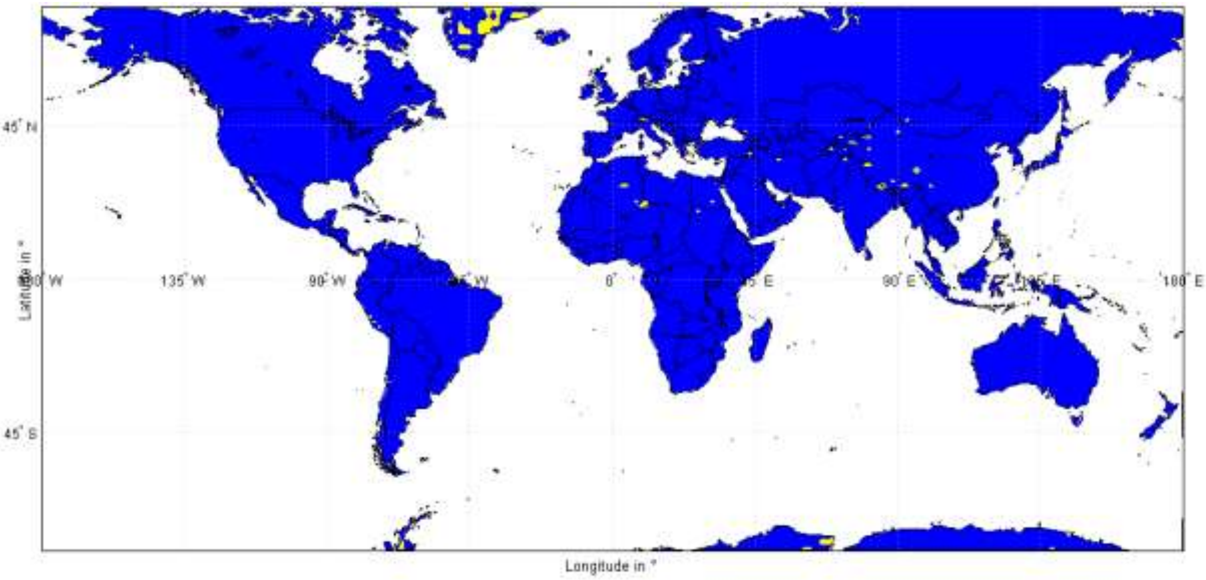


TABLE A2-39

Characteristics of flight Scenario 6

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Atmosphere
1	Below rain height	Yes	Yes	Yes	Yes
2	Above rain height below cloud top	No	No	Yes	Yes
3	Above cloud top	No	No	No	Yes

No.	Flight altitude of airborne platform	Rain	Trop. scintillation	Clouds	Atmosphere
4	(White) Areas are not considered in the flight scenario				

A 2-4.6.1. Areas where rain attenuation exceeds available link margin

Due to the fact that the final UA height for analysis of the performance is determined by the sum of the flight altitude and the topographic height of the location, the rain attenuation is lower than in flight Scenario 4 for some locations and therefore this scenario provides better availability results compared to scenario 4 although the flight altitude seems to be lower. Additionally the rain rate of this flight scenario is less than the flight Scenario 4, therefore fewer areas remain with rain attenuation exceeding the link margins.

A 2-4.6.1.1. 14/11 GHz frequency ranges

In this frequency band the rain margin does not exceed the link margins for all combinations of UA types and satellite gains antenna. Therefore the links for all locations considered in this scenario can be closed with certain availability.

A 2-4.6.1.2. Uplinks operating in the 30 GHz frequency range

In uplinks operating in the 30 GHz frequency range the rain attenuation is that high, yielding to geographical areas where the link margin is exceeded by the rain attenuation even for high gain satellite antennas and the large UA antenna type.

The rain attenuation for each considered location in flight Scenario 6 of minimum 28 dB has to be compensated with the link margin. Additional margin is needed to cover attenuation by gas, clouds and scintillation where applicable.

Areas with link margins being exceeded by the rain attenuation are highlighted in the following Figure A2-53 for UA type small and low gain satellite antenna (UA types medium and large only provide slightly better results) as well as in Figures A2-54 to A2-56 for all three UA types and high gain satellite antenna.

FIGURE A2-28

Areas where rain attenuation exceeds link margin, uplinks operating in the 30 GHz frequency ranges, unmanned aircraft small, low gain satellite antenna

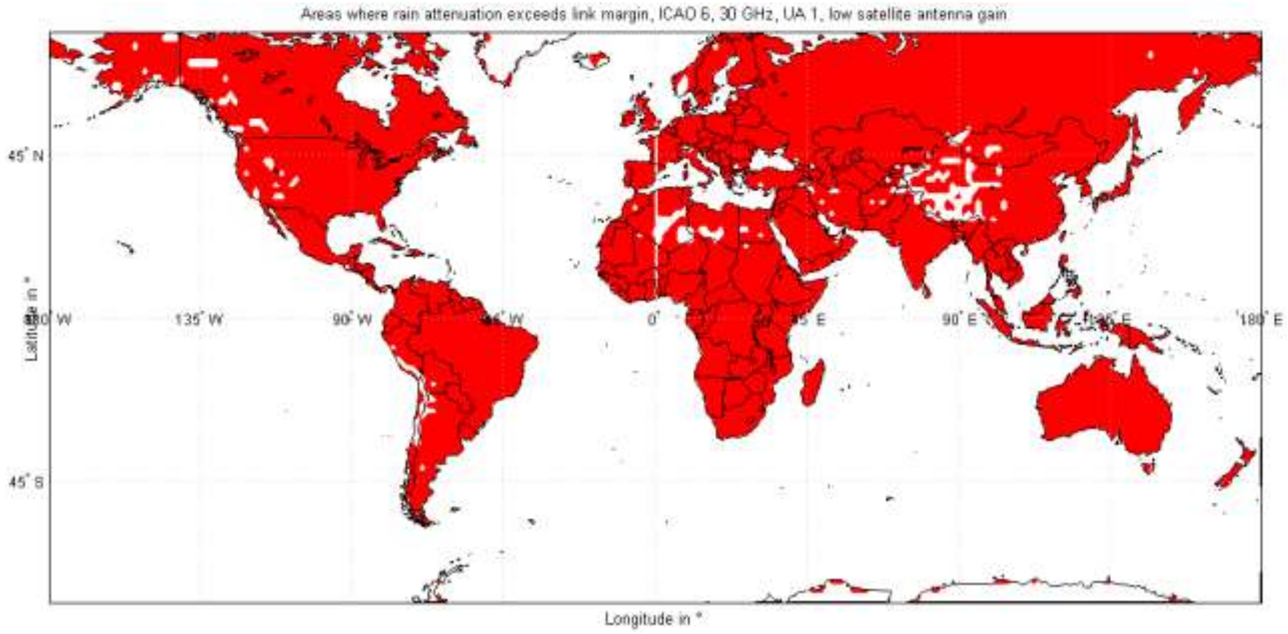


FIGURE A2-28

Areas where rain attenuation exceeds link margin, uplinks operating in the 30 GHz frequency ranges, unmanned aircraft small, high gain satellite antenna

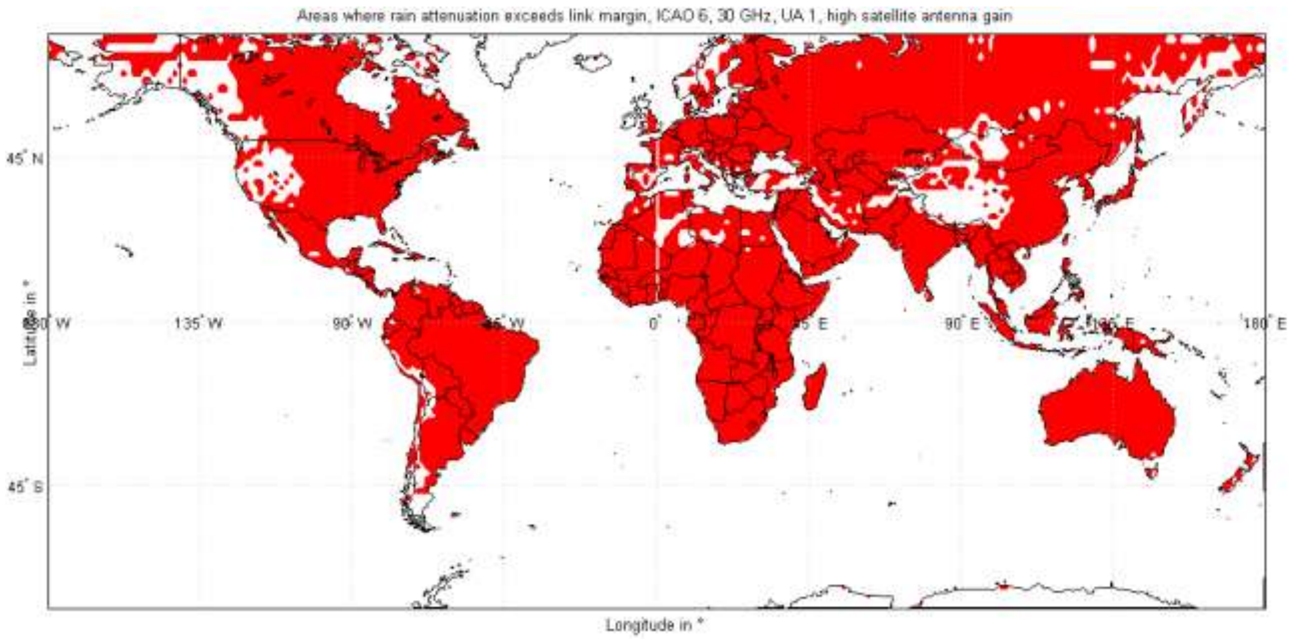


FIGURE A2-30

Areas where rain attenuation exceeds link margin, uplinks operating in the 30 GHz frequency ranges, unmanned aircraft medium, high gain satellite antenna

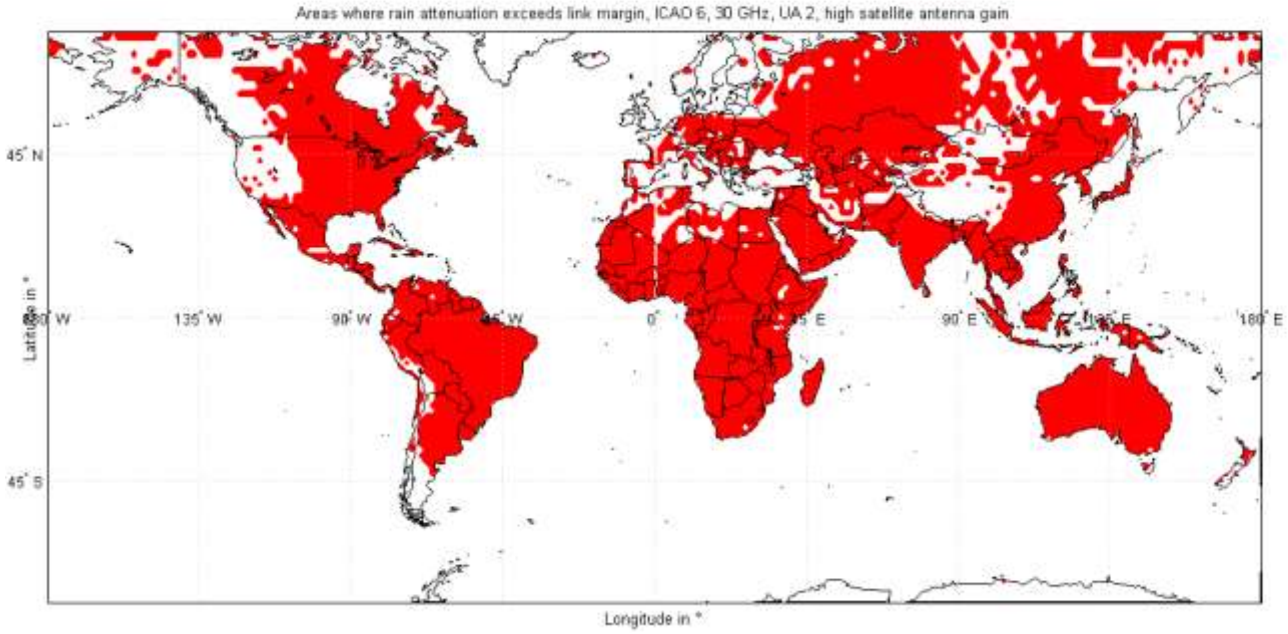
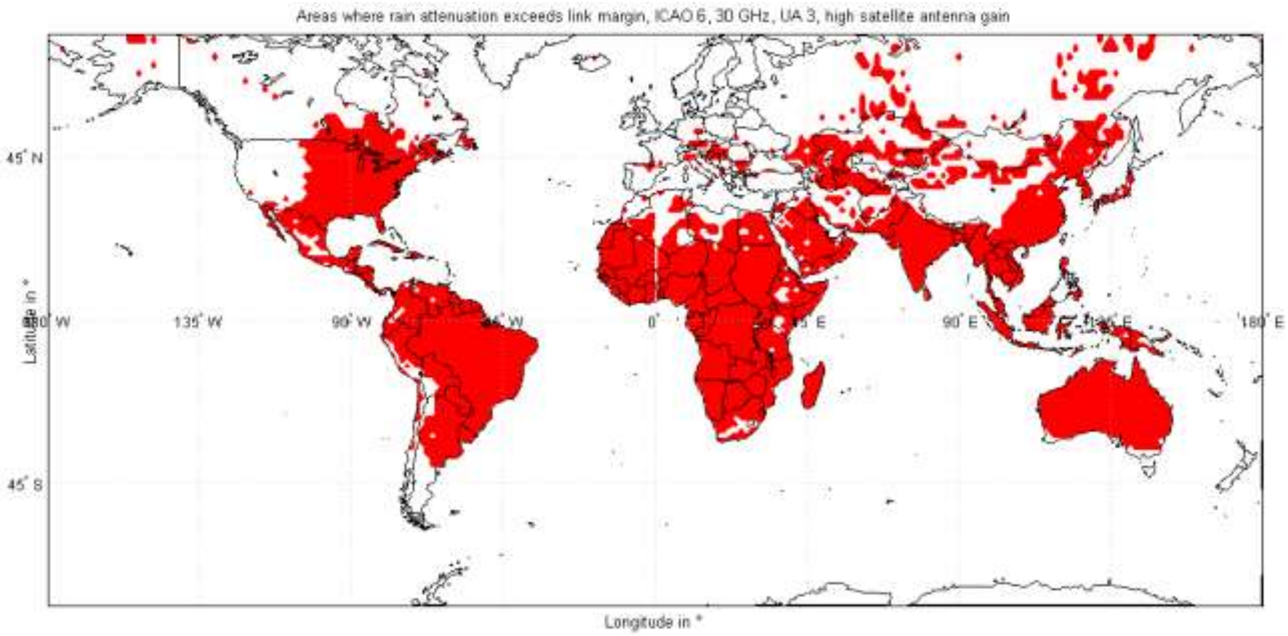


FIGURE A2-31

Areas where rain attenuation exceeds link margin, uplinks operating in the 30 GHz frequency ranges, unmanned aircraft large, high gain satellite antenna



A 2-4.6.1.3. Downlinks operating in the 20 GHz frequency ranges

In downlinks that operate in the 30/20 GHz frequency ranges no areas are detected where the link margin is less than the rain attenuation. Therefore the rain can always be compensated for all UA types and satellite beams.

A 2-4.6.2. Performance of the uplinks operating in the 14 GHz frequency ranges, low gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 14 GHz frequency range uplink, the achievable link availabilities for the different UA types are given below. Although section A 2-4.6.1.1 showed that no areas exists where the link margin is lower than the rain attenuation the residual margin of the link #3 can only compensate other applicable atmospheric impairments for 99.91% of the considered locations.

The availability for the considered locations in flight Scenario 6 for uplinks operating in the 14 GHz frequency ranges via low gain satellite antenna is in minimum:

TABLE A2-40

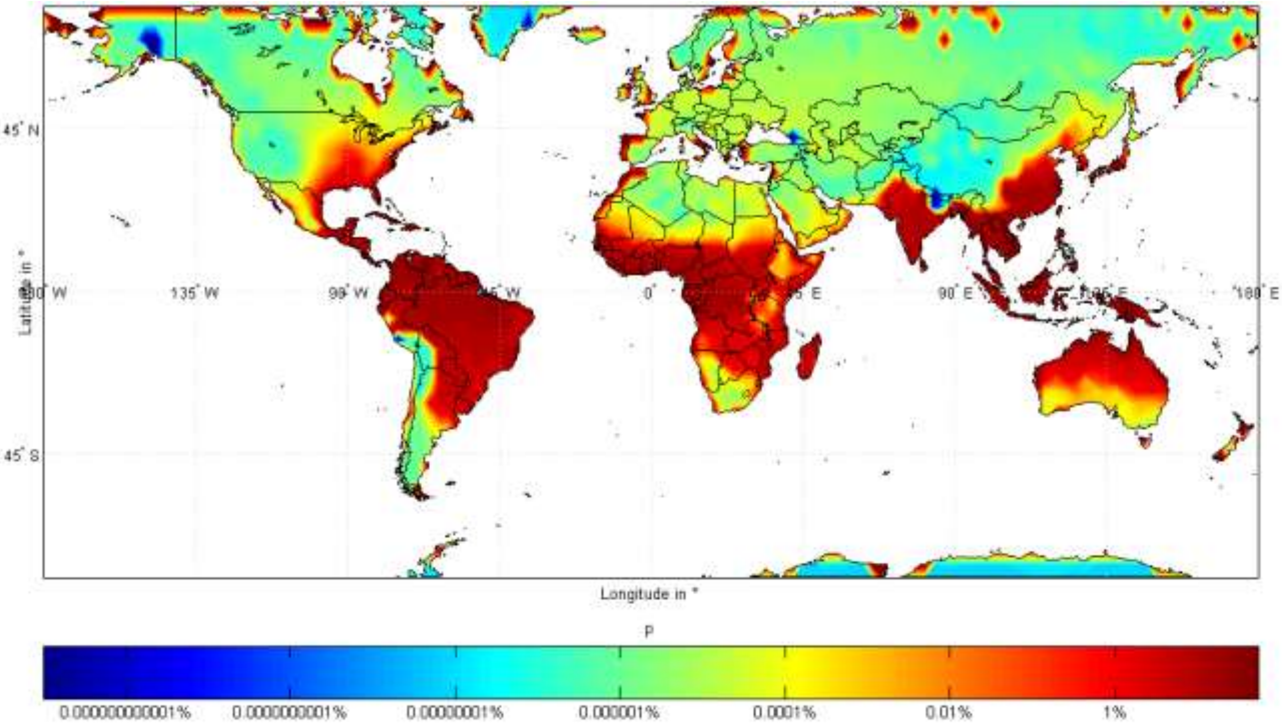
Link availabilities in 14 GHz frequency range Earth-to-space, low satellite gain, flight Scenario 6

UA type	Availability threshold compliance
UA small	≥ 0 % for 100% of the area > 99.999% for 65% of the area
UA medium	> 99.999 % for 100% of the area
UA large	> 99.999 % for 100% of the area

The following Figure A2-58 shows the geographic distribution of the areas with insufficient link availability for UA type small.

FIGURE A2-32

Unavailability of the uplinks operating in the 14 GHz frequency range, unmanned aircraft small, low satellite gain



A 2-4.6.3. Performance of the uplinks operating in the 14 GHz frequency ranges, high gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 14 GHz frequency range uplink, the achievable link availabilities for the different UA types are given below.

The availability for the considered locations in flight Scenario 6 for uplinks operating in the 14 GHz frequency ranges and low gain satellite antenna is in minimum:

TABLE A2-41

Link availabilities in 14 GHz frequency ranges Earth-to-space, high satellite gain, flight Scenario 6

UA type	Availability threshold compliance
UA small	≥ 99.999 % for 100% of the area
UA medium	>> 99.999 % for 100% of the area
UA large	>> 99.999 % for 100% of the area

The high gain satellite antenna provides the necessary margin for link #3 for all UA types to compensate all atmospheric impairments and to close all links with availabilities higher than 99.999%. Hence no unavailability map is shown.

A 2-4.6.4. Performance of the downlinks operating in the 11 GHz frequency ranges, low / high gain antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 11 GHz frequency range downlink, the achievable link availabilities for the different UA types are given below.

The availability for the considered location in flight Scenario 6 for downlinks operating in the 14/11 GHz frequency ranges is in minimum:

TABLE A2-42

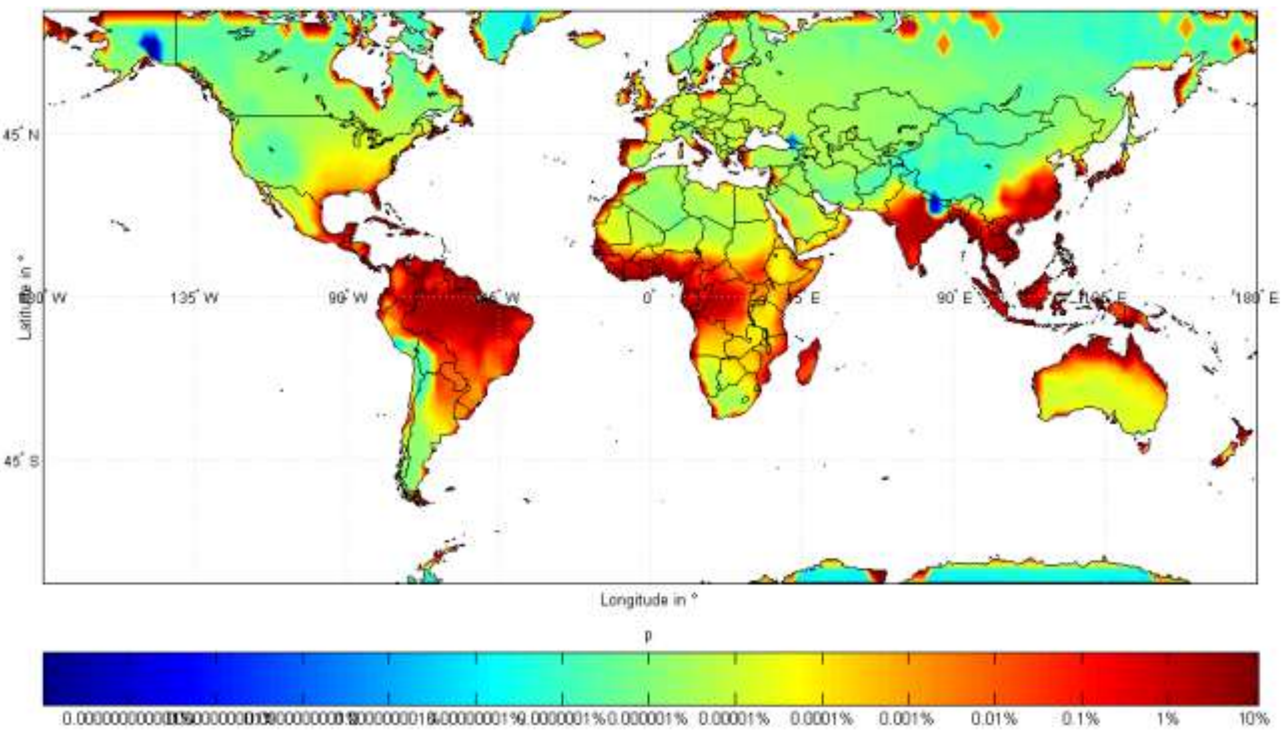
Link availabilities in 11 GHz frequency range space-to-Earth, flight Scenario 6

UA type	Availability threshold compliance
UA small	> 90.0 % for 100% of the area > 99.999% for 80% of the area
UA medium	>> 99.999 % for 100% of the area
UA large	>> 99.999 % for 100% of the area

The following Figure A2-61 shows the geographic distribution of the areas with insufficient availabilities for UA type small.

FIGURE A2-33

Unavailability of the downlinks operating in the 11 GHz frequency range, unmanned aircraft small, low / high gain satellite antenna



A 2-4.6.5. Performance of the uplinks operating in the 30 GHz frequency ranges, low gain satellite antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 30 GHz frequency range uplink to a low gain satellite antenna, the achievable link availabilities for the different UA types are given below. Due to the large signal attenuations very small availability figures can be realized only as shown in Figures A2-62 to A2-64.

FIGURE A2-34

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft small, low gain satellite antenna

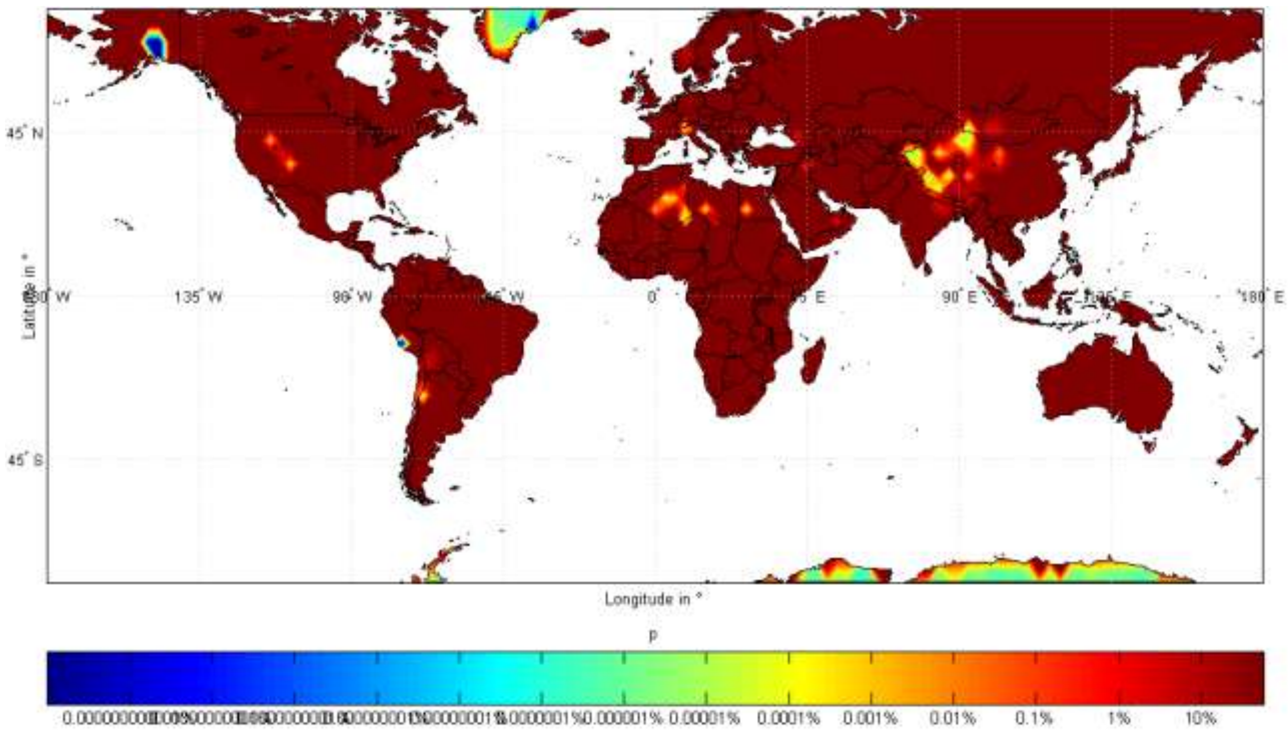


FIGURE A2-35

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft medium, low gain satellite antenna

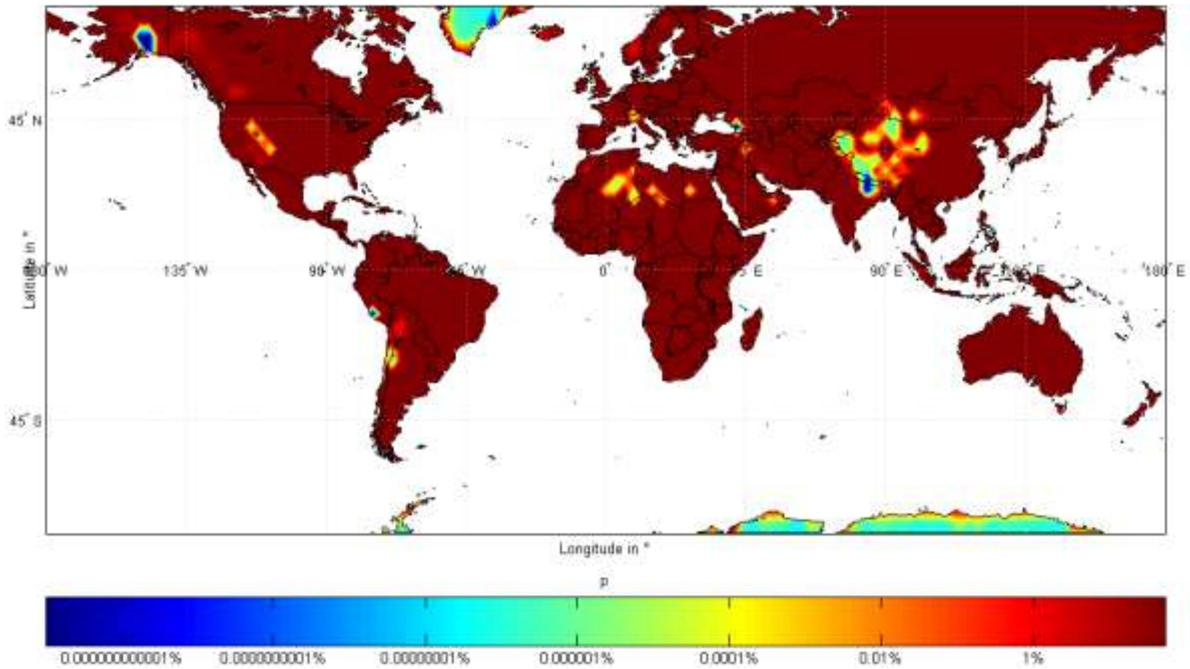
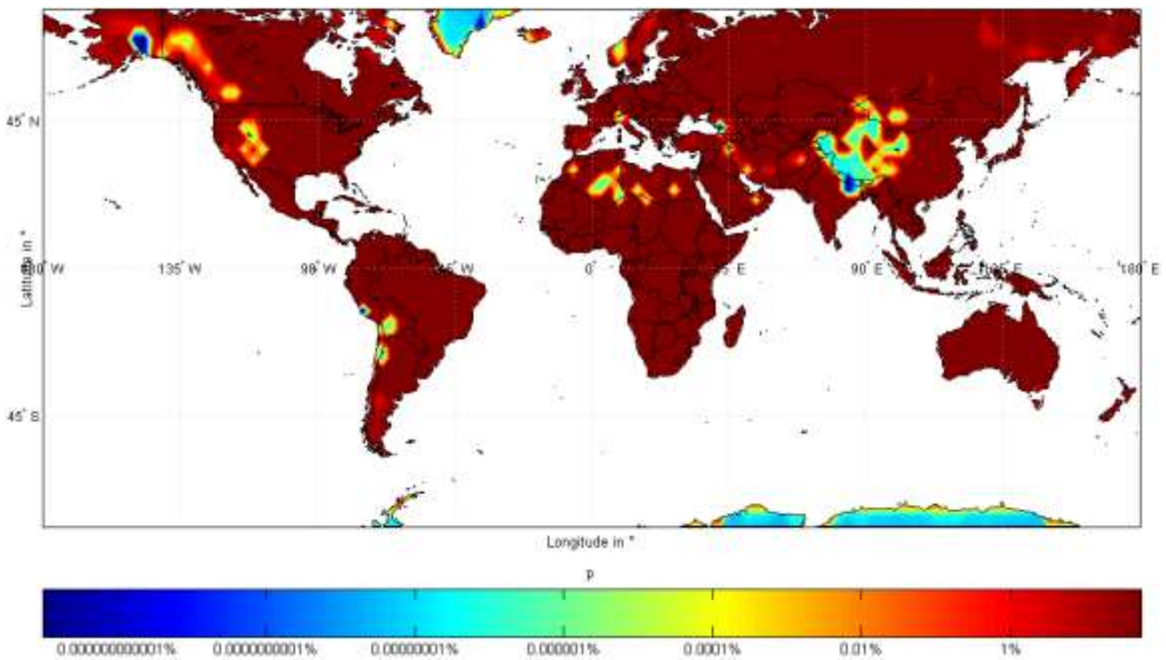


FIGURE A2-36

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft large, low gain satellite antenna



The availability for the considered location in flight Scenario 6 for uplinks operating in the 30 GHz frequency ranges and low gain satellite antenna is in minimum:

TABLE A2-43

Link availabilities in 30 GHz frequency range Earth-to-space, low satellite gain, flight Scenario 6

UA type	Availability threshold compliance
UA small	≥ 0 % for 100% of the area > 99.999% for 5% of the area
UA medium	≥ 0 % for 100% of the area > 99.999% for 75% of the area
UA large	≥ 0 % for 100% of the area > 99.999% for 10% of the area

A 2-4.6.6. Performance of the uplinks operating in the 30 GHz frequency ranges, high gain antenna

Based on the calculation of the resulting unavailability, i. e. the percentage of time when the total attenuation exceeds the available link margin for UA small to large in the 30 GHz frequency range uplink to a high gain satellite antenna, the achievable link availabilities for the different UA types are given below. Due to the large signal attenuations also in case of the high gain satellite antenna small availability figures can be realized only as shown in Figures A2-66 to A2-68.

FIGURE A2-37

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft small, high gain satellite antenna

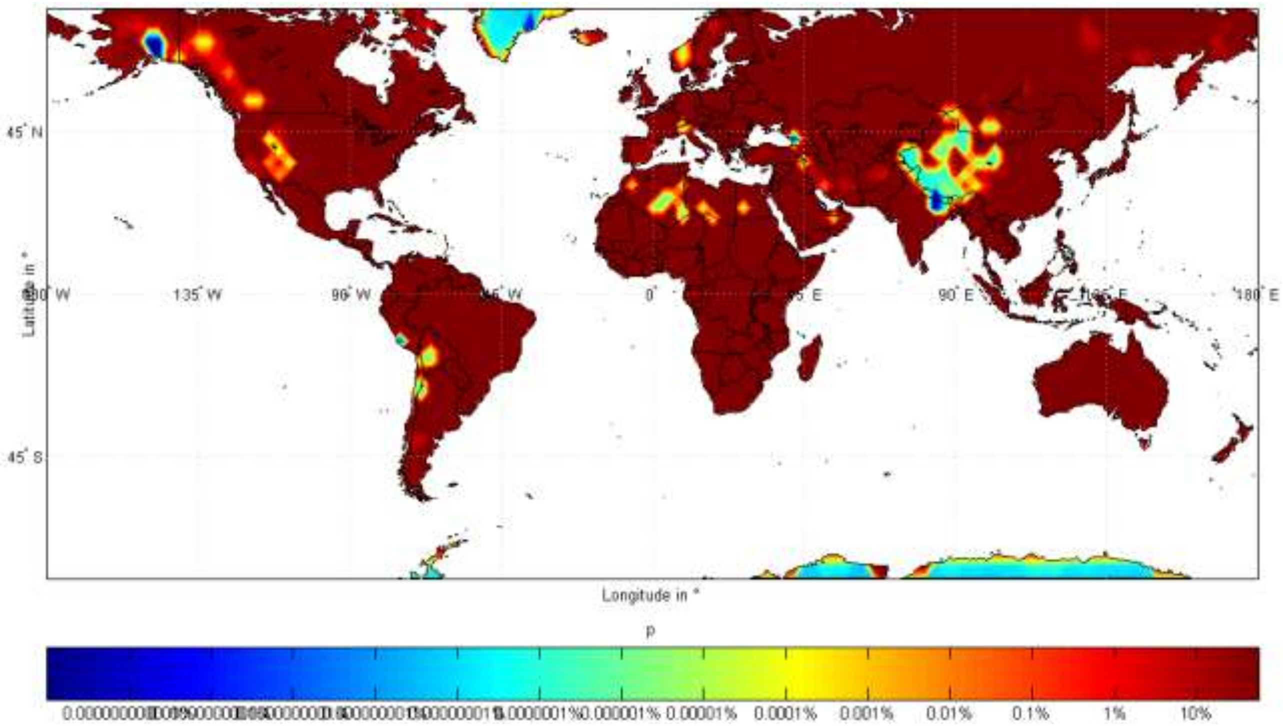


FIGURE A2-38

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft medium, high gain satellite antenna

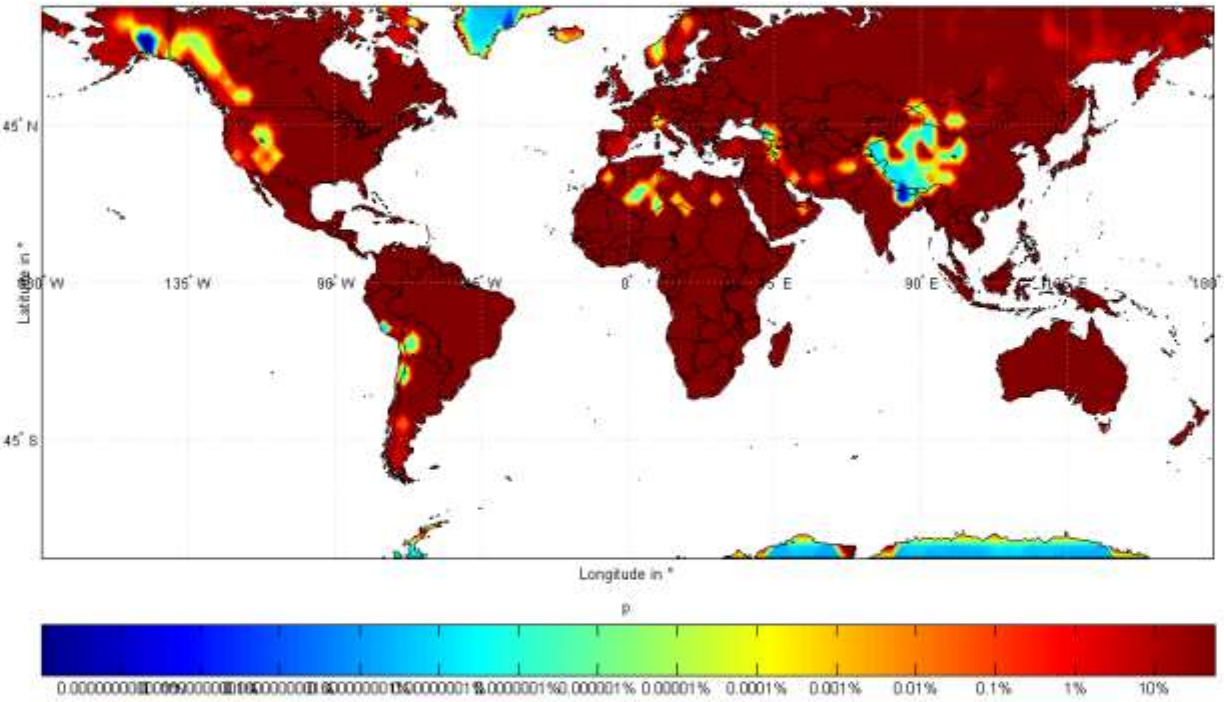
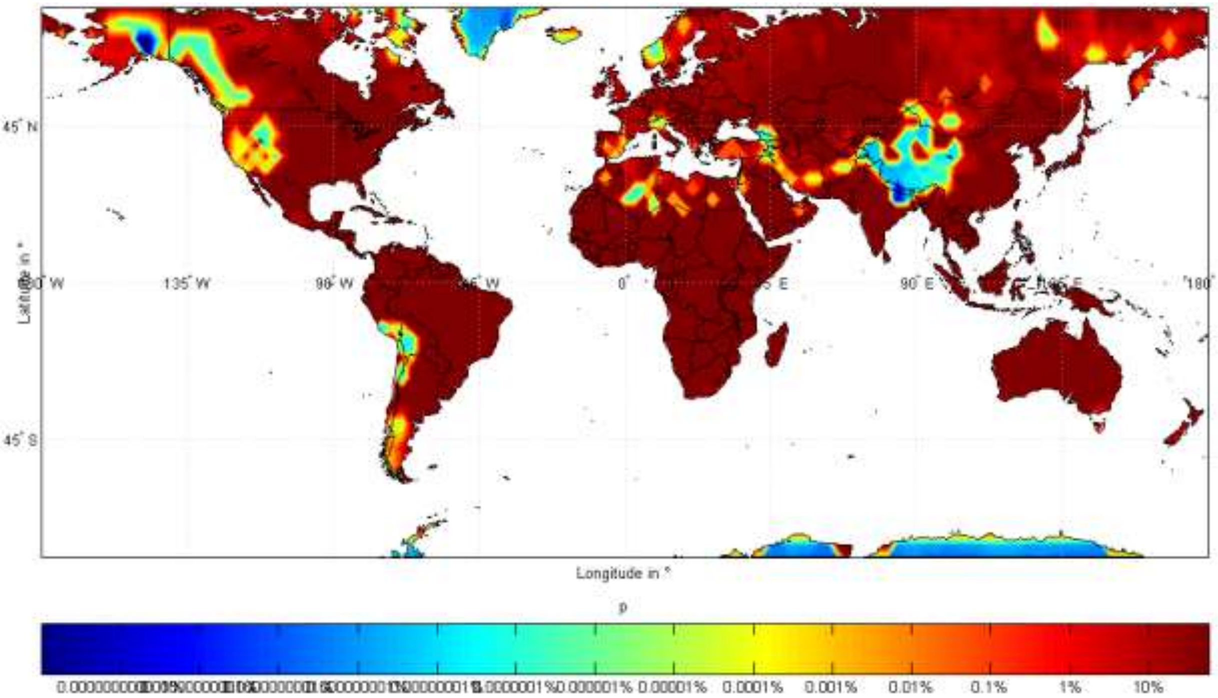


FIGURE A2-39

Unavailability of the uplinks operating in the 30 GHz frequency range, unmanned aircraft large, high gain satellite antenna



The availability for the considered location in flight Scenario 6 for of the uplinks operating in the 30 GHz frequency range and high gain satellite antenna is in minimum:

TABLE A2-44

Link availabilities in 30 GHz frequency range Earth-to-space, high satellite gain, flight Scenario 6

UA type	Availability threshold compliance
UA small	≥ 0 % for 100% of the area > 99.999% for 10% of the area
UA medium	≥ 0 % for 100% of the area > 99.999% for 12% of the area
UA large	≥ 0 % for 100% of the area > 99.999% for 15% of the area

The distribution of areas with insufficient availabilities is comparable with those for small gain satellite antenna and only slightly better.

A 2-4.6.7. Performance of the downlinks operating in the 20 GHz frequency ranges, low / high gain antenna

Based on the calculation of the resulting unavailability for UA small, medium, large whose downlinks operate in the 20 GHz frequency band for both, the low and high gain satellite antenna, the achievable link availabilities for the different UA types are given below.

The availability for the considered location in flight Scenario 6 for of the downlinks operating in the 20 GHz frequency ranges is minimum:

TABLE A2-45

Link availabilities in 20 GHz frequency range space-to-Earth, flight Scenario 6

UA type	Availability threshold compliance
UA small	≥ 0 % for 100% of the area > 99.999% for 55% of the area
UA medium	≥ 0 % for 100% of the area > 99.999% for 70% of the area
UA large	≥ 0 % for 100% of the area > 99.999% for 85% of the area

The following Figures A2-71 to A2-73 are showing the geographic distribution of the areas with insufficient availabilities.

FIGURE A2-40

Unavailability of the downlinks operating in the 20 GHz frequency range, unmanned aircraft small, low / high gain satellite antenna

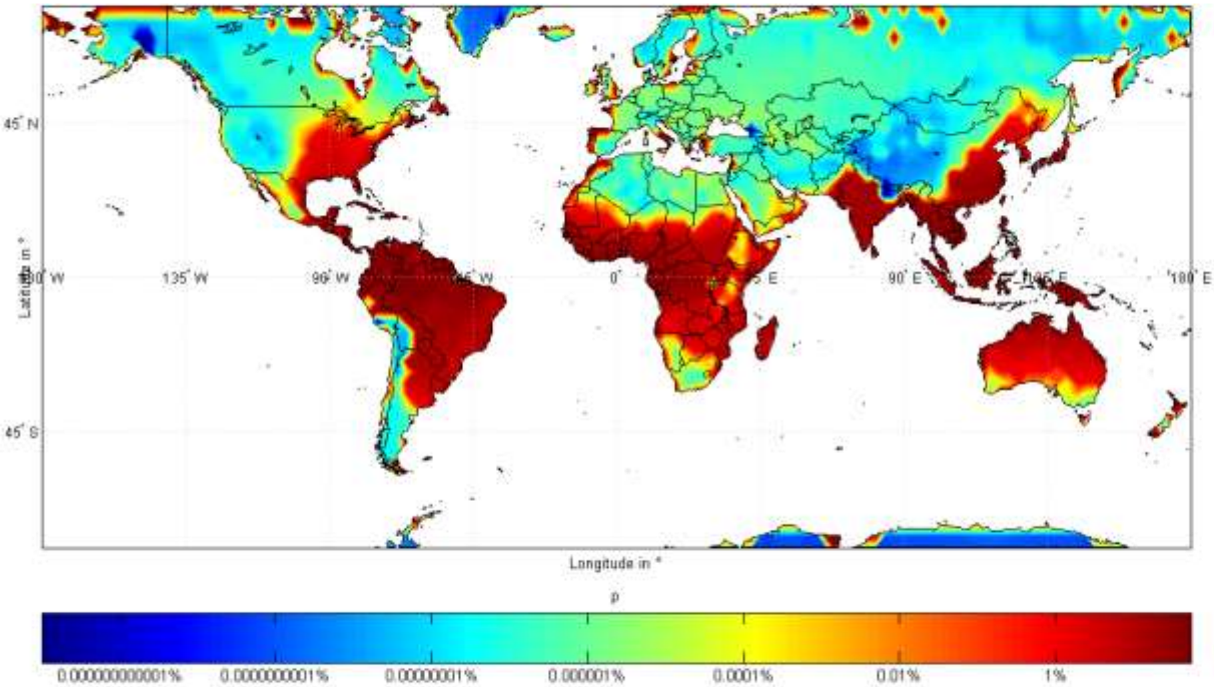


FIGURE A2-41

Unavailability of the downlinks operating in the 20 GHz frequency range, unmanned aircraft medium, low / high gain satellite antenna

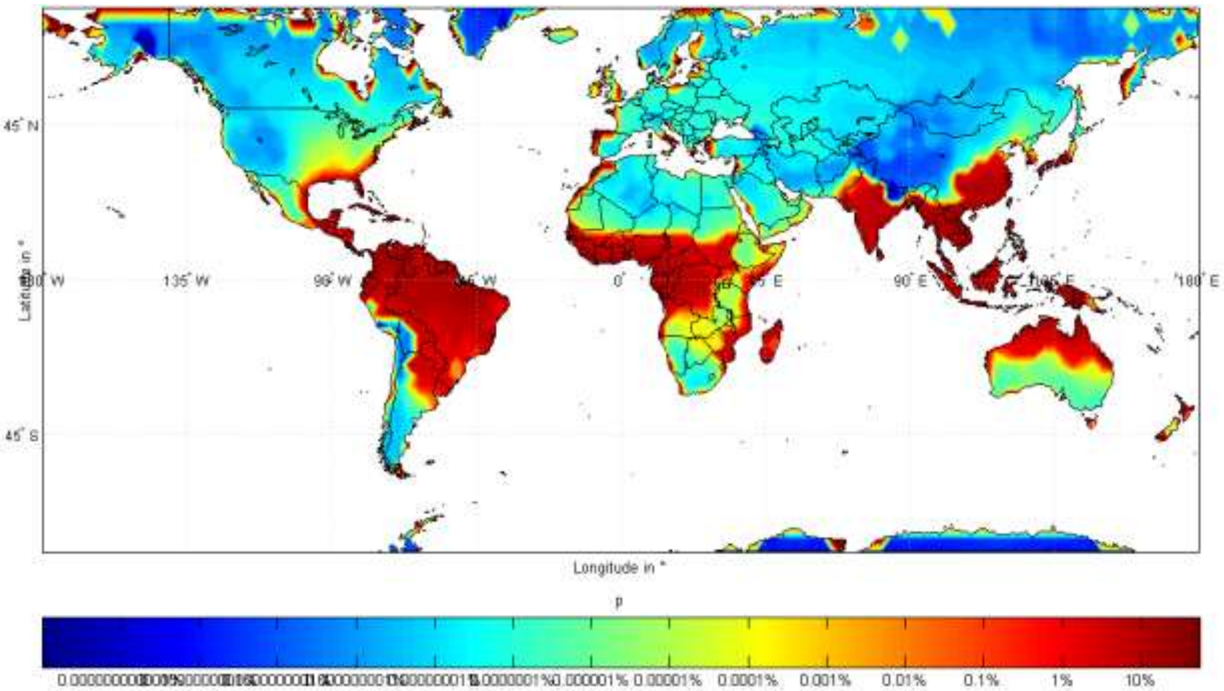
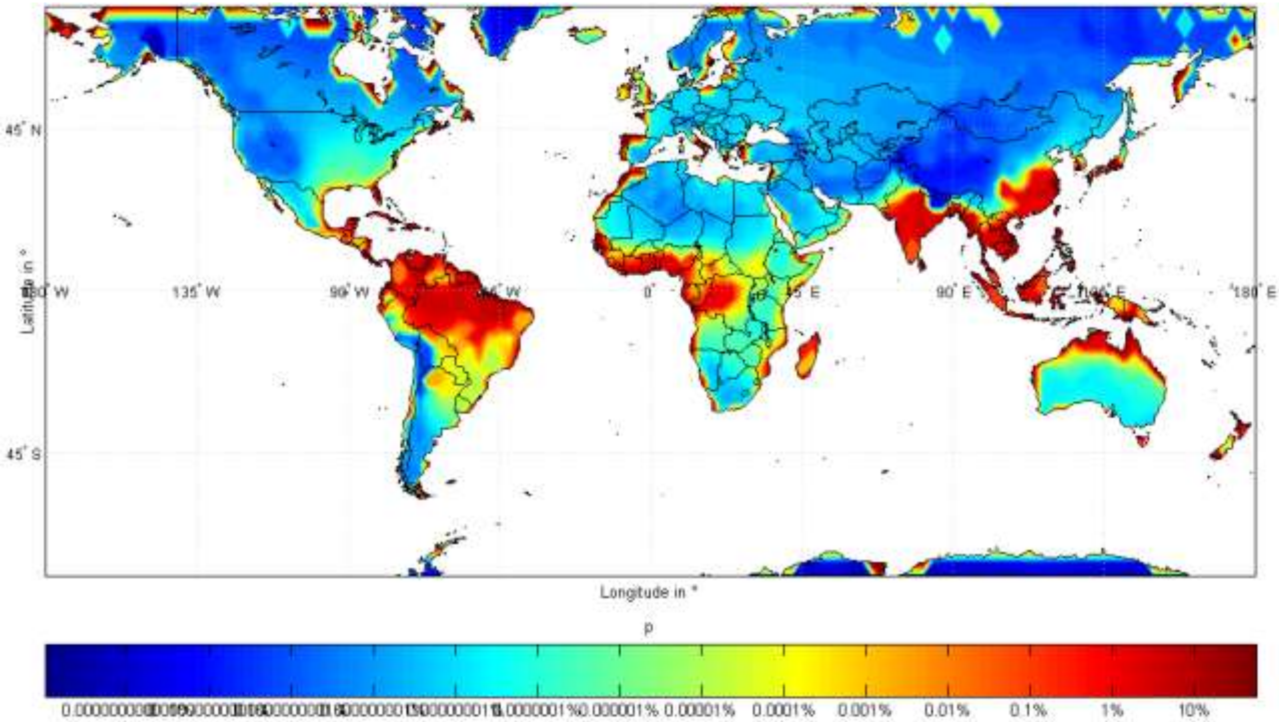


FIGURE A2-42

Unavailability of the downlinks operating in the 20 GHz frequency range, unmanned aircraft large, low / high gain satellite antenna



A 2-4.7. Summary of the simulation results in terms of link availabilities for 14/11 GHz and 29/19 GHz band

The resulting availabilities per scenario, frequency band, per UA type and per satellite antenna gain are shown in the Table below not applying the extrapolation described in Chapter A 2-3.10 for better readability. It should be noted that when showing an availability > 99.999% the real availability is significantly higher for the majority of cases.

TABLE A2-46

Minimum achievable availability for 100% of the flight scenario dependent geographical area

	Frequency band	**14/11 GHz frequency range uplink**		**14/11 GHz frequency range downlink**	**30/20 GHz frequency range uplink**		**30/20 GHz frequency range downlink**
	Satellite antenna gain	**low**	**High**	**low / high**	**Low**	**high**	**low / high**
Scenario 1	**UA small**	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %
	UA medium	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999%
	UA large	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %
Scenario 2	**UA small**	> 99.999 %	> 99.999 %	> 99.999%	> 88 %	> 99.99 %	≥ 99.999 %
	UA medium	> 99.999 %	> 99.999 %	> 99.999 %	> 95 %	> 99.999 %	≥ 99.999 %
	UA large	> 99.999 %	> 99.999%	> 99.999 %	> 99.999 %	> 99.999%	≥ 99.999 %
Scenario 3	**UA small**	> 99.999 %	> 99.999%	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %
	UA medium	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %
	UA large	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999 %	> 99.999%
Scenario 4	**UA small**	> 0 %	> 57.9 %	> 0 %	> 0 %	> 0 %	> 0 %
	UA medium	> 88 %	≥ 99.999%	> 99.92 %	> 0 %	> 0 %	> 0 %
	UA large	> 99.96 %	≥ 99.999 %	> 99.999 %	> 0 %	> 0 %	> 0 %
Scenario 5	**UA small**	> 99.999%	> 99.999%	> 99.999%	> 0 %	> 0 %	> 99.999%
	UA medium	> 99.999%	> 99.999%	> 99.999%	> 0 %	> 0 %	> 99.999%
	UA large	> 99.999%	> 99.999%	> 99.999%	> 0 %	> 0 %	> 99.999%
Scenario 6	**UA small**	> 0 %	≥ 99.999 %	> 90.0 %	> 0 %	> 0 %	> 0 %
	UA medium	> 99.999 %	> 99.999%	≥ 99.999%	> 0 %	> 0 %	> 0 %
	UA large	> 99.999%	> 99.999%	≥ 99.999%	> 0 %	> 0 %	> 0 %

A 2-5. Supplementary study for the resulting link availability on chosen flight scenarios, with reference to the link budgets in sec. A 2-2.2

This section supplements the above link availability analyses by showing the dependencies on different elevation angles, on different rain heights, (i.e. climatic zones) and also by different satellite antenna gains for the service area.

In this contribution, the software implementation of the relevant ITU propagation models by CNES[4] has been extensively used.

In particular, the following atmospheric impairments have been taken into account in estimating the propagation losses:

- Rain attenuation;
- Gaseous attenuation;
- Cloud attenuation;
- Tropospheric scintillation.

Very conservative assumptions have also been made:

- the maximum rain rate suggested by ICAO for each scenario is considered as constant thorough the flight;
- the entire slant path (from sea level to the top of the atmosphere) is considered for gas, cloud and scintillation attenuation, even when the minimum UAV height is, for instance, 300 m (1000ft);
- the minimum flight altitude is considered for each scenario, which leads to the maximum possible attenuation.

A 2-5.1. Considerations on signal fading

It should be noticed that, as per Recommendation ITU-R P.618-10 and the methodology described in section 5.1 of Rec. ITU-R P.2041, any time dependency on the attenuation contributions above can be eliminated by considering the following:

- rain attenuation is dependent on the rain rate, which is fixed by the ICAO scenarios; this means, the actual atmospheric attenuation values will be usually lower than those computed, because of the assumption made on a permanent rain rate;
- the maximum gaseous and cloud attenuation are taken into account and their values correspond to those obtained by fixing the value of the probability p of the correspondent models at 1%; in fact, as rain attenuation is also being considered, using the ITU recommended methodology to combine the various contributions to the total attenuation (see Equations 52 and 53 of Recommendation ITU-R P.618-10), there is no need to evaluate gas and cloud attenuation for time percentages lower than 1%.-
- the maximum value of the fading due to atmospheric scintillation is assumed to be that corresponding to a probability p of 0.01%. It should be noted that fading due to atmospheric scintillation is a slow varying phenomenon and even an artificial extrapolation to lower time percentages, when combined with the dominant effect of rain fade, would lead to negligible changes in the results.

4 Available through http://logiciels.cnes.fr/PROPA/en/logiciel.htm

It is on this basis that, if the maximum possible attenuation due to the combination of the four contributions above is lower than the available link margin, it can be stated that, leaving aside the other factors which affect link availability, an availability of 100% can be achieved.

Rain is generally the limiting phenomenon. However, the attenuation due to it can be considered as zero when an UAV flies above rain height. Since the maximum rain height does not exceed a distance of about 6 km, propagation losses due to rain can be neglected worldwide for a UAV flying at altitudes higher than approximately 6100 m (20 000ft).

In terms of evaluating the effects of propagation on a link, this document provides an analysis of three basic types of climatic regions, identified as Temperate, Tropical and Dry. The propagation parameters and sample locations assumed for the scenarios are identified in the Table below.

TABLE A 2-47

Characterisation of climatic regions

	Units	Temperate	Tropical	Dry
Latitude	degrees	+45	-5	70
Longitude	degrees	+10	-60	100
R001	mm/h	39.7	97.4	13.5
Rain height	km	3.3	4.8	2.5
Surface water vapour density	g/m^3	6.9	19.2	0.9

For each region, the propagation impairments and maximum link margins are estimated for the following RF link parameters:

- UAV earth station antenna diameter of 0.45, 0.8, 1.25 meters; antenna efficiency of 65%;
- circular polarisation;
- uplink frequency: 30 GHz;
- downlink frequency: 20 GHz.

Figures A2-74 to A2-77 below show the total maximum attenuation for the UAV downlink and the representative locations in Table A 2-5.1 depending on the elevation angle for Scenarios 4, 6, 7 and 8. Scenario 9 has not been considered as, from a propagation perspective; it is very similar to Scenario 6.

Scenarios 1-3 and 5 have also not been considered because of the high UAV height. With minimum height of 5800 m (19 000 ft) and above, the UAV will practically always be above rain height except, possibly, for a few geographical locations on Earth. Hence, with the available link margins, the availability will be 100% for almost all locations. In those few geographical locations where the rain height is higher than the 5800 m, if the link margins will be too low compared to the atmospheric attenuation for a 10 degrees elevation angle, it should be noted that any required availability criteria could be satisfied by increasing the minimum elevation angle, as these locations will be in tropical regions. This is feasible, by introducing a sufficient number of satellites on the GSO arc.

In a similar manner, Figures A2-78 to A2-81 below show the total maximum attenuation for the UAV Uplink and the representative locations in Table A 2-5.1 as a function of the elevation angle for Scenarios 4, 6, 7 and 8. It can be seen that the uplink case is more critical, mainly due to the higher frequency.

FIGURE A 2-43

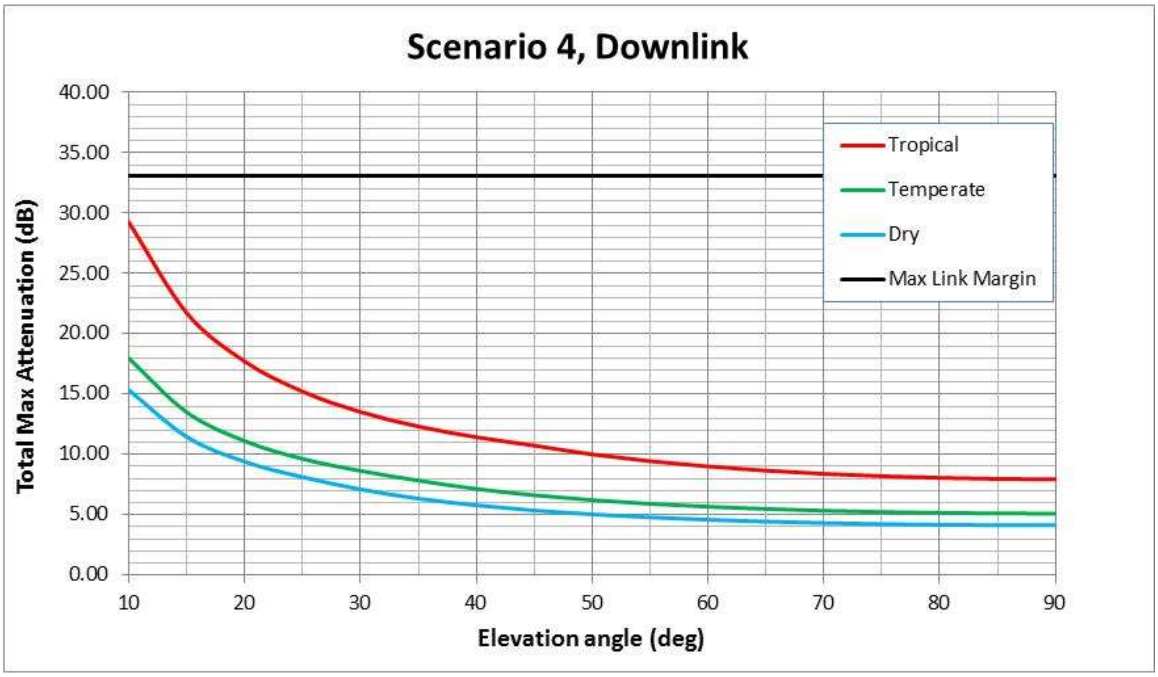


FIGURE A 2-44

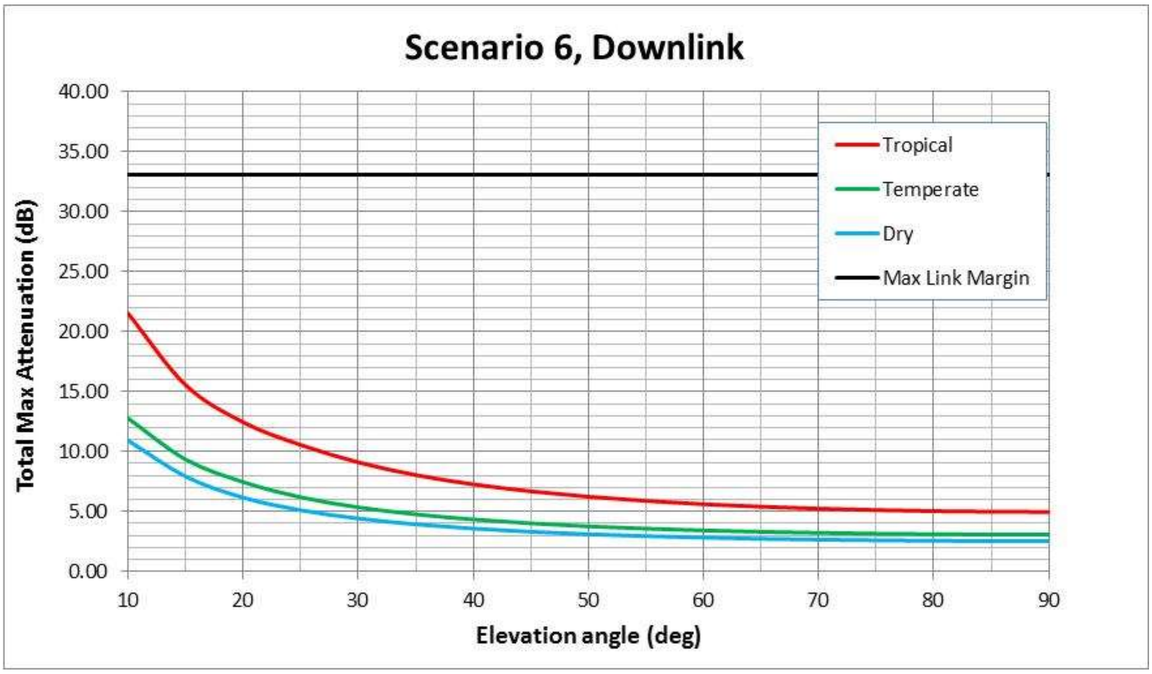


FIGURE A 2-45

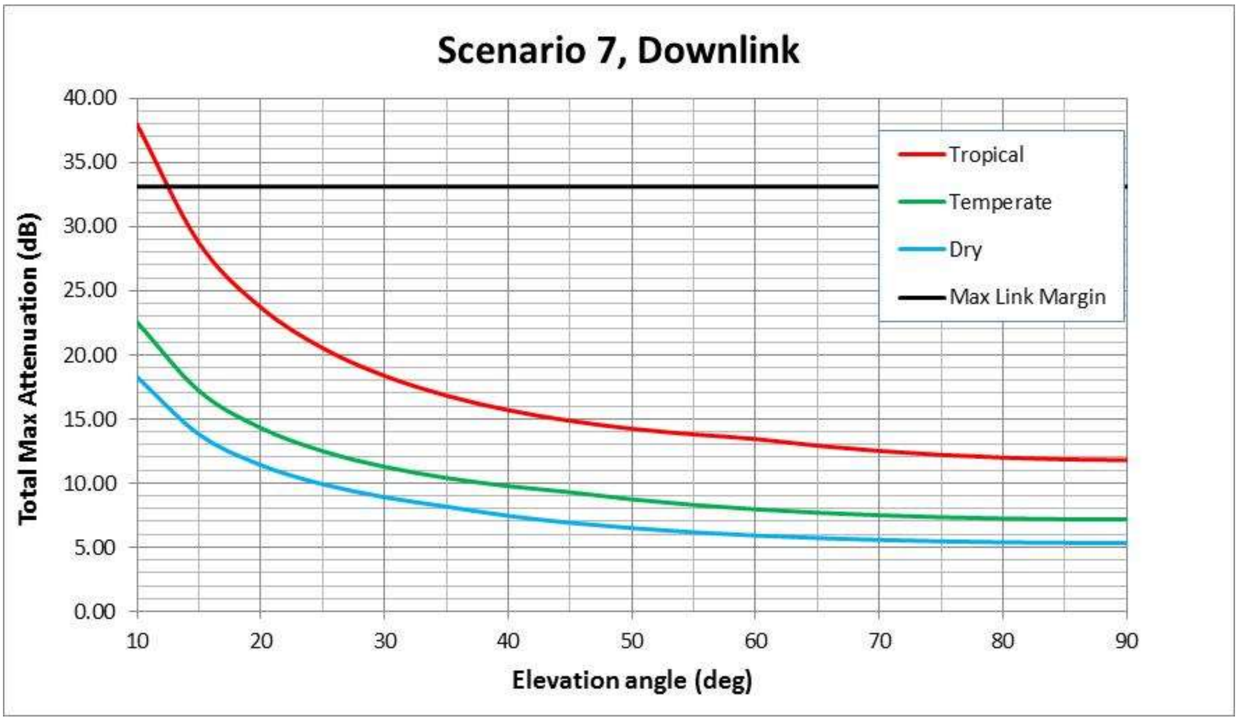


FIGURE A 2-46

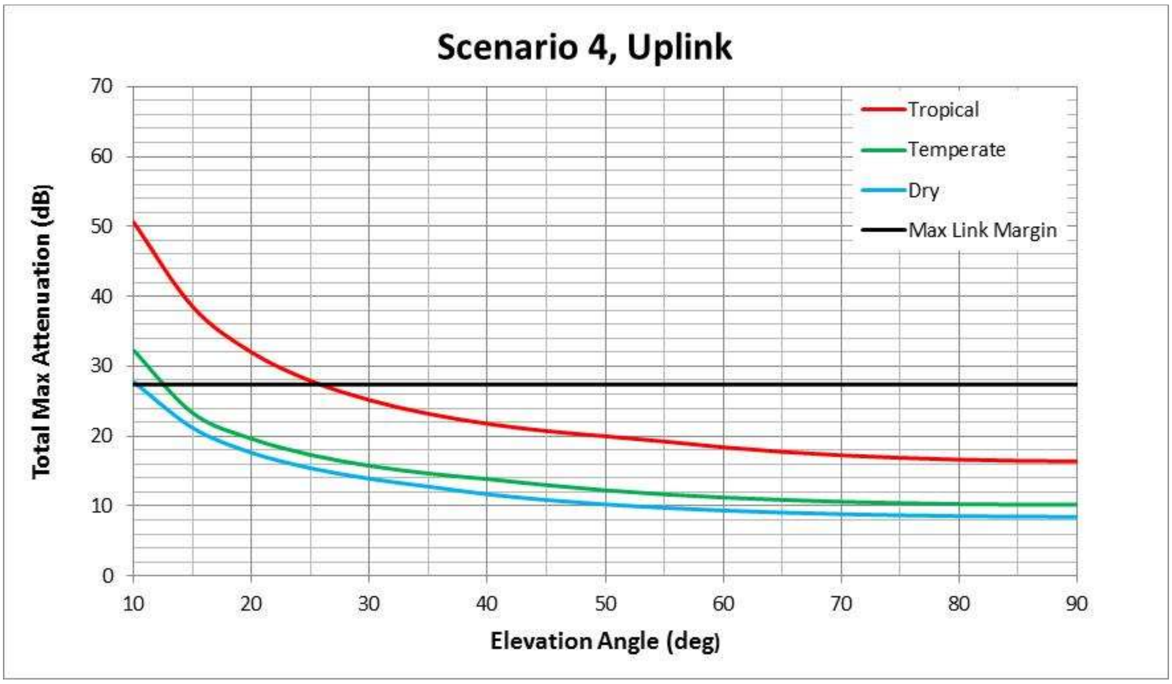


FIGURE A 2-47

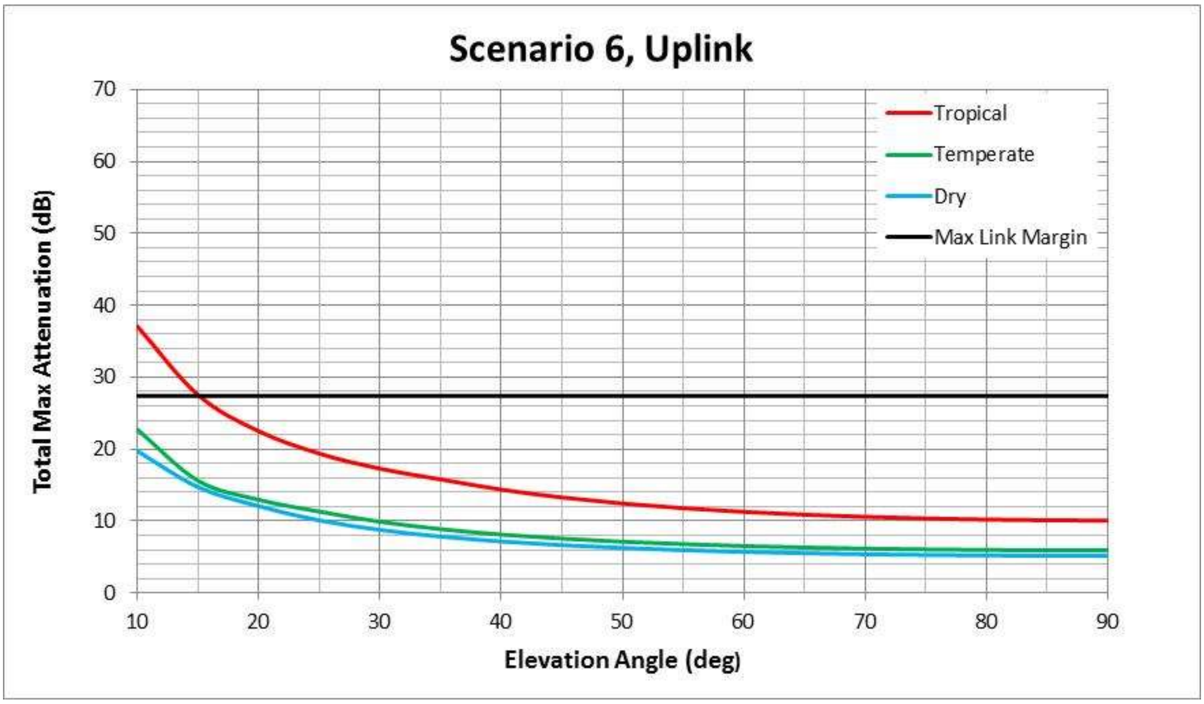
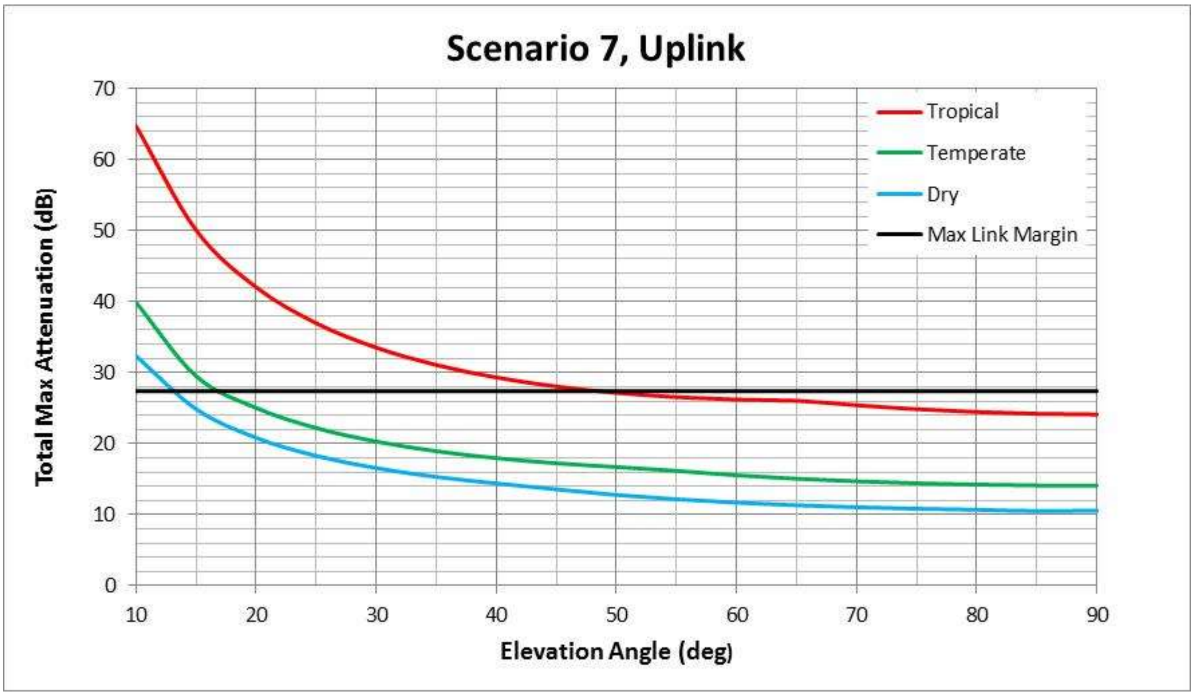


FIGURE A 2-48



A 2-5.2. Considerations on the link availability

This section estimates the conditions in terms of elevation angle and climatic regions for which an availability of 100% can be achieved for FSS CNPC links operating at 30/20 GHz frequency band, taking into account the maximum attenuation for the considered scenarios and the maximum available link margins.

Downlink

Based on the Figures of A2-74 to A2-77, the maximum available link margin (using a 125 cm antenna) is sufficient to cope with the atmospheric attenuation, except for Scenarios 7 and 8, in which an elevation angle higher that 15 degrees may be required, in tropical areas, to achieve 100% availability.

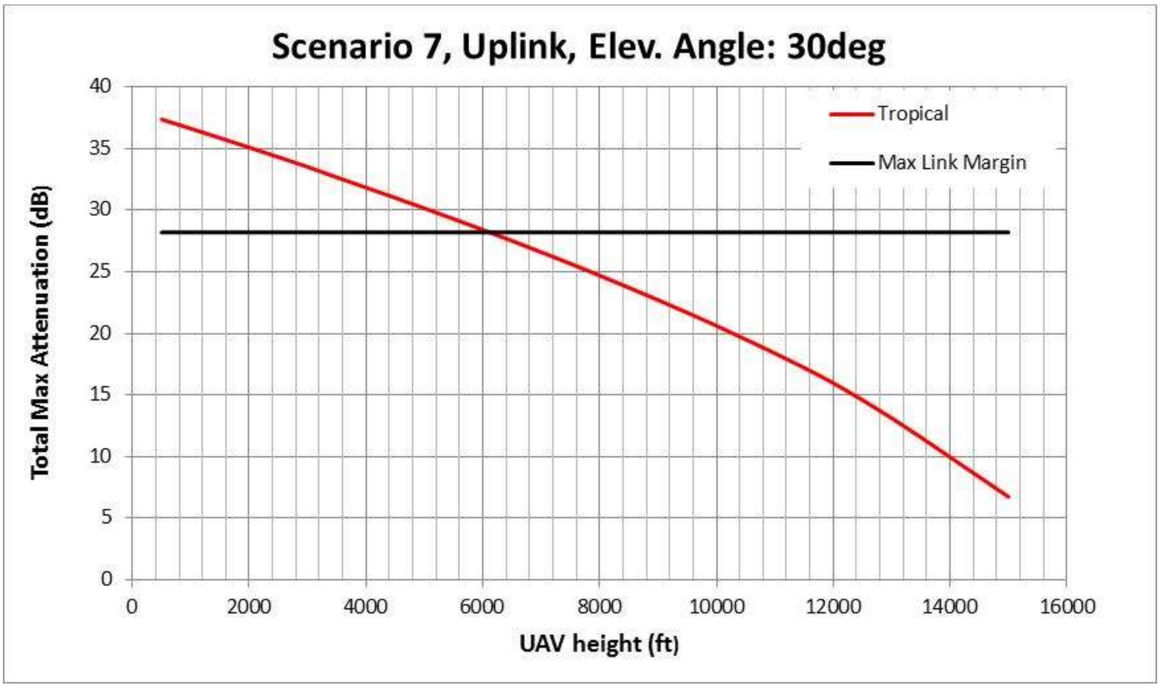
Uplink

Similarly to the downlink, the maximum total attenuation values in the Figures A2-78 to A2-81 can be compared to the link margins in Tables A2-9 to A2-11, for different climatic conditions and elevation angles.

The situation for the uplink is slightly more problematic, because of the higher frequency and correspondingly higher atmospheric attenuation. In any case, considering a maximum available link margin of 28.2 dB for a 1.25 m antenna and beam size 0.3 degrees, availabilities of 100% can easily be achieved for scenarios 4 and 6, by increasing, when necessary, the minimum elevation angle to 25 degrees and 15 degrees, respectively, in the tropical locations.

Scenarios 7 and 8 are more critical for tropical locations as availabilities of 100% can be achieved only for 45 and 90 degrees elevations angles respectively, while a 25 degrees elevation angle is sufficient in dry and temperate areas. However, due to their low altitudes, Scenario 7 and, in particular, Scenario 8 substantially refers to take-off, taxi and landing phases of the flight. In such scenarios, different CNPC links, e.g. Radio Line of Sight (RLOS), could be considered when UAV would operate in tropical locations. In Scenario 7, for a 30 degrees elevation angle, it would be enough for the altitude to be approximately 1830 m (6000ft) to have an availability of 100% in tropical regions (see Figure A 2-82 below).

FIGURE A 2-49



A 2-6. Conclusions

Calculations in this Annex show that very high availabilities (very close to 100%) can be achieved for both the uplink from and the downlink to the UA at 14/11 GHz and 29/19 GHz frequency bands for the different ICAO flight scenarios. Such high availabilities can be achieved for scenarios 1 – 6. Lower availabilities for CNPC links in FSS may occur in tropical regions in Scenario 7 and even more so in Scenarios 8 / 9 because of the low altitudes for take-off and landing. It should be mentioned that those scenarios will be supported by line-of-sight CNPC rather than via satellite.

In case the required availabilities are not met, mitigation techniques addressed in Annex 3 are applicable and sufficiently effective to significantly enhance the availability levels.

ANNEX 3

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

1 Summary

Annex 2 of this Report provides availability figures for typical UAS CNPC FSS links. In line with c*onsidering g)* and *h)* of Resolution **153 (WRC-12)**[1], this Annex then identifies a list of techniques that could be used – if needed – for maintaining or further enhancing the link availability, to meet the required level of link performance.

Such mitigation techniques have been classified as per the list below and described in the relevant sections of this Annex:

1) Redundancy-based mitigation techniques
   a) Link redundancy
   b) UACS site diversity
   c) UAS CNPC System redundancy
2) Signal-based mitigation techniques
   a) use of adaptive code modulation techniques
   b) use of spread-spectrum techniques
   c) utilization of interference detection and cancellation
   d) utilization of uplink power control
   e) automatic re-acquisition
3) Antenna pattern improvements
   a) Use of antennas with improved front-back gain ratios compared to the pattern descriptions in Annex 1 of this report while not degrading the main lobe and sidelobes worse than those ones used in the studies
   b) Improvement of gain roll-off for reducing off-axis e.i.r.p. while meeting the minimum performance as per Annex 1
4) Operational measures
   a) planning of the unmanned aircraft flight
   b) increasing of the elevation angle of the antenna on board the unmanned aircraft.

---

[1] *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;

2 Identification and description of techniques to mitigate the impairments and failures affecting unmanned aircraft system command and non-payload communication links

2.1 Introduction

This Annex provides various mitigation techniques which should be considered when specifying or designing UAS. Application of such techniques may support compliance with given link availability requirements. Options for mitigation measures may be applied individually or in combination, as appropriate. In any case, all nominal link impairments as discussed below are already covered by the typical system characteristics as shown in calculations in Annex 2 which references other annexes for details. The mitigation techniques analyzed below can be used for improving the link availability.

- **Impairments:**
  - Impairments due to atmospheric phenomena:
    - Fading due to rain;
    - Fading due to gaseous absorption;
    - Fading due to cloud attenuation;
    - Fading due to tropospheric scintillation.
  - Interference from other FSS systems;
  - Interference from radio sources other than FSS systems;
  - Miss-pointing of the antennas (that are on board the UAV and/or that are used by the UACS) used for establishing the radio link;
  - Fading due to blockage from the fuselage of the UAV.
- **Failures:**
  - Electronic or mechanical failures of the satellite providing the service;
  - Electronic or mechanical failures of other elements in the UAS CNPC link;

2.2 Redundancy-based mitigation techniques

A technique that could be used for reducing the disruption of the service consists in using an appropriate degree of redundancy in the design of the system.

2.2.1 Link redundancy

Assuming that UAS CNPC links could use two different channels, Channel 1 and Channel 2, once the disruption of the service on the first communication channel would be detected; the UAS terminal should promptly use the other available channel, to maintain the communication with the remote pilot.

The following configurations – or a combination of them – could be implemented for achieving the required redundancy:

1) *Satellite redundancy with "cold" standby*: in this scenario, the UA would be equipped with only one antenna operating at a given frequency band, *Channel 1* and *Channel 2* being provided on two different satellites. *Channel 1* would be the main, while *Channel 2* would be in standby; if interference on the first satellite were detected, the terminal should point the second satellite to re-establish the communication link;

2) *Channel redundancy with "hot" standby*: in this scenario, the UA would be equipped with only one antenna operating at a given frequency band, *Channel 1* and *Channel 2* being provided on the same satellite.

   a) two parallel channels per time: Both channels will be operated simultaneously for link 2 in order to significantly reduce short-term fading by FS interference. In this case the UA is equipped with a two-Channel demodulator but one-channel modulator;

   b) one channel per time: *Channel 1* would be the main, while *Channel 2* would be in standby; if interference on the first channel were detected, the terminal should switch to the second channel to re-establish the communication link. In this case both *Channels* would always be kept "alive", allowing for a quicker swap, if required;

3) *Satellite redundancy with "hot" standby*: same scenario as that illustrated in 1) above, with the only difference that the UA would be equipped with two antennas pointed towards two different satellites. In such case, both *Channels* would always be kept "alive", allowing a quicker swap, if required;

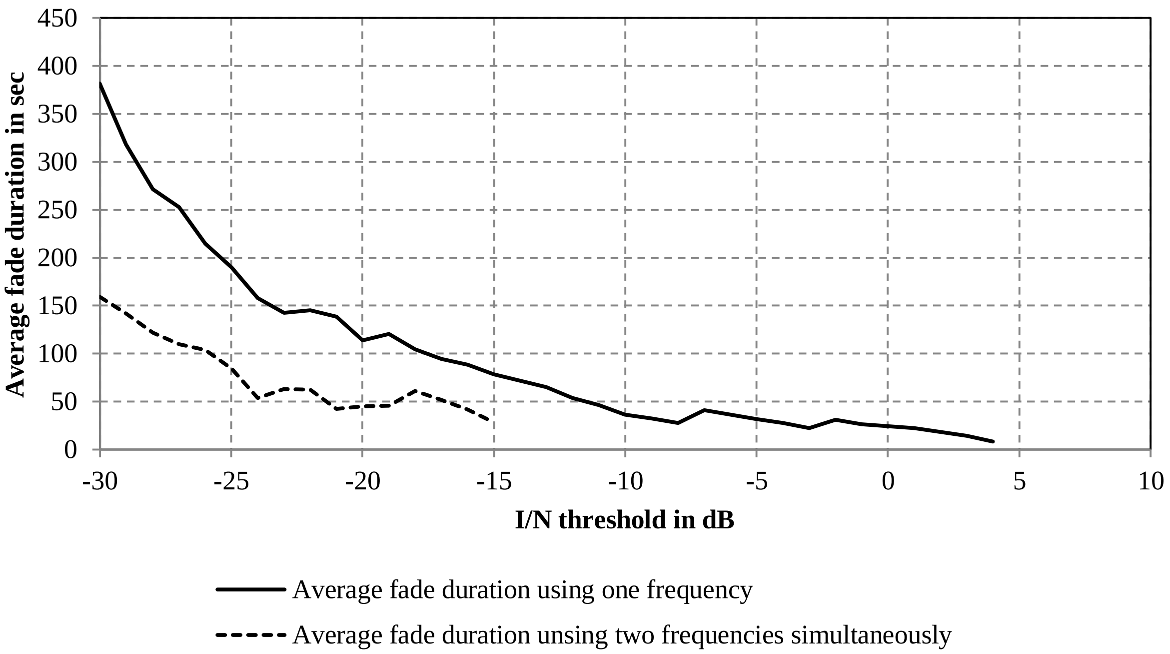
4) *Satellite and band redundancy with "hot" standby*: same scenario as that illustrated in 3) above, with the only difference that the UA would be equipped with two antennas working at different frequency bands (for example, one antenna pointing towards a network working in the frequency ranges 14/11 GHz or 30/20GHz and the other towards a network working at L-band).

2.2.2 Parallel operation of two channels in the same frequency range for link 2

Using a second frequency to receive the UAS CNPC links in hot redundancy the fading durations caused by the terrestrial radio services can be decreased dramatically because of the uncorrelated behavior of the frequencies. The following figure exemplarily shows the reduction of the average fading duration per dedicated I/N threshold when using two frequencies in link 2 simultaneously instead of one only. This diagram should be read as follows: Assuming a permissible I/N of -20 dB the average durations of exceeding this threshold (fading duration) per day would be 115 seconds (one link 2 frequency) and 45 seconds (two link 2 frequencies simultaneously).

FIGURE A3-1

Average fade duration per I/N threshold, flight scenario 2, 11 GHz



2.2.3 Unmanned aircraft control station site diversity for links 1 and 4

In order to enhance the resulting availability of the UAS CNPC links, UACS earth stations could be located in multiple sites on which weather conditions would be independent. If each of the UACS earth stations could serve as a backup of the other(s), since the swap from one to the other(s) can be made in a transparent manner from a system perspective, such a site diversity would overcome the issue of a temporary impairment (such as a thunderstorm affecting one of the sites) or equipment/infrastructure failures that might put the communication from/to the UA at risk.

2.2.4 Equipment redundancy

Equipment on board the satellites, on board the UA and in the UACS can be designed with the customized target of availability (e.g. redundant electronic and RF equipment).

2.2.5 System redundancy

Depending on the flight phase and the airspace actually used by an UA, CNPC messages between the remote pilot and the vehicle can be exchanged by using two independent systems:
one employing a terrestrial link and another one employing a satellite link.

2.3 Signal-based mitigation techniques

2.3.1 Use of adaptive code modulation techniques

The margins offered by typical UAS CNPC links analyzed in Annex 2 of this report are determined by assuming modulation and coding schemes which use state-of-the-art waveform standards.
In order to allow the correct demodulation and decoding of the CNPC messages, a minimum threshold in terms of E_b/N_0 is needed to achieve the required bit error rate (*BER*) for a pre-determined link bitrate. If, for any reason, the E_b/N_0 of the link falls below such a pre-determined threshold, the waveform used can quickly be “adapted”, such that a lower minimum threshold is required to achieve the same *BER*. This comes at the expense of the bandwidth occupied by the

carrier, such that, by maintaining the required bitrate and BER, a lower E_b/N_0 threshold generally requires a wider carrier. Such feature is commonly referred to as ACM and is usually part of modern state-of-the-art modems used in satellite communications.

2.3.2 Use of spread-spectrum techniques

The minimum $C/(N+I)$ threshold to receive a digital signal can be significantly reduced by using spread-spectrum techniques. Such techniques usually consist in multiplying the transmitted signal by a pseudorandom direct-sequence such that the final transmission resembles to white noise. When the wanted recipient receives the signal, the latter is multiplied by the same sequence in order to obtain the information originally transmitted. This technique allows increasing the total e.i.r.p. of the wanted CNPC signal while maintaining the same e.i.r.p. spectral density (such as those indicated in Recommendation ITU-R S.524 and RR Article **21**), at the expense of an increased bandwidth use and higher HPA requirements. It is then particularly effective for increasing the margin available to those sections of the links where the compliance with an off-axis e.i.r.p. spectral density is a limiting factor, and also reduces the impact of interference caused by narrow band signals. It should be noted that, for example, a link employing a spread-spectrum factor coding equal to 8, together with the use of a BPSK modulation, is able to realize an additional link margin of more than 10 dB if compared to one using a QPSK modulation over a carrier not spread.

2.3.3 Utilization of interference detection and cancellation

Interference cancellation techniques can be applied to compensate potential impact of harmful co-channel interference. The active interference cancellation is based on the signal processing on the receiver side, e. g. by

– active antennas (phased array or multibeam antennas) can be used to cancel interference which is spatially separated from the wanted signal;

– extracting the wanted signal by subtracting the independently measured co-channel interference signal from the aggregate. Such measures are particularly well suited to compensate interference from terrestrial service transmissions.

2.3.4 Utilization of uplink power control

2.3.4.1 For link 1

UPC mechanisms are assumed to be permanently installed and operated in all UACS; therefore, this technique has already been taken into account in the link budgets in Annex 2. UPC provides constant uplink power level at the satellite independent from the actual propagation conditions.

2.3.4.2 For link 3

UPC on board the UA is also an appropriate means for the compensation of the uplink propagation impairments. Because of the adaptive characteristics, the e.i.r.p. spectral density allowed limits (e.g. those contained in Recommendation ITU-R S.524) can be maintained also under rain conditions.

2.3.5 Automatic re-acquisition

Automatic re-acquisition schemes, where the UA and UACS automatically attempt to re-connect after a temporary loss of the UAS CNPC link, are standard practice in current UAS.

2.4 Antenna improvements

The analysis of the short term interference uses the antenna pattern of Recommendation ITU-R S.580 according to the Annex 1 characteristics. This antenna pattern is a design objective for earth station operating with geostationary satellite to optimize the spacing between satellites. The main use is for fixed location and defined for efficient sidelobe characteristics. For these kinds of stations there is no need for précising the back lobe performance and therefore the back lobe gain is generally limited to -10 dB.

For the special kind of UA operations the back lobe gain plays a more significant role in the sharing studies (especially those in Annex 6) and therefore an alternative antenna gain model has been introduced.

FIGURE A3-2

Comparison Rec. ITU-R S.580-6 antenna envelope with ideal Airy pattern

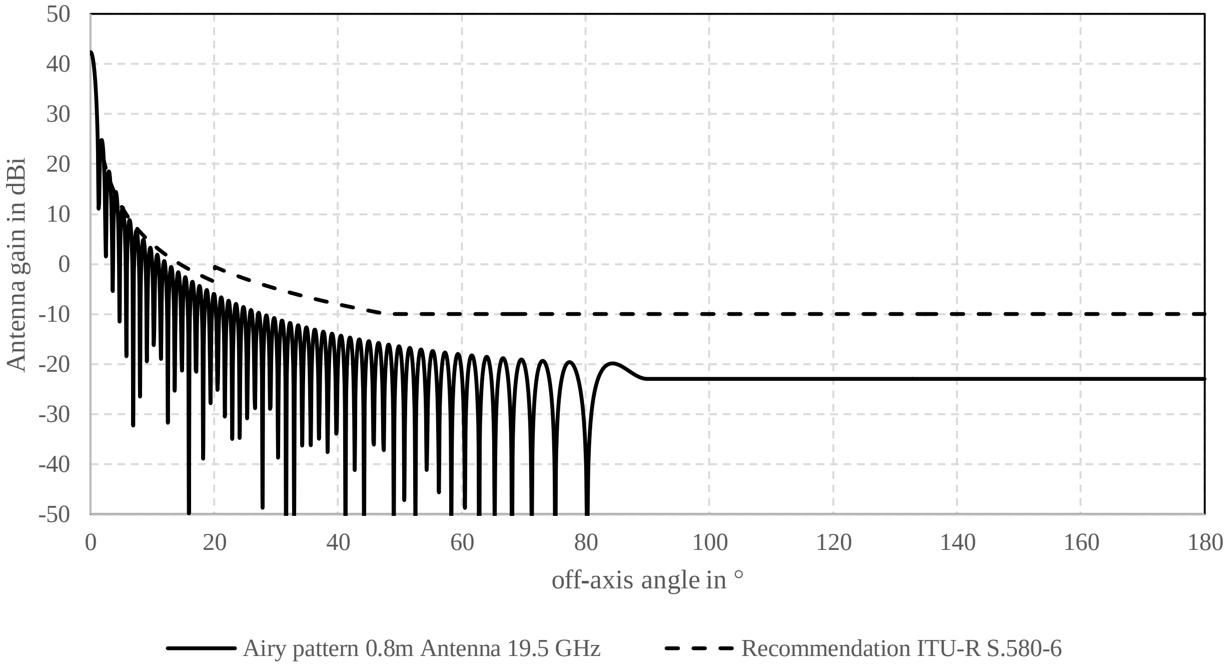


Figure A3-2 compares the envelope of Recommendation ITU-R S.580 with the ideal Airy pattern for circular apertures describing the best focused antenna pattern with circular apertures. The Airy pattern describes the lower ("perfect") boundary of achievable antenna performance and the pattern for the circular aperture antenna is calculated by:

$$G(\varphi) = G_{max} + 20 \cdot \log_{10}\left(\left|2\frac{J_1\left(\pi\frac{D}{\lambda}\sin\varphi\right)}{\pi\frac{D}{\lambda}\sin\varphi}\right|\right) \quad \text{A3-1}$$

where:

G_{max} as the on axis antenna gain in dBi;

J_1 as the Bessel function of the first kind;

D as antenna diameter in m;

λ as wave length in m;

φ as the off-axis angle in °.

The side lobe and back lobe performance of a measured antenna could be approximately 10 dB better than Recommendation ITU-R S.580 even for a small antenna of 0.8 m diameter. This improved performance leads to a better performance in terms interference isolation from FS stations than achieved in the analyses based on Recommendation ITU-R S.580.

2.5 Operational measures

While the discussion above has identified technical means of mitigating link impairments, in addition other complementary operational measures could be used to further enhance the link performance, in order to meet the aviation authorities' communication requirements. Operational measures for UAS could be implemented such that the likelihood for the impairments listed in Section 2.1 above to occur would be reduced or even eliminated. The following represent some examples on how the operational planning of these systems could benefit their safe operation.

2.5.1 Planning of the unmanned aircraft unmanned aerial vehicle flight

Flights of aircraft are generally planned before that they actually occur. The process is usually agreed with the aviation authorities of those countries whose airspace the aircraft is foreseen to fly through. For an UA, that plan can be designed such that the unmanned aircraft avoids areas and flight scenarios where it is more likely for an impairment to occur. For example, an UA should avoid:

– operation outside the appropriate satellite service area;

– operation causing obstruction of the terminal antenna;

– operation in areas affected by adverse weather phenomena;

– operation in areas expected to be affected by known interference.

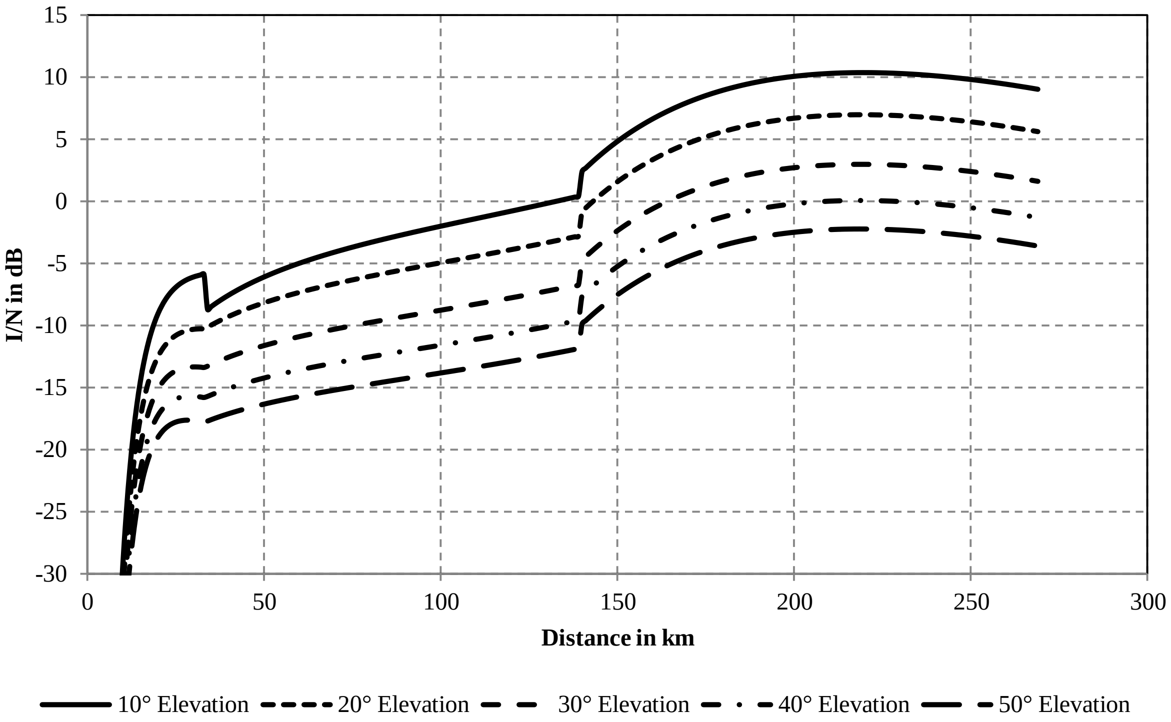
2.5.2 Increase of the elevation angle of the antenna on board the unmanned aerial vehicle

Those link impairments due to weather phenomena affect the radio links between the UA and the wanted satellite particularly at low elevation angles, both in the downlink and uplink directions. As shown in the analysis carried out in Annex 2, a simple method to overcome such issue consists in operating the UA antenna with a higher elevation angle. For any given area of UAS operations, a minimum required elevation angle can be determined at which the availability requirements are just met. The design of the UAS should be such that within the area of concern, the expected range of elevation angles to the satellite(s) always exceeds the minimum value. Since atmospheric phenomena are more important in tropical regions near the equator, where high elevation angles are typical, such a system design condition should not represent a significant constraint.

The increase of elevation will also support the interference isolation performance of the UA antenna against interference from incumbent terrestrial services. The following Figure A3-3 exemplarily shows the reduction of *I/N* as a plot over the distance between FS station and the UA. For example, increasing the elevation from 10° to 20° reduces the interference impact by about 3 to 4 dB compared to the worst case analyses being done in Annexes 2, 6 and 7.

FIGURE A3-3

***I/N* into the unmanned aircraft antenna main lobe per distance to the fixed service station for different unmanned aircraft antenna elevation angles flight scenario 2, 11GHz**



3 Relationship between the link impairments and failures affecting unmanned aircraft system command and control links and corresponding mitigation techniques

The following table summarizes the suitability of techniques to mitigate different impairments and failures.

TABLE A3-4

Relationship between link impairments and failures of the techniques to mitigate the impairments and failures affecting unmanned aircraft system command and non-payload communication links and corresponding mitigation techniques

Category of mitigation techniques	Mitigation technique	Trigger for mitigation		
		Impairments		Failures
		Propagation	Interference	
Redundancy-based	Link redundancy	✓✓	✓✓	✓✓✓
	UACS site diversity	✓✓✓	✓	✓✓
	Equipment redundancy	N/A	N/A	✓✓✓
	System redundancy	✓✓	✓✓	✓✓
Signal-based	ACM	✓✓	✓	N/A
	Spread Spectrum	✓✓	✓	N/A
	Interference detection and cancellation	N/A	✓✓✓	N/A
	Uplink Power Control	✓✓✓	✓	N/A
	Automatic signal re-acquisition	✓✓	✓✓	✓✓
Antenna improvement	Improvement of front-back gain ratio	N/A	✓✓✓	N/A
	Improvement of gain roll-off for reducing off-axis EIRP	N/A	✓✓✓	N/A
Operational measures	Planning of the UAV flight	✓✓✓	✓✓	N/A
	Increase of the elevation angle of the antenna on board the UAV	✓✓✓	✓	N/A

✓ = Partially relevant, applicable in few cases
✓✓ = Relevant, applicable in most cases
✓✓✓ = Very relevant, applicable for all cases
N/A = Not Applicable

ANNEX 4

Characteristics of incumbent terrestrial services used in sharing studies

A 4-1 Introduction

Tables 3 and 4 of the report define the frequency bands allocated to the FSS which are considered to qualify for studies on UA CNPC application. Services allocated as direct table entries and services which are allocated through country footnotes will be summarized in this Annex. FSS is shared with incumbent services with primary allocations.

In the 14/11 GHz frequency range:

- Fixed service
- Mobile service
- Broadcasting satellite service (Region 3)
- Radionavigation service
- Space research service.

In the 30/20 GHz frequency range:

- Fixed service
- Mobile service
- Space research service
- Earth exploration-satellite service.

A 4-2 Fixed service

The fixed service characteristics shown in Table A4-1 through Table A4-4 are taken from Recommendations

F.699-7 (04/06) "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz"

ITU-R F.758-5 " 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".

This Recommendation refers further to ITU-R Recommendations describing FS systems operated in the frequency bands under study.

ITU-R F.1094 "Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources".

F.1245-2 (03.12) "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.1494 "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 “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 “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 SF.1006 “Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service”.

ITU-R SF.1650 “The minimum distance from the baseline beyond which in-motion earth stations located on board vessels would not cause unacceptable interference to the terrestrial service in the bands 5 925-6 425 MHz and 14-14.5 GHz”.

TABLE A4-1

Typical fixed service parameters 10.7-11.7 GHz

(Extracted from Recommendation ITU-R F.758 Table-7)

Frequency range	Units	10.7-11.7 GHz	
Reference ITU-R Recommendation		F.387	
Modulation		16-QAM	64-QAM
Channel spacing and receiver noise bandwidth	MHz	5, 10, 20, 40, **60**, 67, 80	5, 10, 20, **40**, 60, 67, 80
Tx output power range	dBW	3…5.0	0.0
Tx output power density range	dBW/MHz	−14.8...−12.8	−16.0
Feeder/multiplexer loss range	dB	0…9.5	0…7.6
Antenna gain range	dBi	44…51	36…48.0
e.i.r.p. range	dBW	33.1...51.2	13.3…43.0
e.i.r.p. density range(1)	dBW/MHz	15.3...33.4 (Mode 28.5)	−2.7…27.0 (Mode 15.9)
Receiver noise figure typical	dB	5	5
Receiver noise power density typical (=N_{RX})	dBW/MHz	−139	−139
Normalized Rx input level for 1×10^{-6} BER	dBW/MHz	−118.5	−112.5
Nominal long-term interference power density(2)	dBW/MHz	−139 + I/N	−139 + I/N

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by “Receiver noise power density + (required *I*/*N*)” as described in § 4.13 in Annex 2 (see also § 4.1 in Annex 1).

TABLE A4-2

Typical fixed service parameters 14.4.-15.35 GHz

(Extracted from Recommendation ITU-R F.758 Table 8)

Frequency range	**Units**	**14.4-15.35 GHz**	
Reference ITU-R Recommendation		F.636	
Modulation		FSK	128-QAM
Channel spacing and receiver noise bandwidth	MHz	2.5, **3.5**, 7, 14, 28	2.5, 3.5, 7, 14, **28**
Tx output power range	dBW	0	15
Tx output power density range(1)	dBW/MHz	-5.44	0.528
Feeder/multiplexer loss range	dB	0…6.0	0…5.0
Antenna gain range	dBi	37	31.9
e.i.r.p. range	dBW	31…37	41.9…46.9
e.i.r.p. density range(1)	dBW/MHz	25.6…31.6	27.4…32.4
Receiver noise figure typical	dB		8
Receiver noise power density typical (=N_{RX})	dBW/MHz		-136
Normalized Rx input level for 1×10^{-6} BER	dBW/MHz		-106.5
Nominal long-term interference power(2)	dBW/MHz	-136 + I/N	-136 + I/N

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by “Receiver noise power density + (required *I*/*N*)” as described in § 4.13 in Annex 2 (see also § 4.1 in Annex 1).

TABLE A4-3

Typical fixed service parameters 17.7-19.7 GHz

(Extracted from Recommendation ITU-R F.758 Table 8)

Frequency range	**Units**	**17.7-19.7 GHz**	
Reference ITU-R Recommendation		F.595	
Modulation		QPSK	64-QAM
Channel spacing and receiver noise bandwidth	MHz	1.25, 1.75, 2.5, 3.5, 5, **7**, 7.5, 10, 13.75, 20, **27.5**, 30, **40**, 50, **55**, 60(5), **110**, 220	1.25, 1.75, 2.5, 3.5, 5, 7, 7.5, 10, 13.75, 20, 27.5, 30, **40**, 50, 55, 60(5), 110, 220
Tx output power range	dBW	−37…−3.0	−10
Tx output power density range(1)	dBW/MHz	−45.4…−19.0	−26
Feeder/multiplexer loss range	dB	0.0…2	0…9.3
Antenna gain range	dBi	21.7…48.3	32…45
e.i.r.p. range	dBW	−4.4…43	−1.1...33
e.i.r.p. density range(1)	dBW/MHz	−13.1…27.3 (Mode 16.2)	−17.1...17 (Mode 8.0)
Receiver noise figure typical	dB	5.0	5
Receiver noise power density typical (=N_{RX})	dBW/MHz	−139	−139
Normalized Rx input level for 1×10^{-6} BER	dBW/MHz	−125.5	−112.5
Nominal long-term interference power density(2)	dBW/MHz	−139 + *I/N*	−139 + *I/N*

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by "Receiver noise power density + (required *I/N*)" as described in § 4.13 in Annex 2 (see also § 4.1 in Annex 1).

TABLE A4-4

Typical fixed service parameters 24.25-29.5 GHz

(Extracted from Recommendation ITU-R F.758 Table 8)

Frequency range	**Units**	**24.25-29.50 GHz**
Reference ITU-R Recommendation		F.748
Modulation		16-QAM(6)
Channel spacing and receiver noise bandwidth	MHz	2.5, 3.5, 5, **7**, 14, 28, 40(5), 56, **60**(5), 112
Tx output power range	dBW	−39…−19.0
Tx output power density range(1)	dBW/MHz	−53.8…−33.8(6)
Feeder/multiplexer loss range	dB	0.0
Antenna gain range	dBi	31.5
e.i.r.p. range	dBW	−7.5…12.5
e.i.r.p. density range(1)	dBW/MHz	−21.3…-2.3(6)
Receiver noise figure typical	dB	8
Receiver noise power density typical (=N_{RX})	dBW/MHz	−136
Normalized Rx input level for 1×10^{-6} BER	dBW/MHz	−115.5
Nominal long-term interference power density(2)	dBW/MHz	−136 + *I*/*N*

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by "Receiver noise power density + (required *I*/*N*)" as described in § 4.13 in Annex 2 (see also § 4.1 in Annex 1).

(5) Frequency block bandwidth.

(6) These Tx/e.i.r.p. density values are calculated from a channel spacing (bandwidth) of 30 MHz within a 60 MHz frequency block.

A 4-3 Mobile service

No technical characteristics of the systems operating in the land mobile service for the frequency bands 10.95-12.75 GHz, 14.0-14.5 GHz, 17.3-20.2 GHz and 27.5-30.0 GHz have been identified.

A 4-4 Broadcasting-satellite service

In Region 2, the frequency band 12.5-12.7 GHz is allocated to the broadcast satellite service (BSS) however, in Region 2 this frequency band is an RR Appendix 30, 30A, 30B band and was not considered for Region 2 in this analysis.

In Region 3, the frequency band 12.5-12.75 GHz is allocated to the BSS and supports space-to-Earth transmissions. Further, the BSS transmissions operate within a maximum power flux density described in RR **No. 5.493**. Therefore, such provision should be taken into account in application of the procedures under Article **9** as for any typical FSS link and would be considered in the coordination processes.

A 4-5 Radionavigation services

There are no records in the ITU Master Registry 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.

A 4-6 Space research service

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

A 4-7 Earth exploration satellite service

In the frequency band 28.5-30.0 GHz, the EESS allocation supports Earth-to-space transmissions from earth stations in the EESS to satellites of the EESS. The EESS operation in the frequency 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 frequency band 29.5-30.0 GHz 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.

In the frequency 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 will not contribute to that interference. Therefore, the EESS was not considered in the analysis of the frequency band 18.6-18.8 GHz.

ANNEX 5

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

A5-1 Introduction

This Annex provides an estimate of the realistic worst-case interference received by earth stations on board UA as well as the interference received by space stations supporting UA, from other fixed satellite service systems when operating in the frequency bands 14/11 GHz and 30/20 GHz. This estimate can then be taken into account when designing those systems with which UAS will operate. However, the analysis presented does not account for potential interference to and from NGSO FSS systems, and some additional analysis might then be needed in those frequency bands where No. **9.11A** applies (see Nos. **5.523A**, **5.523D**, **5.535A).**

The analysis contained in this Annex does not take into account any interference contribution UAS could suffer from systems other than FSS, as this aspect is already covered and addressed in Annexes 6 and 7 of this Report.

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 applicable for the use of the FSS frequency bands 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.

No analysis of interference into other FSS earth or space stations was performed in Annex 5 because, based on the fundamental assumption stated above, that UAS-FSS systems will operate under the same constraints as any other FSS and so will not cause any more interference than any non-UAS FSS earth or space station.

It should be noted that ICAO, other standards bodies and the designers of the earth stations on board UA will have to take care to ensure compliance with ITU-R S.524, in particular during aircraft maneuvering, so that the off-axis e.i.r.p. density levels stated therein are never exceeded.

The characteristics and performance values used for the analysis carried out in this Annex are the same as those used elsewhere in this Report for computing the margins available to links #2 and #3 in the frequency bands 14/11 GHz and 30/20 GHz. These margins are more than adequate to compensate for the interference received by the UA or the space station supporting the UA.

It should be noted that the analysis is generally based on realistic worst-case assumptions and that interference levels lower than those indicated in this Annex are more likely in real world scenarios.

Furthermore, it is highlighted 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.

A5-2 Summary of the analysis

GSO FSS satellite systems can share the same frequency bands in the same geographical area thanks to the directivity of the antennas used by earth stations, including those on the UA, and to the fact that GSO FSS satellites are separated sufficiently by an appropriate geocentric angle on the GSO arc. In order to maximise the efficiency of the use of the GSO arc, a certain amount of inter-system interference to FSS earth stations and space stations is usually tolerated and GSO FSS systems are required to be designed to take this interference into account.

The FSS inter-system interference levels are known to FSS operators, after coordination of satellite frequency assignments. These coordination and notification processes are carried out in accordance with Articles **9** and **11** of the Radio Regulations.

Taking into account the information contained elsewhere in this Report, the analysis presented in the following Section 3 provides analysis of the realistic worst-case level of the interfering signals received by the earth station on a UA from other GSO FSS satellites[A5-1]. Details for those calculations can be found in Section 5.

The analysis presented in Section 4 focuses on the computation of the realistic worst-case level of interference received by the GSO FSS satellites used by UAS CNPC links from earth stations operating with other GSO FSS space stations. Details for those example calculations can be found in section 6.

The results of this analysis may be taken into account in the design of UAS operating CNPC links in FSS allocations.

A5-3 Realistic worst-case interference received by earth stations on board unmanned aircraft (Link #2)

Like any other typical FSS earth station, those operating on board UA for the provision of CNPC links can receive interference from signals transmitted by other GSO FSS space stations adjacent to the wanted one using the same frequencies in the same geographical area as that served by the wanted satellite. As explained in Section 2, in addition to the directivity of the earth station antennas used for FSS applications, the sharing of the same resources by distinct GSO FSS systems is possible when the space stations are located at different longitudes sufficiently apart in the GSO arc. There is no minimum orbital separation required by the ITU regulatory procedures, as specific arrangements among administrations and satellite operators can be reached through the provisions of RR Article **9**. Nevertheless, in the 14/11 GHz and 30/20 GHz bands, it is common practice to have satellites spaced in the GSO arc by at least 2 degrees from each other to ensure their effective operation.

Computation of the interference has been carried out assuming the following:

[A5-1] Since UACS stations are expected to be equipped with very large antennas, the FSS inter-system contribution received by them is expected to have much a lower impact on the overall CNPC link performance. So the interference received by UACS stations from other GSO FSS satellites is not considered in this analysis.

– The assumptions made are consistent with the information contained in other parts of this Report

– In order to consider a realistic worst-case scenario, it is assumed that the UA operates from a location which is at the edge of coverage of the wanted satellite footprint and at the centre of the respective beams of the interfering satellites.

– Still to depict a realistic worst-case scenario, it is assumed that the adjacent satellites transmit either with powers consistent with the limits contained in Section V of RR Art. **21** and averaged over 1 MHz at the centre of the beam or with typical downlink powers but not limited by any agreement usually achieved in coordination;

– The example analysis is limited to the interference received by the UA from the nearest four space stations on each side of the satellite being used. From the calculations illustrated in Section 5 below, it can be seen that the impact of satellites which are farther away on the GSO arc is negligible;

– Various satellite orbital spacing's are considered, from ±2 deg. to ±3.5 deg. in steps of 0.5 deg. These small orbital separations are certainly worst case scenarios and should not be interpreted as a recommended practice of the accommodation of UAS FSS in GSO FSS space stations. In practice, the orbital separation distances for co-frequency and co-coverage operation of different GSO FSS satellites are very variable around the geostationary orbit.

The following Table A5-1 summarises the realistic worst-case interference expected to be received by the UA in the case of a spacing regime of ±2 deg. Section 5 contains a breakdown of the calculation carried out for obtaining these results.

TABLE A5-1

Summary of *C/N* degradation at the unmanned aircraft receiver

Parameter	Unit	11 GHz band	18 GHz band (relative to parts in which Art. 21 applies)	20 GHz band (relative to parts in which Art. 21 does not apply)
Frequency	MHz	11 000	18 000	20 000
I (total of 8 satellites)	dBW/Hz	–200.75	–195.31	–201.53
I/N	dB	4.8	11.2	3.6
C/N degradation	dB	6.1	11.5	5.1

When comparing the degradation in C/N caused by non-coordinated realistic worst-case interference with the minimum link margins shown in Annex 2 of:

- 6.2 dB in 11 GHz band,
- 16.4 dB in 19 GHz band

it can be noted these allowances are more than adequate to compensate for the interference received by the UA.

A5-4 Realistic worst-case interference received by space stations supporting unmanned aircraft control and non-payload communication links (Link#3)

Like any other typical FSS space station, those used for the provision of UAS CNPC links are subject to the interference caused by earth stations operating with adjacent satellites.
The interference is due to the off-axis power spilled-over from the boresight of their antennas.

A basic assumption taken into account for the computation of such interference is the compliance of any earth station with Recommendation ITU-R S.524, which recommends maximum e.i.r.p. spectral density values averaged over 40 kHz for earth stations communicating with GSO FSS satellites. Although specific arrangements among the interested operators and administrations are always possible, these recommended levels provide a good reference point for these studies.
The following analysis assumes the UA antenna off-axis power to comply with Recommendation ITU-R S.524 as is also indicated elsewhere in this Report.

The figures summarised in the following Table A5-2 (14 GHz) and Table A5-3 (30 GHz) are computed by taking into account the interference caused by those earth stations operating with the nearest four GSO FSS satellites (on each side) on the geostationary arc. Like in the analysis presented in the preceding section, a 0.1 deg. station keeping box for the various space stations has been taken into account[A5-2].

Furthermore, as a realistic worst-case assumption, it is assumed that all those satellites are operating co-frequency in the same geographical area as the UA operates.

TABLE A5-2

Aggregate off-axis e.i.r.p. spectral density in the direction of the wanted geostationary orbital position of a satellite operating in the fixed satellite service at 14 GHz supporting unmanned aircraft system control and non-payload communication links[A5-3]

Satellite spacing regime	Aggregate uplink off-axis e.i.r.p. spectral density
(deg)	(dB(W/Hz))
±2.0	–11.0
±2.5	–13.4
±3.0	–15.3
±3.5	–16.9

A5-2 This means that the topocentric angle between the boresight of the interfering earth station and the wanted satellite is (x – 0.1) 1.1, where x is the difference (in degrees) of the longitudes of the two space stations considered.

A5-3 The interference is evaluated at the receiving antenna of the satellite.

TABLE A5-3

Aggregate off-axis e.i.r.p. spectral density in the direction of the wanted geostationary orbital position of a satellite operating in the fixed satellite service at 30 GHz supporting unmanned aircraft system control and non-payload communication links[A5-4]

Satellite spacing regime	Aggregate uplink off-axis received e.i.r.p. spectral density
(deg)	(dB(W/Hz))
±2.0	–31.0
±2.5	–33.4
±3.0	–35.3
±3.5	–36.9

It should be noted the UA CNPC interference allowance in the link budgets presented in Annex 2 of this Report are higher than the degradation in the CNPC link due to inter-system interference as estimated within this annex. Consequently these allowances are more than adequate to compensate for the interference received by the space station supporting the UA. It would therefore be possible to counter the effects of a set amount of inter-system interference, because all calculated link margins are higher than any potential C/N degradations that the CNPC links will encounter even the worst case inter-system interference.

A5-5 Computation of the interference received by earth stations on board unmanned aircraft

In general, the antennas of earth stations on board UA always point to the wanted satellite. So the most significant interference to earth stations on board UA is caused by those GSO satellites which are adjacent to the wanted satellite, operate in the same frequency band and in the same geographical area as the wanted satellite.

The aggregate interference received by earth stations on board UA from four adjacent GSO satellites at both sides, i.e. the total number is eight, is calculated.

It is assumed that the minimum orbital separation in the GSO arc is 2 degrees in the 11 and 20 GHz frequency bands. These small orbital separations are certainly worst case scenarios and should not be interpreted as a recommended practice to accommodate UAS FSS in GSO FSS space stations. The orbital separation distances for co-frequency and co-coverage operation of different GSO FSS satellites are very variable around the geostationary orbit.

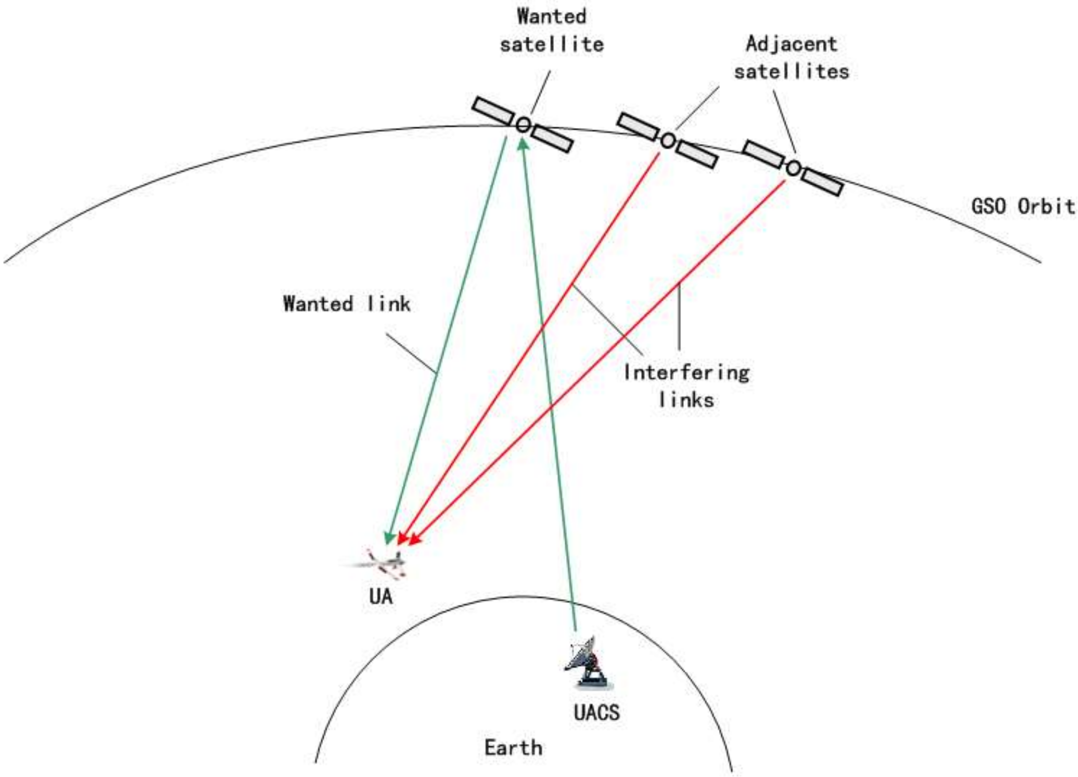
In order to consider an example realistic worst-case scenario, it is assumed that the UA operates from a location which is at the edge of coverage of the wanted satellite footprint and at the centre of the respective beams of the interfering satellites.

The scenario of the study is shown in Figure A5-1.

A5-4 The interference is evaluated at the receiving antenna of the satellite.

FIGURE A5-1

Scenario of the study



The UAS characteristics used in this study are consistent with the information contained in Annex 1 of this Report.

TABLE A5-4

Parameters for unmanned aircraft systems control and non-payload communications links

Parameter	**Units**	**11 GHz frequency band**	**20 GHz frequency band**
Frequency	GHz	11	20
Satellite e.i.r.p. spectral density	dB(W/MHz)	39	51.5
Antenna Temperature	K	200	220
Maximum Antenna Gain	dBi	$20 \log \frac{D}{\lambda} + 7.7$	$20 \log \frac{D}{\lambda} + 7.7$
Antenna Pattern		ITU-R S.580	ITU-R S.580
Antenna Diameter	m	0.45, 0.8 and 1.25	0.45, 0.8 and 1.25
Antenna elevation angle	deg	10.0	10.0

The characteristics of the interfering satellites can be found in Section V of RR Art. **21**, as listed in the second row of Table A5-5.

TABLE A5-5

Power flux density for interfering satellites

Parameter	Units	11 GHz frequency band	20 GHz frequency band
Frequency	GHz	10.7-11.7	19.3-19.7
Formula for limit for angles of arrival 5-25° above the horizontal plane	dB(W/m^2)	−150 + 0.5(δ − 5) (/4kHz)	−115+0.5(δ − 5) (/MHz)
Value of limit for 10°angles of arrival above the horizontal plane	dB(W/m^2)	–123.5 (/MHz)	–112.5 (/MHz)

For time harmonic (sinusoidal) fields, the mean power flux-density can be written

$$\Phi = \frac{\left|\left[\vec{E} \times \vec{H}^*\right]\right|}{2} = \frac{\left|\vec{E}\right|^2}{2\eta}$$

where:

- Φ – time mean value of Pointing's vector spectral density (W/m^2)
- E – Maximum magnitude of electrical field strength (Volt/meter)
- H – Maximum magnitude of magnetic field strength (Ampere/meter)
- $\boldsymbol{\eta}=120\pi$ – wave impedance of free space (Volt/Ampere)
- R – slant path distance.

The factor ½ in the above formulation arises from the time average of the sinusoidal field functions.

The above mean power flux-density could be averaged over frequencies and converted into power spectral density $EIRP_d$ available from an isotropic antenna located at the same point density transmitted by the satellite following this expression

$$EIRP_d = 4\pi R^2 \Phi$$

With Table A5-6, the signal power spectral density received by earth stations on board UA from the wanted satellite can be calculated as following:

$$S = EIRP_{Wanted} + G_{\max} - L$$

where:

- S– wanted signal power received by earth stations on board UA, dB(W/MHz)
- $EIRP_{wanted}$ – Equivalent isotropic radiated power from the wanted satellite, dB(W/MHz)
- G_{max} – maximum gain of the UA antenna, dBi
- L– propagation loss, dB.

Applying the above formula, this equates to a satellite e.i.r.p spectral density of 39.6 dB (W/MHz) for the 11GHz band and 50.7 dB(W/MHz) for the 18/20GHz band corresponding to the maximum pfd limits at 10 degree elevation angle specified in Table 5-5. While in parts of the 18/20GHz band where Article **21** limits do not apply, the maximum interference satellite e.i.r.p spectral density is assumed to be 44 dB(W/MHz) as representative of the maximum downlink power densities in use within these sub-bands.

The aggregate interference received by earth stations on board UA can be derived by accumulating the interference caused by four adjacent GSO satellites on each side adjacent to the wanted satellite (eight in total). The impact of satellites which are farther away on the wanted satellite is negligible. Table A5-6 gives the details of the calculation of the aggregate interference.

TABLE A5-6

Results of aggregate interference

Parameter	**Units**	**11 GHz frequency band**	**18 GHz frequency band (relative to parts in which Art. 21 applies)**	**20 GHz frequency band (relative to parts in which Art. 21 does not apply)**
Frequency	MHz	11 000	18 000	20 000
Eirp_adj	dB(W/MHz)	39.6	50.7	44
Geocentric separation (1st adjacent satellite)	degrees	2	2	2
Geocentric separation (2nd adjacent satellite)	degrees	4	4	4
Geocentric separation (3rd adjacent satellite)	degrees	6	6	6
Geocentric separation (4th adjacent satellite)	degrees	8	8	8
off-axis angle (1st adjacent satellite)	degrees	2.09	2.09	2.09
off-axis angle (2nd adjacent satellite)	degrees	4.29	4.29	4.29
off-axis angle (3rd adjacent satellite)	degrees	6.49	6.49	6.49
off-axis angle (4th adjacent satellite)	degrees	8.69	8.69	8.69
Gr(θ) (1st adjacent satellite)	dBi	21.00	21.00	21.00
Gr(θ) (2nd adjacent satellite)	dBi	13.19	13.19	13.19
Gr(θ) (3rd adjacent satellite)	dBi	8.69	8.69	8.69
Gr(θ) (4th adjacent satellite)	dBi	8	8	8
Path Distance	km	40 586	40 586	40 586
Path loss	dB	205.40	210.6	210.6
I (1st adjacent satellites)	dBW/Hz	–201.8	–196.0	–202.6
I (2nd adjacent satellites)	dBW/Hz	–209.6	–203.8	–210.4
I (3rd adjacent satellites)	dBW/Hz	–214.1	–208.3	–214.9
I (4th adjacent satellites)	dBW/Hz	–214. 9	–208.9	–215.6
I (total of 8 satellites)	dBW/Hz	–200. 8	–194.9	–201.6

A5-6 Realistic worst-case aggregate interference received by geo stationary space stations supporting Unmanned Aircraft control and non payload communications links

This section provides the detailed steps through which the values listed in Table A5-4 and A5-5 were derived.

A5-6.1 Computation of the realistic worst-case aggregate interference at 14 GHz due to GSO satellites on both sides of the satellite supporting the UA

The following tables estimate the maximum aggregate off-axis e.i.r.p. density transmitted from earth stations towards an adjacent satellite. The calculation assumes the transmitting earth stations are in compliance with Recommendation ITU-R S.524-9 levels at 14 GHz, which is expressed in a reference bandwidth of 40 kHz. In order to facilitate a simplified modelling, it is assumed that the signal power is evenly distributed within the reference bandwidth so as the e.i.r.p. spectral density can be converted into a 1 Hz reference bandwidth by subtracting 46 dB from the 40 kHz reference bandwidth values.

TABLE A5-8

Analysis of 2.0 degree satellite spacing scenario

Frequency		14	GHz	
lamda		0.021	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
2	2.09		31.00	-15.0
4	4.29		23.19	-22.8
6	6.49		18.69	-27.3
8	8.69		18.00	-28.0
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-14.0**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-11.0**

TABLE A5-9

Analysis of 2.5 degree satellite spacing scenario

Frequency		14	GHz	
lamda		0.021	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
2.5	2.64		28.46	-17.6
5	5.39		20.71	-25.3
7.5	8.14		18.00	-28.0
10	10.89		16.07	-29.9
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-16.4**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-13.4**

TABLE A5-10

Analysis of 3.0 degree satellite spacing scenario

Frequency		14	GHz	
lamda		0.021	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
3	3.19		26.41	-19.6
6	6.49		18.69	-27.3
9	9.79		17.23	-28.8
12	13.09		14.08	-31.9
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-18.3**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-15.3**

TABLE A5-11

Analysis of 3.5 degree satellite spacing scenario

Frequency		14	GHz	
lamda		0.021	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
3.5	3.74		24.68	-21.3
7	7.59		18.00	-28.0
10.5	11.44		15.54	-30.5
14	15.29		12.39	-33.6
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-19.9**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-16.9**

A5-6.2 Computation of the realistic worst-case aggregate interference at 30 GHz due to GSO satellites on both sides of the satellite supporting the UA

The following tables estimate the aggregate off-axis e.i.r.p density transmitted from earth stations towards an adjacent satellite. The calculation assumes the transmitting earth stations are in compliance with Recommendation ITU-R S.524-9 levels at 30 GHz, which is expressed in a reference bandwidth of 40 kHz. In order to facilitate a simplified modelling, it is assumed that the signal power is evenly distributed within the reference bandwidth so as the e.i.r.p. spectral density can be converted into a 1 Hz reference bandwidth by subtracting 46 dB from the 40 kHz reference bandwidth values.

TABLE A5-12

Analysis of 2.0 degree satellite spacing scenario

Frequency		30	GHz	
lamda		0.010	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
2	2.09		11.0	-35.0
4	4.29		3.2	-42.8
6	6.49		-1.3	-47.3
8	8.69		-2.0	-48.0
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-34.0**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-31.0**

TABLE A5-13

Analysis of 2.5 degree satellite spacing scenario

Frequency		30	GHz	
lamda		0.010	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
2.5	2.64		8.5	-37.6
5	5.39		0.7	-45.3
7.5	8.14		-2.0	-48.0
10	10.89		-3.9	-49.9
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-36.4**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-33.4**

TABLE A5-14

Analysis of 3.0 degree satellite spacing scenario

Frequency		30	GHz	
lamda		0.010	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
3	3.19		6.4	-39.6
6	6.49		-1.3	-47.3
9	9.79		-2.8	-48.8
12	13.09		-5.9	-51.9
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-38.3**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-35.3**

TABLE A5-15

Analysis of 3.5 degree satellite spacing scenario

Frequency		30	GHz	
lamda		0.010	m	
Geocentric separation	**E/S Topocentric angle**		Rec. 524 dB(W/40 kHz)	eirpd dB(W/Hz)
3.5	3.74		4.7	-41.3
7	7.59		-2.0	-48.0
10.5	11.44		-4.5	-50.5
14	15.29		-7.6	-53.6
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (1 side)				**-39.9**
Aggregated oaeirpd from co-freq, co-pol, co-coverage adjacent sat E/S (2 sides)				**-36.9**

A5-7 Results

The analysis contained in this Annex provides the realistic worst-case interference, caused by non-participating FSS networks, that could be experienced by UA (Sections A5-3 and A5-5) earth stations on board UA and by space stations supporting UAS CNPC links (Sections A5-4 and A5-6) when operating in FSS allocations in the 14/11 GHz and 30/20 GHz bands under normal operating conditions. . It should be noted that the analysis is generally based on realistic worst-case assumptions for uncoordinated cases (without any improvement which could be made through coordination of operations, interference mitigation techniques, etc.) and that lower interference levels are more likely in real world scenario.

Based on typical link budget computations 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 adjacent satellite networks with the minimum allowance in the link budget presented in this document, 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 presented in this Annex, no improvements of the achieved link performance due to the implementation of the different mitigation techniques described in Annex 3 of this report are taken into account.

____

ANNEX 6 TO REPORT ITU-R M.[UAS-FSS]

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

Scope of Annex

This Annex provides studies on the effects of emissions from stations operating in the fixed service, MS, EESS (passive) and SRS (passive) on the FSS receiver on-board unmanned aircraft. Analyses show that the interference impact from fixed service is the determining one:

− MS: no technical characteristics of systems for the frequency bands 10.95-12.75 GHz and 17.3-20.2 GHz have been identified

− EESS and SRS: these services are passive services generating no additional interference towards FSS

Consequently only fixed service interference is assessed.

The studies estimate the interference levels into the UA receiver and describe the methodologies for analyzing the interference based link impairments:

− for long term interference into the earth station on-board the UA presented as a cumulative distribution function (CDF)(see Appendix 1 and 1A)

Appendix 1 provides long-term interference assessments using an UA antenna characteristic described by a Bessel function.

Appendix 1A provides a similar assessment taking into the flight speed, not taking into account the fuselage attenuation, but using UA antenna characteristic described by a peak envelope Bessel function and an UA antenna characteristic mask as defined by Recommendation ITU-R S.580.

− for short term interference into the UA receiver (see Appendix 2 and 2A) by means of a parametric methodology in the time domain presented as fade / interfade durations and link availabilities

Appendix 2 provides the short-term interference assessments in the time domain for ICAO scenarios 2 and 4 using a uniformly distributed rural FS station density and an UA antenna characteristic mask as defined by Recommendation ITU-R S.580. Appendix 2A provides a similar assessment but using a mix of rural suburban an urban FS station densities and two additional antenna characteristics (one described by a peak envelope Bessel function and one described by ITU BR Antenna Pattern Library file, Ref. APL-UM-001 available on IFICs).

− for long term and short term interference into the UA receiver (see Appendix 3)

Appendix 3 provides the long-term and short-term interference assessment of the UA under ICAO scenarios 2 and 4.

The assessments use a parametric approach regarding the UA antenna pattern, and results are provided for five types of pattern (ITU-RR AP7, ITU-RR AP8, Rec. ITU-R S.465, Rec. ITU-R S.580 and its extension for D/Lambda <50 as per ITU BR Antenna Pattern Library file, Ref. APL-UM-001 available on IFICs, and a Bessel function limited to -10dBi for large off-axis angles). For the distribution of FS stations over the area covered, it uses a realistic mix of four different FS densities corresponding to urban (i.e. high density), suburban (i.e. medium density), rural (i.e. low density) and white (i.e. no FS at all) areas. Simulations are performed for a 24 hours flight with a 1 second step, and are repeated 100 times, corresponding each to a new set of FS parameters within the defined characteristics, in order to ensure that all possible UA/FS configurations are met (Monte Carlo method). Results are presented under the form of cumulative distribution functions (CDF) in order to show the exact statistic of I/N levels taking all of the whole 8 640 000 calculated samples into account without average.

All appendices are based on

- Flight scenarios 2 and 4 described in section 2.3 to this Report
- Satellite and UA characteristics described in Annex 1 to this Report
- Link margins derived in Annex 2 to this Report
- Characteristics of incumbent services described in Annex 4 to this Report.

ICAO is particularly interested in the effects into the receive section of an earth station on-board an aircraft using the Fixed Satellite Service (FSS) bands when applying the given flight scenarios and how it is affected by incumbent services sharing the same FSS frequency bands.

ICAO would prefer results of the studies mentioned above to be based on the CNPC link 2 performance in the time domain since the advantage of such method is to capture time-variant effects on this link e.g. outage durations during defined flight time periods.

Therefore, this link performance during a continuous flight time of 24 hours (or other time periods, as appropriate) is requested, depending on interference-to-noise thresholds.

This performance could be demonstrated by using the following propagation related C2 link details:

- the maximum time period of a single link outage;
- the aggregate link outage time;
- the average time period per single link outage;
- the aggregate duration between two outages, and
- the average duration between two outages.

ICAO also asks for specifics on what are the underlying end-to-end assumptions for each of the metrics.

Because of the 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 the UA cannot ask for any reductions in interference from other services already operating in bands allocated to FSS, so will have to compensate through design and mitigations, for any additional interference they receive when they fly over other incumbent services. Annex 6 provides ICAO, other standards bodies and UAS designers with information on the levels of interference and their temporal characteristics that earth stations on board UA will receive during flight. It must be those organizations who determine how these levels of interference can be accommodated to ensure safe and efficient UAS operation.

It should be noted that ICAO, other standards bodies and the designers of the earth station on board the UA should not develop requirements that will force additional constraints on those incumbent services that operate in bands allocated to the FSS when those FSS support UAS CNPC operation.

A6-1 Summary

A6-1.1 Long-term interference assessments (Appendix 1 and 1A)

This analysis – including statistical methods, systems characteristics, assumptions, results and conclusions – is conducted with FS systems, since they have been identified as having the highest interference potential out of the incumbent services listed in Annex 4.

Analysis results for frequency bands as per Table 2 and 3 of this report

− The results show I/N versus probability of exceedance based on simulations that include, Recommendations ITU-R S.580-6, S.580-6 APL-UM001 and peak envelope Bessel antenna characteristics and UA speeds and altitudes based on the ICAO scenarios 2 and 4 for the same FS distribution used in the Appendix 1 and 1A (actual distribution from one Administration).

− the probability of exceedance for I/N was reduced with the peak envelope Bessel antenna as compared to the Recommendation ITU-R S.580 antenna

− the probability of exceedance for I/N was reduced at higher UA speeds

− the probability of exceedance for I/N was reduced with lower latitudes

− the probability of exceedance for I/N was reduced for 17.3 to 20.2 GHz

A6-1.2 Short-term interference assessments (Appendix 2 and Appendix 2A)

The synthesis presents interference levels and interference event results in the time domain during a 24h flight of the UA and allows detecting how many seconds a parametric set of I/N ratios is exceeded during such 24h flight while interference level changes rapidly (short term) at the UA receiver input.

Results of Appendix 2 show that the maximum possible peak I/N ratios derived from the link margin for small / medium / large UA antennas

− is not exceeded for the flight scenario 2 (also covering scenarios 1, 3, 5) as specified in Table 1 of Section 2.3.1 of the report

− is not exceeded for the flight scenario 4 (also covering scenario 7) as specified in Table 1 of Section 2.3.1 of the report for flight heights above clouds

− is not exceeded for the majority of cases for the flight scenario 4 (also covering scenario 7) as specified in Table 1 of Section 2.3.1 of the report for flight heights below clouds

Link availability is shown for each frequency band and flight scenario.

In case of operating the link 2 with two uncorrelated frequencies as a possible mitigation technique (see Annex 3) no link interruption was detected at all. The resulting link availabilities against those kinds of interference are very close to 100%.

The analyses in Appendix 2A shows following results:

− Likewise in Appendix 2 the results of this analysis are presented as CDFs as well as fade and interfade durations over a range of I/N thresholds including derivation of 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 8dB.

– For each antenna size two different models describing the antenna pattern have been used. Changing the antenna size from 0.45 m to 1.25 m result in a reduction of the interference level by 6dB.

– Depending on the model describing the antenna pattern the interference level is further reduced by 10 dB

– The dependency on the speed above ground is as follows: At high ground speed, the FS causes shorter average fades compared to lower ground speeds of the UA.

– The interference level in 19 GHz are significantly lower than those in 11 GHz, mainly due to larger gaseous attenuation and the lower spectral density emitted by FS stations in 11 GHz. Generally, I/N level in the 19 GHz range are about 20 dB lower than those in 11 GHz.

– 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.

A6-1.3 Long and short-term interference assessments (Appendix 3)

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. It can be noted that the interference levels received by the UA in the 19 GHz frequency range is significantly lower than the levels received in the 11 GHz range.

A6-2 Methodology

The overall performance of UAS CNPC link 2 when operating within the FSS needs to be assessed under the influence of external interference, for both, the long-term and the short-term, because of the dynamic nature of the UAS operation.

The long-term interference is assessed as being time-invariant and the results are presented as CDF.

For the short-term interference the maximum possible peak I/N ratios derived from the link margins were applied for all three UA antenna types. The analysis for short term interference presents fade durations and interfade durations for a set of *I/N* thresholds for link 2 during a UA flight over areas where FS stations operate (see Figure A6-35).

The interference impact assessments for time-variant interference are performed in three steps:

(1) Deriving the usable link margin *M* from the end-to-end link budgets in Annex 2;

Remark: The usable link margin M includes already the gaseous attenuations (see Tables A6-2-2, A6-2-3, A6-2-4, and A6-2-5).

(2) Calculating the maximum possible peak I/N ratios derived from the link margins for each flight scenario, each UA antenna type and each satellite antenna type;

(3) Simulating the interference environment caused by the FS into the UAS receiver within FSS in terms of *I/N*, as described in A6-5 through A6-7 (Appendices 2, 2A and 3)

APPENDIX 1

A6-3 Long term effects into unmanned aircraft receiver caused by fixed service stations

A6-3.1 Summary of long term interference analysis

This appendix contains the compatibility studies to assess the potential harmful interference caused by FS into UA operating in the FSS. This analysis includes methods, systems characteristics, assumptions, results and conclusions. No compatibility studies are conducted with systems other than the FS, since there are no detailed system characteristics available for them.

For the FS distribution used, an aggregate I/N of -10 dB is met with CDF probability not exceeding 20% of the samples analyzed.

A6-3.2 Introduction

This appendix contains compatibility studies between the UA system operating in the FSS and the FS ground stations including analysis methods, systems characteristics, assumptions, results and conclusions. An important aspect of the analysis is the determination of the applicable level of fuselage attenuation which is taken into account in the interference to noise calculations according to Annex 10.

A6-3.3 Analysis

A6-3.3.1 Methodology

For this analysis, a large number of FS stations in the frequency ranges 10.95 - 12.75 GHz and 17.3 - 20.2 GHz are assumed. The simulation considered real FS stations data from one administration for both frequency bands (https://sms-sgs.ic.gc.ca/frequencySearch/searchByFrequencyRange/index?execution=e2s1&lang=en_CA). The data collected includes geographical locations, antenna height, antenna elevation, antenna azimuths, antenna gain, and antenna feeder loss. The transmit power and the feeder loss is made consistent with Recommendation ITU-R F.758-5.

The interference power level is modified by the fuselage attenuation depending on the relative angels between the UA and each FS station. Two UA flight altitudes of 3 000 feet and 19 000 feet and three evaluation latitude positions of 10°, 40° and 70° are simulated.

The UA is randomly placed in a 400 km radius (about 503 000 km^2 area) for 1,000,000 samples, and the aggregate interference to noise values is collected from all FS stations that are within the radio line of sight of the UA all the way out to the edge of the 400 km radius and beyond. The CDF is generated. See Figure A6-1 for a pictorial of the scenario. Sharing studies are conducted on frequency bands in the space-to-Earth direction.

A6-3.3.2 Characteristics of FSS Earth Stations and Fixed Service stations

The following are the input parameters and general assumptions made for the space to earth frequency bands 10.95-12.75 GHz, and 17.3-20.2 GHz.

1) UA input parameters:

   a. a Bessel function antenna pattern is used to better approximate the real antenna sidelobe and backlobe levels. Figure A6-1 shows a comparison of the Bessel pattern to measured antenna pattern. This comparison shows how close the Bessel antenna pattern is to that of a real UA antenna;

b. the 3 dB receiver reference bandwidth is 40 kHz;

c. the UA antenna tracks a GSO satellite that is at the same longitude as the center point where the FS stations are distributed;

d. three latitude positions and at two UA antenna heights above ground level are evaluated. The heights evaluated are 914 meters (3 000 feet) and 5 791 meters (19 000 feet);

e. The UA frequency for the simulations is 11 GHz and 19.7 GHz. The value of each I/N is adjusted by the aircraft fuselage attenuation. The fuselage attenuation is assumed to be symmetric around the UA aircraft fuselage. This loss varies, as shown in table A6-3 due to the relative positions of the FSS antenna on the UA and each FS station on the ground.

2) FS stations input parameters are listed below:

a. Transmitter and antenna parameters used are:

i. antenna elevation angles;

ii. antenna azimuth directions;

iii. antenna heights above ground in meters;

iv. transmit power as shown in table A6-4;

v location (latitude and longitude).

b. antenna pattern is from Recommendation ITU-R F.1245-1 Annex-1. Note that real FS antenna pattern may provide improved front to back ratio and lower sidelobe levels;

c. transmitter reference bandwidth is set to 1 MHz;

d. The simulations contained 1 900 FS for 11 GHz band and 2 833 FS stations for 19.7 GHz. There are 137 FS stations that are co-frequency with the UA receiver frequency in the 11 GHz band analysis, and 169 FS stations that are co-frequency with the UA receiver frequency for the 19.7 GHz band analysis. These numbers of co-frequency FS stations is obtained from the mode value for the one administration FS station data collected;

e These FS stations positions are shifted to 10°, 40° and 70° latitudes for the simulations. At 70° latitude this is a worst case scenario as actual population densities would support would not support that many FS stations.

3) General simulation assumptions:

a. no polarization loss between the UA and FS stations antennae;

b. ITU-R radio wave propagation Recommendations ITU-R P.525, and ITU-R P.676 as well as an additional constant 30 dB loss beyond radio horizon are taken into account since terrain data is not considered;

d. Frequency dependent rejection is calculated for each transmitter to receiver coupling.

e one million samples are taken for each simulation.

FIGURE A6-1

Comparison of the Bessel pattern to an actual measured antenna pattern

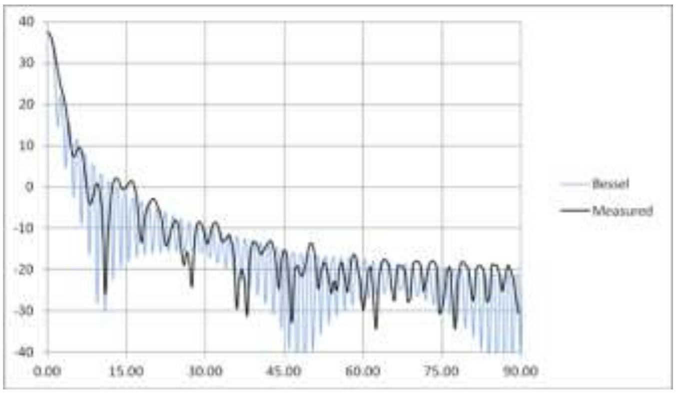
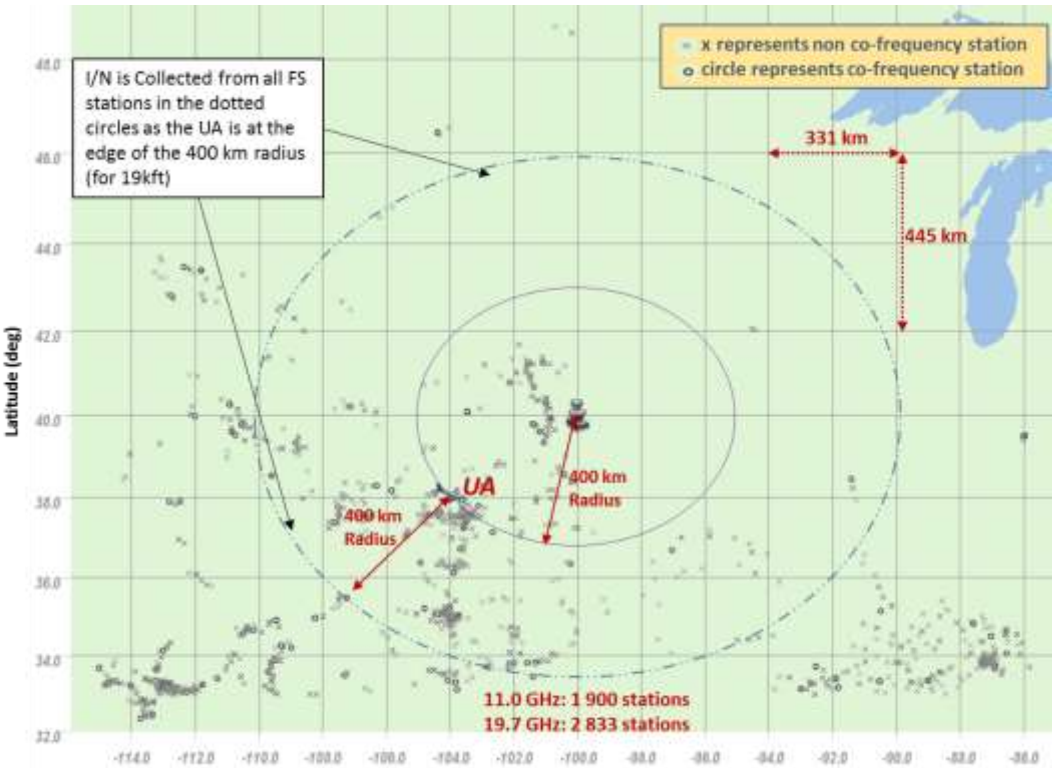


FIGURE A6-2

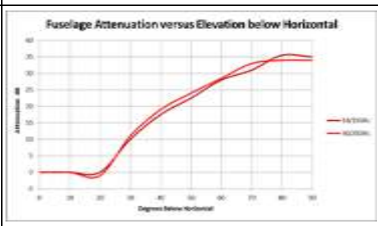
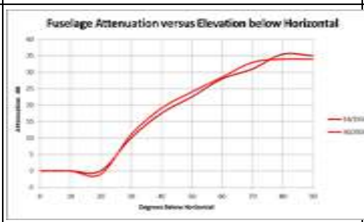
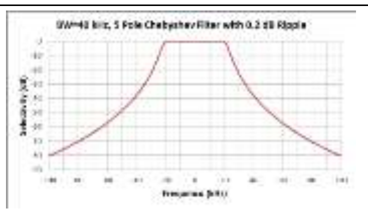
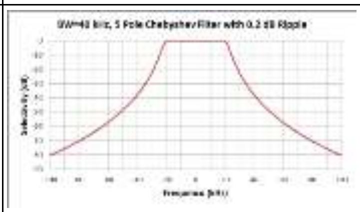
Example scenario setup



The characteristics of typical FSS system that could provide UA CNPC applications are provided in Annex 1 for 14/11 GHz and 30/20 GHz frequency bands. Table A6-1 provides the characteristics of the Earth station on-board the UA that are used in these studies.

TABLE A6-1

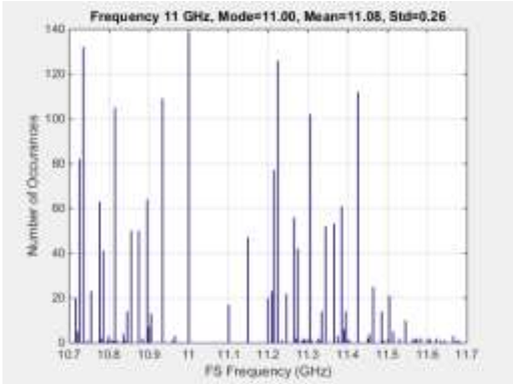
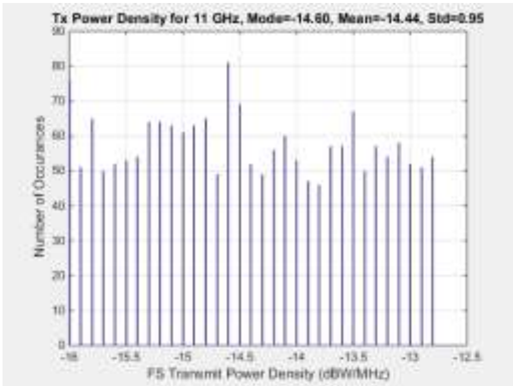
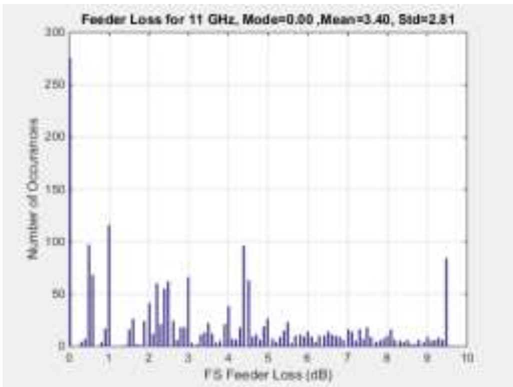
Unmanned aircraft input parameters

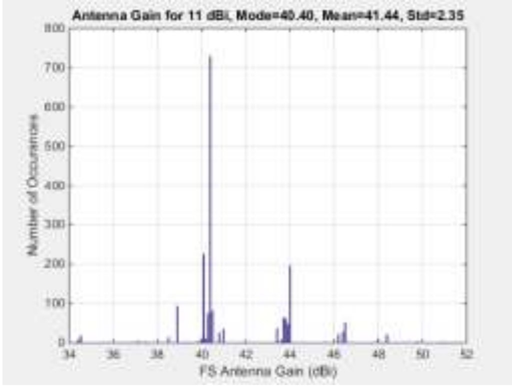
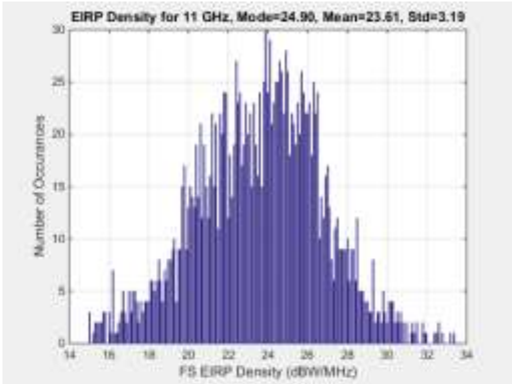
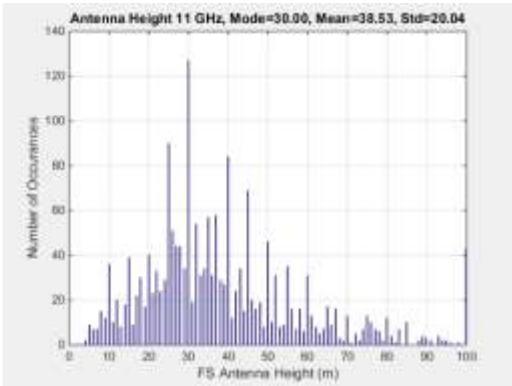
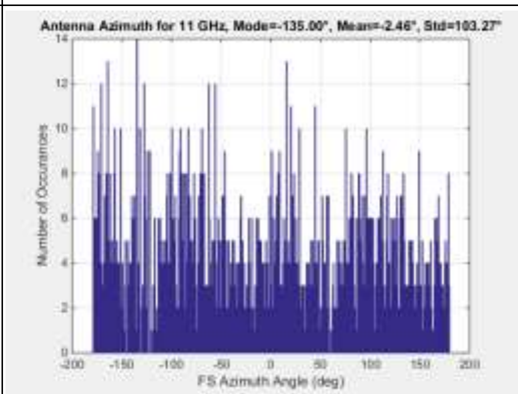
Unmanned aircraft	Units	11 GHz parameter	18 GHz parameter	Comment
Frequency	GHz	11.0	19.7	This is the value used as co-frequency with the FSs
Height above ground level,	m	Two UA heights above ground level are considered. These are 914.4 m (3 000 ft) and 5 791.2 m (19 000 ft).	Two UA heights above ground level are considered. These are 914.4 m (3 000 ft) and 5 791.2 m (19 000 ft).	Minimum heights used are from the ICAO suggested minimum heights
Center point, latitude,	degrees	10, 40 and 70	10, 40 and 70	The center longitude is set such that it is in line with a GSO longitude
Receiver bandwidth	kHz	40	40	From UA characteristics
System noise temperature	K	200	220	From UA characteristics
Feeder loss	dB	0	0	
Antenna pattern		Bessel function antenna pattern	Bessel function antenna pattern	
Antenna diameter (cm)	cm	45 and 125	45 and 125	The 80 cm antenna radius results will be bounded by the minimum and maximum antenna radii. No analysis is done for the 80 cm antenna
Antenna efficiency		0.55	0.55	
Fuselage attenuation				Fuselage attenuation depends on the line of sight between each FS and the UA.
UA receiver filter selectivity				3 dB bandwith BW=40 kHz, 5 Pole Chebyshev filter with 0.2 dB ripple.
Radome loss	dB	1	1	Value is not used

The fixed service stations parameters are shown in Tables A6-2 and A6-3.

TABLE A6-2

Fixed service input parameters for the frequency band 10.7 to 11.7 GHz

Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Frequency range	GHz	10.7-11.7	10.7-11.7	
Reference Rec. ITU-R		F.387	F.387	F.758-5
Modulation		16-QAM	64-QAM	Not needed in analysis
Channel spacing and receiver noise bandwidth	MHz	5, 10, 20, 40, 60, 67, 80	5, 10, 20, 40, 60, 67, 80	Not needed in analysis
Tx output power range	dBW	3…5.0	0.0	Transmit power density is used
Tx output power density range	dBW/MHz	−14.8... −12.8	−16.0	
Feeder/multiplexer loss range	dB	0…9.5	0…7.6	

Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Antenna gain range	dBi	44…51	36…48.0	
e.i.r.p. range	dBW	33.1...51.2	13.3…43.0	EIRP density in dBW/MHz is used in analysis
e.i.r.p. density range	dBW/MHz	15.3...33.4 (Mode 28.5)	−2.7…27.0 (Mode 15.9...)	
Receiver noise figure typical	dB	5	5	5
Antenna polarization		Linear	Linear	Linear
Antenna height distribution	m	10 to 100	10 to 100	
Antenna azimuth angle distribution	degrees	0 to 360	0 to 360	

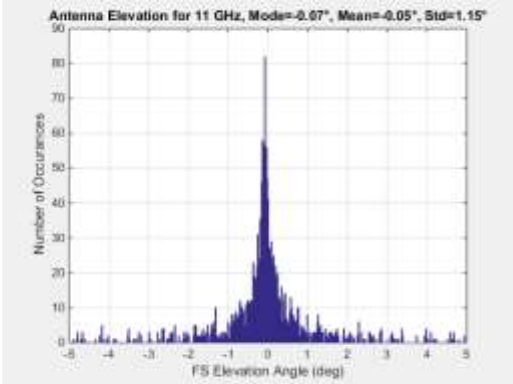
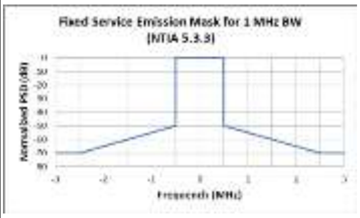
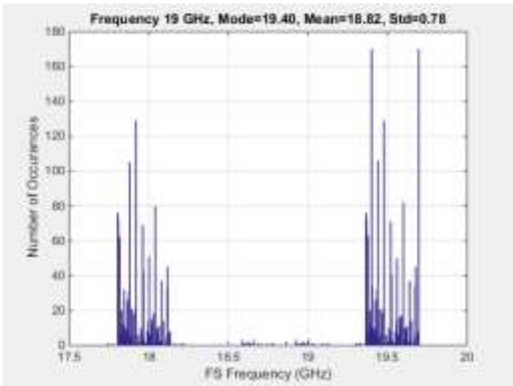
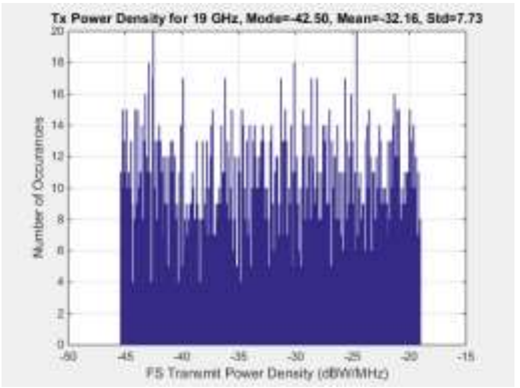
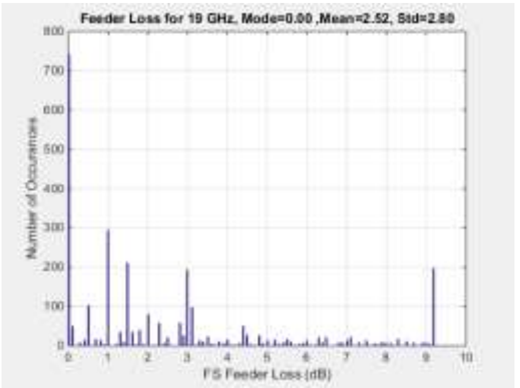
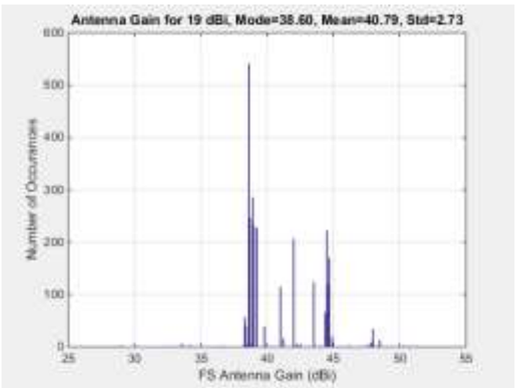
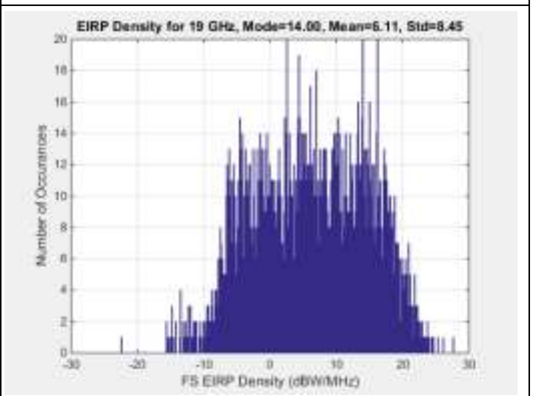
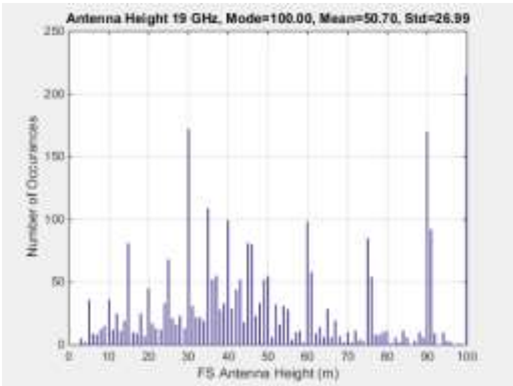
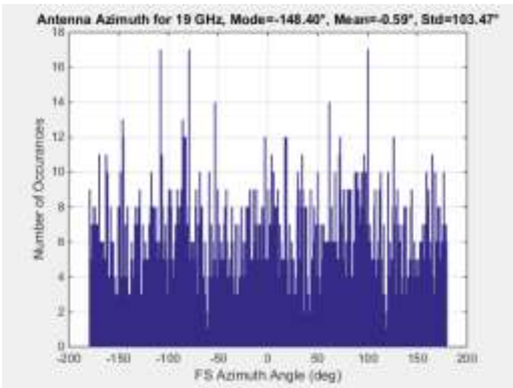
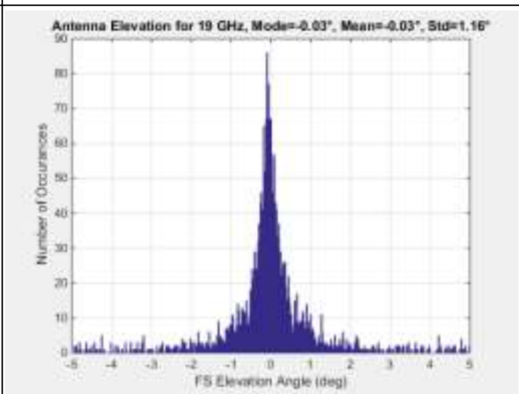
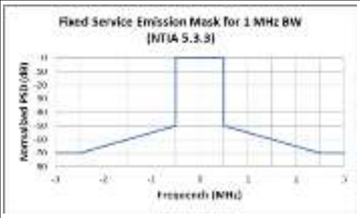
Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Antenna elevation angle distribution in degrees	degrees	-5 to +5	-5 to +5	
Emission mask for 1 MHz BW				From NTIA Red Book Section 5.3.3 for fixed service http://www.ntia.doc.gov/files/ntia/publications/redbook/2014-05/5_14_5.pdf

TABLE A6-3

Fixed service input parameters for the frequency band 17.7 to 19.7 GHz

Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Frequency range	GHz	17.7-19.7	17.7-19.7	
Reference ITU-R Recommendation		F.595	F.595	F.758-5
Modulation		QPSK	64-QAM	Not needed in analysis
Channel spacing and receiver noise bandwidth	MHz	1.25, 1.75, 2.5, 3.5, 5, 7, 7.5, 10, 13.75, 20, 27.5, 30, 40, 50, 55, 60(5), 110, 220	1.25, 1.75, 2.5, 3.5, 5, 7, 7.5, 10, 13.75, 20, 27.5, 30, 40, 50, 55, 60(5), 110, 220	Not needed in analysis
Tx output power range	dBW	−37…−3.0	−10	Transmit power density is used

Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Tx output power density range	dBW/MHz	−45.4…−19.0	−26	
Feeder/multiplexer loss range	dB	0.0…2	0…9.3	
Antenna gain range	dBi	21.7…48.3	32…45	
e.i.r.p. range	dBW	−4.4…43	−1.1...33	EIRP density in dBW/MHz is used in analysis
e.i.r.p. density range	dBW/MHz	−13.1…27.3 (Mode 16.2)	−17.1...17 (Mode 8.0)	
Receiver noise figure typical		5	5	5
Antenna polarization		Linear	Linear	Linear

Parameter	Units	From ITU-R F.758-5	From ITU-R F.758-5	Analysis Values
Antenna height distribution	m	10 to 100	10 to 100	
Antenna azimuth angle distribution	degrees	0 to 360	0 to 360	
Antenna elevation angle distribution	degrees	-5 to +5	-5 to +5	
Emission mask for 1 MHz BW				From NTIA Red Book Section 5.3.3 for fixed service. http://www.ntia.doc.gov/files/ntia/publications/redbook/2014-05/5_14_5.pdf

Additional simulation parameters are shown in Table A6-5.

TABLE A6-5

Additional simulation parameters

Analysis	Parameter	Comment
Terrain Data	Smooth Earth. No Terrain Data. No Building obstruction	Adding terrain and building losses could potentially reduce the I/N level
Frequency Dependent Rejection (FDR)	Yes	FDR is calculated for all UA and FS station links using FS emission mask and UA receiver selectivity
Polarization Mismatch Loss (dB)	None	Not used. Polarization loss applies if antenna coupling is within the main lobe of -3 dB beamwidth. Outside of the -3 dB beamwidth, the polarization mismatch loss is assumed to be zero dB
Propagation Models	Recommendations ITU-R P.525, ITU-R P.676	An additional 30 dB loss beyond radio line of sight for all UA and FS station links

The FS stations used in the analysis is real data from one administration.

A6-3.4 Results for the frequency range 10.95 - 12.75 GHz

This section provides the results of the compatibility analyses for link 2 in the frequency ranges 10.95 - 12.75 GHz.

The results of using 1 900 FS stations with many of them concentrated in a dense area show the aggregate interference by means of I/N ratios versus probability of exceedance (CDF). Results of I/N over different FS density will be different and can potentially be much lower.

Obviously flying over geographical areas that do not have FS stations, such as oceans and underpopulated areas, are not a problem at all.

FIGURE A6-4

Probability of exceedance of I/N at Results for 11 GHz at a latitude of the unmanned aircraft latitude of 10°

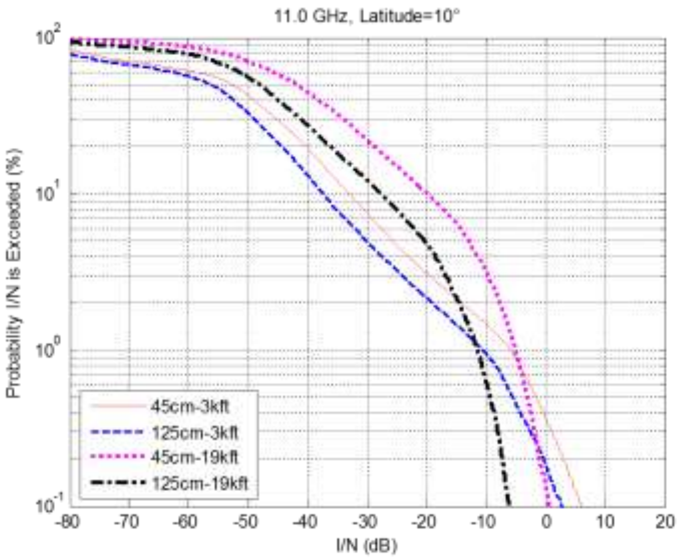


FIGURE A6-5

Probability of exceedance of I/N at 11 GHz at a latitude of the unmanned aircraft of 40°

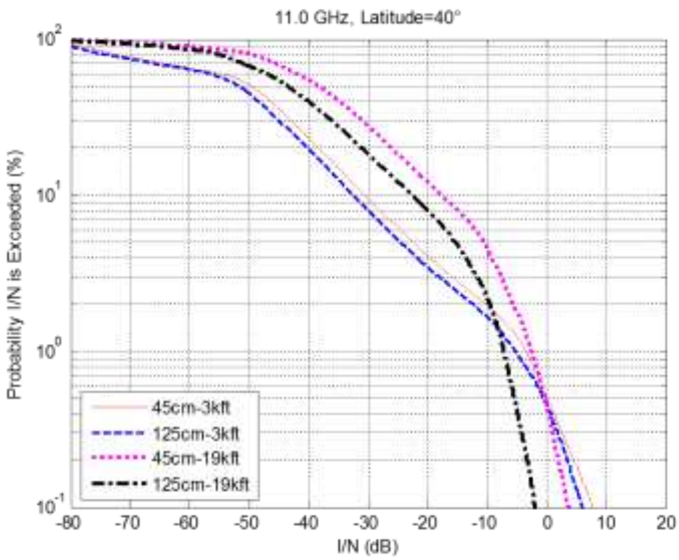
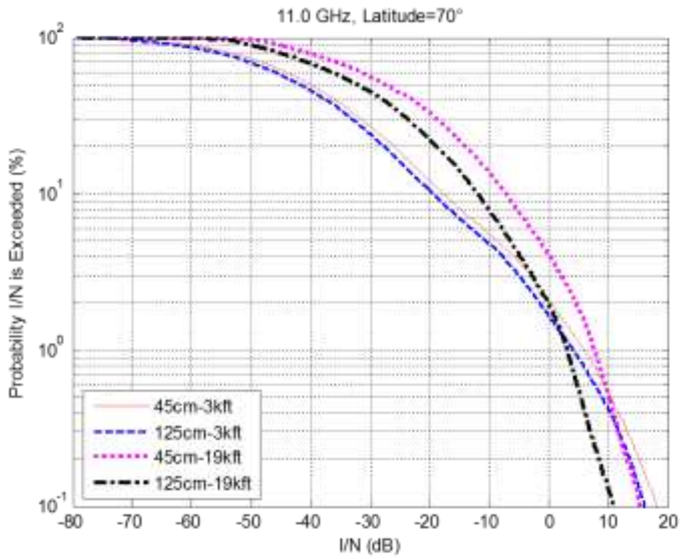


FIGURE A6-6

Probability of exceedance of I/N at 11 GHz at a latitude of the unmanned aircraft of 70°



A6-3.5 Results for the frequency range 17.3-20.2 GHz

This section provides compatibility analyses for link 2 of UA CNPC in the frequency bands 17.3 - 20.2 GHz.

The results of using 2 833 FS stations with many of them concentrated in a dense area show that the aggregate interference by means of I/N ratios versus probability of exceedance (CDF). Results of I/N over different FS density will be different and can potentially be lower. Obviously flying over geographical areas where no FS stations operate, such as oceans and low populated areas, will result in no interference at all.

FIGURE A6-7

Probability of exceedance of I/N at 19 GHz at a latitude of the unmanned aircraft of 10°

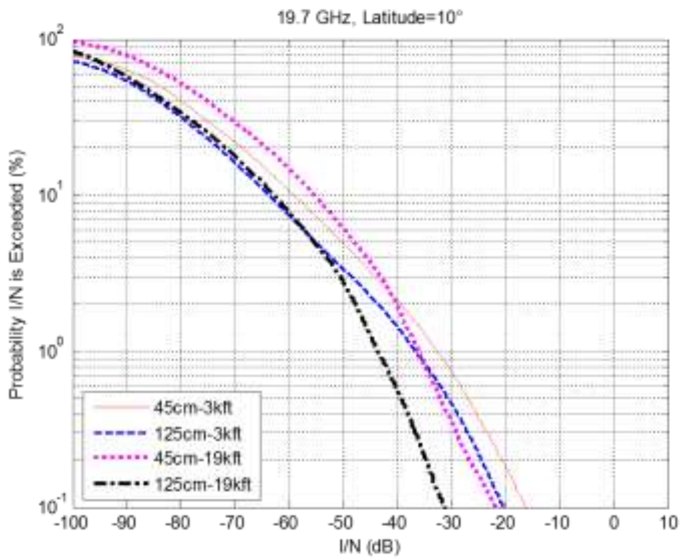


FIGURE A6-8

Probability of exceedance of I/N at 19 GHz at a latitude of the unmanned aircraft of 40°

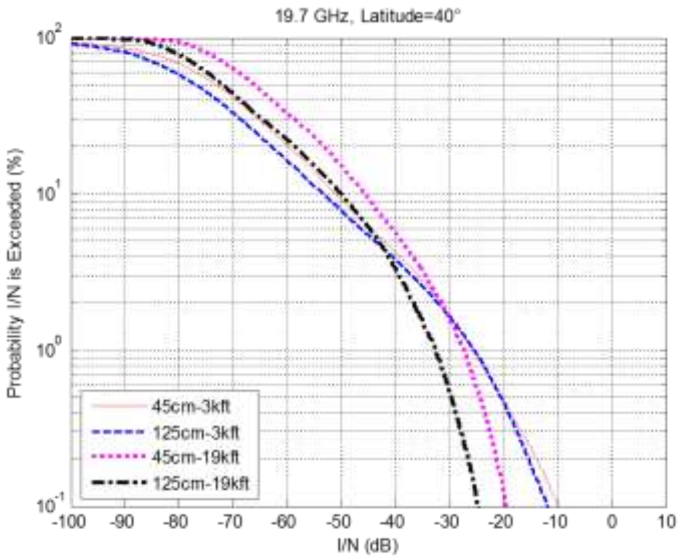
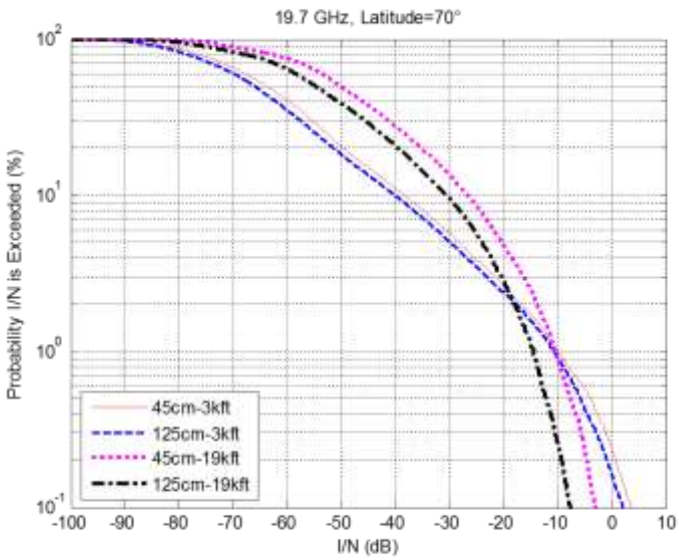


FIGURE A6-9

Probability of exceedance of I/N at 19 GHz at a latitude of the unmanned aircraft of 70°



APPENDIX 1A

A6-4 Long term effects into unmanned aircraft receiver caused by fixed service stations (flight conditions as per ICAO scenarios 2 and 4)

Appendix 1A supplements the studies performed in Appendix 1 by applying different antenna patterns for the Earth station on board UA and different flight speed.

A6-4.1 Summary

Further compatibility studies have been performed to assess the interference conditions potentially caused by FS stations into the UA receiver. ICAO scenarios 2 and 4 are used to generate CDFs that are a function of UA flight speed, height and using FS emission mask given by European Telecommunication Standardisation Institute (ETSI) referenced below. The results are summarised on Table A6-7.

This appendix contains compatibility studies to assess the potential for interference caused by Fixed Service (FS) stations distribution to UA FSS receiver like Appendix 1 but:

- including UA flight speed for ICAO scenarios 2 and to generate CDF results that are a function of speed
- employing the ETSI (ETSI EN 302 217-2-2 V2.0.0 (2012-09) FS emission mask
- adding antenna pattern Recommendations for antenna diameter to operating frequency wavelength (D/λ) < 50 be considered. Several options were provided. In this study we used S.580-6 APL-UM001 antenna pattern (Reference: ITU-R Antenna Pattern Library version 1.1.7 dated May 28, 2007).
- not including the Fuselage attenuation.

Analysis results of this study

- The results show I/N versus probability of exceedance based on simulations that include, ITU-R S.580 and peak envelope Bessel antenna characteristics and UA speeds and altitudes based on the ICAO scenarios 2 and 4 for the same FS distribution used in the appendix 1 (actual distribution from one Administration)
- the probability of exceedance for I/N was reduced with the peak envelope Bessel antenna as compared to the ITU-R S.580 antenna
- the probability of exceedance for I/N was reduced at higher UA speeds
- the probability of exceedance for I/N was reduced with lower latitudes
- the probability of exceedance for I/N was reduced for 17.3 to 20.2 GHz.

A6-4.2 Introduction

This appendix contains long term interference sharing studies results between the UA system operating in the FSS and the FS stations. The interferer and victim systems characteristics are the same as the ones used in Appendix 1. In contrast to Appendix 1, fuselage attenuation is not included in this Appendix 1A. Should Fuselage attenuation be included in the analysis, the resulting I/N would be reduced.

A6-4.3 Analysis

A6-4.3.1 Methodology

In Appendix 1 and 1A, the same number of FS stations in the frequency ranges 10.95 to 12.75 GHz and 17.3 to 20.2 GHz are employed. The difference is that in this appendix ICAO scenarios found in Table A6-8, are taken into consideration.

TABLE A6-6

US speed and heights for ICAO scenario 2 and 4

ICAO Scenario	Maximum altitude (kft)	Minimum altitude (kft)	Maximum ground speed including wind (kts)	Minimum ground Speed (kts)
2	30	19	300	100
4	10	0.5	250	80

Simulations were done for each altitude and speed combinations and for one fixed service distribution at low medium and high latitudes. The total number of one-second-samples vary depending on UA speed and latitude and longitude locations. In the simulation, the UA flight paths are in east to west and north to south grids pattern with distance separation between flight paths set to 10 nmi. The I/N values are calculated and the CDFs are generated. See Figure A6-10 and A6-11 for a pictorial representation of the scenarios.

A6-4.3.2 Sharing scenario assumptions

The following are the input parameters and general assumptions made for the space to earth frequency bands 10.95-12.75 GHz, and 17.3-20.2 GHz.

1) UA input parameters are the same as Appendix 1 except for the following:

   a. Two UA antenna patterns are used in the simulation. These are the ITU-R S.580-APL-UM001 and a Bessel peak envelope function antenna pattern that is used to better approximate a real antenna sidelobe and backlobe levels;

   c. the UA antenna tracks a GSO satellite located at the same longitude as the higher FS density (109W in this analysis);

   d. fuselage attenuation is not used

   e. ICAO scenarios 2 and 4 including minimum and maximum heights and speeds are simulated.

2) FS stations input parameters are listed below:

   a. same parameters as in Appendix 1;

   b. the ETSI EN 302 217-2-2 V2.0.0 (2012-09) FS emission mask is used;

3) General simulation assumptions:

   a. same as Appendix 1;

   e the number of simulation samples and flight duration in days, as a function of UA speed and latitude, are:

TABLE A6-7

Example scenario setup for 12 GHz

Latitude (degrees)	ICAO Speed (kts)	Number of seconds / Days	CDF Plot Provided
70	80	1 207 542 / 13.97	Yes
70	100	966 049 / 11.18	Yes
70	250	386 472 / 4.47	No as the 80 kts plot is worst case
70	300	322 068 / 3.72	No as the 100 kts plot is worst case
40	80	2 093 580 / 24.23	Yes
40	100	1 674 882 / 19.38	Yes
40	250	670 021 / 7.75	No as the 80 kts plot is worst case
40	300	558 361 / 6.46	No as the 100 kts plot is worst case
10	80	2 617 016 / 30.28	Yes
10	100	2 093 638 / 24.23	Yes
10	250	837 534 / 6.69	No as the 80 kts plot is worst case
10	300	697 952 / 8.078	No as the 100 kts plot is worst case

FIGURE A6-10

Example scenario setup for 12 GHz

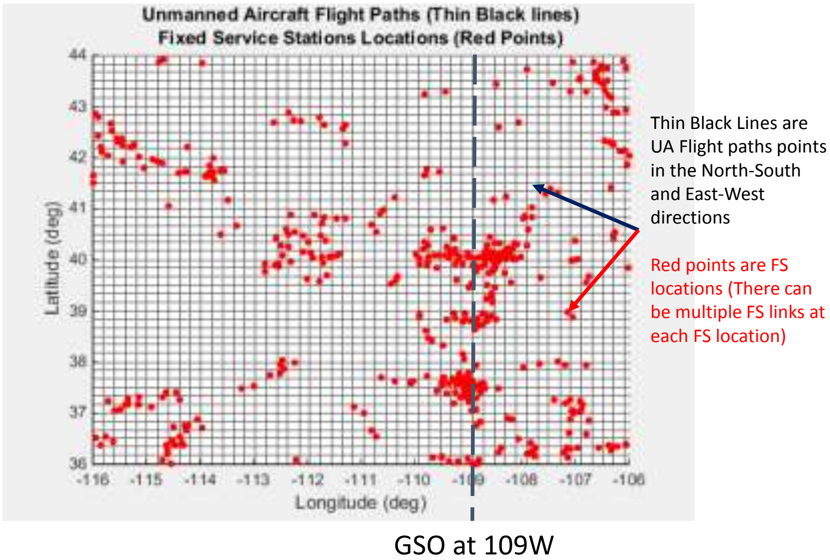
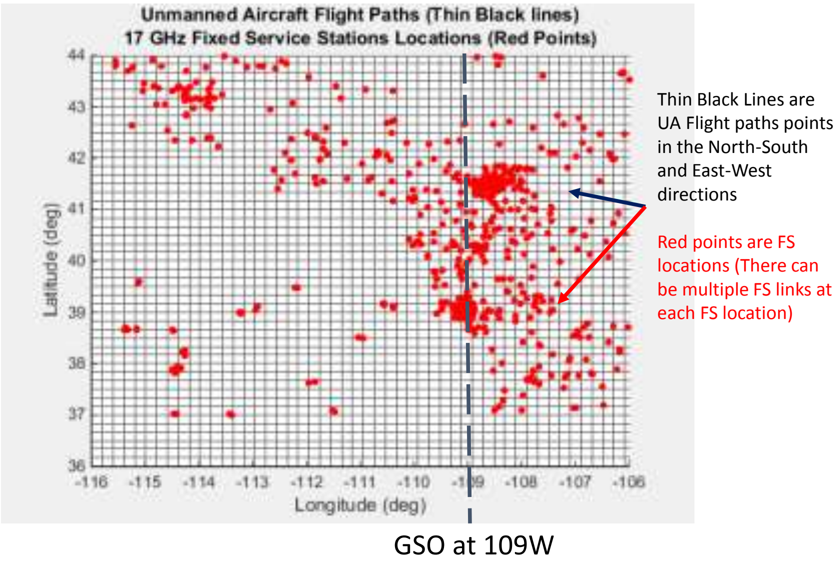


FIGURE A6-11

Example scenario setup for 17 GHz



A6-4.4 Results for the frequency bands 10.95 - 12.75 GHz

The results show the aggregate interference by means of a CDF of I/N ratios versus probability of their exceedance for ICAO scenarios 2 and 4. Results of I/N over different FS densities will be different and can potentially be much lower. In conclusion:

– the probability of exceedance for I/N was reduced with the Bessel peak envelope antenna pattern as compared to the ITU-R S.580-APL-UM001 antenna pattern

– the probability of exceedance for I/N was reduced at higher UA speeds

– the probability of exceedance for I/N was reduced with lower latitudes

Obviously flying over geographical areas that do not have FS stations, such as oceans and underpopulated areas, are not a problem at all.

FIGURE A6-12

Probability of exceedance of I/N for 11 GHz at low latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

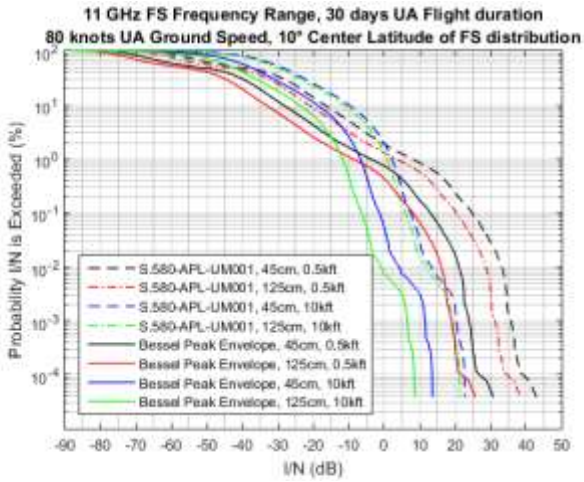


FIGURE A6-13

Probability of exceedance of I/N for 11 GHz at low latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

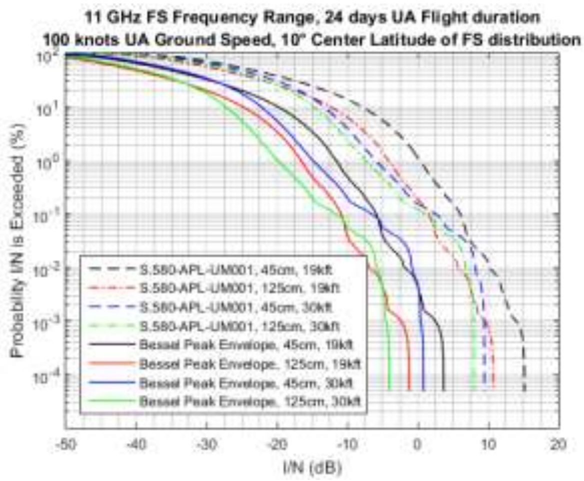


FIGURE A6-14

Probability of exceedance of I/N for 11 GHz at medium latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

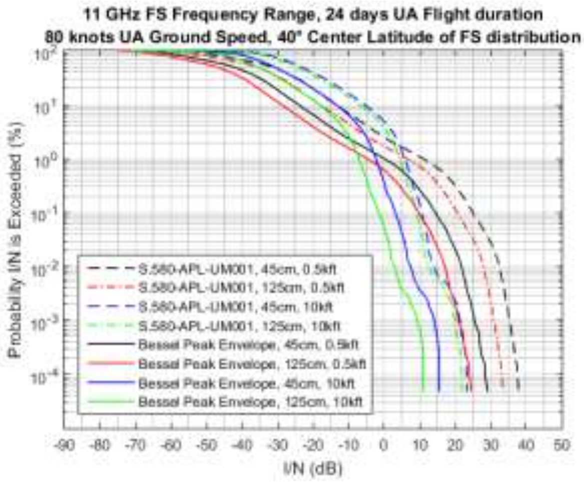


FIGURE A6-15

Probability of exceedance of I/N for 11 GHz at medium latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

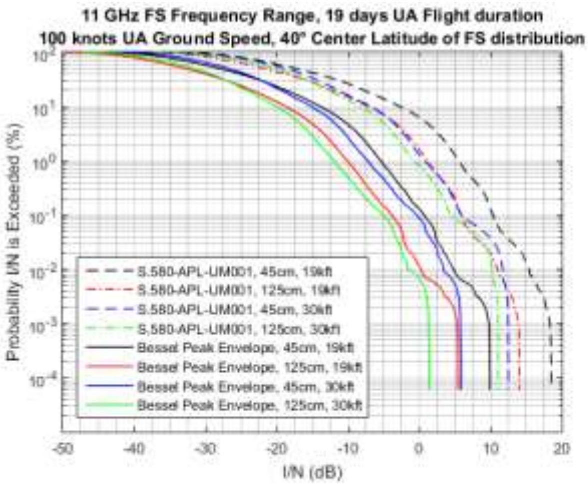


FIGURE A6-16

Probability of exceedance of I/N for 11 GHz at high latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

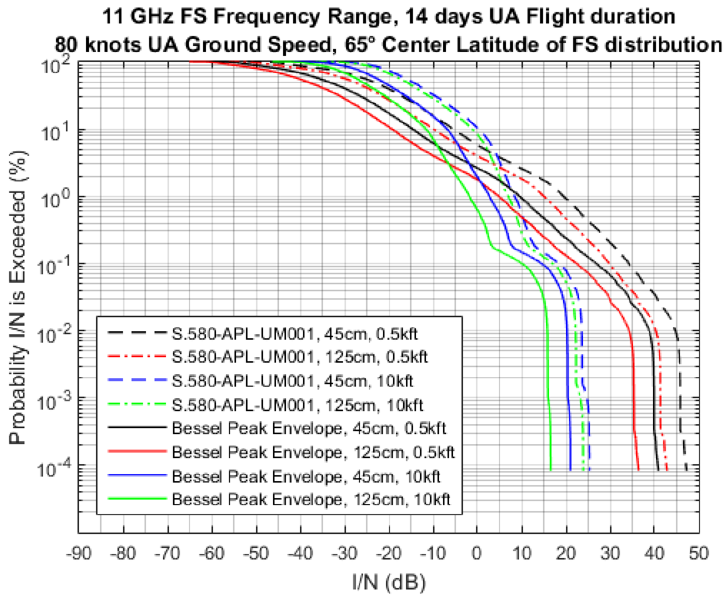


FIGURE A6-17

Probability of exceedance of I/N for 11 GHz at high latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

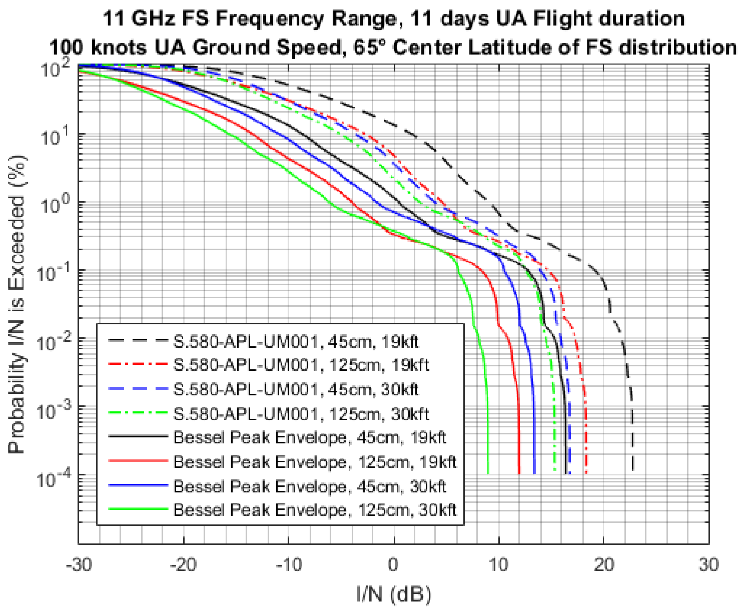


FIGURE A6-18

Probability of exceedance of I/N for 11 GHz at medium latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

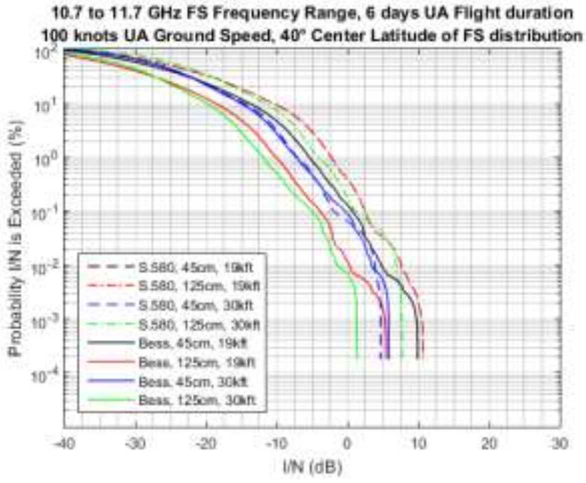


FIGURE A6-19

Probability of exceedance of I/N for 11 GHz at high latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

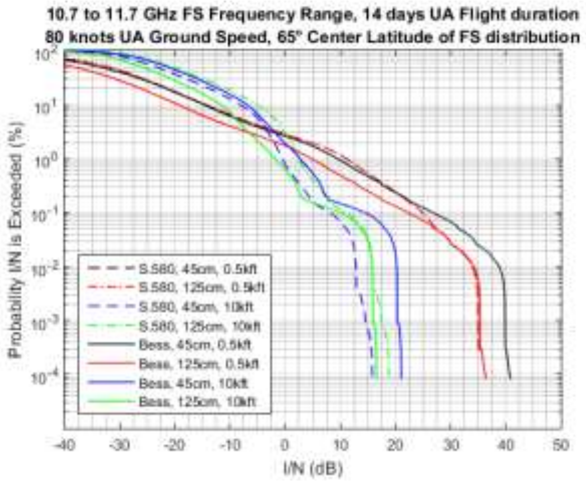
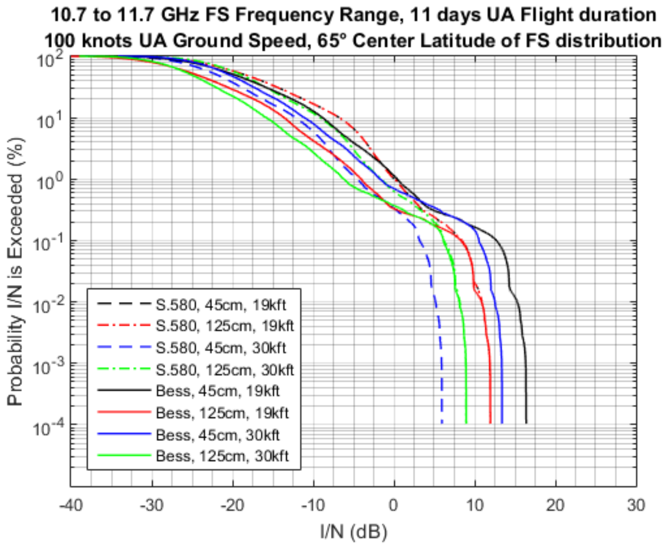


FIGURE A6-20

Probability of exceedance of I/N for 11 GHz at high latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)



A6-4.5 Results for the frequency band 17.3-20.2 GHz

The results show the aggregate interference by means of a CDF of I/N ratios versus probability of their exceedance for ICAO scenarios 2 and 4. Results of I/N over different FS densities will be different and can potentially be much lower. In conclusion:

– the probability of exceedance for I/N was reduced with the peak envelope Bessel antenna as compared to the ITU-R S.580 antenna

– the probability of exceedance for I/N was reduced at higher UA speeds

– the probability of exceedance for I/N was reduced with lower latitudes

Obviously flying over geographical areas that do not have FS stations, such as oceans and underpopulated areas, are not a problem at all.

FIGURE A6-21

Probability of exceedance of I/N for 19.7 GHz at low latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

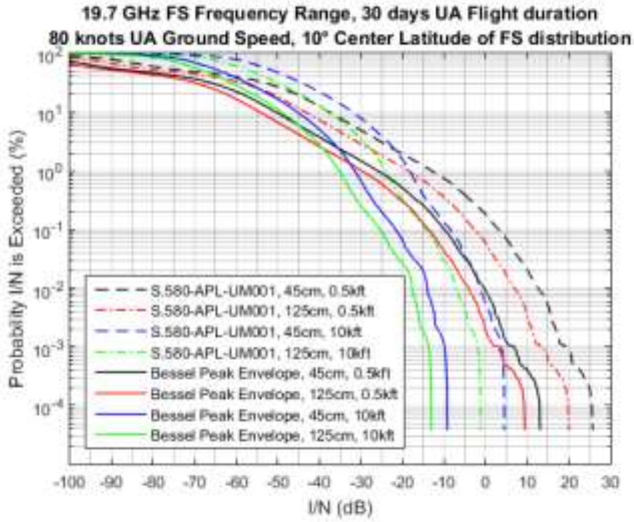


FIGURE A6-22

Probability of exceedance of I/N for 19.7 GHz at low latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

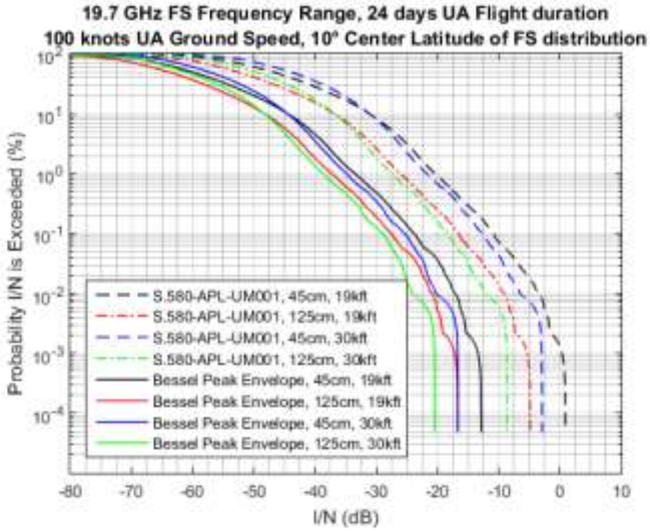


FIGURE A6-23

Probability of exceedance of I/N for 19.7 GHz at medium latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

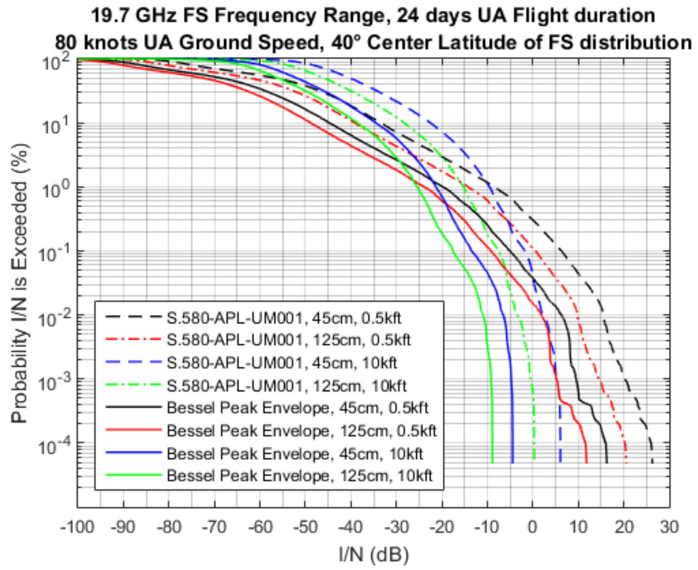


FIGURE A6-24

Probability of exceedance of I/N for 19.7 GHz at medium latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

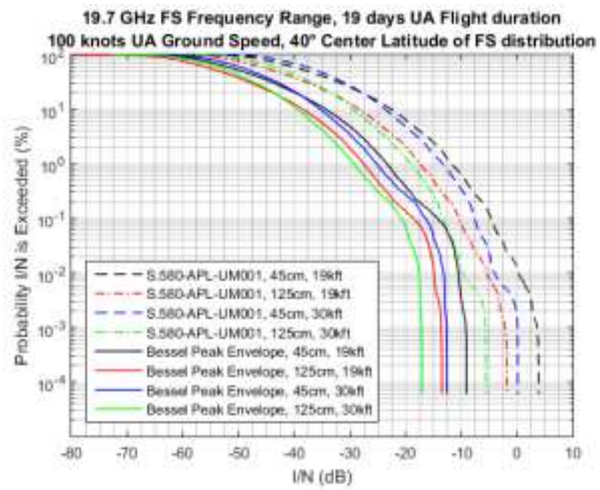


FIGURE A6-25

Probability of exceedance of I/N for 19.7 GHz at high latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

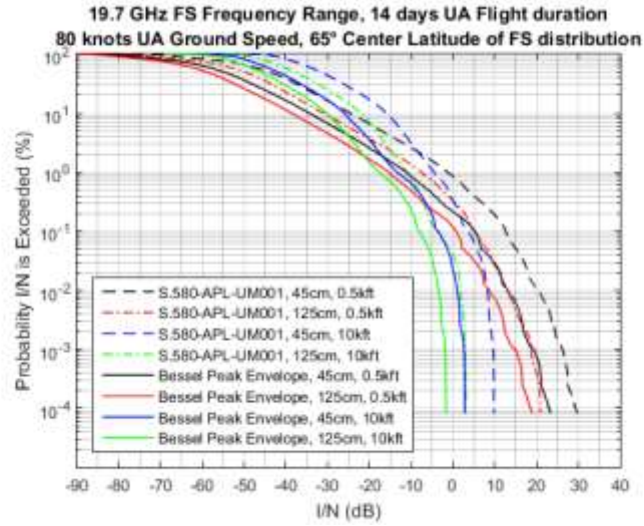


Figure A6-26

Probability of exceedance of I/N for 19.7 GHz at high latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

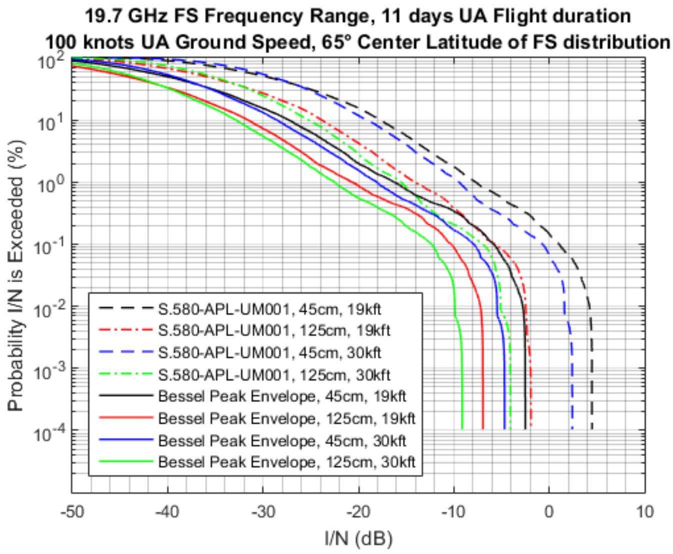


FIGURE A6-27

Probability of exceedance of I/N for 19.7 GHz at medium latitude with 300 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

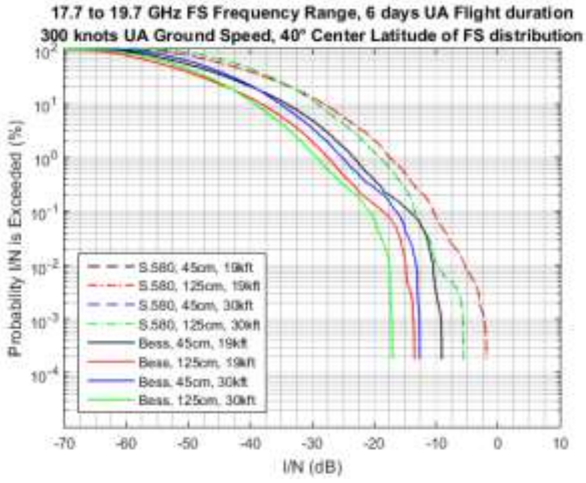


FIGURE A6-28

Probability of exceedance of I/N for 19.7 GHz at high latitude with 80 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

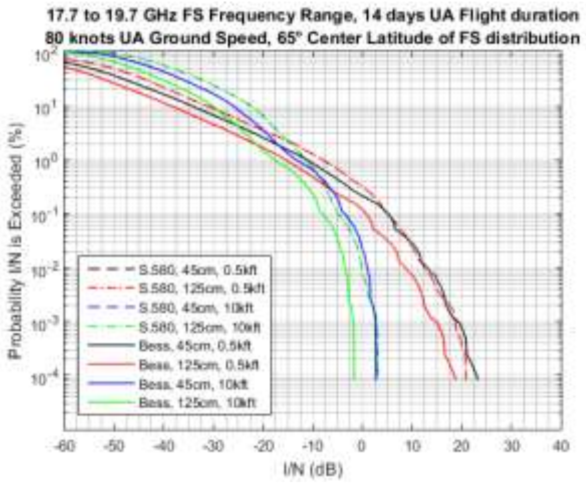


FIGURE A6-29

Probability of exceedance of I/N for 19.7 GHz at high latitude with 250 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

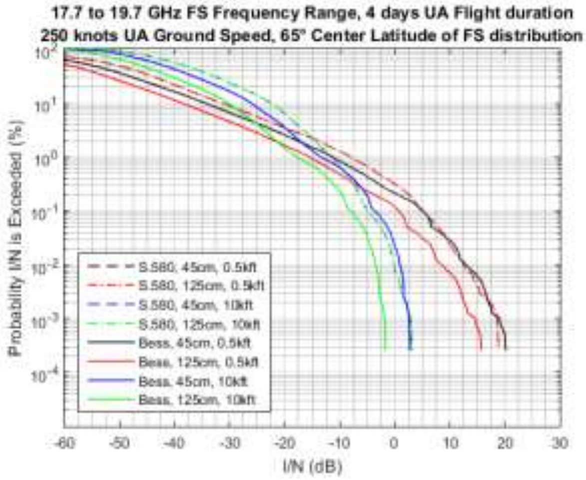


FIGURE A6-30

Probability of exceedance of I/N for 19.7 GHz at high latitude with 100 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)

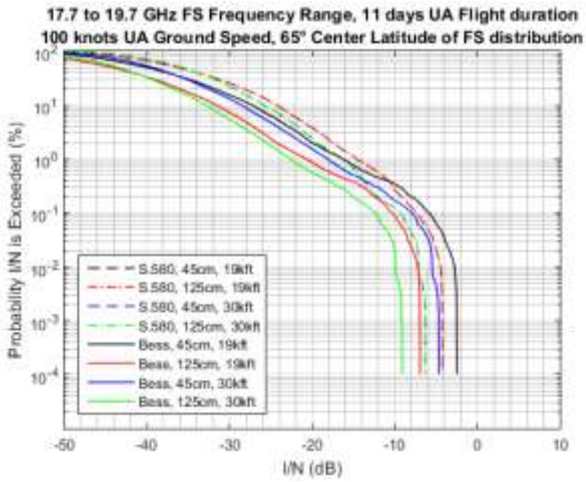
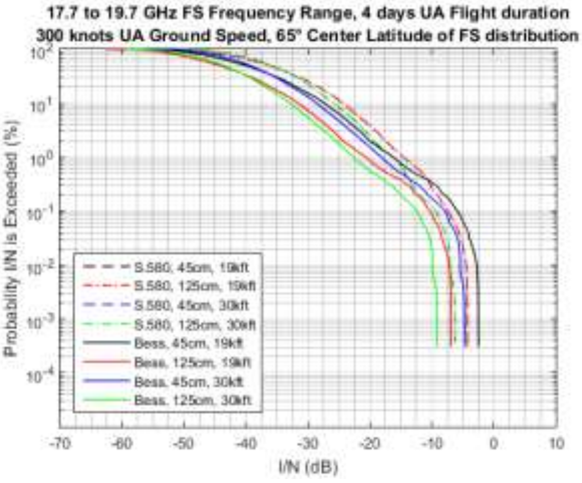


FIGURE A6-31

Probability of exceedance of I/N for 19.7 GHz at high latitude with 300 knots speed (in the plot Bess is a peak envelope Bessel function antenna pattern)


17.7 to 19.7 GHz FS Frequency Range, 4 days UA Flight duration
300 knots UA Ground Speed, 65° Center Latitude of FS distribution
Probability I/N is Exceeded (%)
I/N (dB)
S.580, 45cm, 19kft
S.580, 125cm, 19kft
S.580, 45cm, 30kft
S.580, 125cm, 30kft
Bess, 45cm, 19kft
Bess, 125cm, 19kft
Bess, 45cm, 30kft
Bess, 125cm, 30kft

APPENDIX 2

A6-5 Short term effects into unmanned aircraft receiver caused by fixed service stations

A6-5.1 Summary

Appendix 2 provides the sharing studies to assess the potential harmful short-term interference caused by FS into UA (CNPC link #2) operating in the FSS. This Appendix includes the method, the systems characteristics and interference interactions, study inputs and results. Due to the fact that the interference caused by FS is by far the determining interference effect towards UA operating in the FSS the compatibility studies are conducted with the FS only.

The analyses shows that the maximum possible peak I/N ratios derived from the link margin for small / medium / large UA antennas

− is not exceeded for the flight scenario 2 (also covering scenarios 1, 3, 5) as specified in Table 1 of Section 2.3.1 of the report

− is not exceeded for the flight scenario 4 (also covering scenario 7) as specified in Table 1 of Section 2.3.1 of the report for flight heights above clouds

− is not exceeded for the majority of cases for the flight scenario 4 (also covering scenario 7) as specified in Table 1 of Section 2.3.1 of the report for flight heights below clouds

Link availability is shown for each frequency band and flight scenario.

In case of operating the link 2 with two uncorrelated frequencies as a possible mitigation technique (see Annex 3) no link interruption was detected at all. The resulting link availabilities are very close to 100%.

The maximum possible peak I/N derived from the link margin for three UA antenna types depend on the link margin and are in the range of:

− 14/11 band: 3.1 dB up to 14.5 dB

− 30/20 band: 0.8 dB up to 21.1 dB

A6-5.2 Introduction

This appendix determines the main influencing elements of interference from fixed service towards the UA receiver:

– the average, maximum and aggregate fading durations due to short-term interference from FS stations;

– the average and aggregate interfade durations due to interference from FS stations;

– and the resulting link availabilities due to those interference from FS stations.

The link and transmission characteristics of the UAS CNPC links have to be taken into account. The *BER* performance objective can be translated into a signal-to-noise ratio performance objective.

$$C/N_{req} = E_b/N_0 + 10 \log (r_b / B) \qquad \text{(A6-1)}$$

Where r_b is the net bitrate of the CNPC link defined in Report ITU-R M.2171, B is the bandwidth of the CNPC radio link and E_b/N_0 is the required Bit energy to noise power spectral density ratio to achieve the *BER* performance.

This link margin, *M* (being derived from the link budget analyses of this report) could be considered for the mitigation of interference from stations operating in incumbent services.

If the available link margin is used to cover the interference from incumbent services the final signal-to-noise ratio – which is the ratio of signal power to interference-plus-noise power – is equal to the available signal-to-noise ratio of the UAS CNPC link without interference and propagation impairments minus the remaining link margin.

$$C/N_{avail} - M = C / (N + I_{FS}) \quad \text{(A6-2)}$$

From this equation the maximum possible peak *I/N* can be derived, which only depends on the achieved UAS CNPC link margin and can be written as

$$I/N_{maximum\ possible\ peak} = 10 \log (m - 1) \quad \text{(A6-3)}$$

with *m* as the linear value of the link margin *M* after deducting an appropriate value for clear sky propagation impairments which is gaseous attenuation, only.

The four tables below show the maximum possible peak *I/N* ratios derived from the available link margins and the maximum gaseous attenuation for all flight scenarios and UA antenna sizes.

TABLE A6-8

Maximum possible peak I/N for the 14/11 GHz frequency bands, low / high gain satellite antenna, flight scenario 1 to 3

	14/11 GHz frequency bands low / high gain satellite antenna								
Flight scenario	1			2			3		
UA antenna size	small	medium	large	small	medium	large	small	medium	large
Available link margin	6.2	10.9	14.8	6.2	10.9	14.8	6.2	10.9	14.8
Max. gaseous attenuation	0.2	0.2	0.2	0.4	0.4	0.4	0.2	0.2	0.2
Maximum possible peak I/N	4.8	10.3	14.5	4.4	10.1	14.2	4.7	10.3	14.4

TABLE A6-9

Maximum possible peak I/N for the 14/11 GHz frequency bands, low / high gain satellite antenna, flight scenario 4 to 6

	14/11 GHz frequency bands low / high gain satellite antenna								
Flight scenario	4			5			6		
UA antenna size	small	medium	large	small	medium	large	small	medium	large
Available link margin	6.2	10.9	14.8	6.2	10.9	14.8	6.2	10.9	14.8
Max. gaseous attenuation	1.2	1.2	1.2	0.4	0.4	0.4	1.4	1.4	1.4
Maximum possible peak I/N	3.3	9.2	13.4	4.4	10.1	14.2	3.1	9.0	13.2

TABLE A6-10

Maximum possible peak I/N for the 30/20 GHz frequency bands, low/high gain satellite antenna, flight scenario 1 to 3

	30/20 GHz frequency bands low / high gain satellite antenna								
Flight scenario	1			2			3		
UA antenna size	small	medium	large	small	medium	large	small	medium	large
Available link margin	16.4	19.5	23.2	16.4	19.5	23.2	16.4	19.5	23.2
Max. gaseous attenuation	2.1	2.1	2.1	4.6	4.6	4.6	2.5	2.5	2.5
Maximum possible peak I/N	14.2	17.4	21.1	11.5	14.8	18.6	13.8	17.0	20.7

TABLE A6-11

Maximum possible peak I/N for the 30/20 GHz frequency bands, low / high gain satellite antenna, flight scenario 4 to 6

	30/20 GHz frequency band low / high gain satellite antenna								
Flight scenario	4			5			6		
UA antenna size	small	medium	large	small	medium	large	small	medium	large
Available link margin	16.4	19.5	23.2	16.4	19.5	23.2	16.4	19.5	23.2
Max. gaseous attenuation	11.2	11.2	11.2	4.6	4.6	4.6	13.0	13.0	13.0
Maximum possible peak I/N	3.6	7.6	11.7	11.5	14.8	18.6	0.8	5.4	9.8

It should be noted that the maximum gaseous attenuation was derived from extracting the maximum value of the complete earth (using extrapolation) and 10 degrees elevation of the UA antenna towards the GSO space station and is therefore representing a worst case.

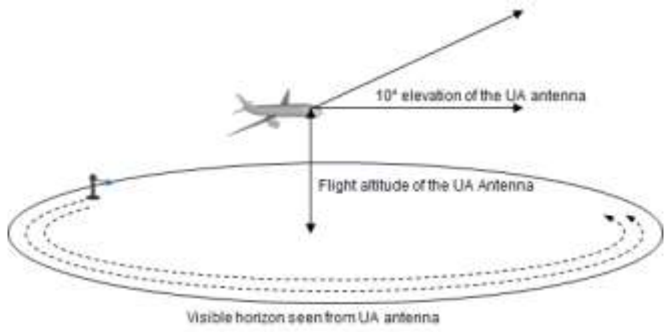
A6-5.2.1 Analysis setup

This analysis setup exemplarily presents the behaviour of the influencing elements of interference caused by fixed services into the UA receiver. It shows the factors which determine the major interference contribution towards UA FSS receiver.

For this a FS station test probe was used as the interfering source with an antenna height of 100 m and 0 degree elevation being placed in 360 degrees circles of different radii around the UA antenna always looking towards the center of the visibility area of the UA. The UA antenna is fixed in pointing direction (flight direction) and in elevation (10 degrees). The resulting *I/N* ratios as the function of the distance between FS antenna and UA antenna was recorded for two frequencies and flight altitudes of the UA. The simulation setup is shown in Figure A6-32.

FIGURE A6-32

Analysis setup single fixed service station interference



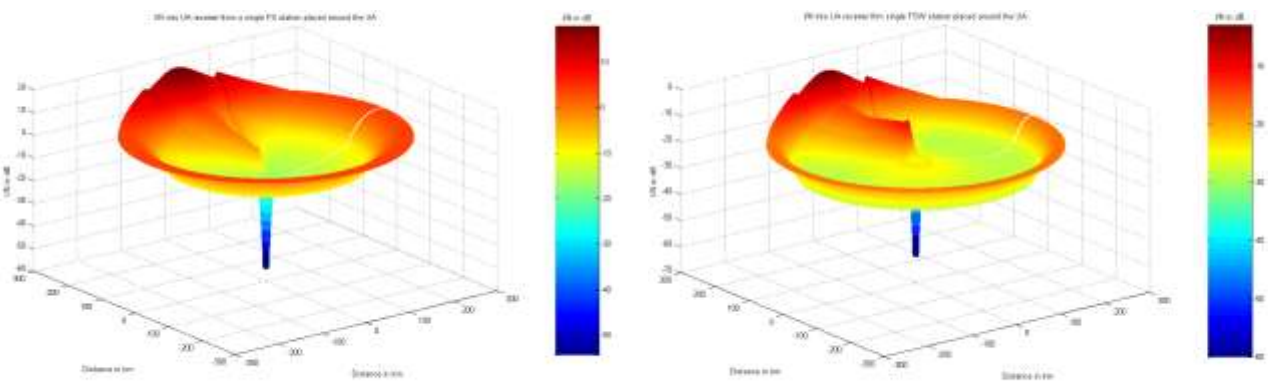
It should be noted that for all *I/N* ratios are identical for different UA antenna sizes This is due applying antenna pattern of Recommendation ITU-R S.580-6 (symmetrical and identical side lobe gains), the identical system noise temperature of 200 K and the fixed elevation of the UA antenna of 10 degrees.

A6-5.2.2 Results and conclusion for the interference driving elements

The analysis results for flight scenario 2 and 11 GHz / 19 GHz frequencies are shown in Figure A6-33.

FIGURE A6-33

***I/N* for 11 GHz (left) and 19 GHz (right) at 19 000 ft flight altitude**



The above figures show the following main characteristics of FS interference:

– The highest interference contributions into the UA receiver are being received by the main lobe for low off-axis angles causing low antenna gain discriminations where no fuselage attenuation is reducing the interfering signal. The fuselage attenuation of the UA is only effective for small areas below the UA (blue parts) where the angle between the UA and FS station is larger than 20° (see Annex 10).

– The interference levels decreases for higher frequency due to larger gaseous attenuations and free space losses.

– Large UA flight altitudes help to reduce the interference load due to larger distances at higher off-axis (decoupling) angles and higher atmospheric attenuations between the FS and UA stations.

– For the same flight altitudes the larger distances inherently result in lower decoupling angles from both UA and FS stations as well as low fuselage based signal attenuation and thus representing the principal worst cases.

– The main influencing elements are the UA antenna patterns (It is assumed that FS patterns cannot be changed) and the decoupling angles from FS stations and UA stations. Proposals for resulting mitigation measures in this context are given in Annex 3.

A6-5.3 Short term interference simulation

The methodology of the analysis provides statistical results on the fading due to interference. It is based on 24h flight of the UA over an area with equally distributed fixed service stations having different antenna heights, antenna sizes, elevation and azimuth, transmit power, feeder losses and frequencies.

The aggregate interference from these FS stations into the UA receiver is calculated and plotted over the complete simulation time for a defined time step / sampling rate over 24h. The important characteristics of fade and interfade durations as well as availability due to FS interference with different *I/N* thresholds are derived from this data.

A6-5.3.1 Propagation model used

For the propagation attenuation between the FS stations and the UA the free-space attenuation of Recommendation ITU-R P.525-2 and the gaseous attenuation of Recommendation ITU-R P.676 was used.

Additional losses e.g. diffraction or tropospheric scatter are not included as they are strongly depending on the geographic location of the UA and would additionally reduce the interference from the FS in to the UA receiver.

A6-5.3.2 Flight path and flight scenario

The flight path and its characteristics are chosen in accordance with the flight scenarios containing information on flight altitude, velocity and flight area.

For this simulation the scenarios 2 and 4 are selected as they represent all remaining flight scenarios as well.

Table A6-12 shows the relevant information from the flight scenarios used for the simulation:

TABLE A6-12

Used parameter from selected flight scenarios

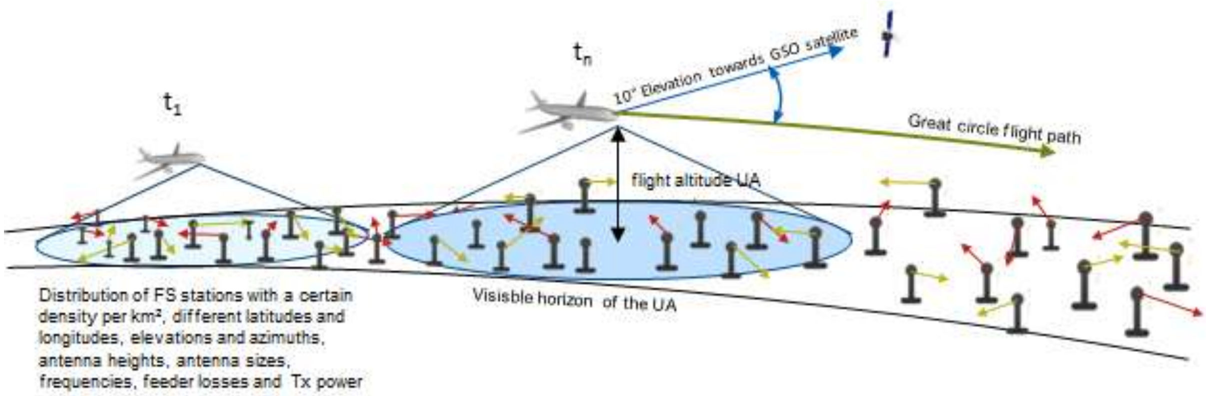
Flight scenario	2	4
Description	Medium altitude surveillance/ Aerial work (search pattern)	Low level surveillance Maritime patrol

Flight scenario	2	4
Max altitude (feet above MSL, unless otherwise specified)	30 000	10 000
Min altitude (feet above MSL, unless otherwise specified)	19 000	500
Max ground speed including wind (knots = NM/h)	300	250

To be independent from the flight path itself a generic flight movement model is chosen in order to guarantee consistency with the performance analysis of Annex 2.

FIGURE A6-34

Simulation model



The airplane moves on a great circle flight path for 24 hours without any changes in direction. FS stations are equally distributed over the visible area below the UA providing the needed independence from the location and the flight path; a change of direction will not change the number of visible FS stations.

The length and duration of the flight and the repetition of simulations provides the representative statistical basis and allow generic and statistical conclusions.

A6-5.3.3 Fixed service station parameters

The performance parameters of the FS stations are taken from Recommendation ITU-R F.758-5. Whenever some parameter is not given by the Recommendation reliable sources are used to complete the needed set of information. The parameters of the FS station are listed in the following table including the source of origin.

TABLE A6-13

Fixed service station parameters used in simulation

	Unit	Distribution	11 GHz frequency range	20 GHz frequency range	Source	Comparison with long term studies
Antenna diameter	m	Uniform Discrete	0.54; 1.25; 3.5 see Note	0.08; 0.89; 1.7 see Note	Rec. ITU-R F.758	
Azimuth	degrees	Uniform	0-360	0-360	Canadian database	Identical
Elevation	degrees	Normal	N(-5°, +5°)	N(-5°, +5°)	Canadian database	Identical
Height	m	Uniform	Between 10 and 100	Between 10 and 100	Annex 4	Identical
Tx power	dBW/MHz	Uniform	Between -16 and -12.8	Between -45.4 and -19	Rec. ITU-R F.758	Larger range used
Fixed service station density	stations/km^2	Uniform	0.0001 for Scenario 4 0.0009 for Scenario 2	0.001 for Scenario 4 0.009 for Scenario 2	ECC REPORT 173, Excel attachment	Different to cover specific density areas
FS co-frequency	%	none	7.2	5.9	Canadian database	Identical
Feeder loss	dB	Uniform	Between 0 and 9.5	Between 0 and 9.3	Rec. ITU-R F.758	Identical

Note – These values are calculated from Rec. ITU-R F.758 and represent the largest, average and smallest antenna diameter of the antenna gain range with an antenna efficiency of 65%.

A6-5.3.4 Fixed service station densities

In a first step a rural scenario in terms of the FS link distribution was analyzed. According to a CEPT study[1] 9300 P-P links are in service in the 11 GHz frequency range in Europe. Therefore it is concluded that the FS density for Europe used in the simulation as an area with high population density is calculated to:

$$Dens_{FS}\ (11\ GHz) = N_{FS} / A_{EUR} = 9\ 300 / 10\ 180\ 000\ km\text{^}2$$
$$= 0.000913\ FS/km\text{^}2 \approx 0.0009\ FS/km\text{^}2 \quad (A6\text{-}4)$$

The equally distributed FS stations over the visible area below the UA provides the independence from the location and the flight path, as a change of direction will not change the number of visible FS stations.

According to the report, the density of FS station in the 19 GHz bands is 10 times higher than the density in the 11 GHz frequency range, therefore the FS density used in the simulation for the 19 GHz frequency range is.

$$Dens_{FS}\ (19.7\ GHz) = 10\ Dens_{FS}\ (11\ GHz) = \approx 0.009\ FS/km\text{^}2 \quad (A6\text{-}5)$$

[1] ECC Report 173 with collected information dated 2010 containing released numbers of FS links in European countries, see http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCRep173.PDF

For areas with low FS stations densities like flight scenario 4 for maritime patrol densities listed in Table A6-14 are chosen.

As the definition of the scenario inherit a flight over populated land implying high FS densities and flights over maritime areas implying low densities the different densities represent the realistic values to be used in the analysis.

TABLE A6-14

Fixed service station densities used for simulation of the flight scenarios

Flight scenario	**2**	**4**
Description	Medium altitude surveillance/ Aerial work (search pattern)	Low level surveillance Maritime patrol
FS densities	11 GHz: 0.0009 FS/km^2 19.7 GHz: 0.009 FS/km^2	11 GHz: 0.0001 FS/km^2 19.7 GHz: 0.001 FS/km^2

A6-5.3.5 Unmanned aircraft station parameters

The simulation results are independent from the size of the UA antenna as the system noise for all antenna sizes is identical (see Annex 1). Moreover, the interference is never received with the main lobe of the UA antenna when assuming an elevation of 10 degrees and the used antenna pattern of Recommendation ITU-R S.580.

A6-5.3.6 Fading parameters

The analysis for short term interference presents additional knowledge upon the behaviour of the link 2 during a flight over regions where FS stations operate by presenting information on the fade durations and interfade durations for a set of parametric *I/N* thresholds in the range of -15 dB up to 25 dB.

Fade duration need to be taken into account for several reasons:

– link outage and unavailability: fade duration statistics provide information on number and duration of outages for certain thresholds and link unavailability due to interference on the given link;

– it is important from an operational point of view to be aware of the statistical duration of an event in order to assign the needed threshold / allowable *I/N* for UAS CNPC links;

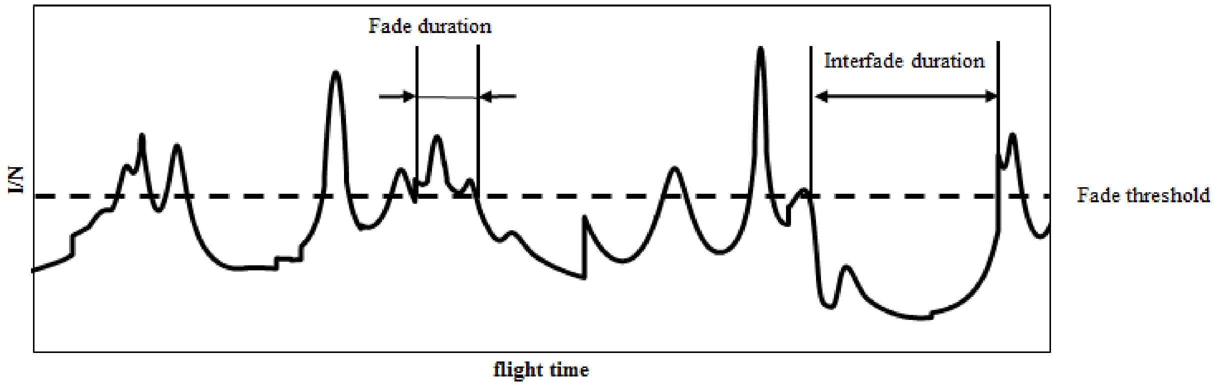
– fade duration is of concern to determine statistical duration for the link to stay in a compensation configuration (applied mitigation measures) before coming back to its nominal mode;

– signal coding and modulation: fade duration is a key element in the process of choosing / adapting forward error correction codes and best modulation schemes; fade duration impacts directly the choice of the coding scheme (size of the coding word in block codes, interleaving in concatenated codes, etc.).

Apart from fade duration statistics, it is also useful to characterize the time interval between two fades, the interfade duration. Once the level of the received signal has just crossed back the margin threshold after an outage event – based on a certain fade threshold – it is essential to capture the time durations between such *I/N* threshold crossings for building a statistical basis.

FIGURE A6-35

Definition of fade and inter-fade duration



As highlighted in the example shown in figure A6-35, the fade duration is defined as the time interval between two crossings above the same *I/N* threshold whereas inter-fade duration is defined as the time interval between two crossings below the same *I/N* threshold.

A6-5.4 Structure of study results

For the representative flight scenarios 2 and 4, the average and maximum fading durations per 24 h flight as well as the aggregate fading duration during this flight are determined for both, the 14/11 GHz band and 30/20 GHz band space-to-Earth frequency bands.

The structure of the following subchapters is as follows:

- Frequency range (11 GHz / 19.7 GHz)
  - Flight scenario (#2 and #4)
    - Fade duration exceeding different I/N levels (in the range of -15 dB up to 25 dB) in terms of:
      - average fade durations per 24 h flight time
      - maximum fade durations per 24 h flight time
      - aggregate fade durations per 24 h flight time
    - Inter-fade durations, i.e. time between fading events, in terms of:
      - average inter-fade durations per 24 h flight time (needed for determining the chance of re-acquisition of the signal)
      - aggregate fade durations per 24 h flight time

The results presentation per CDF needs to be evaluated carefully because of the aggregating character of CDF without showing any differences for different flight speeds.

A6-5.5 Simulations results for 11 GHz

A6-5.5.1 Flight scenario 2

The following diagrams show the fade and interfade durations for flight scenario 2 (flight height 19 kft) for *I/N* ratios from -15 dB up to 25 dB in comparison with the maximum possible peak I/N according to section A6-5.2.

All diagrams show compliance with the thresholds, all interference effects can be covered.

A6-5.5.1.1 Fade durations

FIGURE A6-36

Average fade duration flight scenario 2, 11 GHz, for 24h flight time

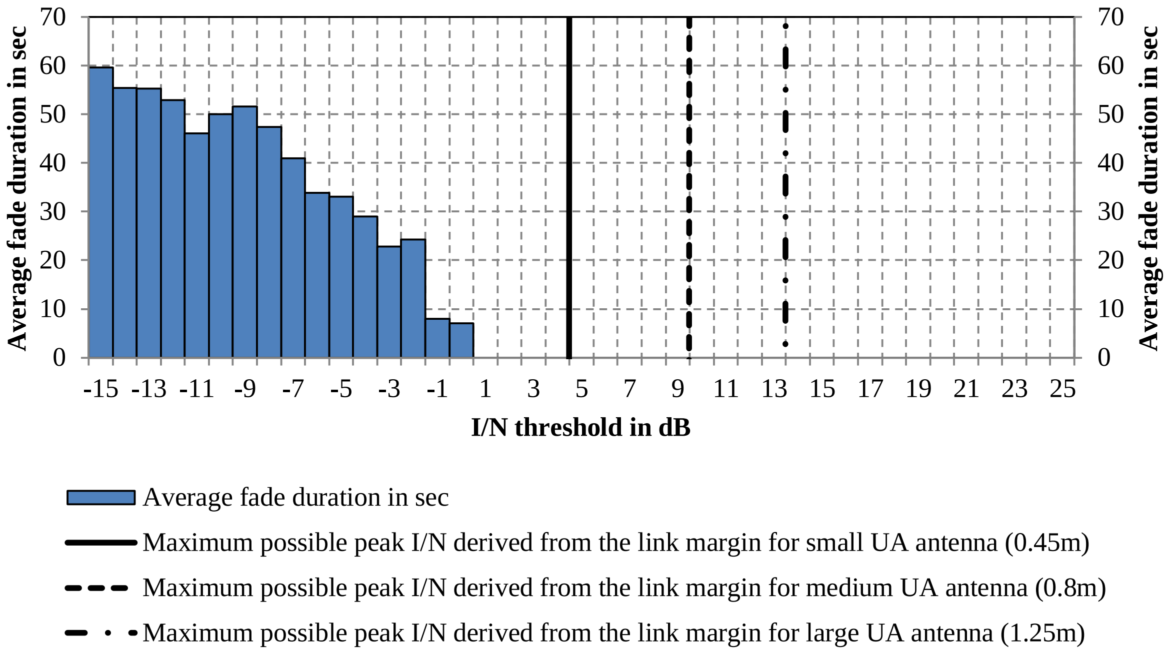


FIGURE A6-37

Maximum fade duration flight scenario 2, 11 GHz, for 24h flight time

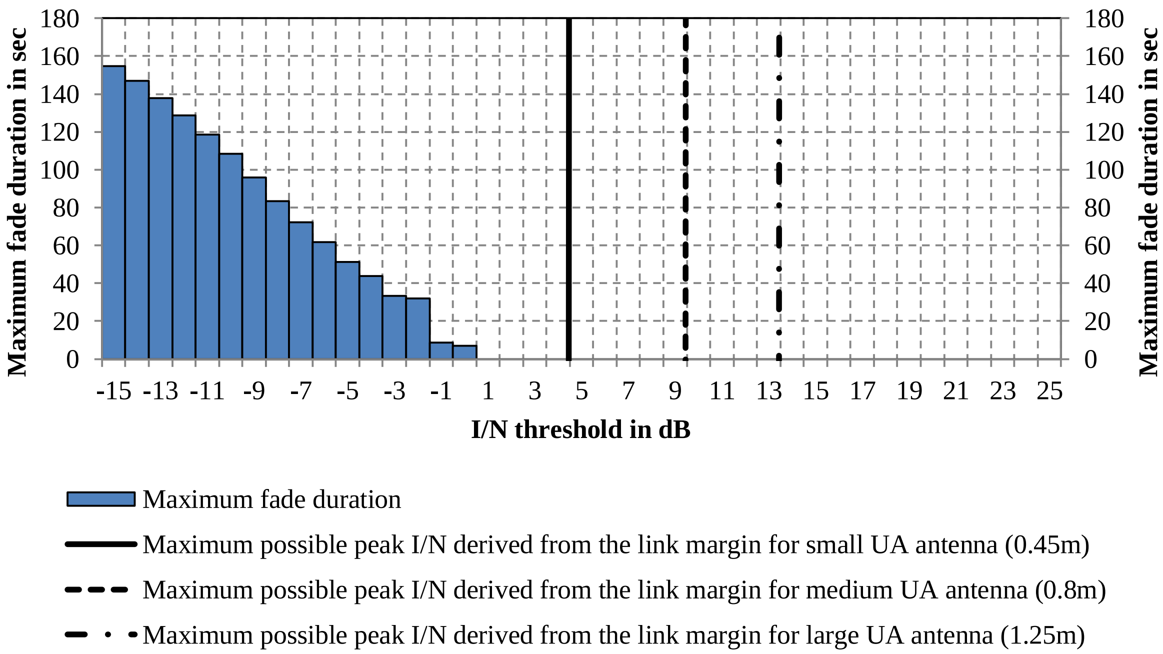
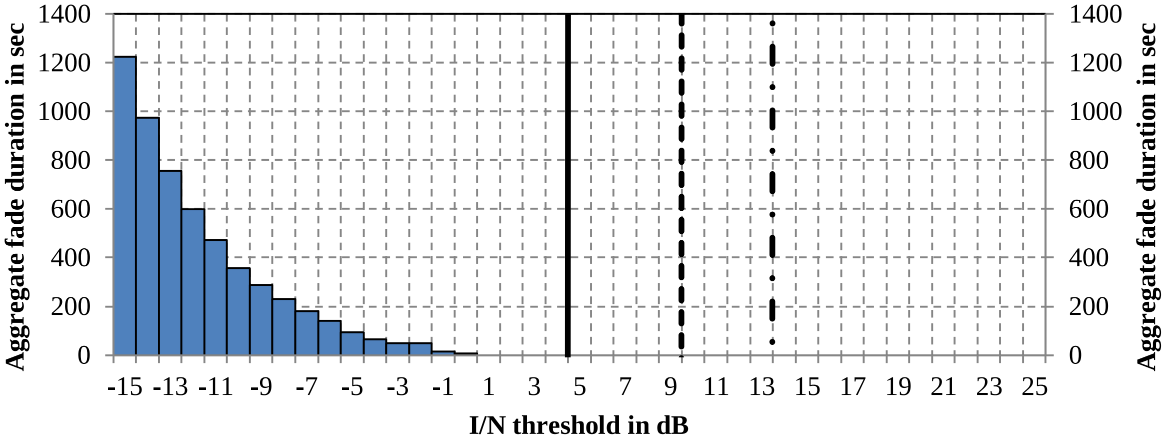


FIGURE A6-38

Aggregate fade duration flight scenario 2, 11 GHz, for 24h flight time



Aggregate fade duration

Maximum possible peak I/N derived from the link margin for small UA antenna (0.45m)

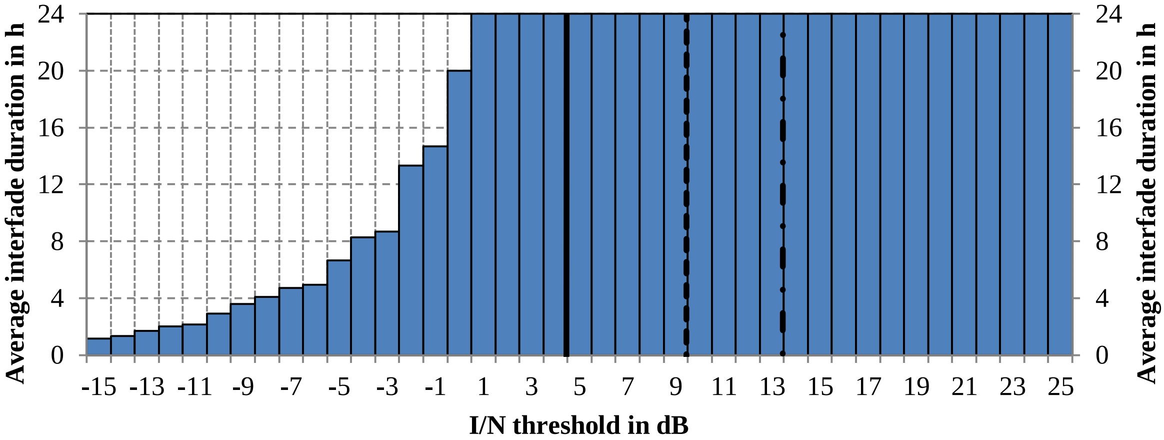
Maximum possible peak I/N derived from the link margin for medium UA antenna (0.8m)

Maximum possible peak I/N derived from the link margin for large UA antenna (1.25m)

A6-5.5.1.2 Inter-fade duration

FIGURE A6-39

Average inter-fade duration, flight scenario 2, 11 GHz, for 24h flight time



Average interfade duration in h

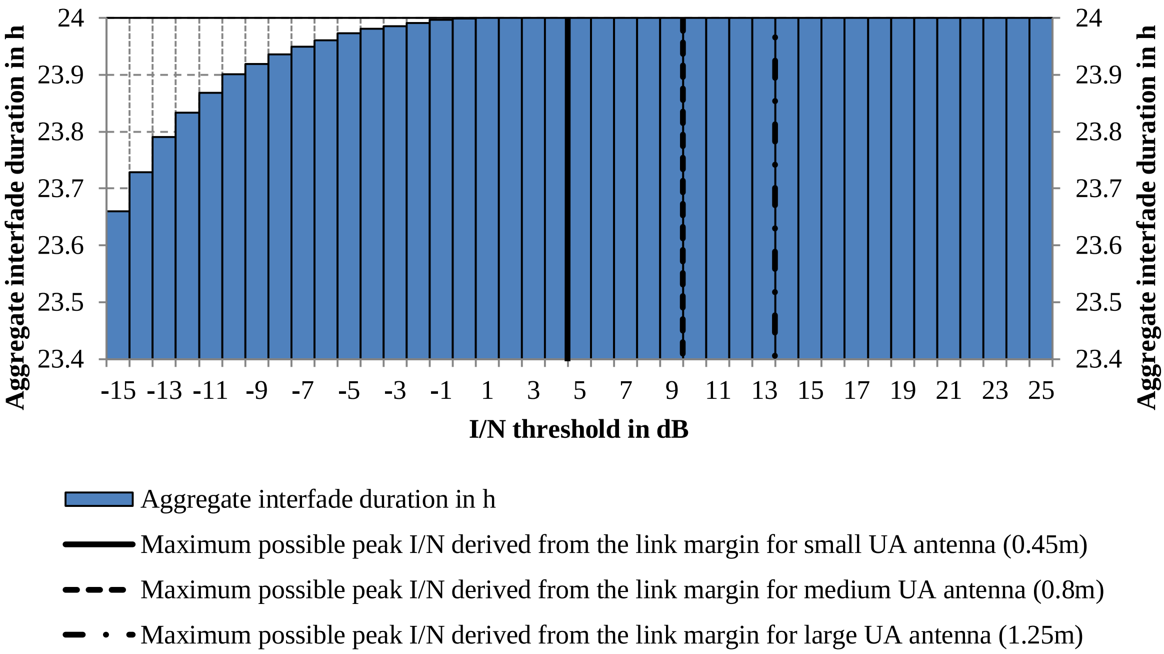
Maximum possible peak I/N derived from the link margin for small UA antenna (0.45m)

Maximum possible peak I/N derived from the link margin for medium UA antenna (0.8m)

Maximum possible peak I/N derived from the link margin for large UA antenna (1.25m)

FIGURE A6-40

Aggregate inter-fade duration flight scenario 2, 11 GHz, for 24h flight time



A6-5.5.2 Flight scenario 4

The following diagrams show the fade and inter-fade durations for flight scenario 4 (flight height 914 m (3 000 ft)) for *I/N* ratios from –15 dB up to 25 dB in comparison with the maximum possible peak I/N according to section A3.2.

The diagrams show only short fade durations for the Maximum possible peak I/N. Mitigation measured have to be applied to reduce the durations, if needed. Further analyses with two simultaneous frequencies do show significant reductions of the durations and full compliance with the thresholds (see also Annex 3). The inter-fade durations are sufficiently long enough for enabling the re-acquisition of the proper satellite signal reception.

A6-5.5.2.1 Fade durations

FIGURE A6-41

Average fade duration, flight scenario 4, 11 GHz, for 24h flight time

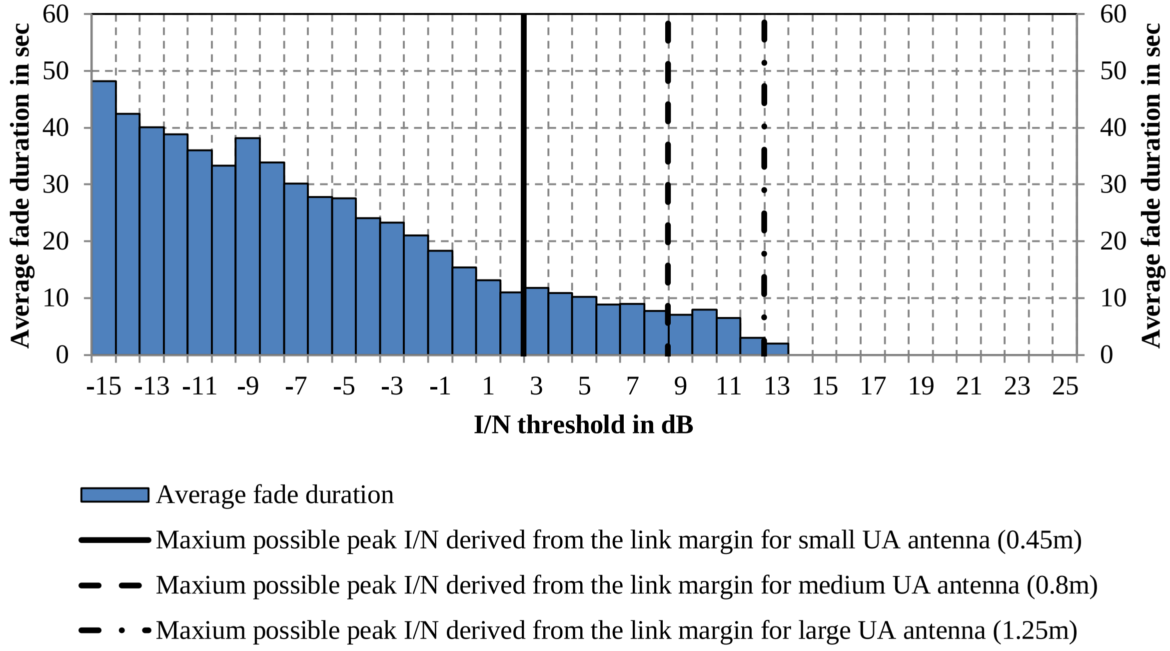


FIGURE A6-42

Maximum fade duration, flight scenario 4, 11 GHz, for 24h flight time

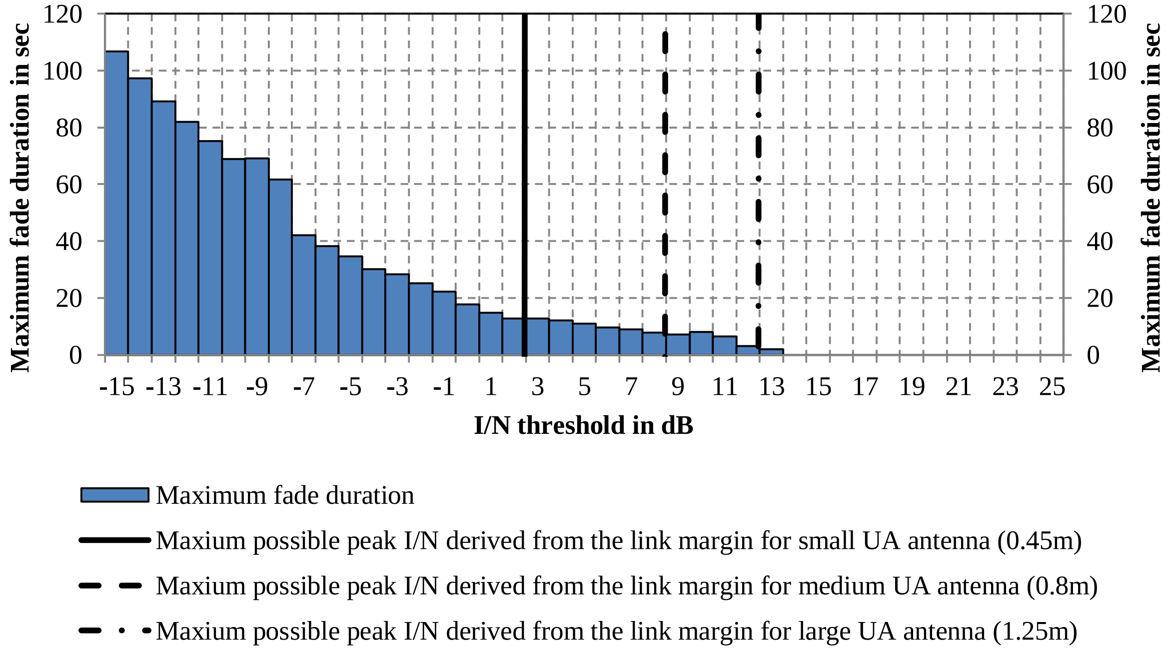
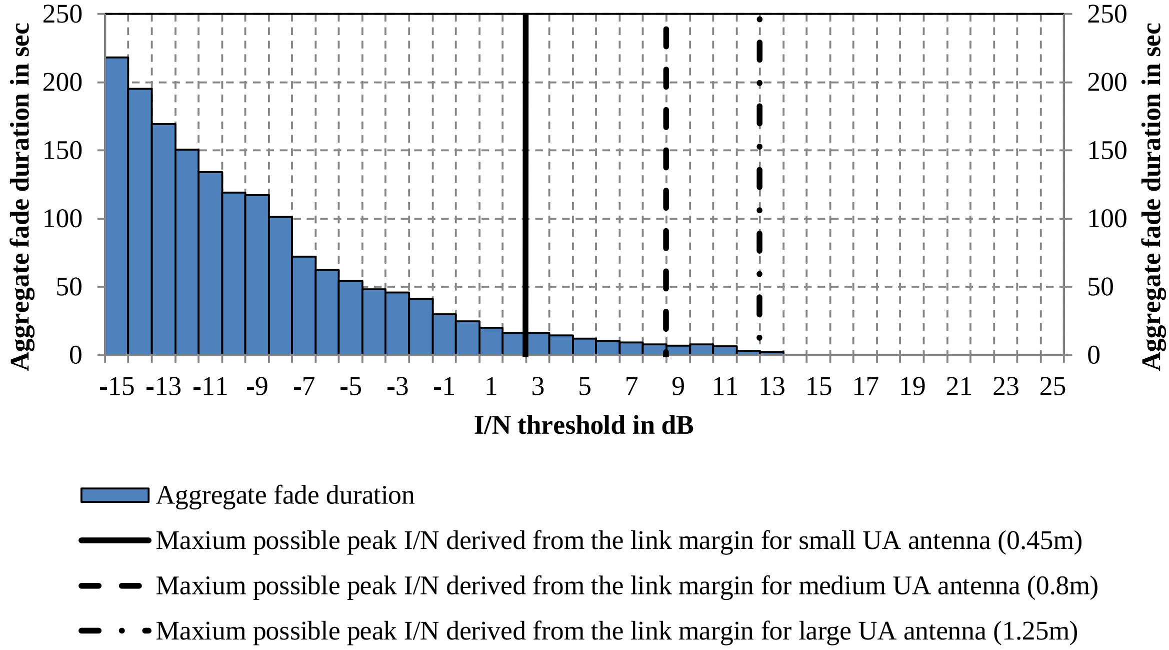


FIGURE A6-43

Aggregate fade duration, flight scenario 4, 11 GHz, for 24h flight time



A6-5.5.2.2 Inter-fade duration

FIGURE A6-44

Average inter-fade duration, flight scenario 4, 11 GHz, for 24h flight time

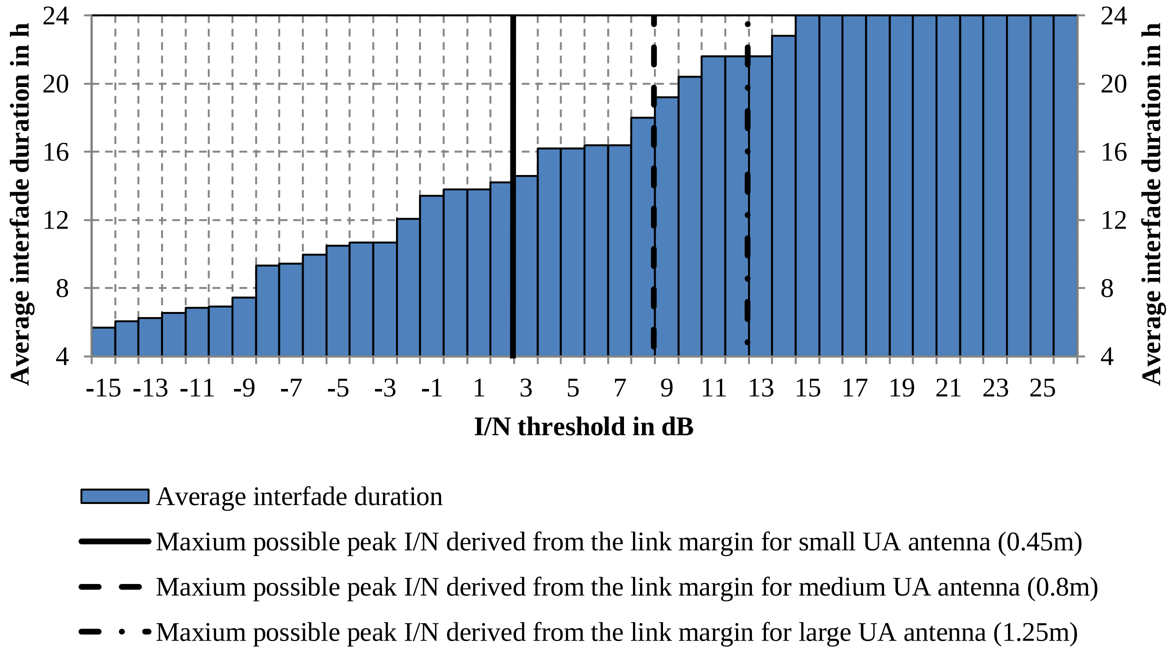
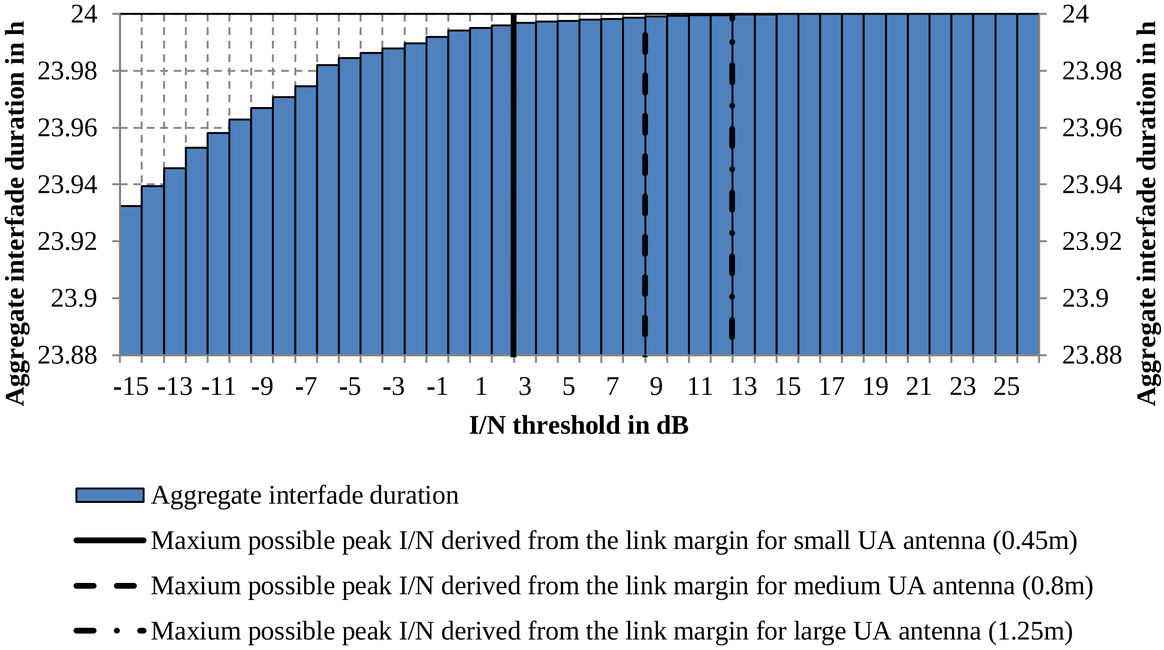


FIGURE A6-45

Aggregate inter-fade duration flight scenario 4, 11 GHz, for 24h flight time



A6-5.6 Simulations results for 19.7 GHz

A6-5.6.1 Flight scenario 2

The following diagrams show the fade and inter-fade durations for flight scenario 2 (flight height 19 000 ft) for *I/N* ratios from -20 dB up to 20 dB in comparison with the maximum possible peak I/N according to section A6-49.

All diagrams show compliance with the thresholds including large margins, all interference effects can be covered.

A6-5.6.1.1 Fade durations

FIGURE A6-46

Average fade duration, flight scenario 2, 19.7 GHz, for 24h flight time

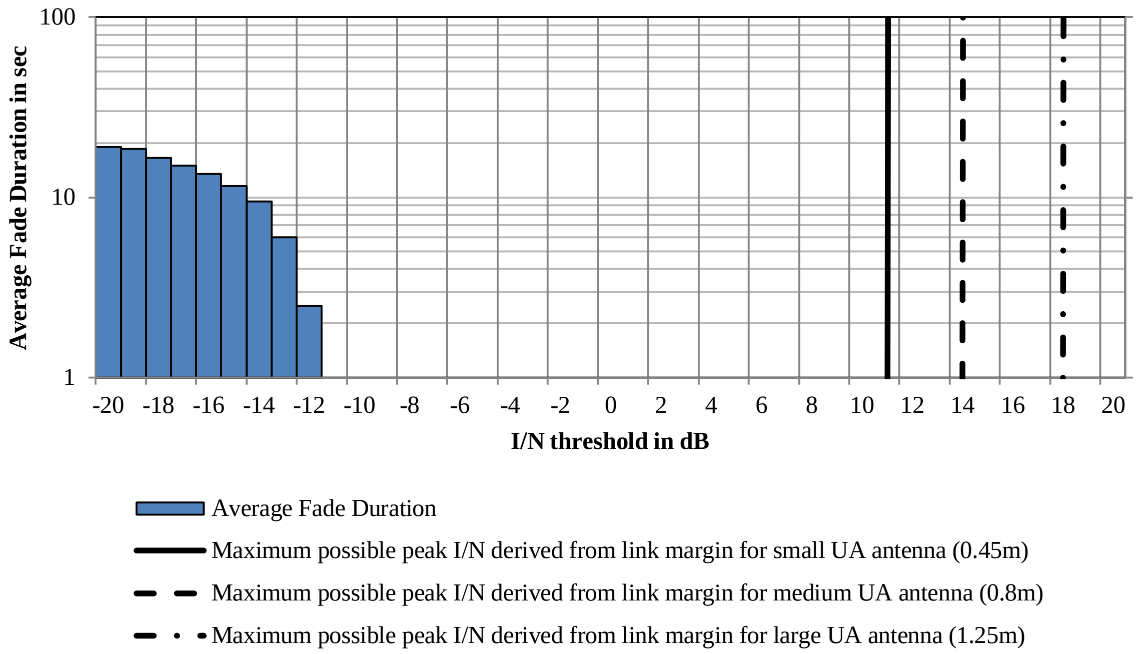


FIGURE A6-47

Maximum fade duration, flight scenario 2, 19.7 GHz, for 24h flight time

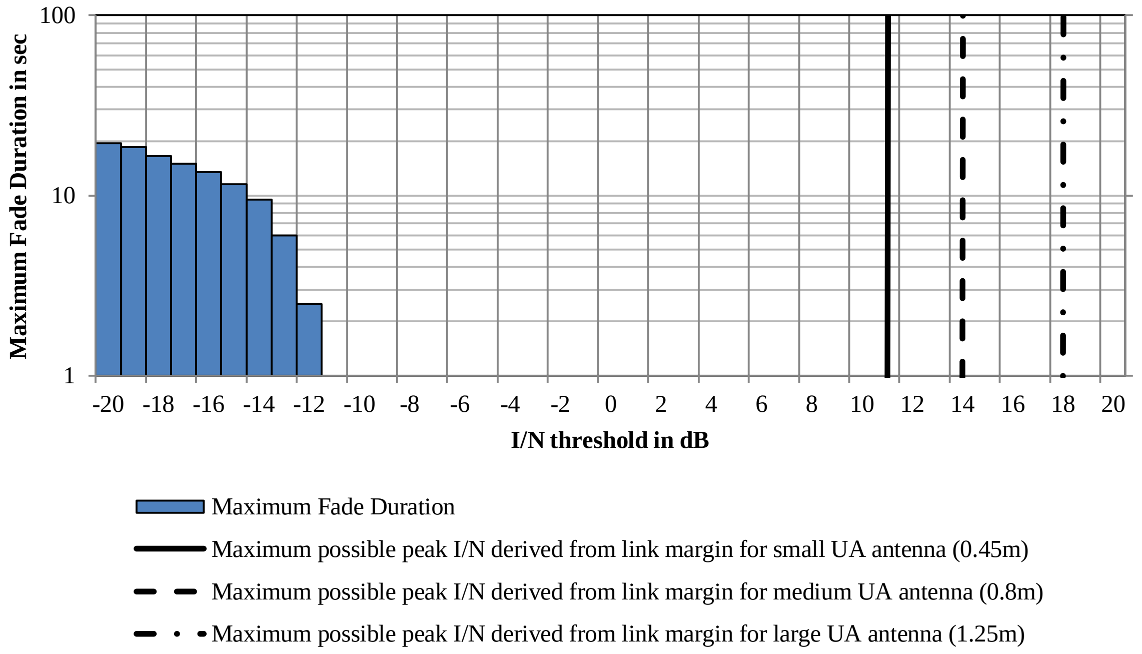
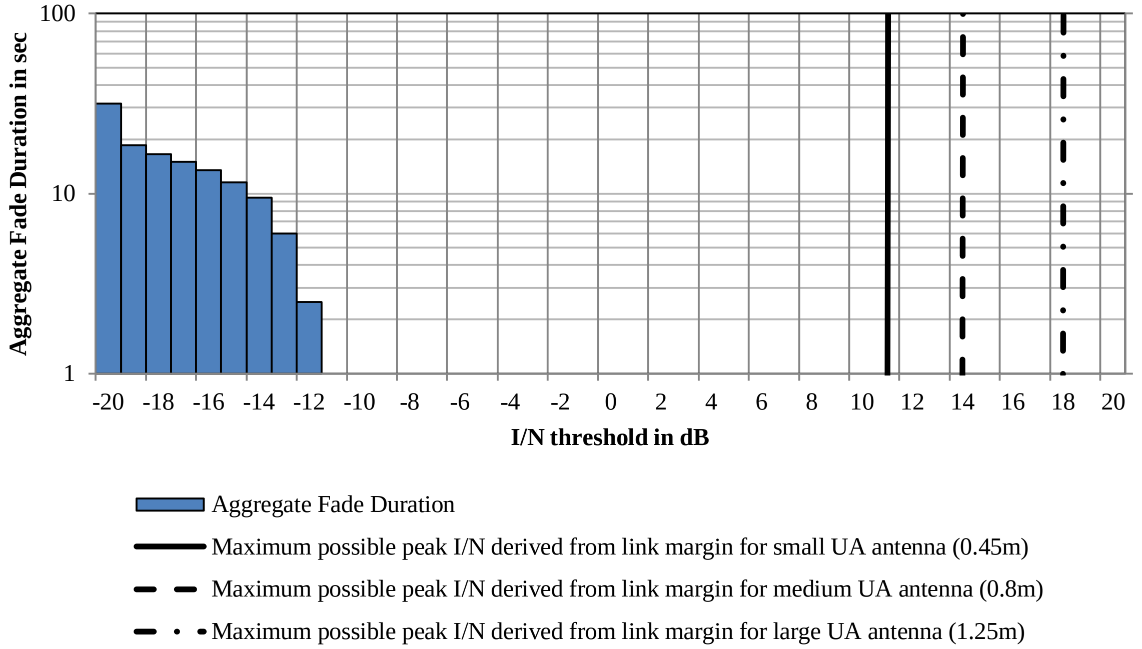


FIGURE A6-48

Aggregate fade duration, flight scenario 2, 19.7 GHz, for 24h flight time



A6-5.6.1.2 Inter-fade duration

FIGURE A6-49

Average inter-fade duration, flight scenario 2, 19.7 GHz, for 24h flight time

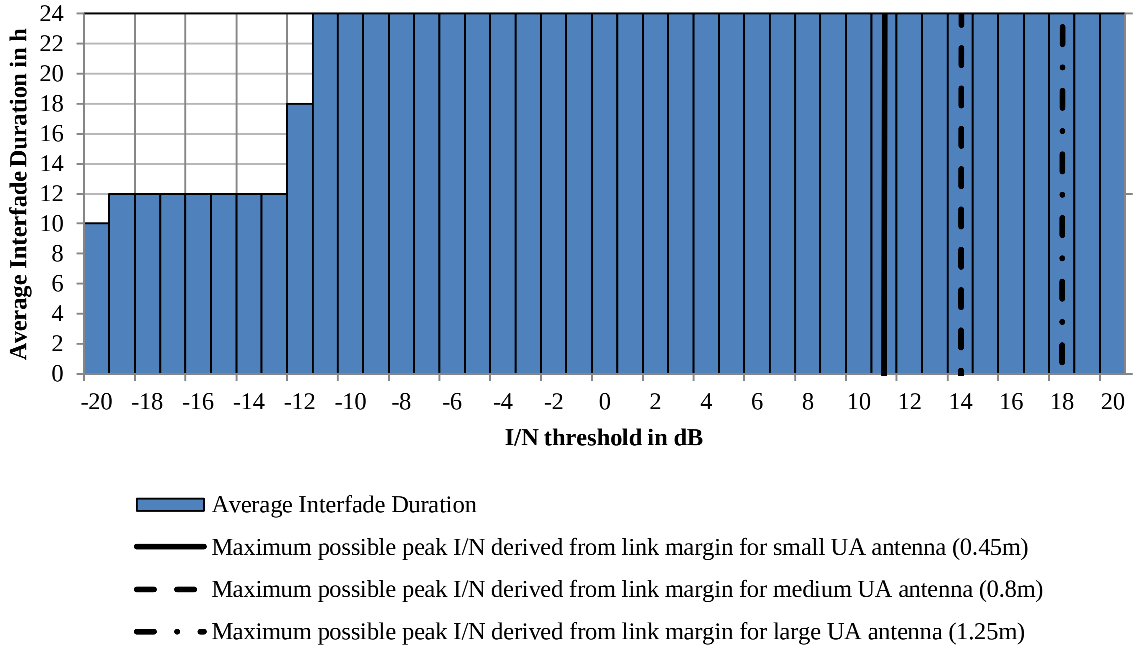
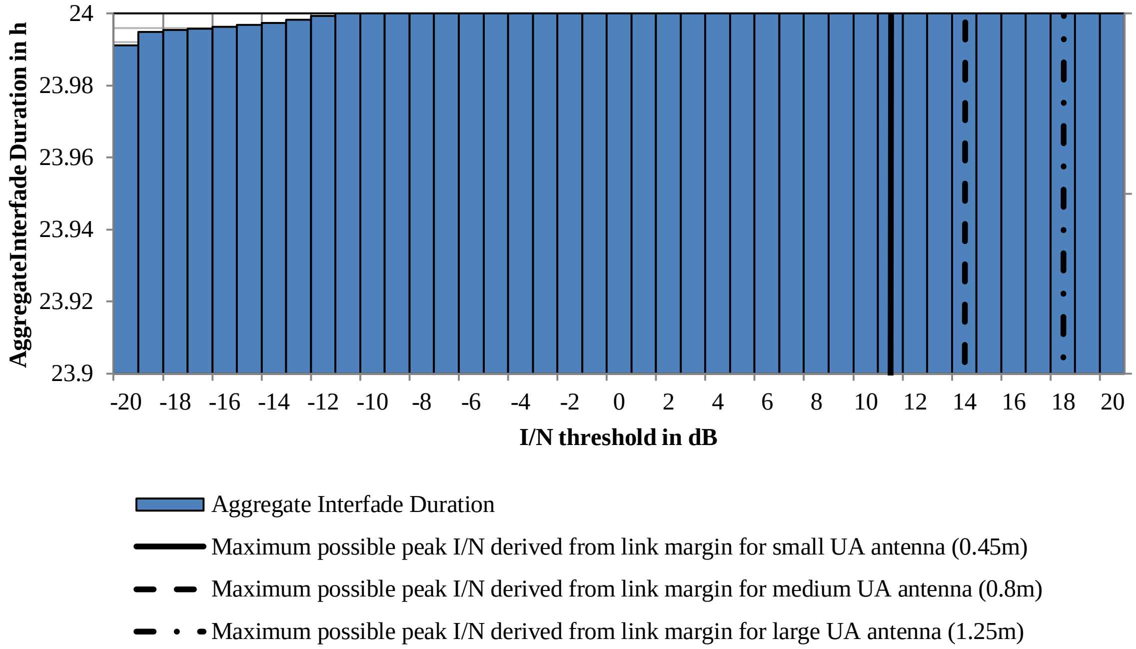


FIGURE A6-50

Aggregate inter-fade duration flight scenario 2, 19.7 GHz, for 24h flight time



A6-5.6.2 Flight scenario 4

The following diagrams show the fade and inter-fade durations for flight scenario 4 (flight height 3 000 ft) for *I/N* ratios from -20 dB up to 20 dB in comparison with the maximum possible peak I/N according to section A6-54.

The diagrams show only short fade durations compared to the maximum possible peak I/N ratios for the three UA types. Mitigation measured have to be applied to reduce the durations, if needed. Further analyses with two simultaneous frequencies do show significant reductions of the durations and full compliance with the thresholds (see also Annex 3). The inter-fade durations are sufficiently long enough for enabling the re-acquisition of the proper satellite signal reception.

A6-5.6.2.1 Fade durations

FIGURE A6-51

Average fade duration, flight scenario 4, 19.7 GHz, for 24h flight time

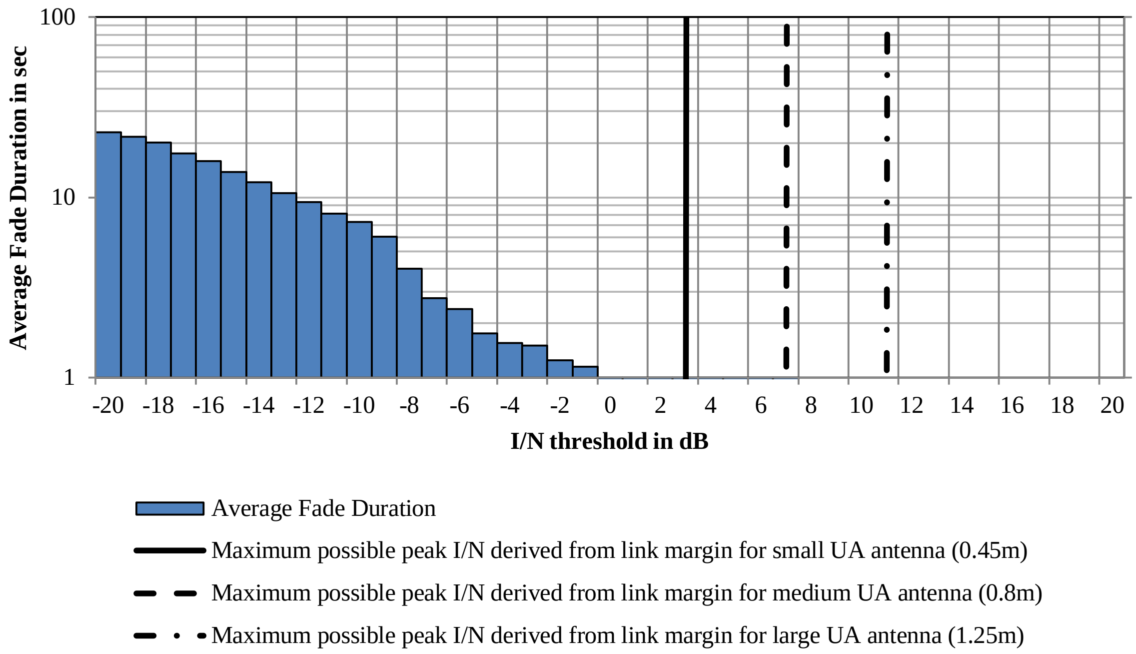


FIGURE A6-52

Maximum fade duration, flight scenario 4, 19.7 GHz, for 24h flight time

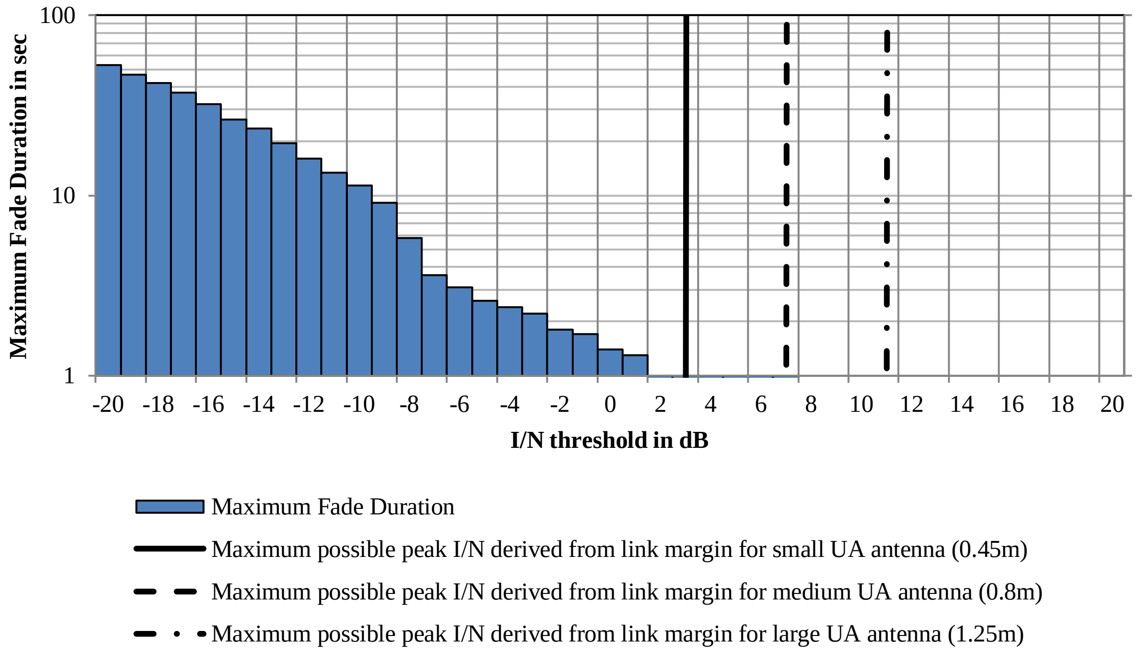
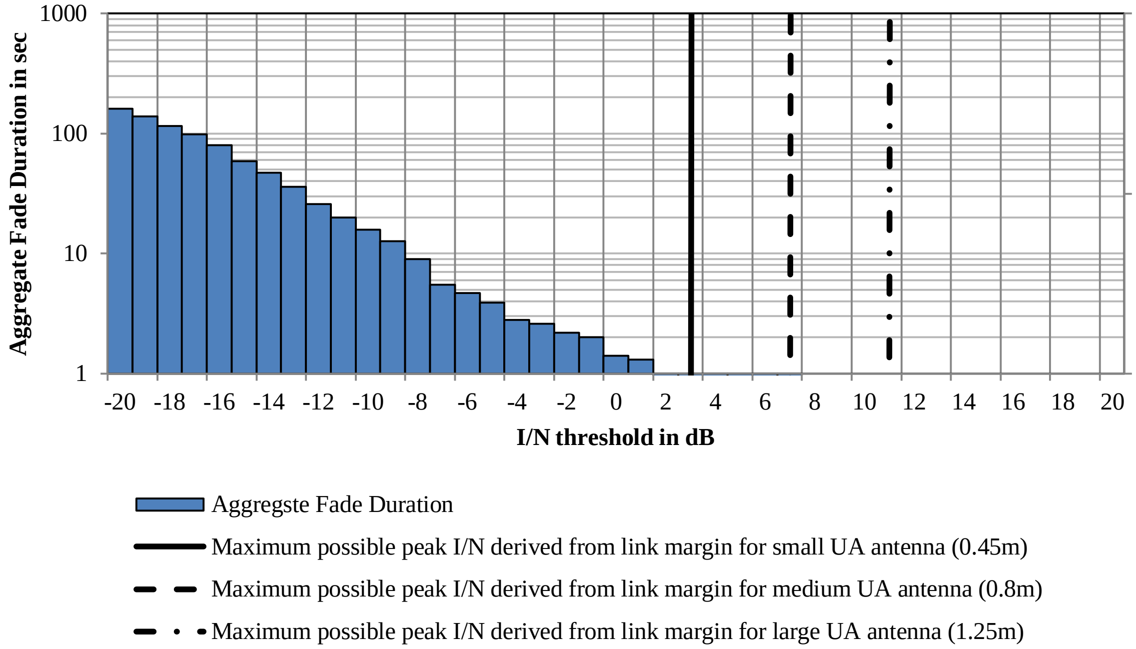


FIGURE A6-53

Aggregate fade duration, flight scenario 4, 19.7 GHz, for 24h flight time



A6-5.6.2.2 Inter-fade duration

FIGURE A6-54

Average inter-fade duration, flight scenario 4, 19.7 GHz, for 24h flight time

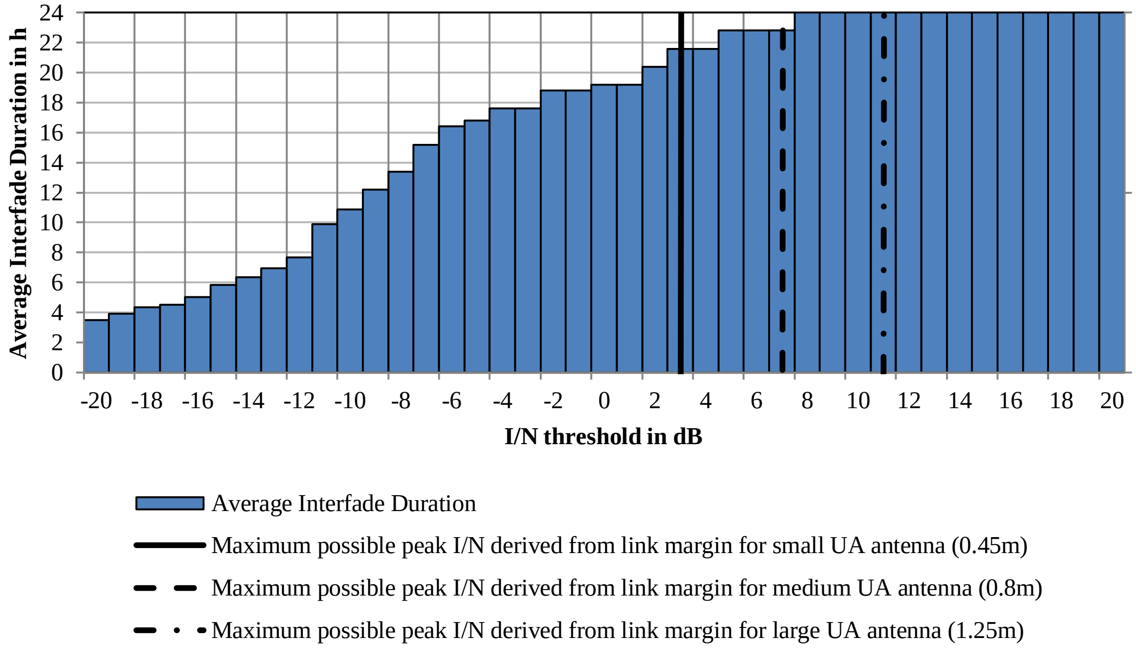
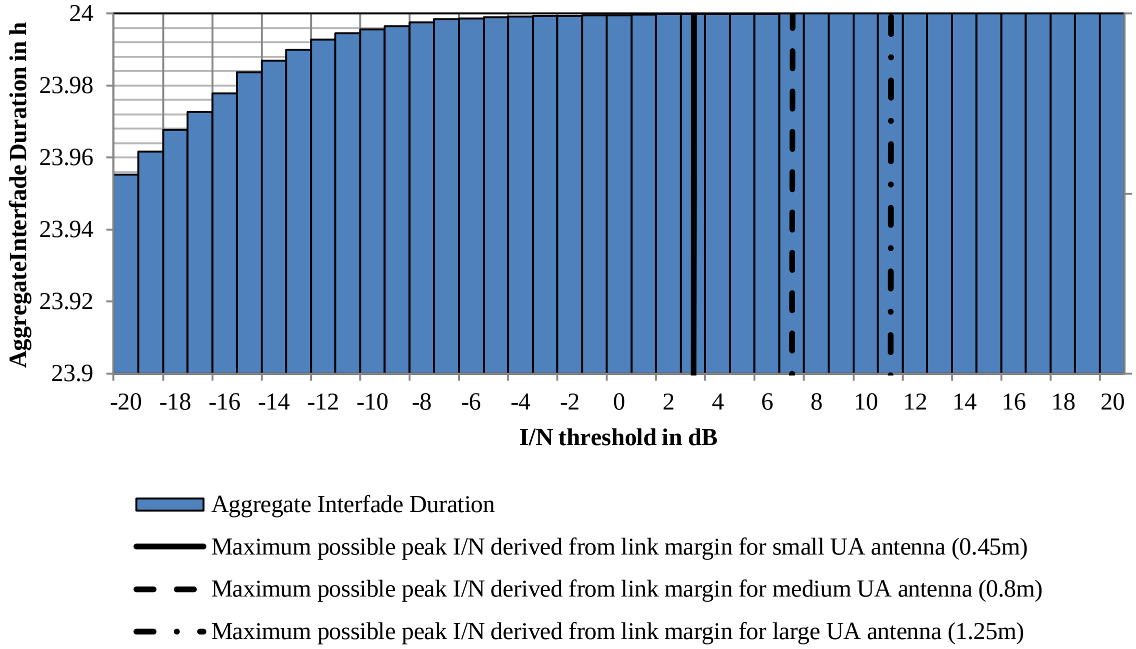


FIGURE A6-55

Aggregate inter-fade duration flight scenario 4, 19.7 GHz, for 24h flight time



A6-5.7 Availability performance with respect to interference from fixed service stations

From the derived results of the fade durations and inter-fade durations, the availability with respect to interference from FS stations depending on different *I/N* ratios of the selected parametric set can be derived. The availability over 24 h flight time is calculated via:

Av. Availability (24h) = 100 % – Av. Unavailability (24h). (A6-6)

With

Av. Unavailability (24h) = Av. fade duration (24h) / (Av. interfade duration (24h) + av. fade duration (24h) (A6-7)

For the reasons of presentation both parameters, the unavailability in logarithmic scale and the availability in linear scale is shown.

The following diagrams show unavailability curves per 24 h flight time and the resulting availabilities for the nominal system characteristics without any mitigation measures.

A65.8 Link availability results for 11 GHz

A6-5.8.1 Flight scenario 2

FIGURE A6-56

Average unavailability over 24h flight time, 11 GHz, flight scenario 2

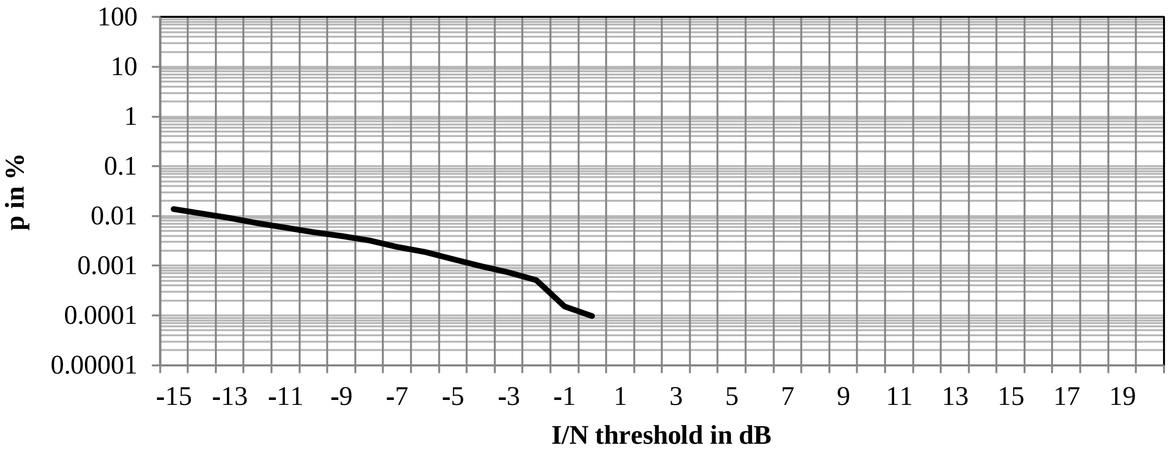
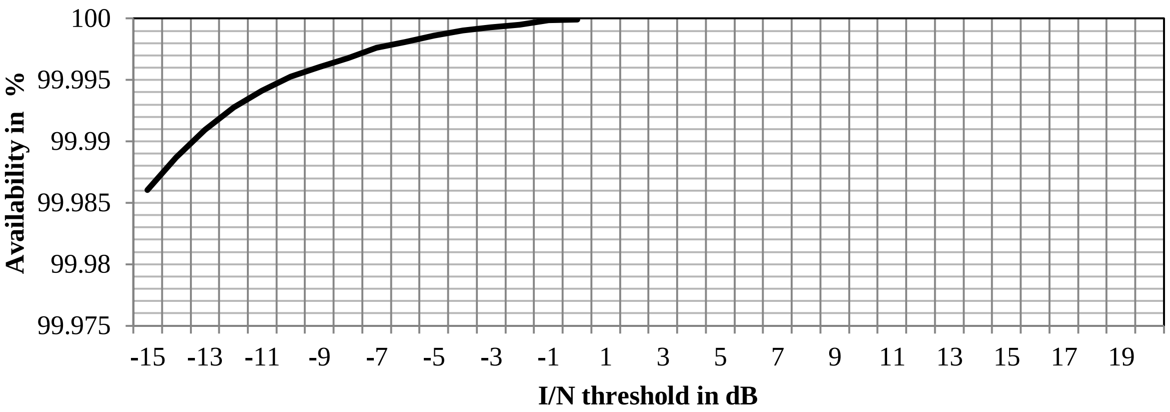


FIGURE A6-57

Average availability for 24h flight time, 11 GHz, flight scenario 2



This figure shows the average availability when applying the different *I/N* ratios. For example, in case the link 2 would provide an assumed *I/N* threshold of 0 dB, the resulting availability against short term interference is very close to the 100%. Because all UA links according to Annex 2 provides even better link margins the resulting availability will not decrease further.

A6-5.8.2 Flight scenario 4

FIGURE A6-58

Unavailability exceeded for 24h flight time, flight scenario 4, 11GHz

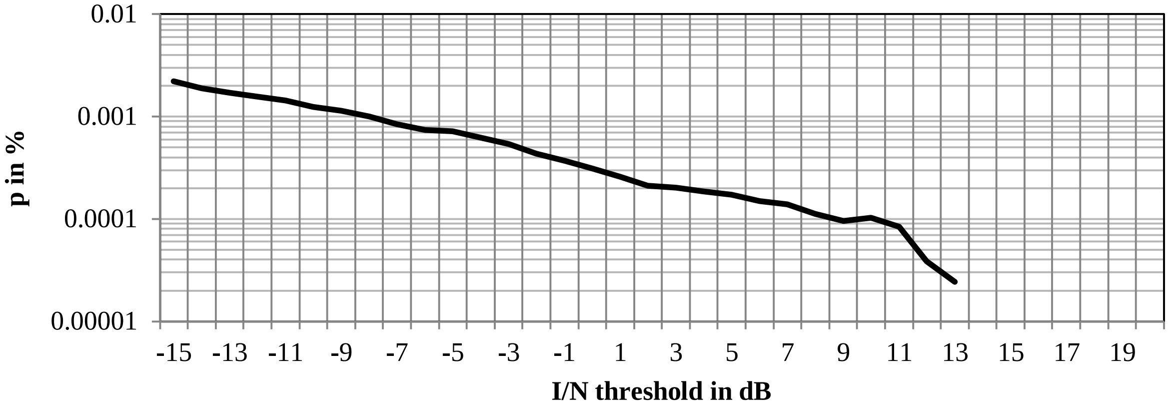
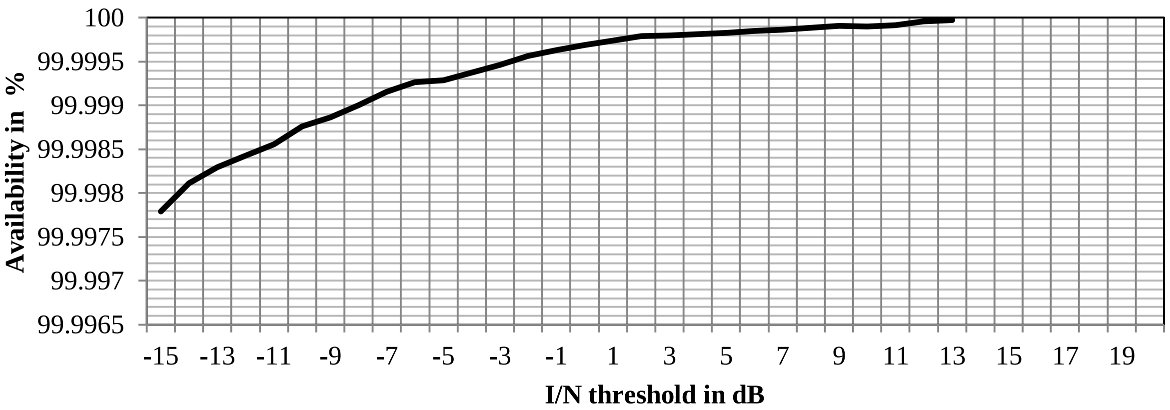


FIGURE A6-59

Average Availability for 24 h flight time, flight scenario 4, 11 GHz



These two diagrams show the availability for flight scenario 4, being > 99.999% for the smallest link margin according to Annex 2 and consequently show sufficient performance with respect to interference.

A 6-5.9 Availability results for 19.7 GHz

A 6-5.9.1 Flight scenario 2

FIGURE A6-60

Average unavailability for 24h flight time, flight scenario 2, 19.7 GHz

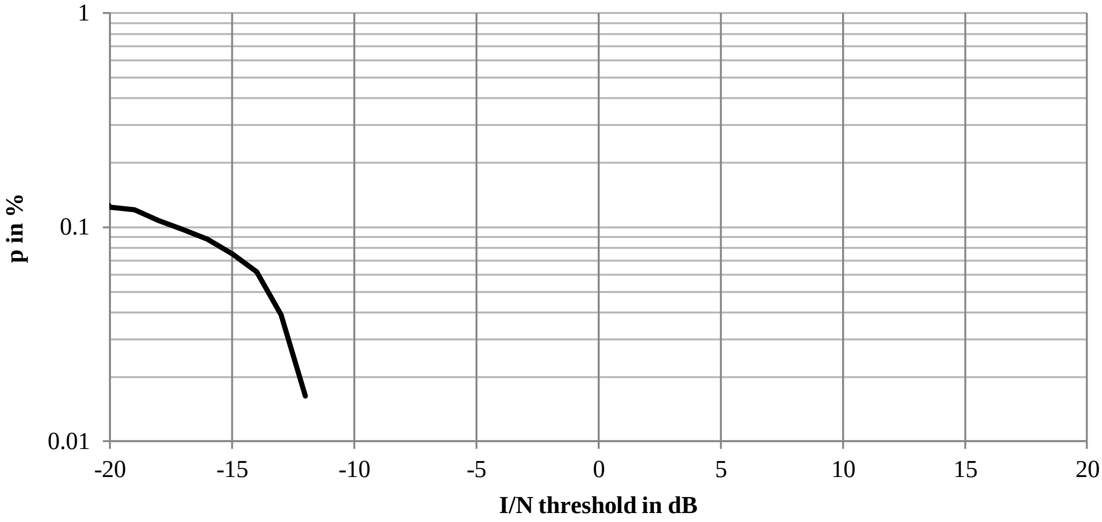
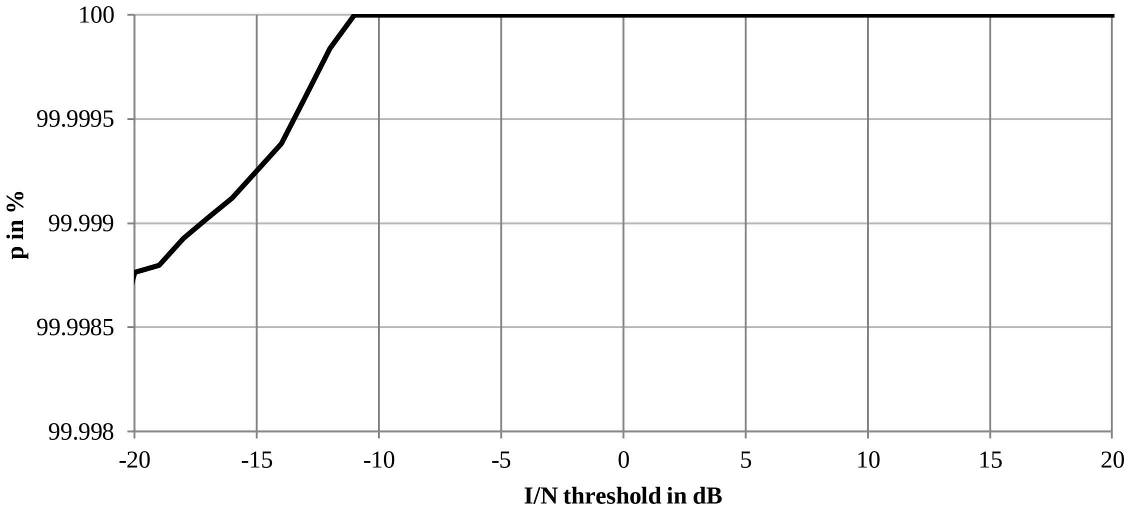


FIGURE A6-61

Average availability for 24h flight time, flight scenario 2, 19.7 GHz



These two diagrams show the availability for flight scenario 2, being very close to the 100% even for the smallest link margin according to Annex 2 and consequently show sufficient performance with respect to interference.

A 6-5.9.2 Flight scenario 4

FIGURE A6-62

Average unavailability for 24h flight time, flight scenario 4, 19.7 GHz

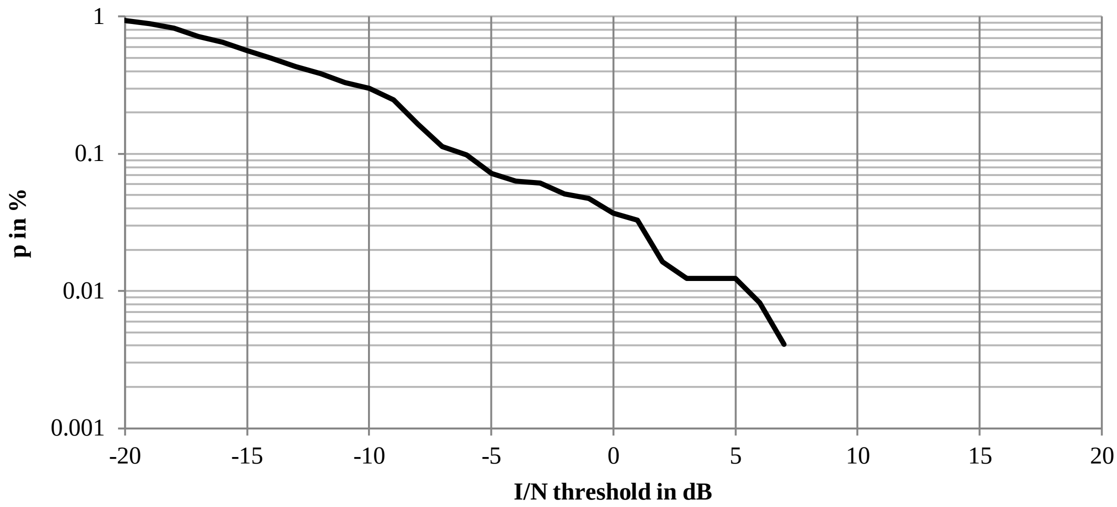
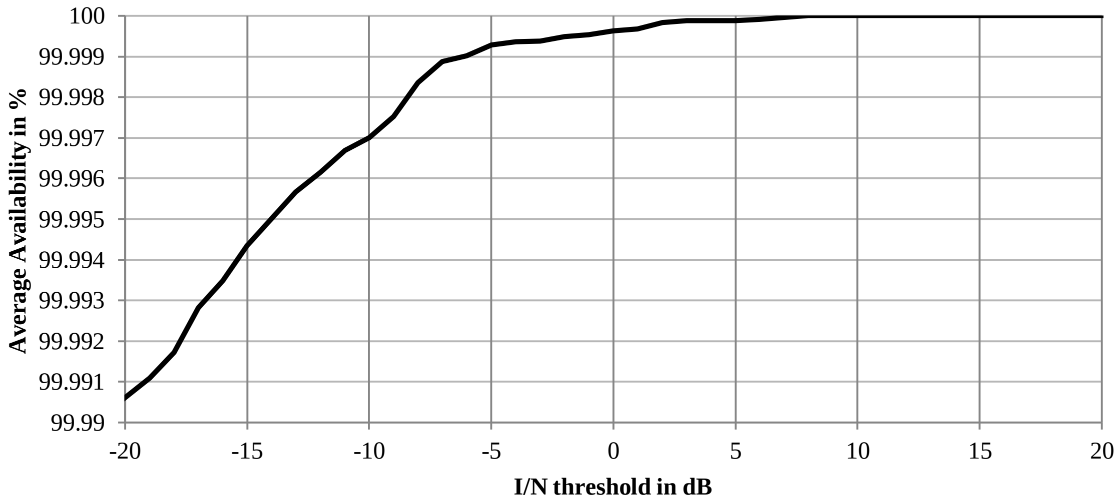


FIGURE A6-63

Average availability for 24h flight time, flight scenario 4, 19.7 GHz



These two diagrams show the availability for flight scenario 4, being > 99.98% for the smallest link margin according to Annex 2 and consequently show sufficient performance with respect to interference.

APPENDIX 2A

A6-6 Short term effects into unmanned aircraft receiver caused by a mix of high and low fixed service densities

This Appendix provides studies supplementing Appendix 2 by applying different densities of FS stations as proposed in Recommendation ITU-R F.758-5 and antenna pattern of the UA Earth station described by a peak envelope Bessel function.

A6-6.1 Summary of results

The analyses in Appendix 2A shows following results:

- Similar as in Appendix 2 study results are presented as CDFs as well as fade and interfade durations over a range of I/N thresholds including derivation of link availabilities.
- The interference levels into the Earth station receiver on board the UA depend on the density of FS operating co-frequency.
- The dependency of the I/N on the elevation towards the GSO is about 8 dB per 10° increase of elevation, e.g. 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 size, two different models describing the antenna pattern are used. Changing the antenna size from 0.45 m to 1.25 m results in a reduction of the interference level by 6 dB.
- Depending on the model describing the antenna pattern the interference level is further reduced by 10 dB
- The dependency on the speed above ground is as follows: At high ground speed, the FS causes shorter average fades compared to lower ground speeds of the UA.
- The interference levels in the 19 GHz frequency range is significantly lower than the levels in the 11 GHz range, mainly due to larger gaseous attenuations and the lower FS emitted spectral density compared to the 11 GHz frequency range. In average the I/N levels in the 19 GHz range are 20 dB lower than that ones in the 11 GHz range.
- The respective link availabilities for the largest assumed I/N thresholds are listed in Tables A6-8 through A6-14 and are 99% or better for all cases. The link availabilities for the peak envelope Bessel function antenna pattern are almost 100%.
- The simulations for rural and remote areas and for the ICAO defined maritime flight scenarios show low I/N levels and low fading durations resulting in very high link availabilities even for small I/N thresholds.

A6-6.2 Introduction

For this sharing analysis the same basic methodology is used as for the previous time-variant analysis as explained in Section A6-5.3.

Specific issues of this study are

- It is to be seen as addition to Appendix 2.
- This Study assumes four classes of FS station densities inside the affected visibility area of the UA receiver as proposed in Recommendation ITU-R F.758-5.
- Two simulation scenarios have been assessed:

- Simulation case 1: This case is set to a flight altitude of 914 m (3 000 ft) / 1 500 m (5 000 ft) and 80 / 250 knots ground speed as well as 3 100 m (10 000 feet) for 80 / 250 knots covering the characteristics of flight scenarios 4 and 6 for three different elevations (10°, 20°, 30°) of the UA earth station antenna.
- Simulation case 2: This case is based on the characteristics of flight scenario 2 which comprises the characteristics of flight scenarios 1, 3 and 5, too at the minimum (100 kts) and maximum ground speed (300 kts) for three different elevations (10°, 20°, 30°) of the UA antenna.

A6-6.3 Short term interference simulation

The methodology of the analysis is the same as used in section A6-5.3. All simulations are based on a 24 h flight track.

A6-6.3.1 Propagation model used

The same propagation model is used as in section A6-5.3.1.

A6-6.3.2 Flight path and flight scenario

The flight path and its characteristics are chosen in accordance with the flight scenarios containing information on flight altitude, velocity and flight area and are the same used in Appendix 2 complemented by additional flight altitude and minimum and maximum UA ground speed.

TABLE A6-15

Used parameter from selected flight scenarios

Simulation scenario	**1**		**2**	
Frequency Range (GHz)	11	19.7	11	19.7
Max altitude (feet above MSL, unless otherwise specified)	10 000		30 000	
Min altitude (feet above MSL, unless otherwise specified)	5 000 (NOTE)	3 000 (NOTE)	19 000	
Max ground speed including wind (knots = NM/h)	250		300	
Min ground speed including wind (knots = NM/h)	80		100	
Time step (s)	1		1	
Simulation repetitions	100		100	

NOTE – The minimum altitudes in simulation scenario 1 are adapted to the results of the sharing study with the FS. For an UA antenna elevation of 10° the minimum flight altitude of the UA shall not exceed 5 000 ft in the 11 GHz frequency range and 3 000 ft in the 19.7 GHz frequency range.

A convergence analysis has been conducted in order to figure out whether the amount of repetitions of the 24 h flight in this simulation is sufficient or will significantly change the results as well as the trend for I/N levels when increasing simulation samples.

Due to the round trip time of a satellite link of approximately 1s a time step in the simulation of 1s is chosen. Therefore the CDF for the I/N levels needs to be stable for a 24 h flight time down to 0.001% representing 0.864 s. The convergence analysis shows that with increasing flight altitude of the UA less repetitions are necessary to provide a stable distribution of I/N values at the desired probabilities of occurrence. This is due to the larger visible area below the UA including more FS stations having the complete set of parameter ranges.

At low altitudes, e.g. 914 m (3 000 ft), less FS station are seen during the 24 h flight time therefore more repetitions have to be applied to provide the statistical basis for a stable CDF compared to the higher altitude. The convergence analysis showed that for these lower flight altitudes and minimum cruising speeds of the UA 100 simulation repetitions are sufficient. This number of repetitions provide 8 640 000 samples per simulation scenario thus representing 100 times 24 hs.

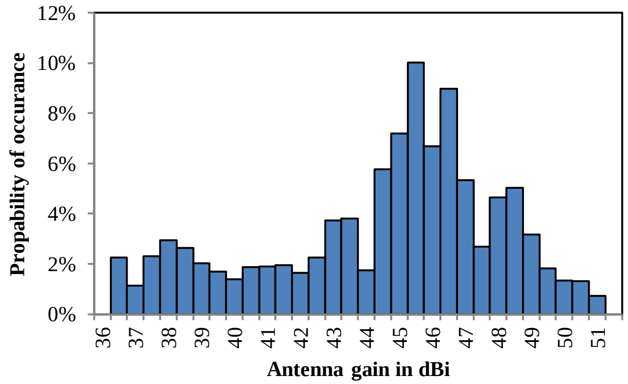
A6-6.3.3 Fixed service station parameters

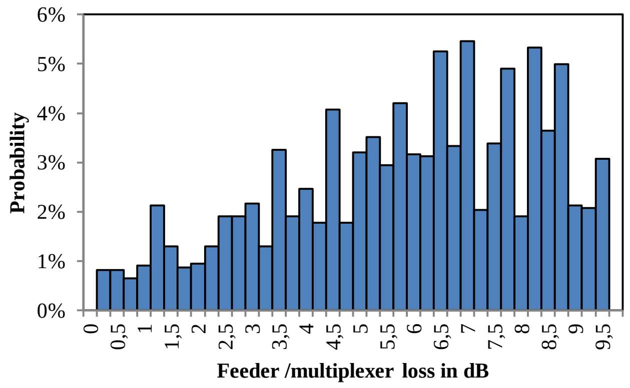
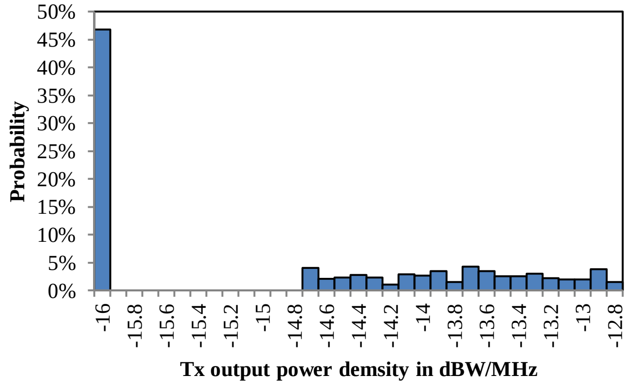
Extreme caution was taken in selecting the assumed characteristics for the FS stations. All parameters are based on Recommendation ITU-R F.758-5, Recommendation ITU-R F.699-7 and Recommendation ITU-R F.1245. When additional characteristics are needed which are not provided in these Recommendations, information from Liaison Statements from Working Group 5C and of real data (also used in the long-term study Appendix 1 and 1A) are used.

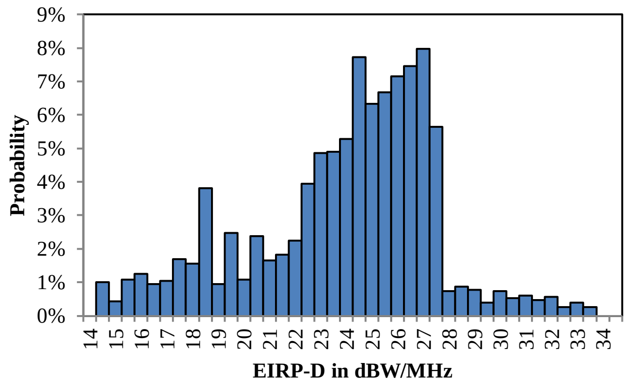
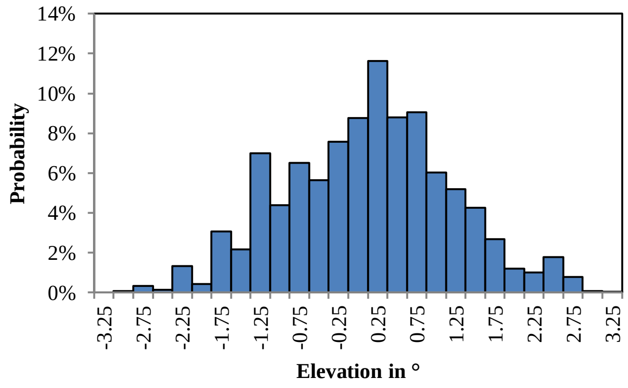
A6-6.3.3.1 FS station characteristics at 11 GHz

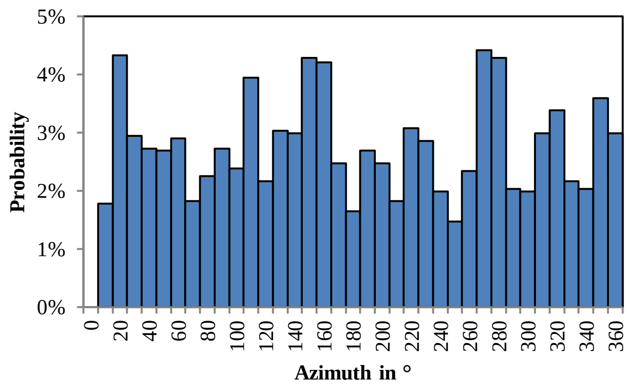
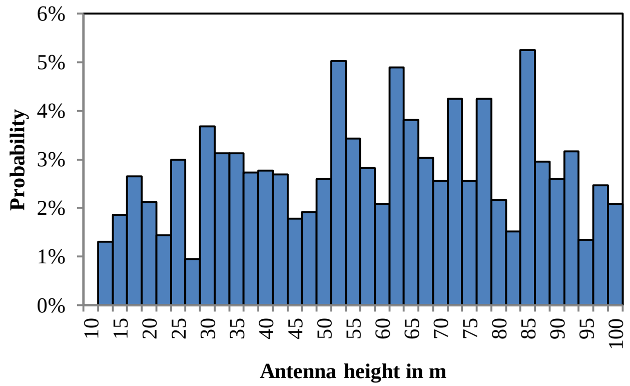
TABLE A6-16

FS station characteristics used in simulation for the 11 GHz range

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
Modulation	-	16-QAM	64-QAM	Uniform (50% 16-QAM; 50% 64-QAM)	Rec. ITU-R F.758-5	-
Antenna gain	dBi	44…51	36…48.0	NOTE	Rec. ITU-R F.758-5	
Antenna efficiency	%	60		Fixed	Rec. ITU-R F.699-7	-
Antenna diagram	-	-		Fixed	Rec. ITU-R F.1245-1	-

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
Feeder/multiplexer loss	dB	0…9.5	0…7.6	NOTE	Rec. ITU-R F.758-5	
Tx output power density	dBW/MHz	-14.8…-12.8	-16.0	NOTE	Rec. ITU-R F.758-5	

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
e.i.r.p. density	dBW/MHz	15.3…33.4	-2.7…27.0	NOTE	Rec. ITU-R F.758-5	
Elevation	°	Mean value: -0.05, Standard deviation:1.15		Normal	Rec. ITU-R F.758-5 Annex 6 Appendix 1	

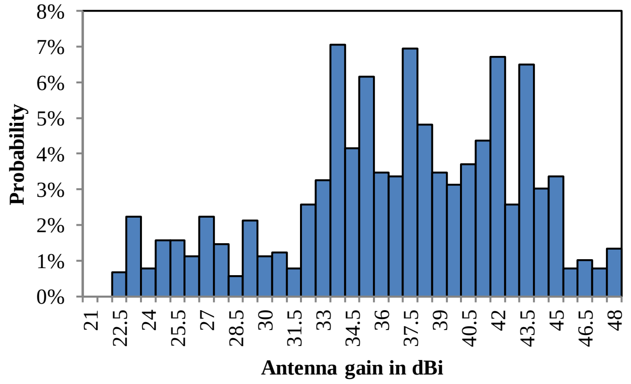
Parameter	Unit	Value	Distribution	Source	Exemplary diagram
Azimuth	°	0…360	Uniform	Rec. ITU-R F.758-5	
Antenna height	m	10…100	Uniform	Annex 6 Appendix 1	
Co-frequency rate	%	7.2	Fixed	Annex 6 Appendix 1	-

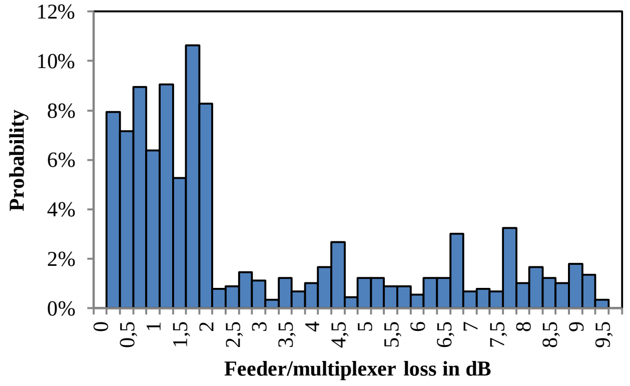
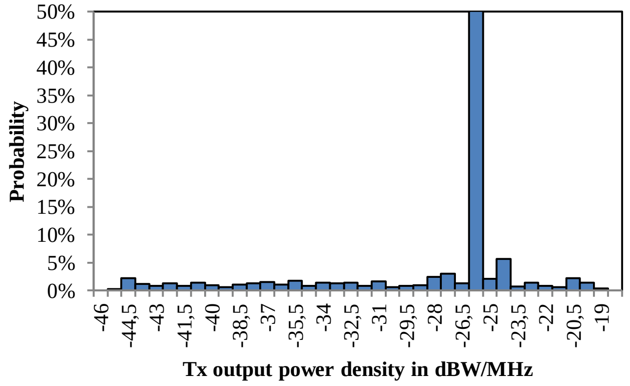
NOTE – The combination of feeder/multiplexer loss, Tx output power density and antenna gain was chosen in such a way that the resulting e.i.r.p. density is in the recommended range. It has to be noted that the combination of Tx output power density range, feeder/multiplexer loss range and antenna gain range of Recommendation ITU-R F.758-5 does not cover the whole e.i.r.p density range in the Table 7 of Recommendation ITU-R F.758-5. Although the listed e.i.r.p. density range starts from -2.7 dBW/MHz the combination of the mentioned input parameter allows a theoretical only minimum e.i.r.p. density of +12.4 dBW/Hz. Hence the interference from FS in the 11 GHz frequency range uses only the higher range and can be considered as worst case.

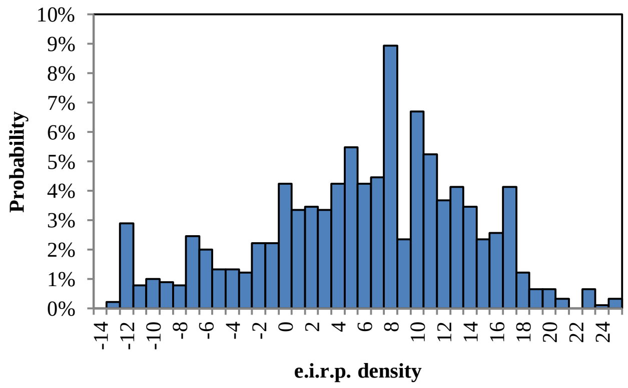
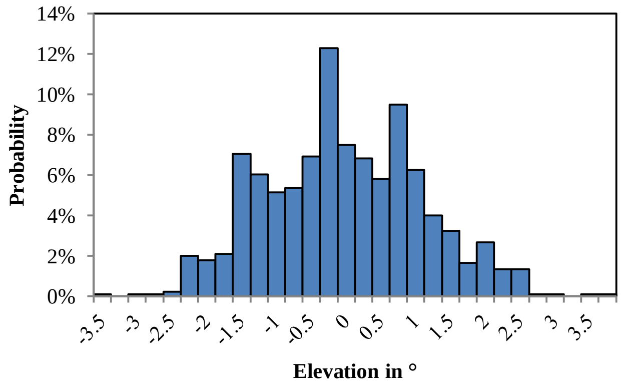
A6-6.3.3.2 FS station characteristics at 19.7 GHz

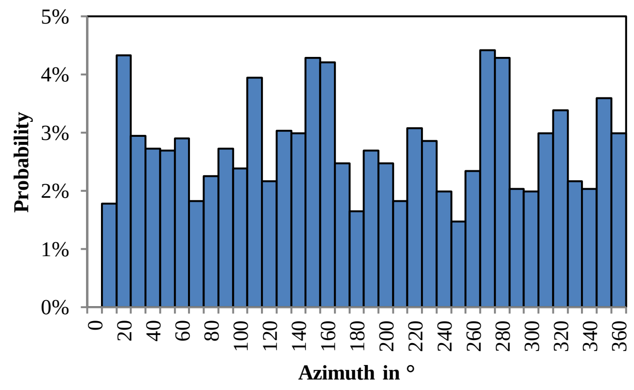
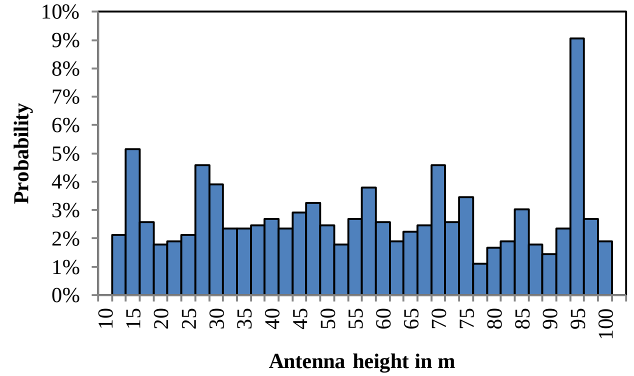
TABLE A6-17

FS station characteristics used in simulation for the 19.7 GHz range

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
Modulation	-	QPSK	64-QAM	Uniform (50% QPSK; 50% 64-QAM)	Rec. ITU-R F.758-5	-
Antenna gain	dBi	21.7…48.3	32…45	NOTE	Rec. ITU-R F.758-5	
Antenna efficiency	%	60		Fixed	Rec. ITU-R F.699-7	-
Antenna diagram		-		Fixed	Rec. ITU-R F.1245-1	-

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
Feeder/multiplexer loss	dB	0.0…2	0…9.3	NOTE	Rec. ITU-R F.758-5	
Tx output power density	dBW/MHz	-45.4…-19.0	-26	NOTE	Rec. ITU-R F.758-5	

Parameter	Unit	Value		Distribution	Source	Exemplary diagram
e.i.r.p. density	dBW/MHz	-13.1…27.3	-17.1…17.0	NOTE	Rec. ITU-R F.758-5	
Elevation	°	Mean value: -0.03, Standard deviation:1.16		Normal	Rec. ITU-R F.758-5 Annex 6 Appendix 1	

Parameter	Unit	Value	Distribution	Source	Exemplary diagram
Azimuth	°	0…360	Uniform	Rec. ITU-R F.758-5	
Antenna height	m	10…100	Uniform	Annex 6 Appendix 1	
Co-frequency rate	%	5.9	Fixed	Annex 6 Appendix 1	-

NOTE – The combination of feeder/multiplexer loss, Tx output power density and antenna gain was chosen in such a way that the resulting e.i.r.p. density is in the recommended range.

A6-6.3.4 Density of Fixed Service stations

To cover the changing interference environment from FS station due to different densely populated areas four different types of FS station densities are defined representing the different types of interference environment affecting link 2 towards the UA receiver as given by Recommendation ITU-R F. 758-5.

– Urban density category comprising high density FS representing areas in very large cities,
– Suburban density category covering areas of medium density population and larger cities,
– Areas with no FS coverage e.g. on the sea or in desert areas,
– Rural areas are not covered by the definitions above.

For each category, different values for density / amount of FS stations were applied as shown in Table A6-18:

TABLE A6-18

Definition of FS station densities per category and frequency band

Category	Fraction of simulations area	Density 11 GHz	Density 19.7 GHz
No FS	10 %	0 FS/km^2	0 FS/km^2
Rural	79.99 %	0.002 FS/km^2	0.016 FS/km^2
Suburban	10%	0.07 FS/km^2	0.07 FS/km^2
Urban	0.01%	3.8 FS/km^2	3.8 FS/km^2

These values, representing the density of FS stations in some European countries were used to develop a more elaborated model of FS interference which were applied for the area seen by the UA during a total simulation over 24h. A more detailed explanation of each FS density category is described in the following subsections.

A6-6.3.4.1 Urban density category

The urban density category only occurs in large metropolises such as e.g. London, Paris, or Beijing. These density categories have a very small size incorporating a lot of FS stations as characterized in Table A6-19.

TABLE A6-19

Characteristics urban density category

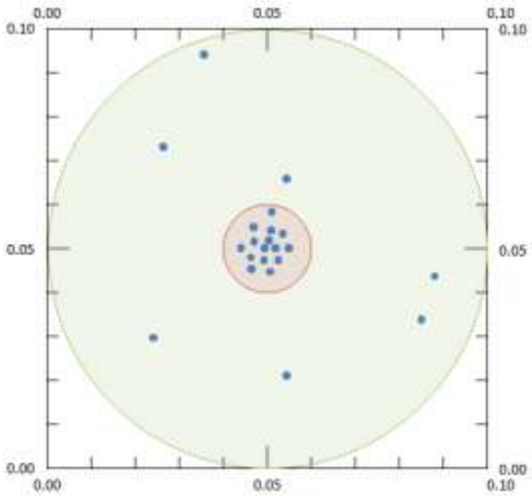
Parameter	Unit	Value			
Simulation scenario		1	2	1	2
Frequency	GHz	11		19.7	
Category radius in radians	°	0.01			
Category radius in km	km	1.1			
Category area	km^2	3.9			
Distribution of density category		Uniform			

Parameter	Unit	Value
Distribution of FS stations		Uniform

This category only occurs in combination with and being surrounded by the suburban density category (see Section below). An example of such a highest density category is shown in Figure A6-63 where a random distribution of FS stations inside the urban and suburban areas is shown.

FIGURE A6-63

Exemplary high density category[2]



A6-6.3.4.2 Suburban density category

The suburban density category represents typical cities whose number is significantly larger than those for large metropolis. In the simulation this density category is characterized as sown in Table A6-20.

TABLE A6-20

Characteristics suburban density category

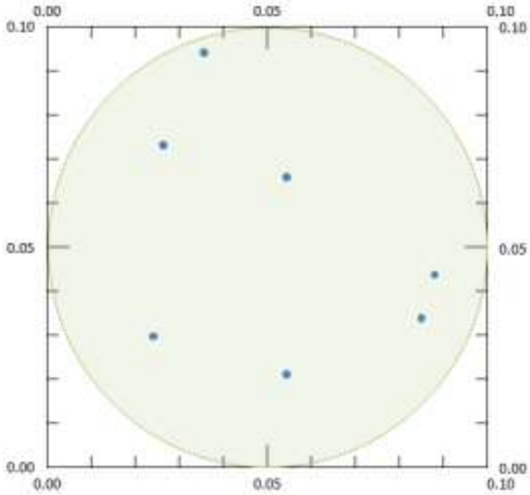
Parameter	Unit	Value			
Simulation scenario		1	2	1	2
Frequency	GHz	11		19.7	
Category radius in radians	°	0.05			
Category radius in km	km	5.6			
Category area	km^2	97.323			
Distribution of density categories		Uniform			
Distribution of FS stations within the category		Uniform			

2 Remark: The area size is given in degrees on the Earth’s surface. A distance of 0.1 degrees represents approximately 11 km.

An example of such a category is shown in Figure A6-64 where a random distribution of FS stations inside the suburban area is shown.

FIGURE A6-64

Exemplary Suburban density category



A6-6.3.4.3 Area with no fixed service

In the operation of an UA it can occur that the visible area below the aircraft has no fixed service e.g. over large waters or deserts. To cover these different conditions three types of such areas are defined which will be randomly applied for each simulation sample all of them covering in total 10% of the simulation area.

A6-6.3.4.4 Rural areas

The rural areas represent the forth category of the simulation areas being not covered by one of the other three above and cover 79.99% of the simulation area. Those areas are filled in the simulation with a uniform distribution of a low FS density.

A6-6.3.5 Unmanned aircraft station parameters

A6-6.3.5.1 Unmanned aircraft earth station antenna pattern

In addition to the antenna pattern of Recommendation ITU-R S.580-6 the radiation diagram for side lobes of a peak envelope Bessel function antenna for 45 cm and 125 cm are analyzed to provide a sensitivity analysis based on different antenna characteristics.

A6-6.3.5.1.1 Radiation diagrams for earth station antennas

The radiation diagrams for earth station antennas operating with geostationary satellites as given by Recommendation ITU-R S.580-6 specifies the side lobe characteristics of antennas having a D/λ greater than or equal to 50. In cases for D/λ less than 50 the side lobe characteristics contained in the ITU-R Antenna Pattern Library is often used. For this study the D/λ for the major amount of used earth stations is less than 50 though ITU BR Antenna Pattern Library file, Ref. APL-UM-001 available on BR IFICs radiation pattern is used.

TABLE A6-21

D/λ for different UA antenna sizes

Antenna size	Frequency range	D/λ	Antenna Pattern
0.45 m	11 GHz	16.5	S.580 APL-UM001 (0.45m)
1.25 m	11 GHz	45.8	S.580 APL-UM001 (1.25m)
0.45 m	19.7 GHz	29.6	S.580 APL-UM001 (0.45m)
1.25 m	19.7 GHz	82.1	Rec. ITU-R S.580-6 (1.25m)

The relevant antenna pattern is taken from the ITU-R Antenna Pattern Library being identical with that one in RR Appendix 8.

Hence, in comparison to the study in Appendix 2 the results for the different antenna sizes are different as the far side lobe characteristics and the back lobe characteristics are depending on the antenna diameter.

A6-6.3.5.1.2 Peak envelope Bessel antenna characteristics

The peak envelope Bessel antenna characteristics is based on the Airy pattern for circular apertures. Due to the minimum elevation of the UA antenna towards the GSO the equation is given starting from 10° off-axis angle describing the far side lobes and the back lobe performance of the antenna.

$$G(\varphi) = G_{max} - 30 \log (D/\lambda \sin \varphi) -10.86 \qquad \text{dBi} \qquad \text{for } 10° \le \varphi \le 90°$$

$$G(\varphi) = G_{max} - 30 \log (D/\lambda) -10.86 \qquad \text{dBi} \qquad \text{for } 90° \le \varphi \le 180°$$

where:

D : antenna diameter (meter)

λ : wavelength (meter)

φ : off-axis angle of the antenna (degrees)

$G_{max} = 20 \log (D/\lambda) +10.77 \qquad \text{dBi}$

A6-6.3.5.2 Fuselage attenuation

The fuselage attenuation is comparable to Appendix 2 included for all analyses based on the characteristics shown in Annex 10.

A6-6.3.5.3 Pitch and Roll

The maximum banking angles of the UA is defined in the flight scenarios and do not exceed 20° for flight scenario 2 and 30° for flight scenario 4. The operation of the UA has to take into account that there is no obstruction of the fuselage between the earth station on board the UA and the respective GSO satellite.

Pitch ant roll do not have an effect on the high I/N levels as they are caused by FS stations which are seen at the horizon where no fuselage attenuation occurs.

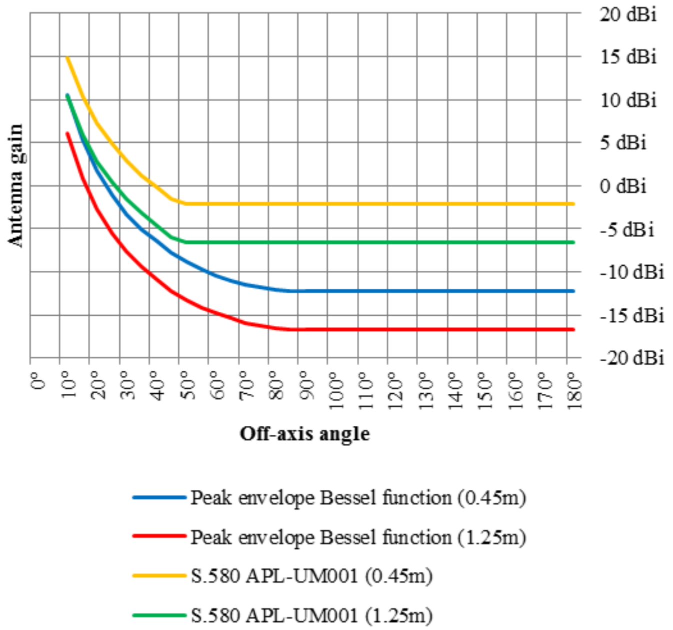
A6-6.3.5.4 Turbulence

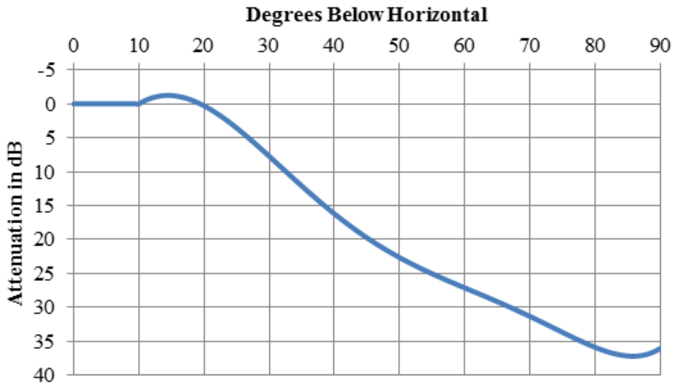
Turbulences are not included in the interference analysis as they have to be mitigated by the pointing mechanism of the UA antenna and which is a design objective for the earth station.

A6-6.3.5.5 Summary UA earth station parameters 11 GHz

TABLE A6-22

Summary unmanned aircraft parameter at 11 GHz

Parameter	Unit	Value	Distribution	Source	Diagram
Antenna diameter	m	0.45; 1.25	Fixed	Annex 1	-
Antenna diagrams		Peak envelope Bessel function; S.580 APL-UM001	Fixed	A6-6-3.5.1	
Antenna Elevation	°	10;20;30;	Fixed	-	-
UA receiver noise	K	200	Fixed	Annex 1	-

Parameter	Unit	Value	Distribution	Source	Diagram
Fuselage attenuation	dB	(Note)	-	Annex 10	
Pitch	°	0	Fixed	Main Body	-
Roll	°	0	Fixed	Main Body	-

Note – the fuselage attenuation of the unmanned aircraft was modelled via a polynomial based on the data of Annex 10 as a function of degrees below horizontal plane of the UA (α). From the data available, the fuselage attenuation in the 11 GHz and 19 GHz range are nearly equal, therefore the same polynomial for both frequency ranges is used.

$$a_{FS} = 0 \qquad \text{for} \quad \alpha < 10°$$

$$a_{FS} = A + B\alpha + C\alpha^2 + D\alpha^3 + E\alpha^4 + F\alpha^5 + G\alpha^6 \qquad \text{for } 10° \leq \alpha \leq 90°$$

Where:

A = 14.7884483814748

B = -2.48255293329139

C = 0.11096491855557

D = -0.000880770843486516

E = -0.0000212820881580518

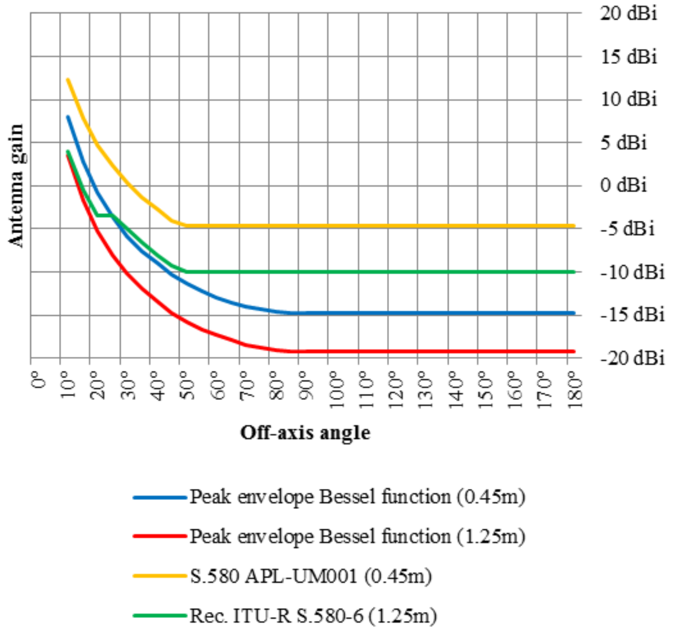
F = 4.10269187039751E-07

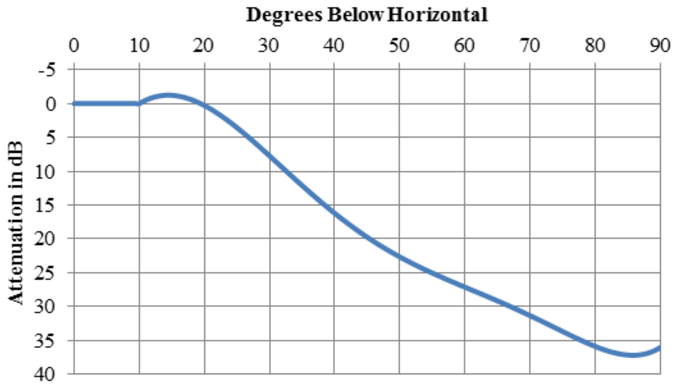
G = -1.95384423629305E-09

A6-6.3.5.6 Summary UA earth station parameters 19.7 GHz

TABLE A6-23

Summary unmanned aircraft parameter at 19.7 GHz

Parameter	Unit	Value	Distribution	Source	Diagram
Antenna diameter	m	0.45; 1.25	Fixed	Annex 1	-
Antenna diagrams		Peak envelope Bessel function; S.580 APL-UM001 Rec. ITU-R S. 580-6	Fixed	A6-6-3.5.1	
Antenna elevation	°	10;20;30;	Fixed	-	-
UA receiver noise	K	200	Fixed	Annex 1	-

Parameter	Unit	Value	Distribution	Source	Diagram
Fuselage attenuation	dB	(Note)	-	Annex 10	
Pitch	°	0	Fixed	Main Body	-
Roll	°	0	Fixed	Main Body	-

Note – The fuselage attenuation of the unmanned aircraft was modelled via a polynomial based on the data of Annex 10 as a function of degrees below horizontal plane of the UA (α). From the data available, the fuselage attenuation in the 11 GHz and 19 GHz range are nearly equal, therefore the same polynomial for both frequency ranges is used.

$$aFS = 0 \qquad \text{for} \quad \alpha < 10°$$

$$aFS = A + B\alpha + C\alpha 2 + D\alpha 3 + E\alpha 4 + F\alpha 5 + G\alpha 6 \qquad \text{for } 10° \leq \alpha \leq 90°$$

Where:

A = 14.7884483814748

B = -2.48255293329139

C = 0.11096491855557

D = -0.000880770843486516

E = -0.0000212820881580518

F = 4.10269187039751E-07

G = -1.95384423629305E-09

A6-6.3.6 Fading parameters

The same assumptions for the definition of fades are used as in Appendix 2 section A6-5.3.6.

A6-6.4 Study results

The results are presented in the same way compared to Appendix 2 showing the average, maximum and aggregate fade duration, as well as the average and aggregate interfade duration depending on the I/N threshold. In addition to that the results are presented in a matrix for the maximum and minimum flight altitudes, three UA antenna elevation angles and the maximum and minimum ground speed of the UA.

In addition the derived I/N levels are presented in a CDF showing the probability of occurrence of each I/N level. Each repetition consists of 86 400 samples which is repeated 100 times. Therefore the CDF is based on data of 8 640 000 samples representing 1s per sample each. As 1s might be a threshold due to the round trip time of the satellite link, the CDF is shown down to 0.001% which corresponds to 0.864 s.

It is important to note that a CDF does not reflect time variant behavior and cannot be used to provide information on the performance of the link 2, as from the probability of occurrence it cannot be concluded how long the outage time caused by interference from FS at that specific I/N level lasts. The cumulative approach provides aggregate fade duration for the different I/N levels.

A6-6.4.1 Simulations results for 11 GHz

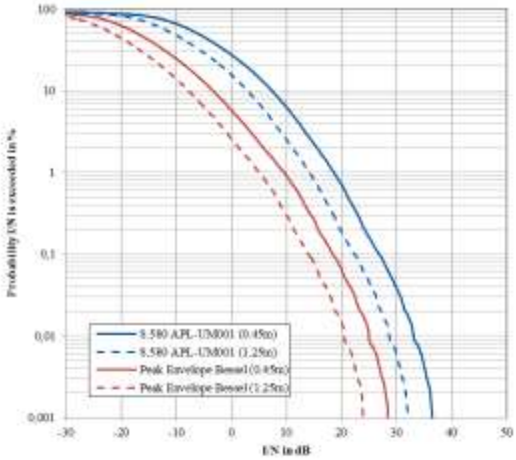
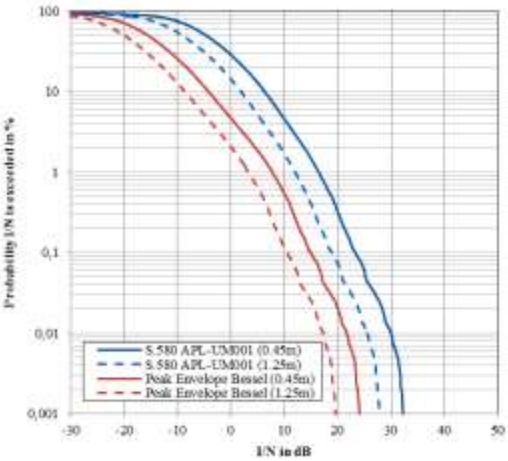
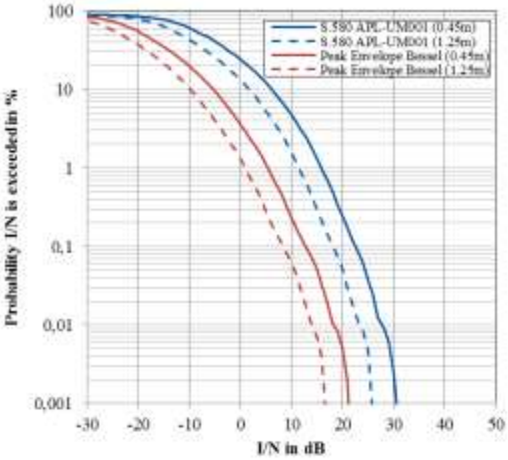
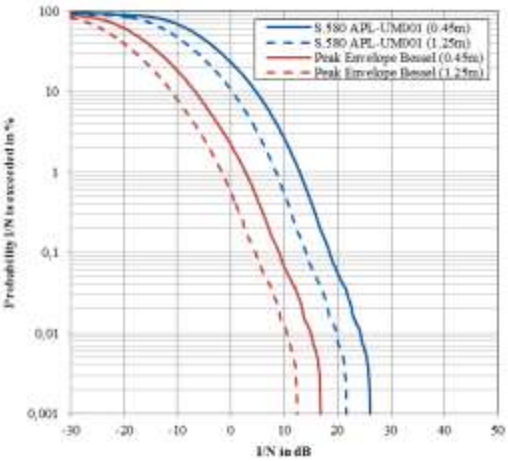
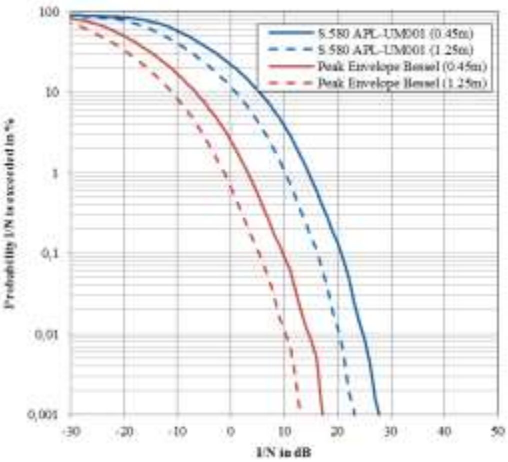
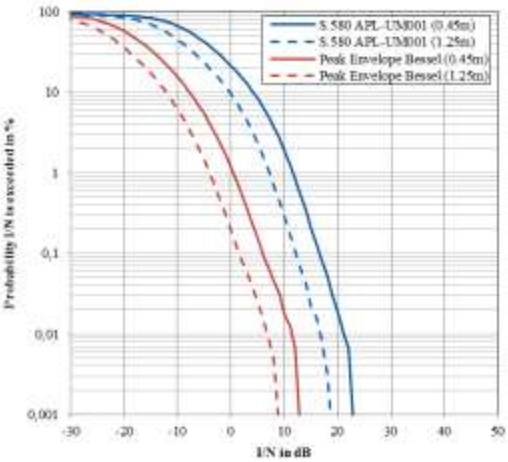
A6-6.4.1.1 Simulation Case 1

The following diagrams show the CDF, fade and interfade durations for simulation scenario 1 (flight altitude 1 500 m (5 000 ft) to 3 000 m (10 000 ft) for I/N ratios from -30 dB up to 50 dB. The values for the maximum possible peak I/N (without any mitigation), when assuming an antenna pattern in accordance with Recommendation ITU-R S.580-6 is listed in Tables A6-8 through A6-11 of section A6-5.2 of Appendix 2 can be compared with these diagrams.

A6-6.4.1.1.1 Cumulative distribution function

TABLE A6-24

CDF simulation Case 1

<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.1.1.2 Fade duration

TABLE A6-25

Average fade duration minimum ground speed (80 kts)

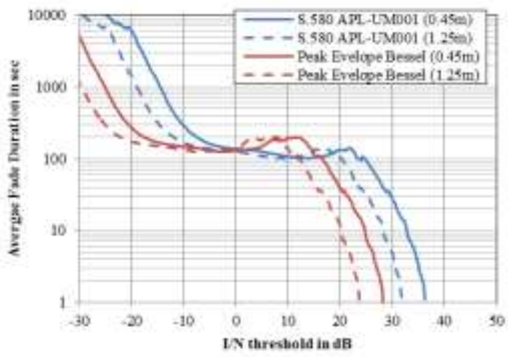
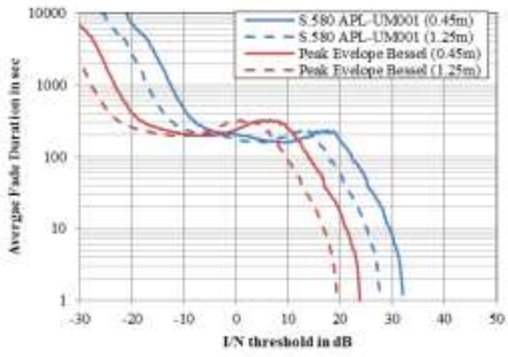
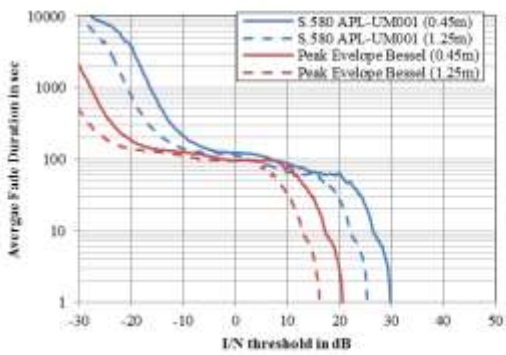
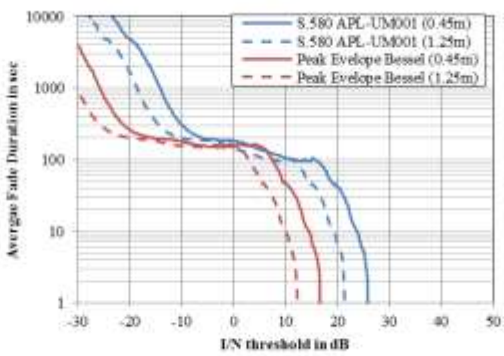
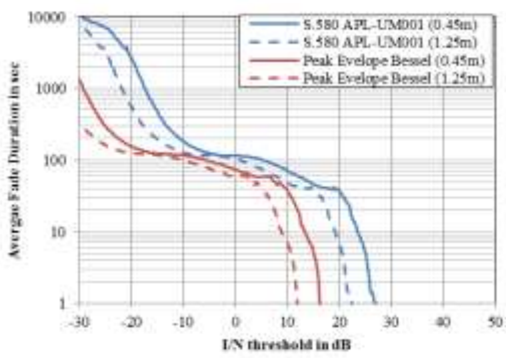
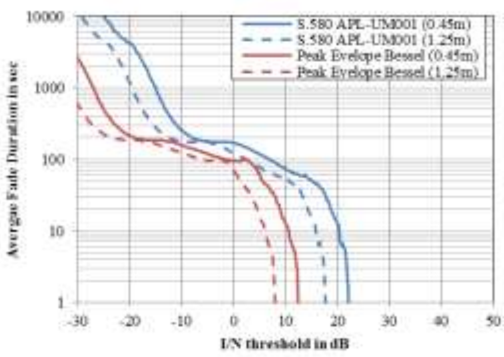
Elevation	1 500 m (5 000 ft)	3 000m (10 000 ft)
10°		
20°		
30°		

TABLE A6-26

Average fade duration maximum ground speed (250 kts)

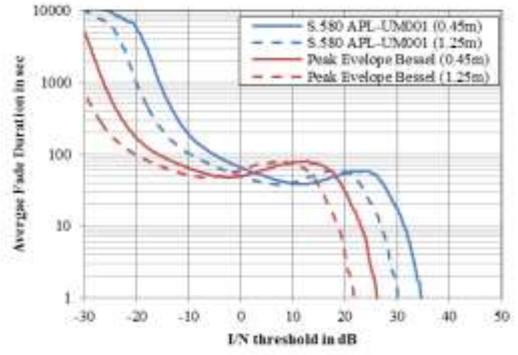
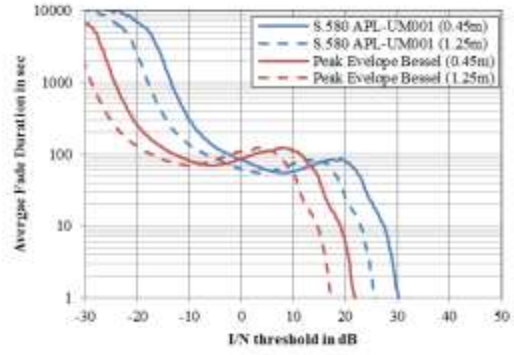
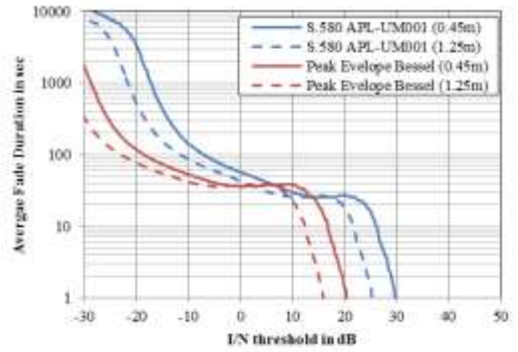
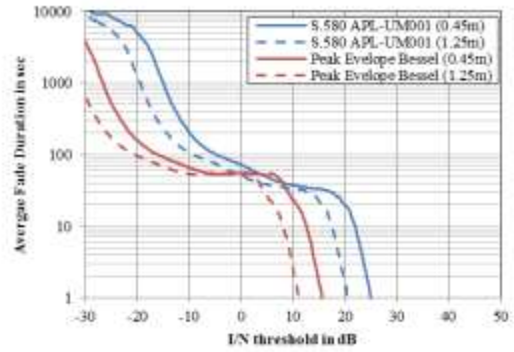
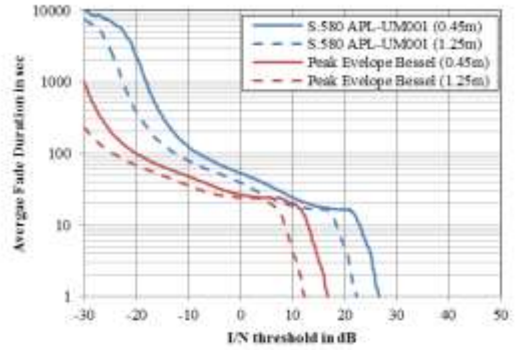
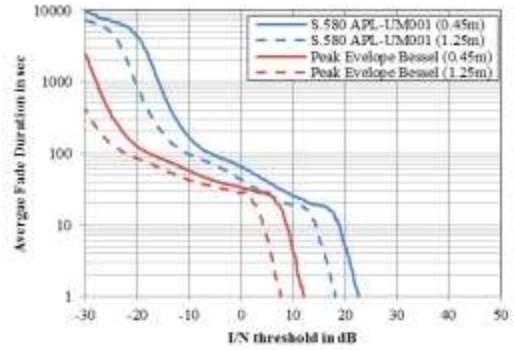
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-27

Maximum fade duration minimum ground speed (80 kts)

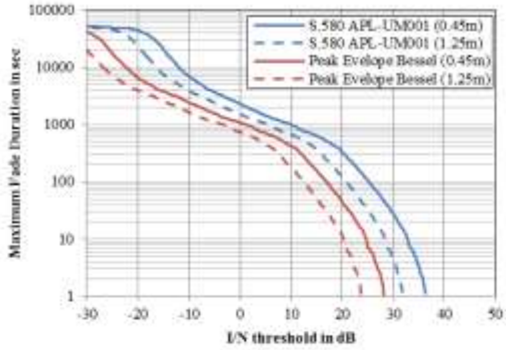
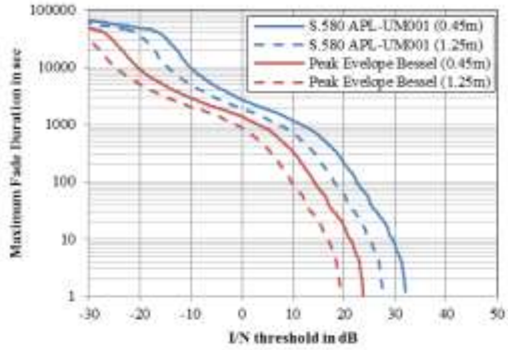
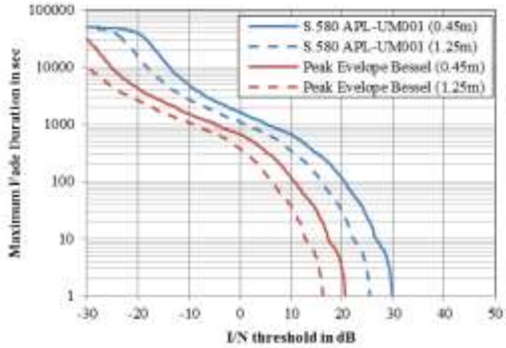
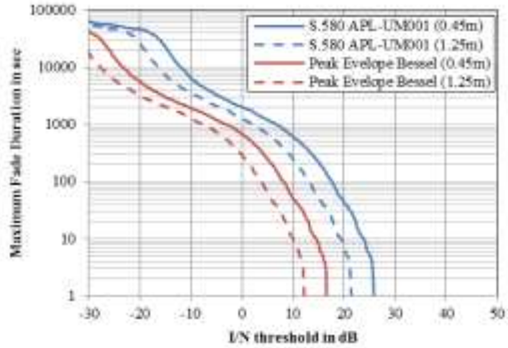
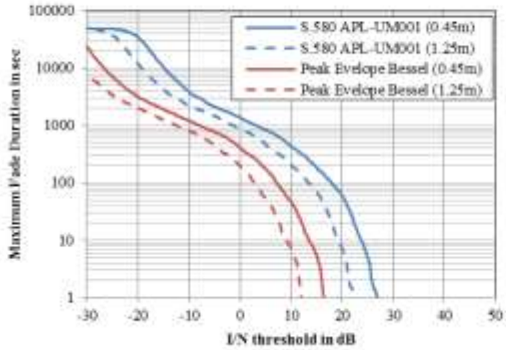
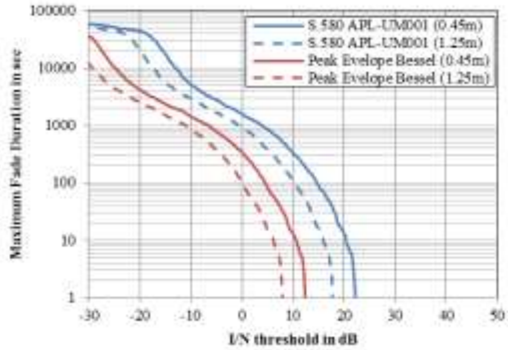
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000m (10 000 ft)</th></tr>
<tr><td>10°</td><td></td><td></td></tr>
<tr><td>20°</td><td></td><td></td></tr>
<tr><td>30°</td><td></td><td></td></tr>
</table>

TABLE A6-28

Maximum fade duration maximum ground speed (250 kts)

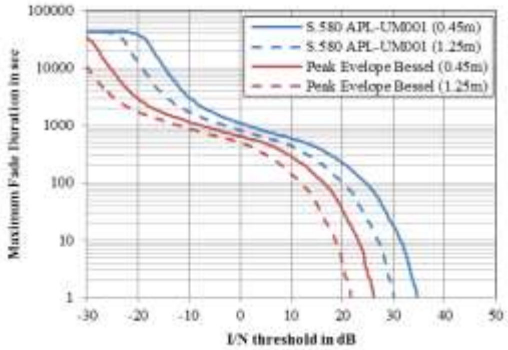
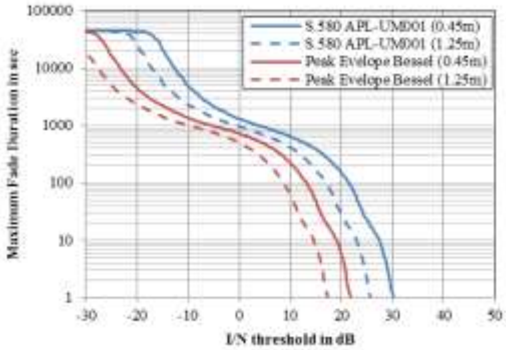
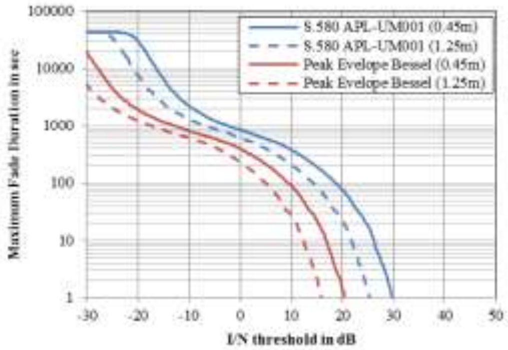
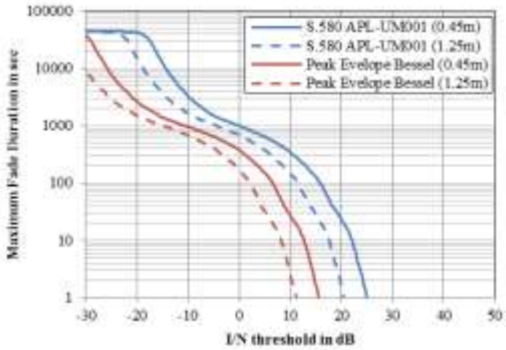
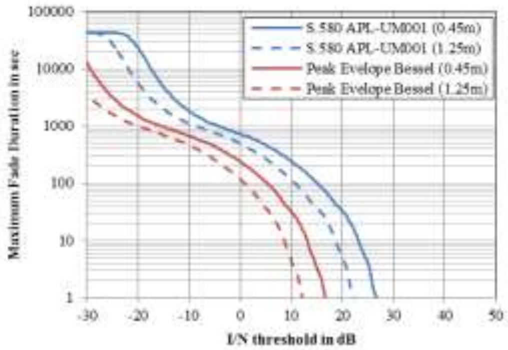
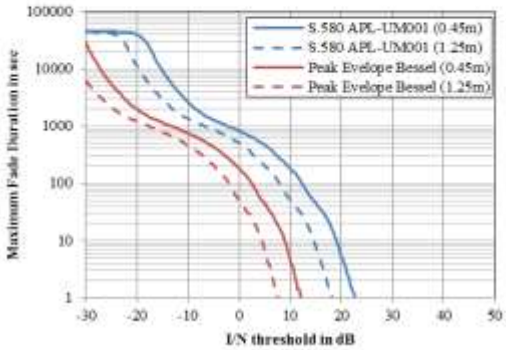
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-29

Aggregate fade duration minimum ground speed (80 kts)

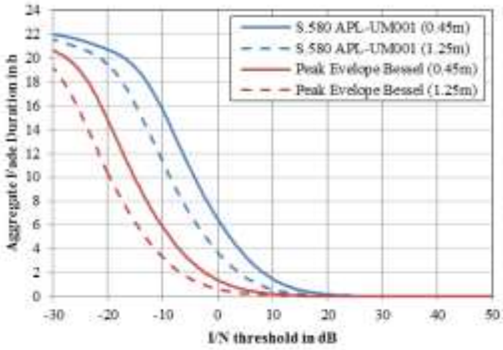
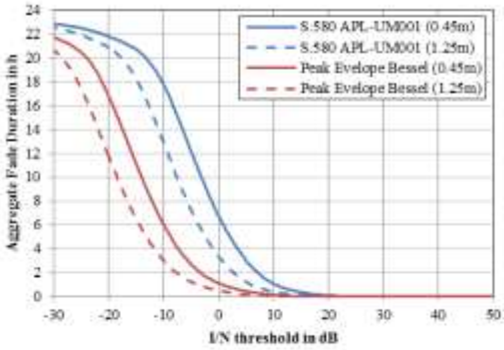
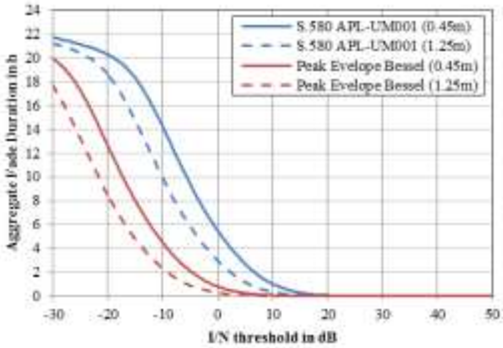
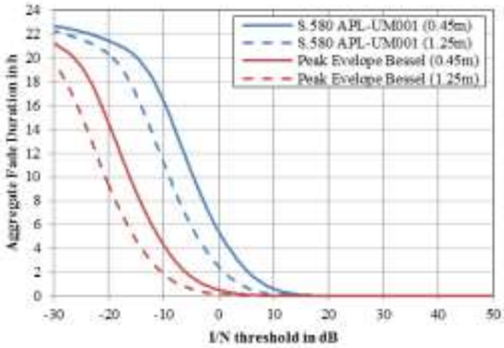
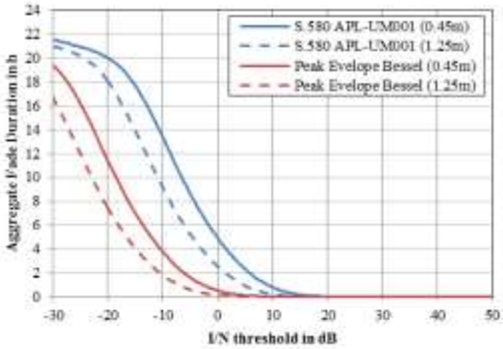
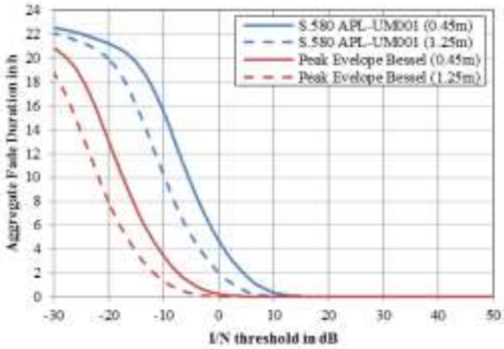
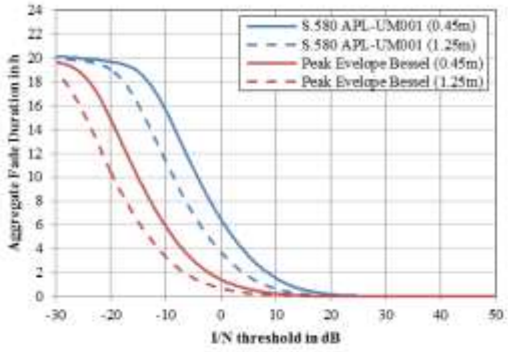
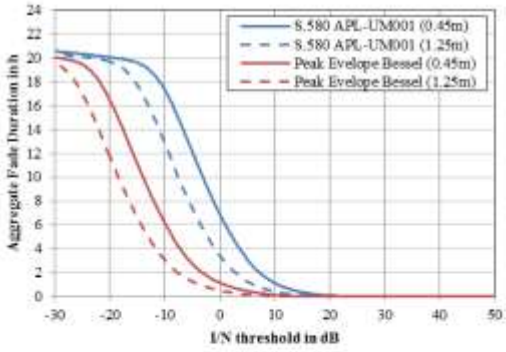
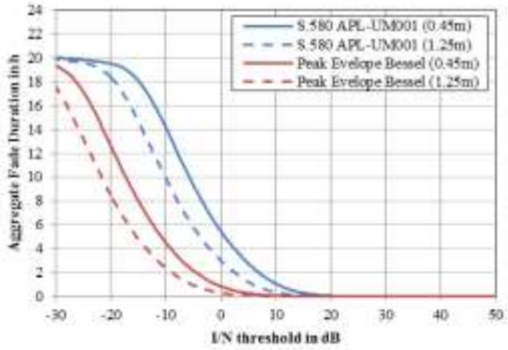
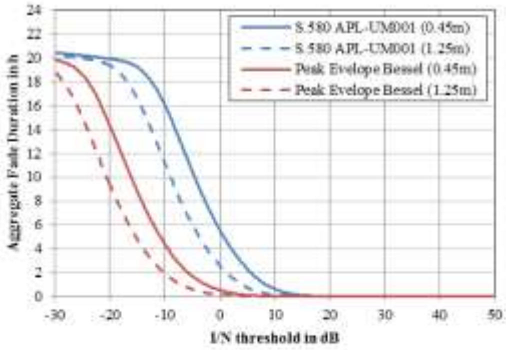
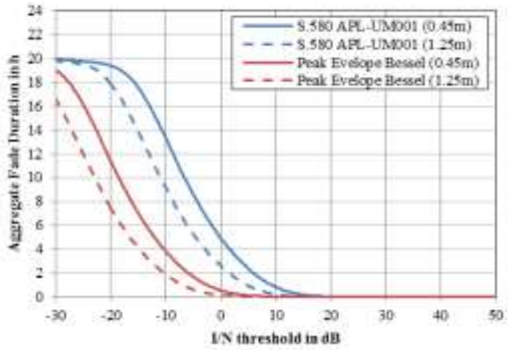
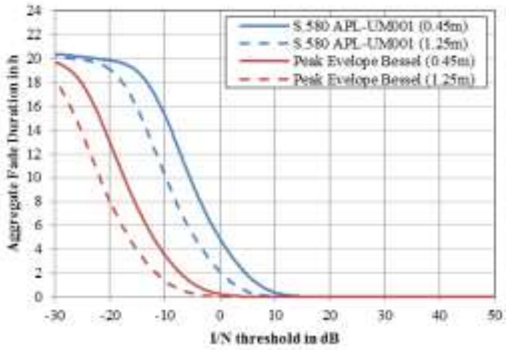
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-30

Aggregate fade duration maximum ground speed (250 kts)

Elevation	1 500 m (5 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

A6-6.4.1.1.3 Interfade duration

TABLE A6-31

Average interfade duration minimum ground speed (80 kts)

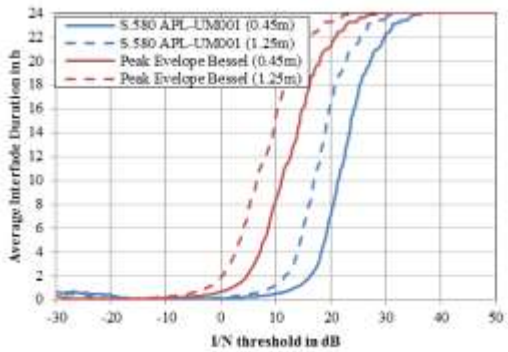
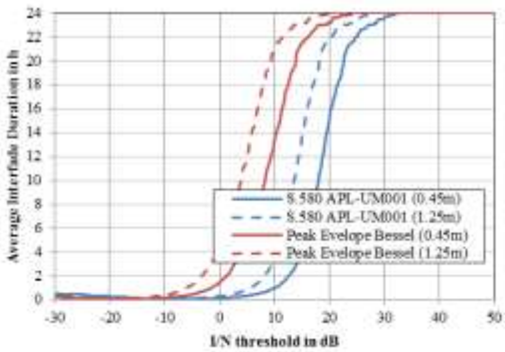
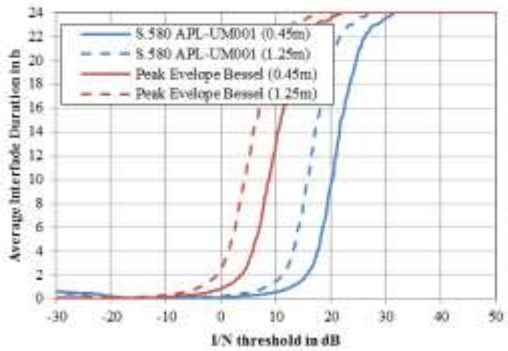
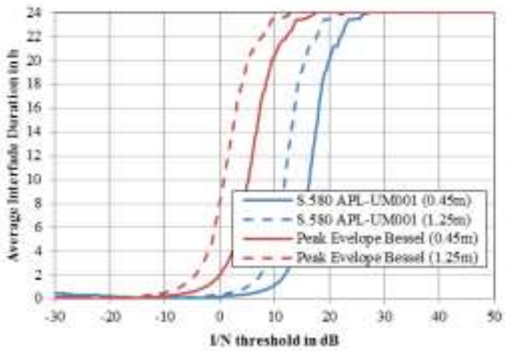
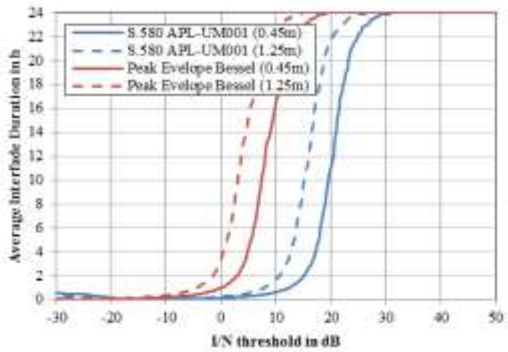
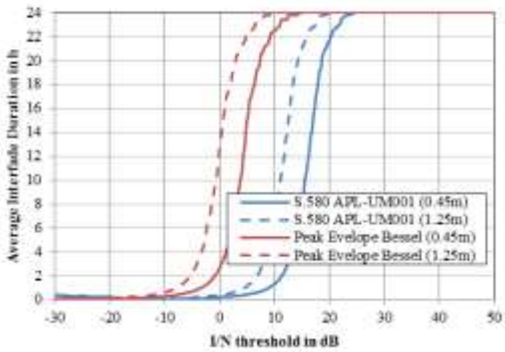
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td></td><td></td></tr>
<tr><td>20°</td><td></td><td></td></tr>
<tr><td>30°</td><td></td><td></td></tr>
</table>

TABLE A6-32

Average interfade duration maximum ground speed (250 kts)

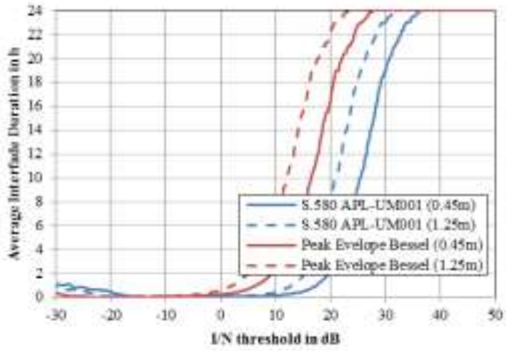
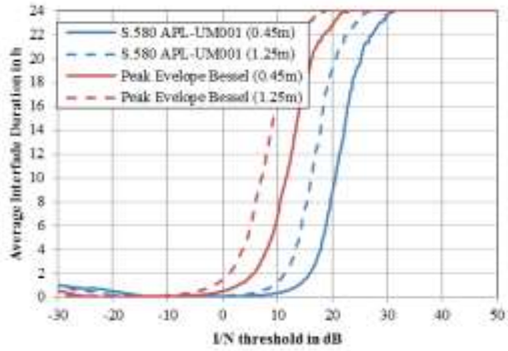
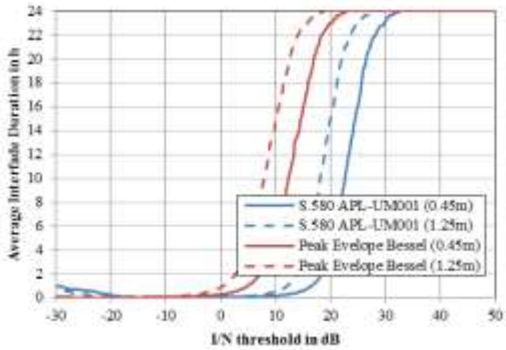
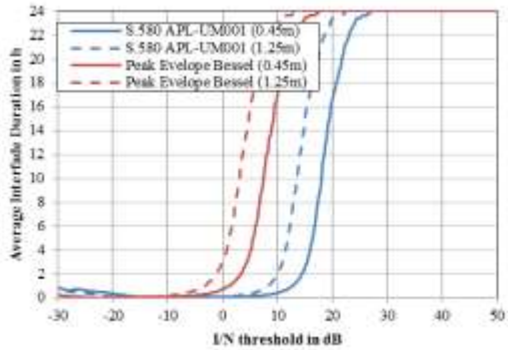
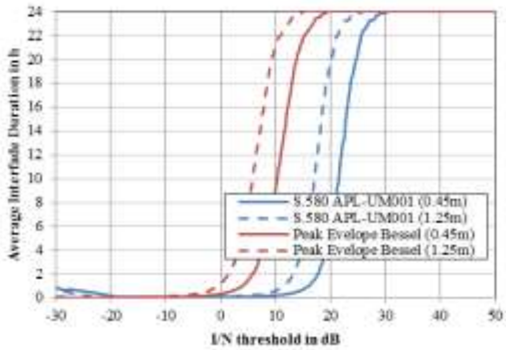
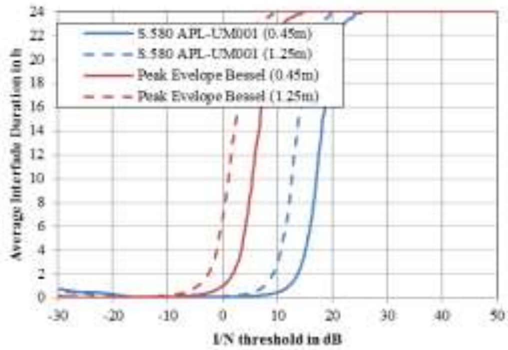
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-33

Aggregate interfade duration minimum ground speed (80 kts)

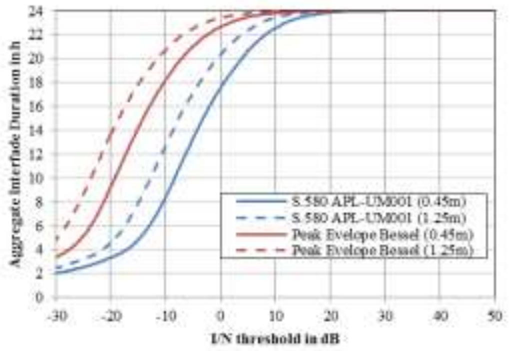
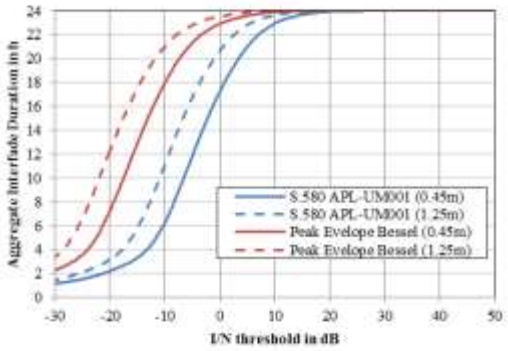
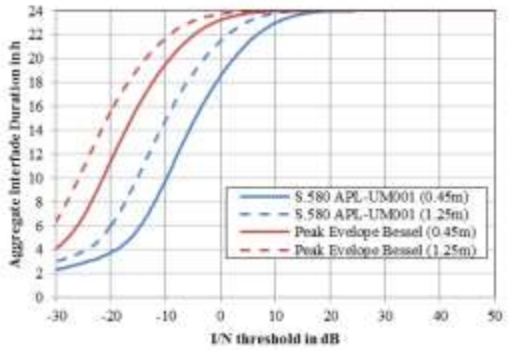
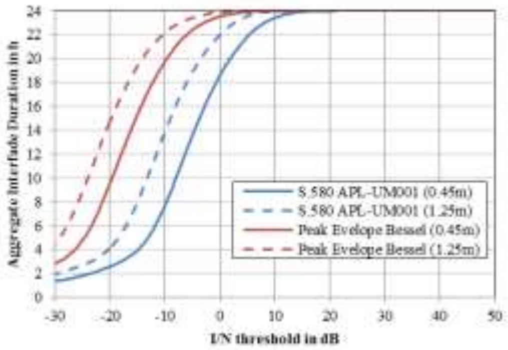
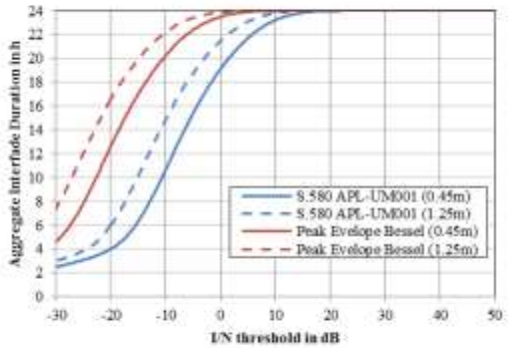
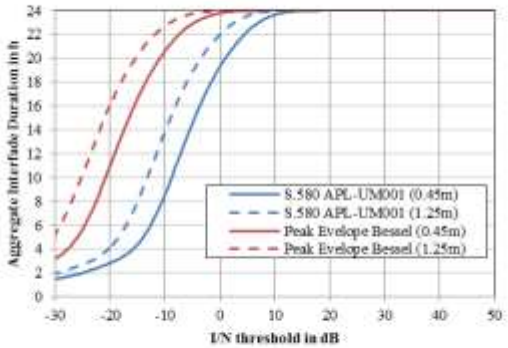
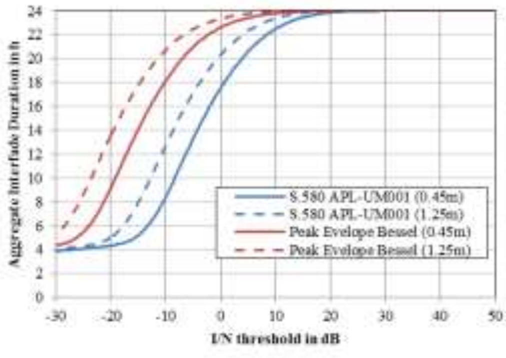
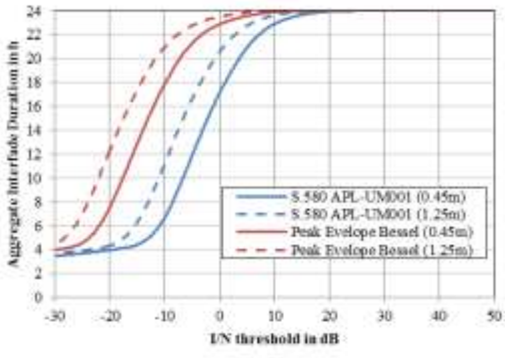
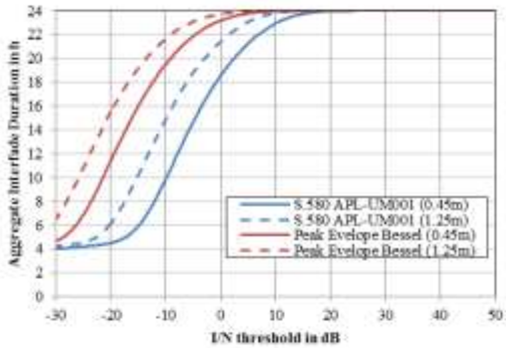
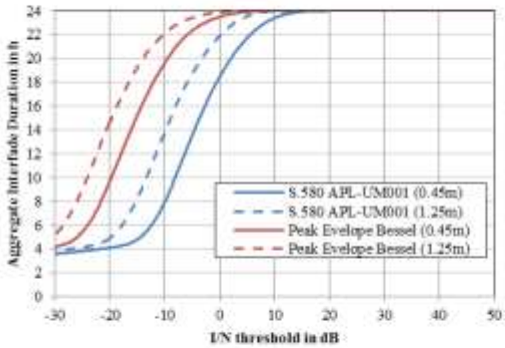
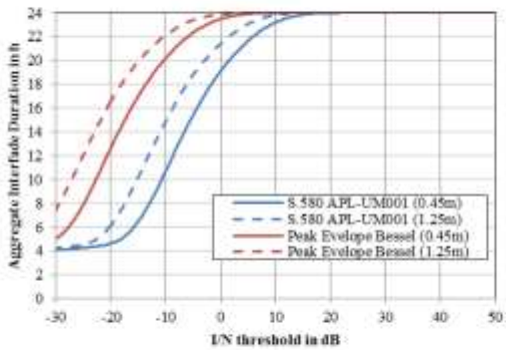
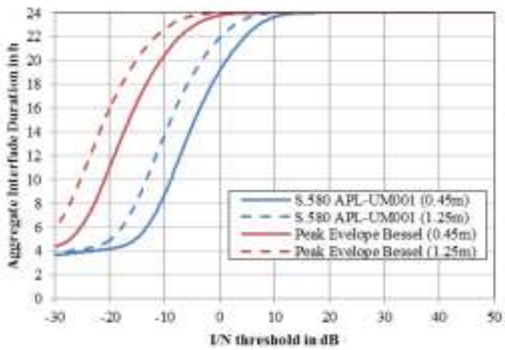
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-34

Aggregate interfade duration maximum ground speed (250 kts)

Elevation	**1 500 m (5 000 ft)**	**3 000 m (10 000 ft)**
10°		
20°		
30°		

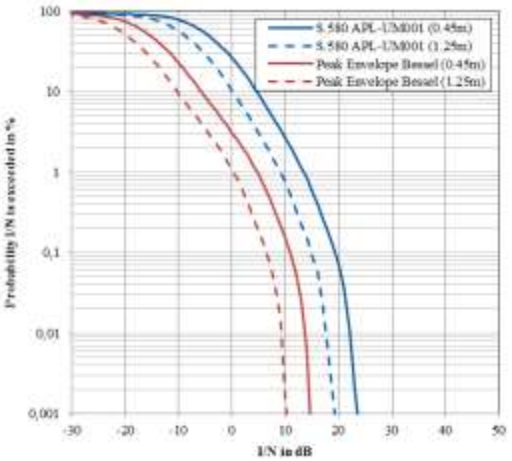
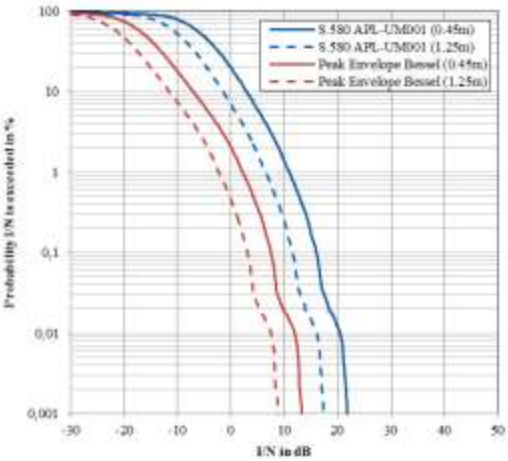
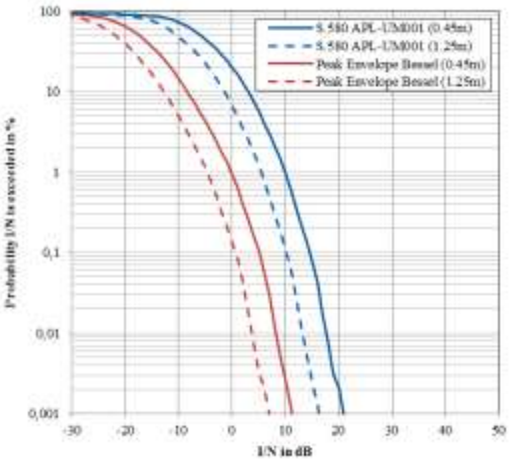
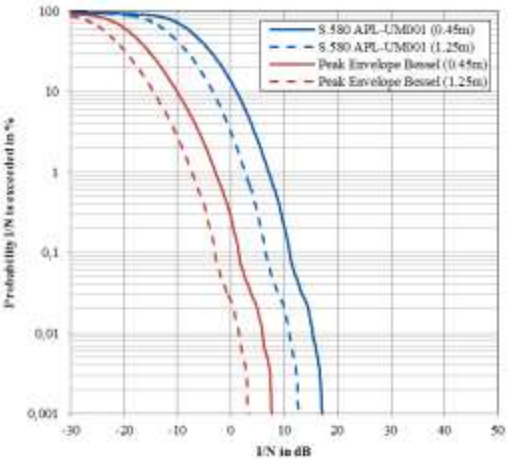
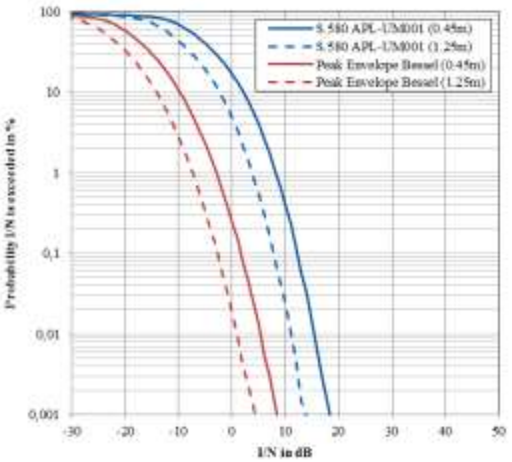
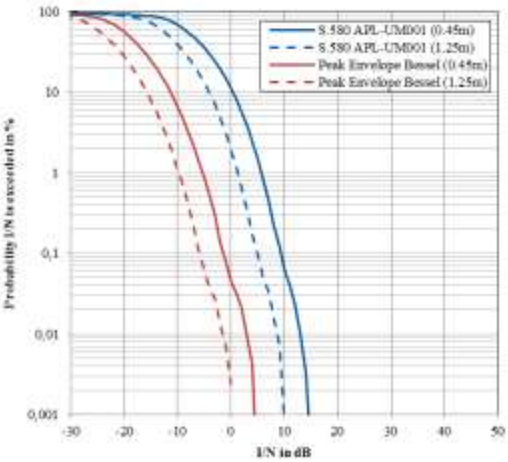
A6-6.4.1.2 Simulation Case 2

The following diagrams show the probabilities of exceedance of I/N (CDF), fade and interfade durations for Simulation Case 2 (flight height 6 000 m (19 000 ft) to 9 000 m (30 000 ft) for I/N ratios from -30 dB up to 50 dB. The values for the maximum possible peak I/N are based on an antenna pattern in accordance with Recommendation ITU-R S.580-6 (as listed in Tables A6-8 to A6-11 of section A6-5.1) which is assumed for the studies in Appendix 2. Therefore, they can be compared with these diagrams.

A6-6.4.1.2.1 Cumulative Distribution Function

TABLE A6-35

CDF simulation scenario 2

<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.1.2.1 Fade durations

TABLE A6-36

Average fade duration minimum ground speed (100 kts)

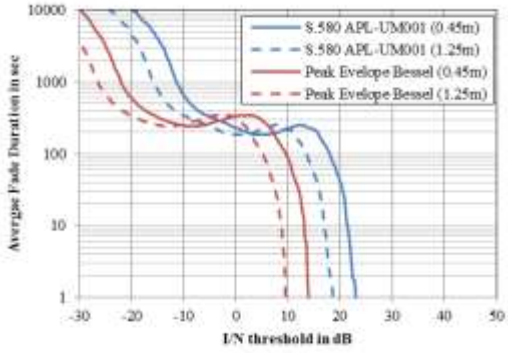
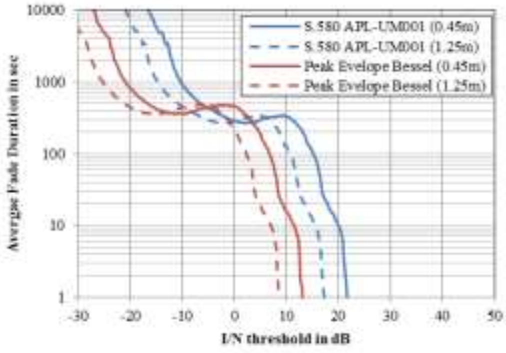
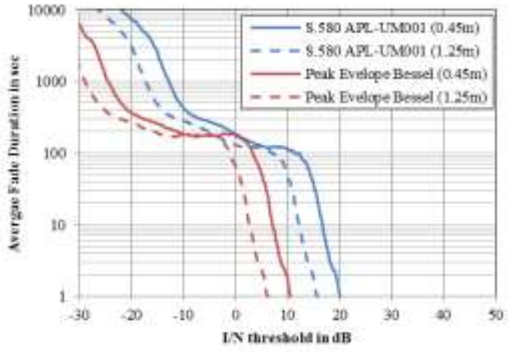
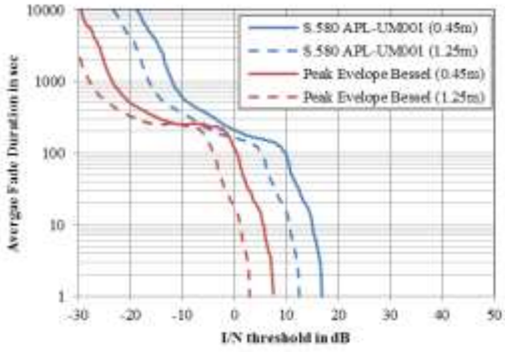
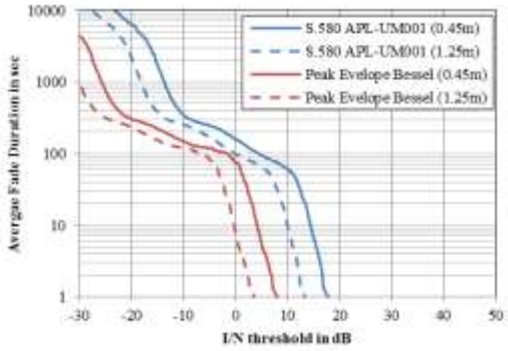
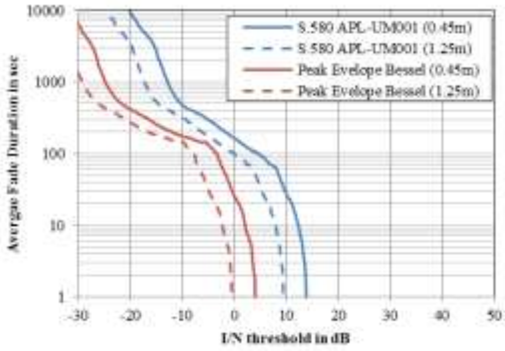
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-37

Average fade duration maximum ground speed (300 kts)

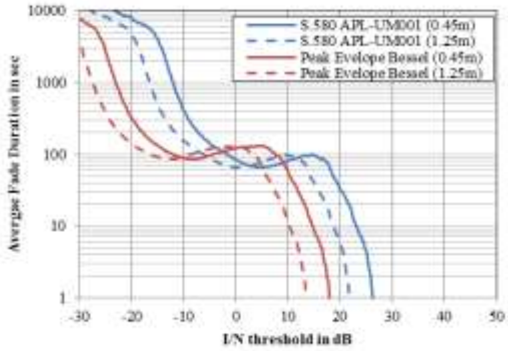
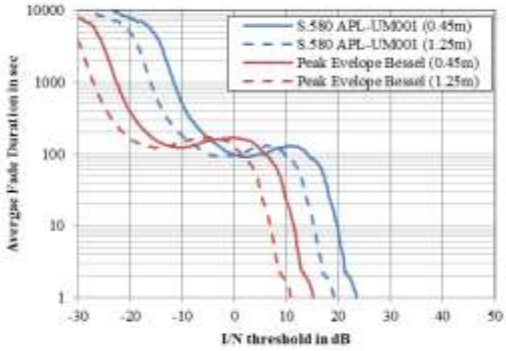
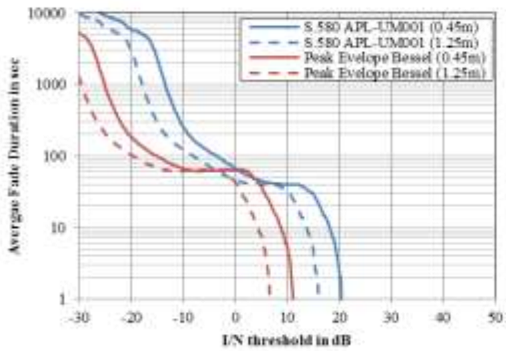
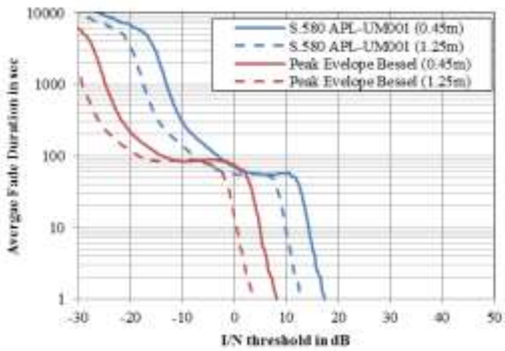
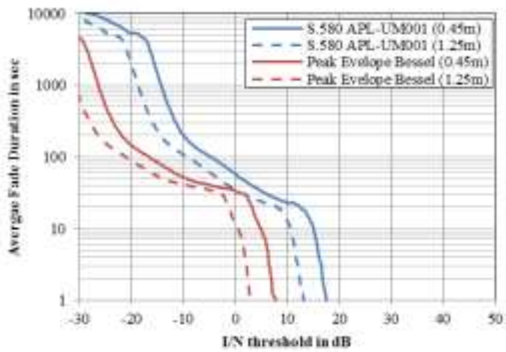
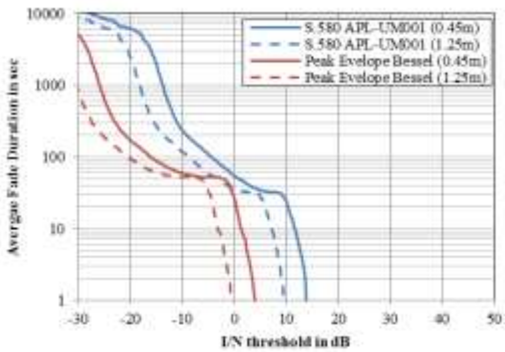
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-38

Maximum fade duration minimum ground speed (100 kts)

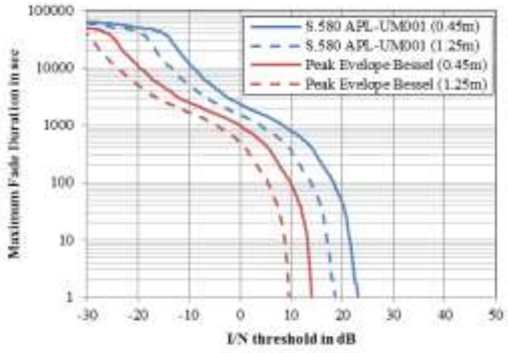
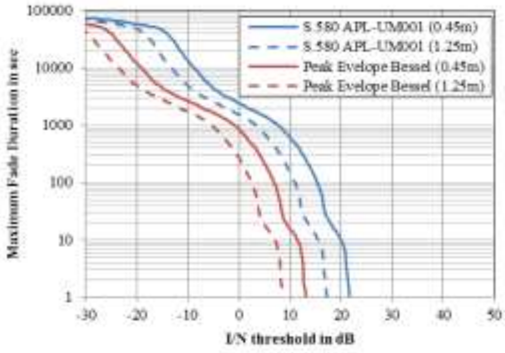
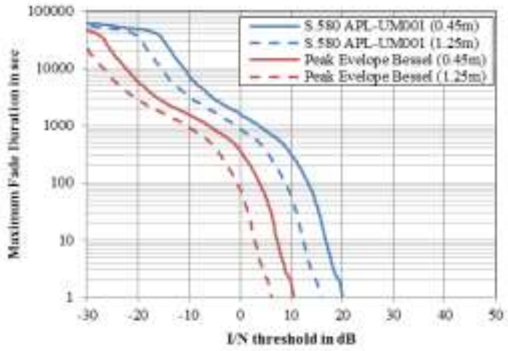
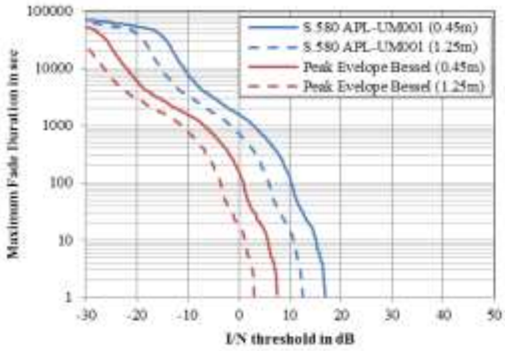
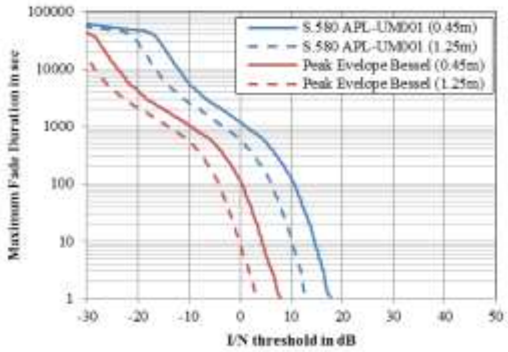
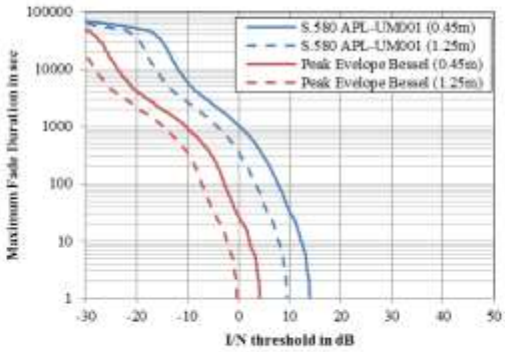
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-39

Maximum fade duration maximum ground speed (300 kts)

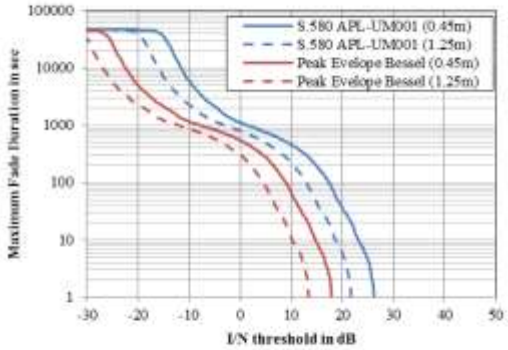
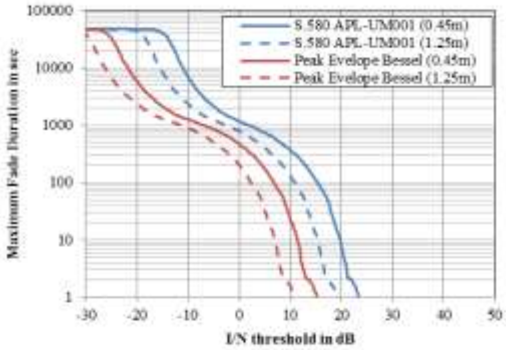
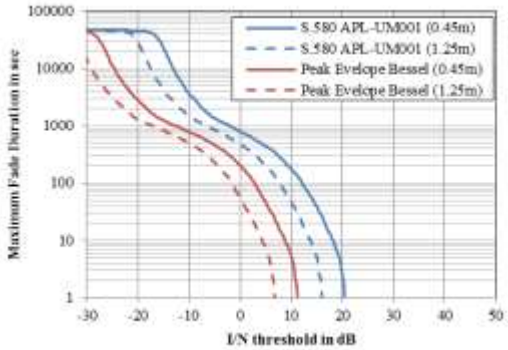
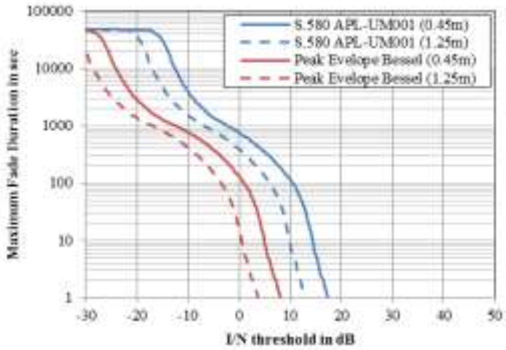
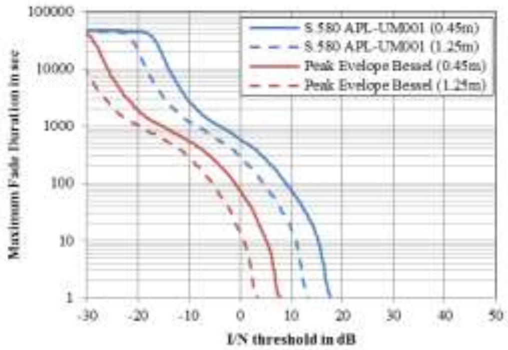
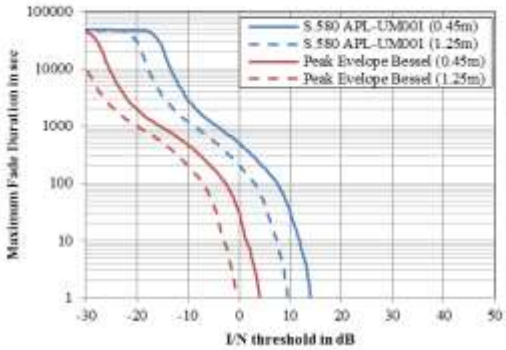
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-40

Aggregate fade duration minimum ground speed (100 kts)

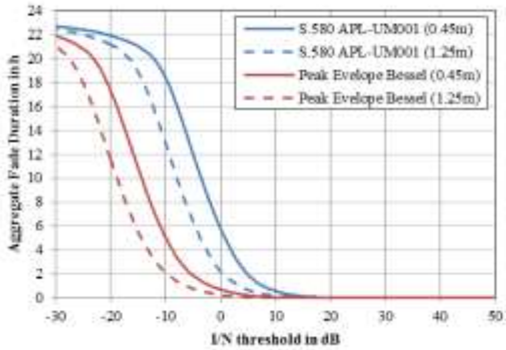
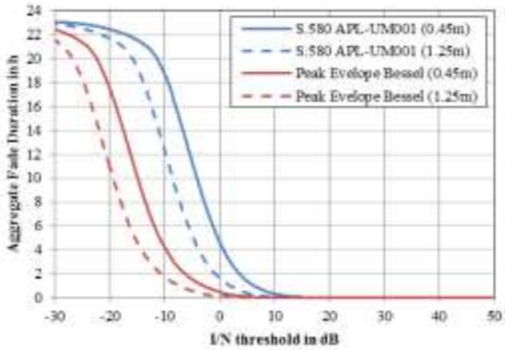
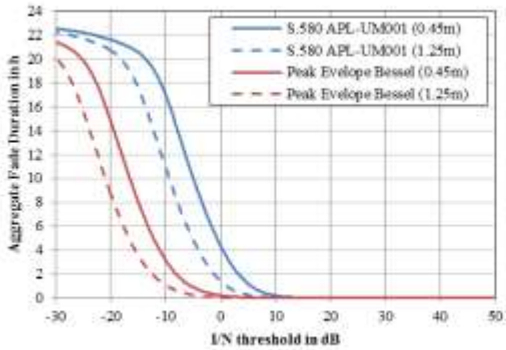
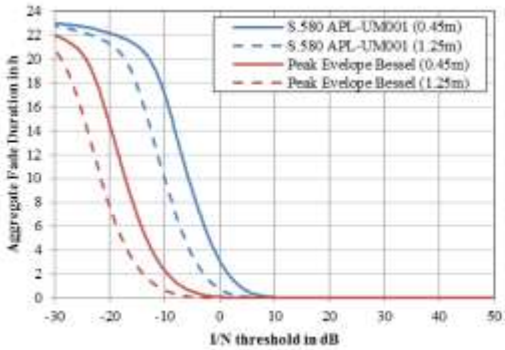
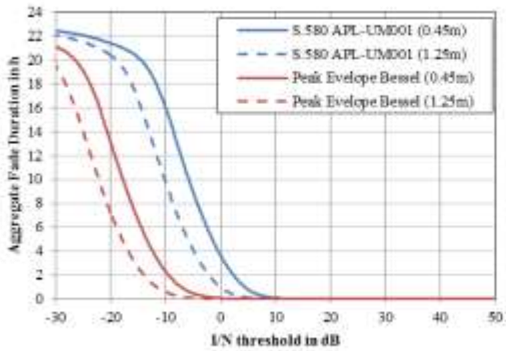
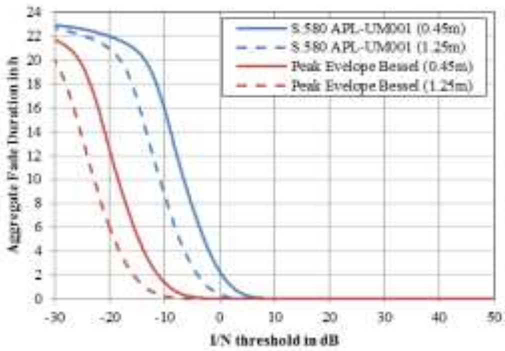
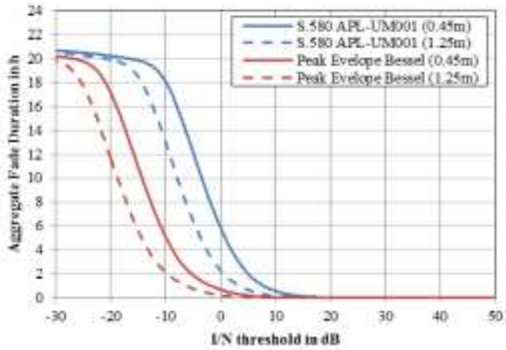
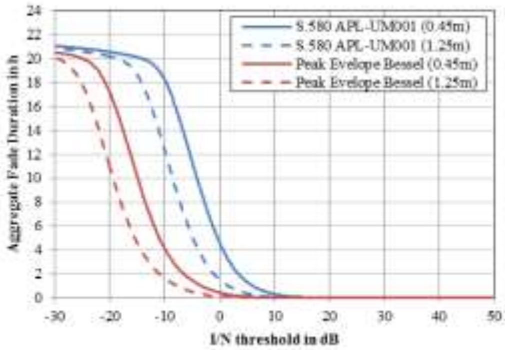
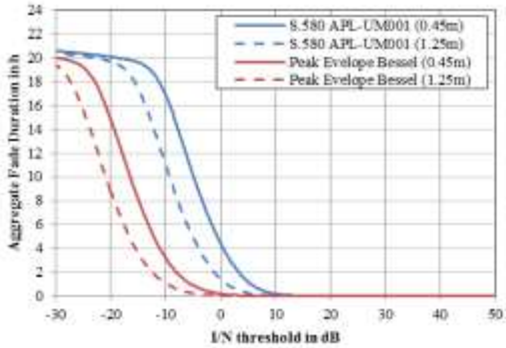
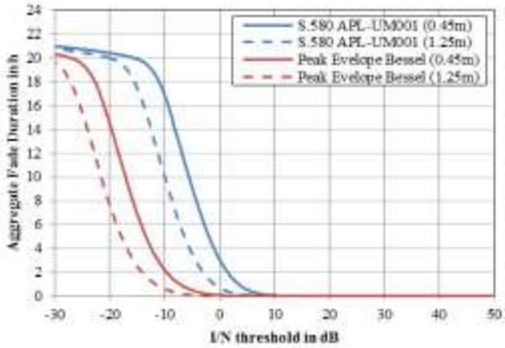
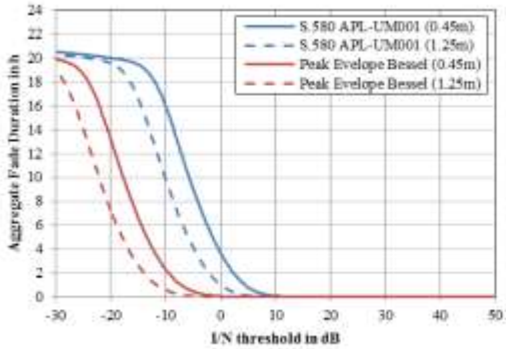
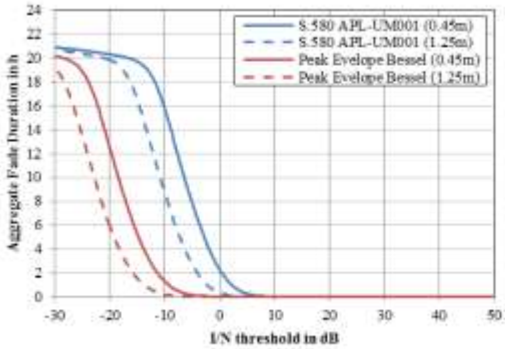
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-41

Aggregate fade duration maximum ground speed (300 kts)

<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.1.2.3 Interfade duration

TABLE A6-42

Average interfade duration minimum ground speed (100 kts)

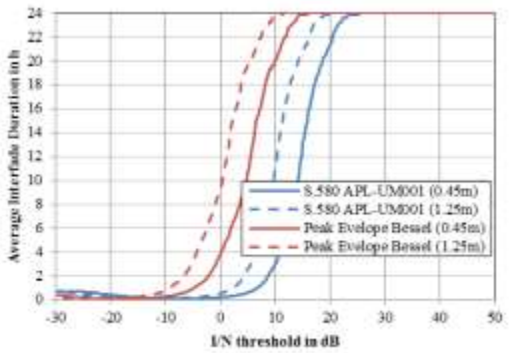
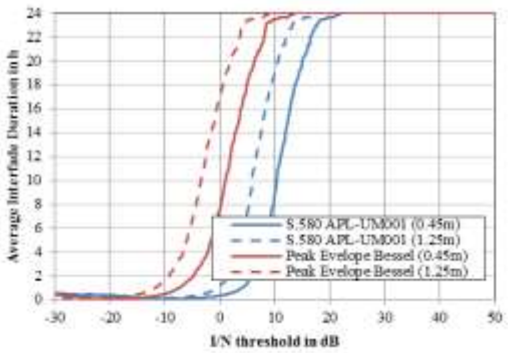
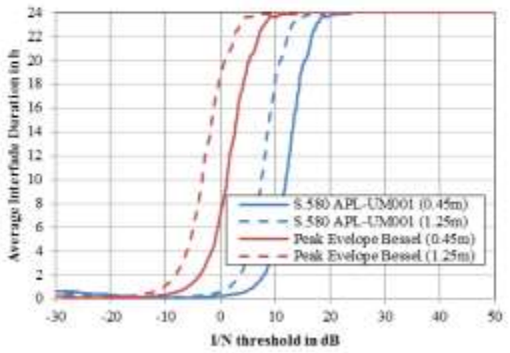
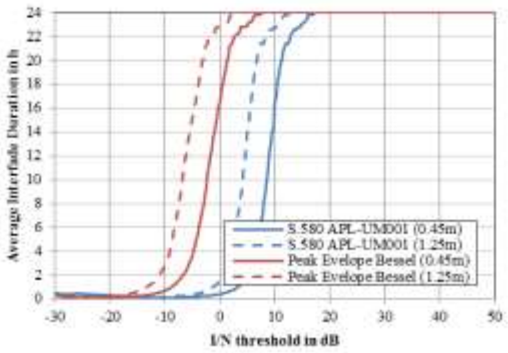
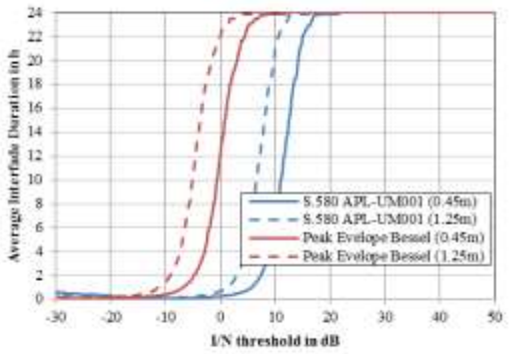
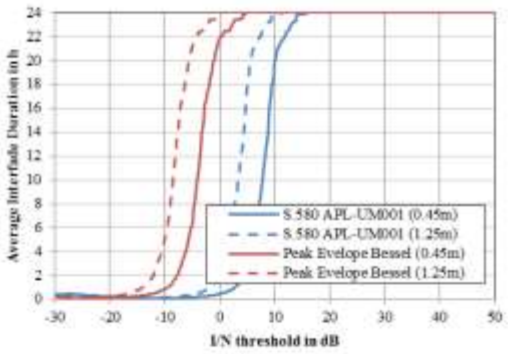
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-43

Average interfade duration maximum ground speed (300 kts)

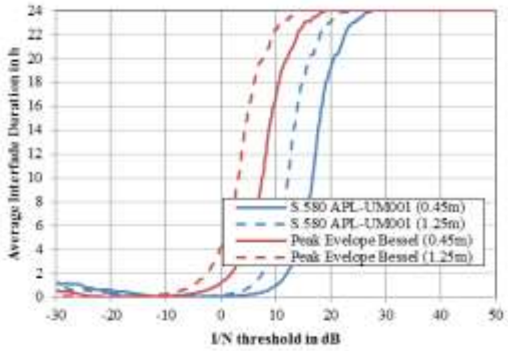
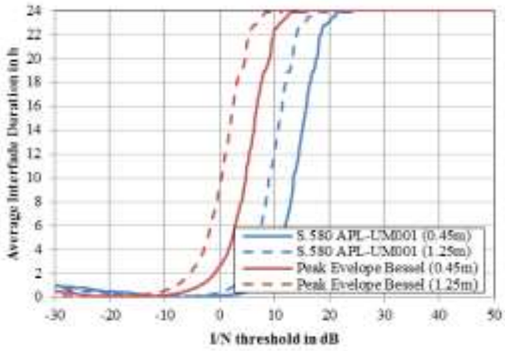
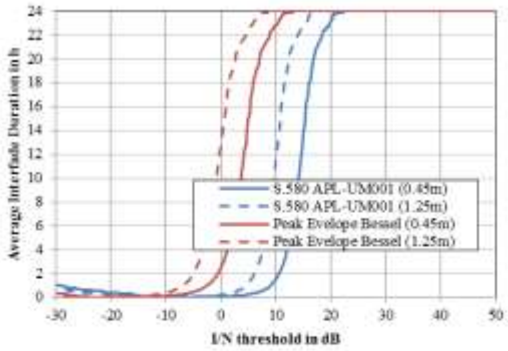
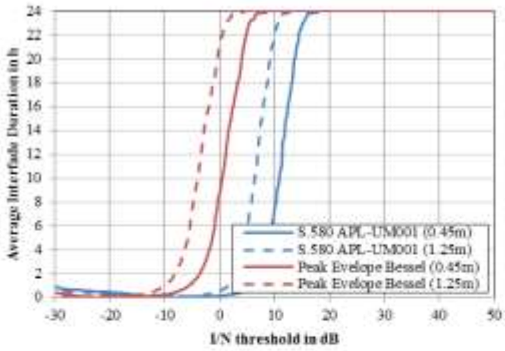
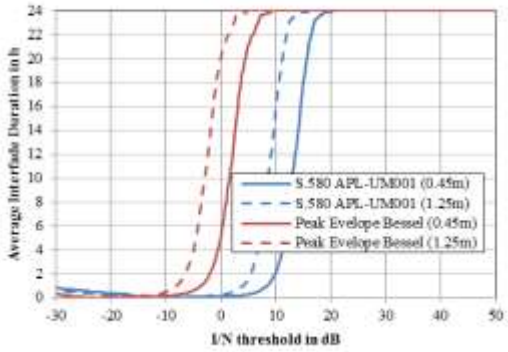
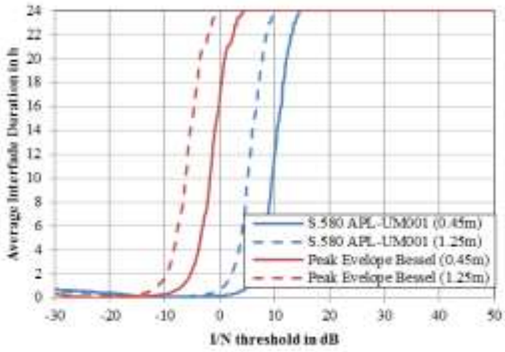
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-44

Aggregate interfade duration minimum ground speed (100 kts)

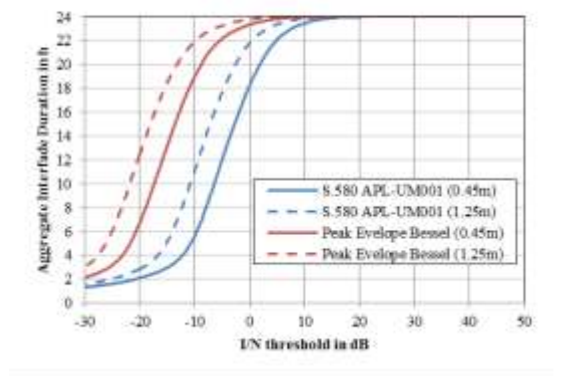
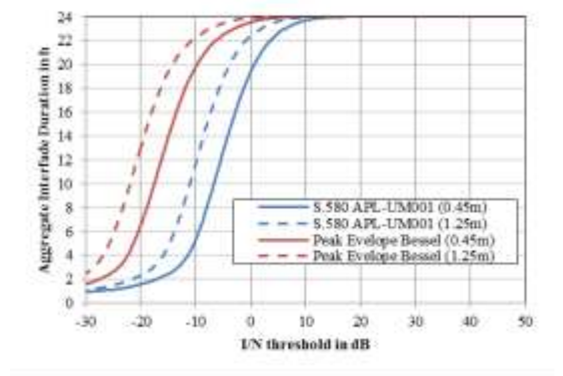
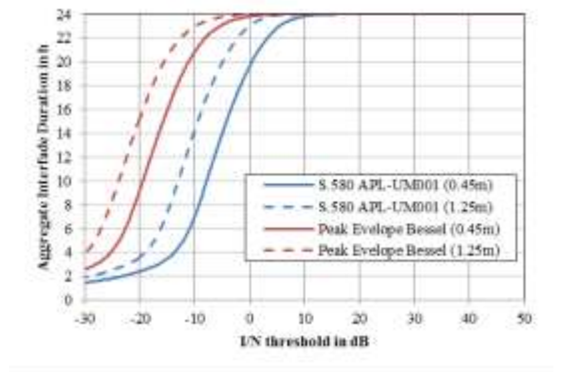
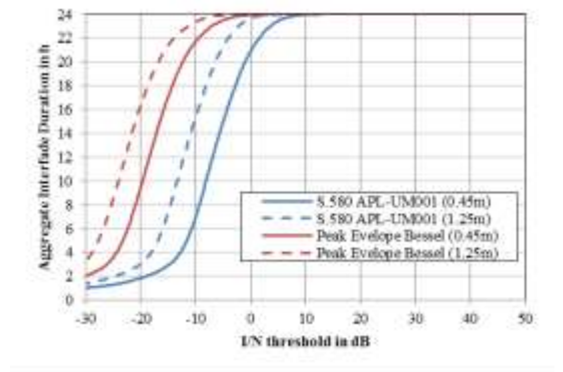
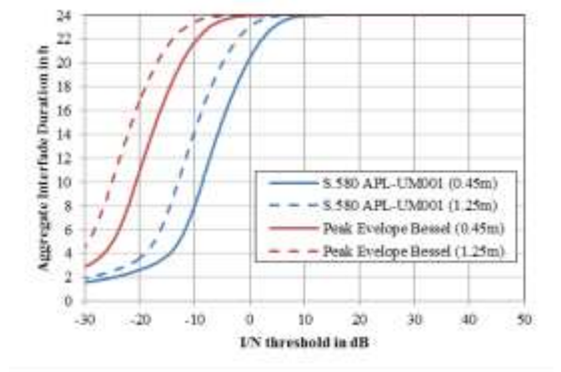
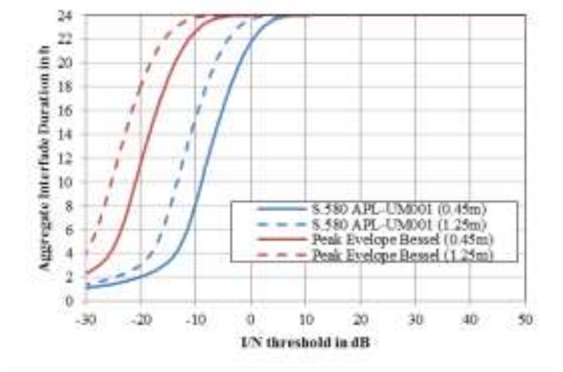
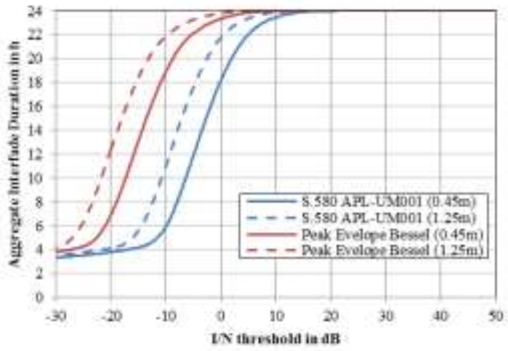
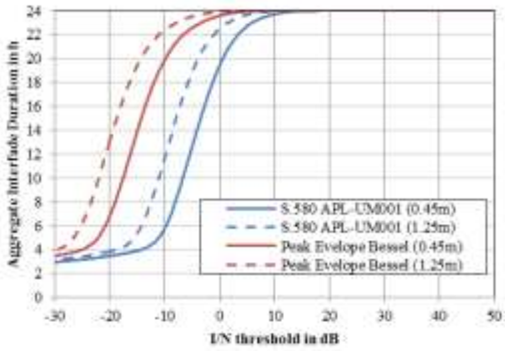
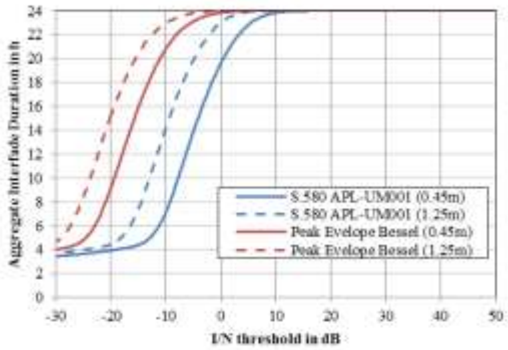
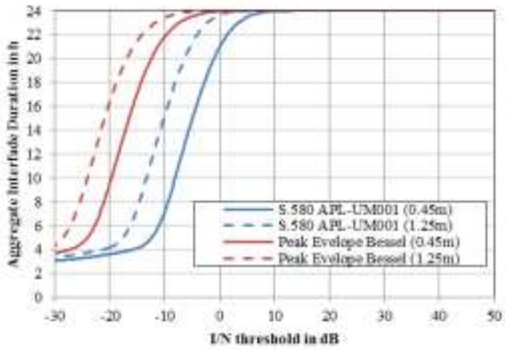
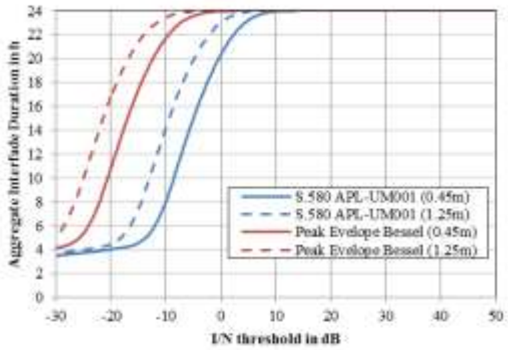
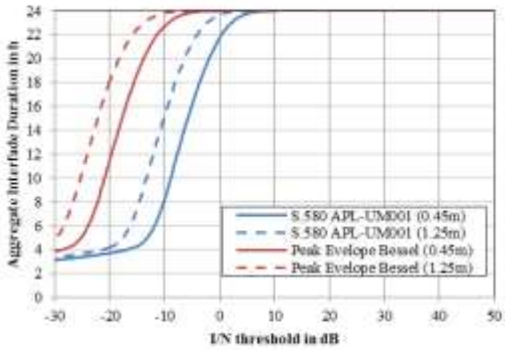
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-45

Aggregate interfade duration maximum ground speed (300 kts)

<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.2 Simulations results for 19.7 GHz

A6-6.4.2.1 Simulation Case 1

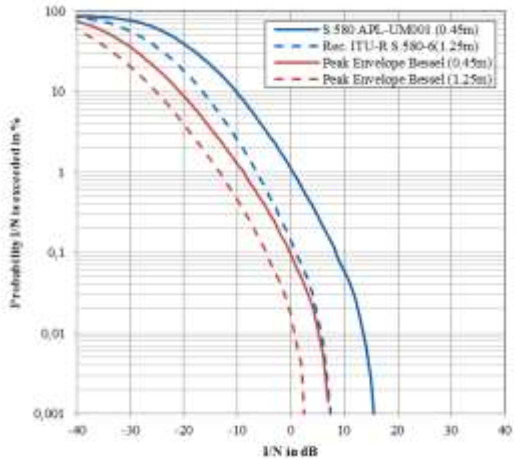
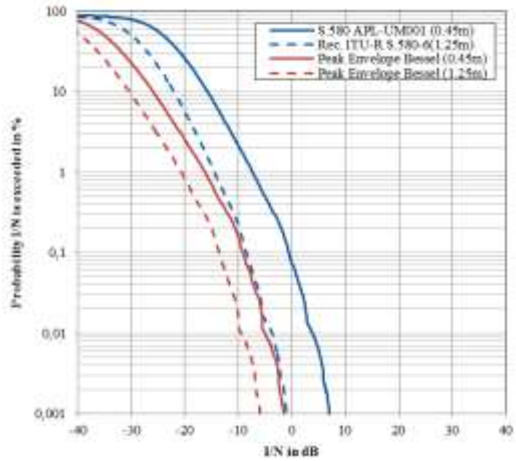
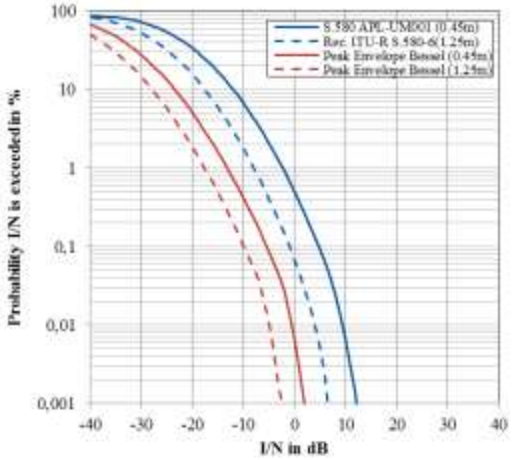
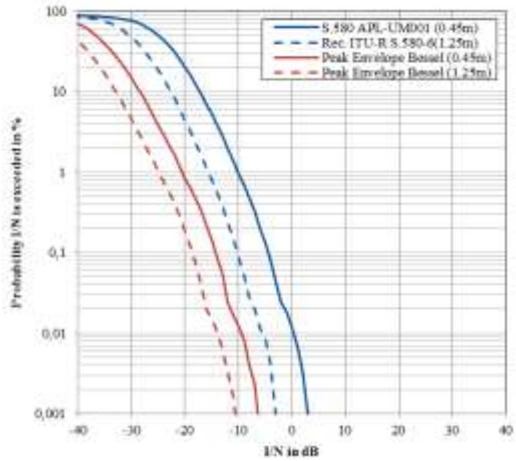
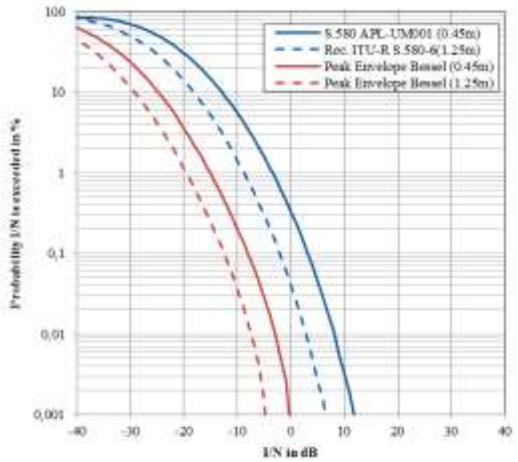
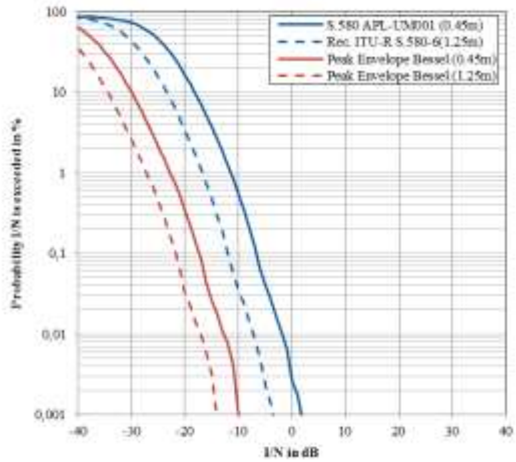
The following diagrams show the CDF, fade and inter-fade durations for Simulation Case 1 (flight altitude 914 m (3 000 ft) up to 3 000 m (10 000 ft) for *I/N* thresholds from -40 dB up to 40 dB. The values for the maximum possible peak I/N without any mitigation based on the usage of the antenna pattern according to Recommendation ITU-R S.580-6 listed in section A6-5.2 of Appendix 2 can be compared with these diagrams.

All diagrams show compliance with the thresholds including large margins, all interference effects can be covered.

A6-6.4.2.1.1 Probabilities for exceeding I/N

TABLE A6-46

CDF simulation scenario 1

<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.2.1.2 Fade durations

TABLE A6-47

Average fade duration minimum ground speed (80 kts)

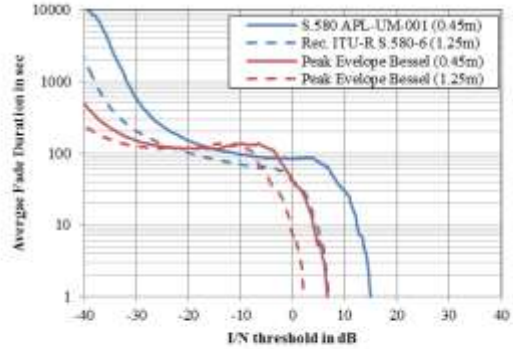
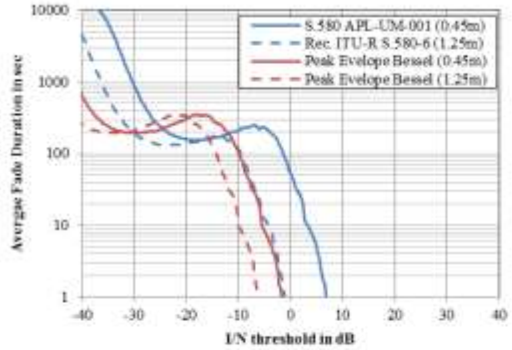
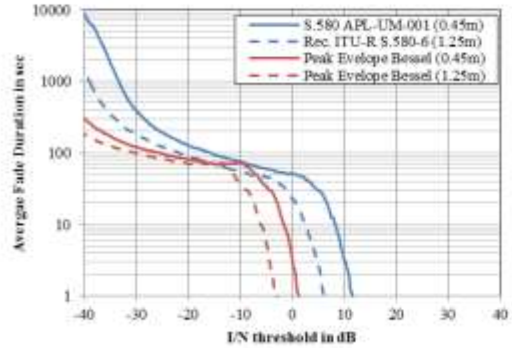
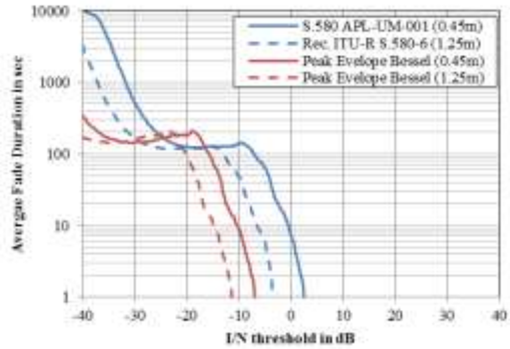
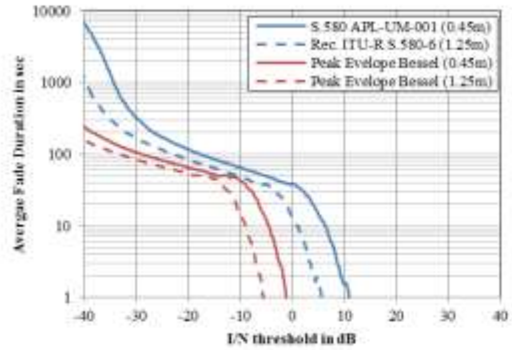
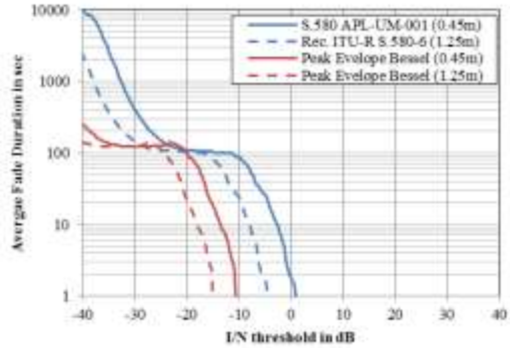
<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-48

Average fade duration maximum ground speed (250 kts)

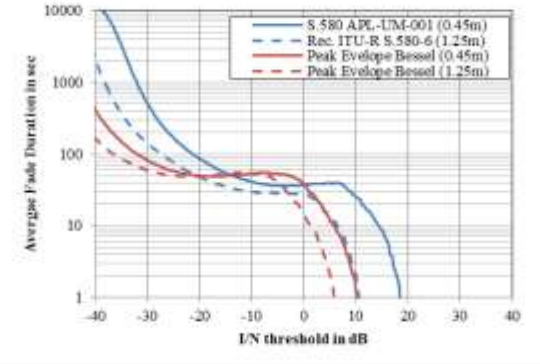
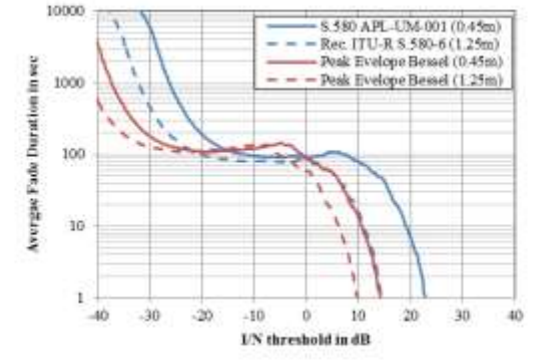
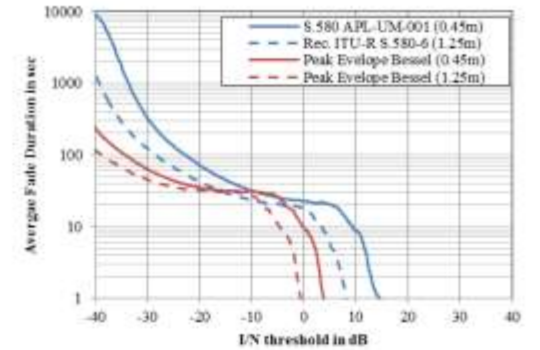
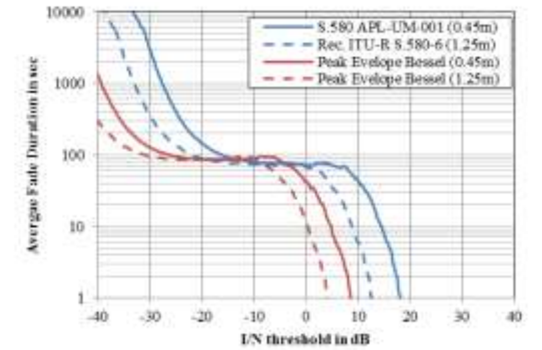
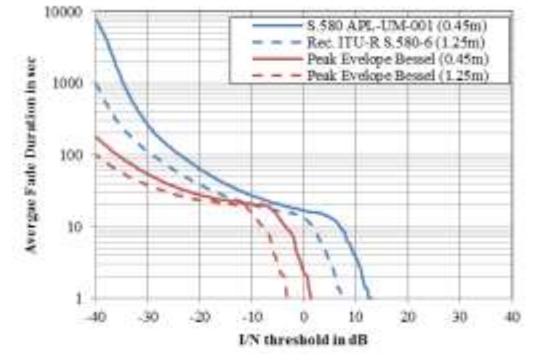
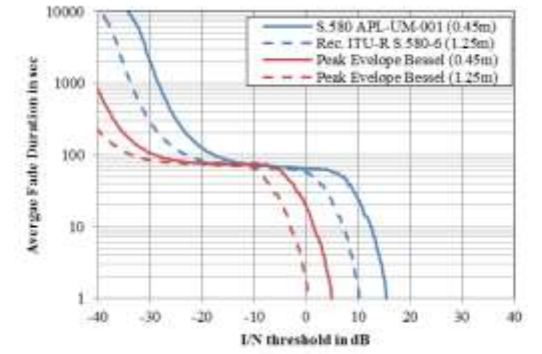
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-49

Maximum fade duration minimum ground speed (80 kts)

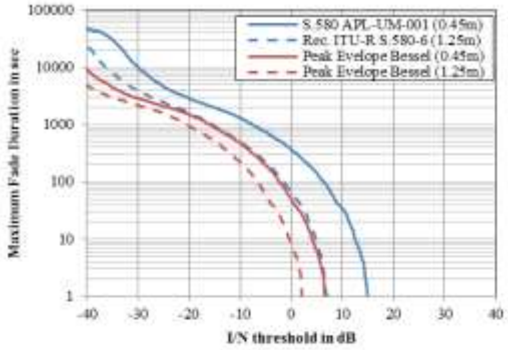
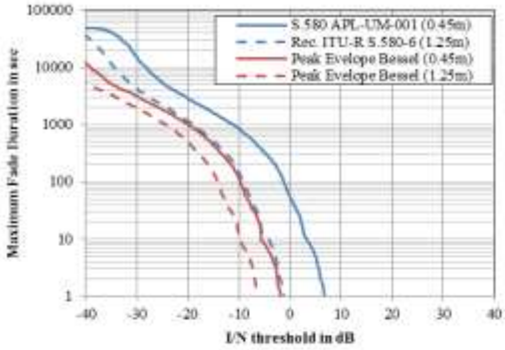
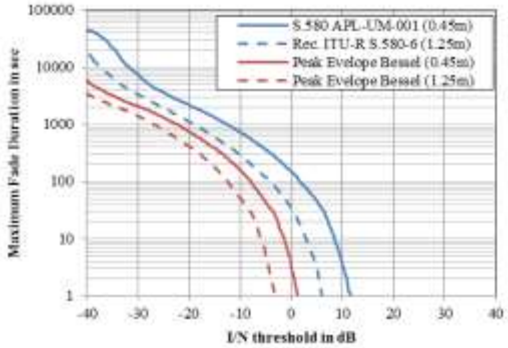
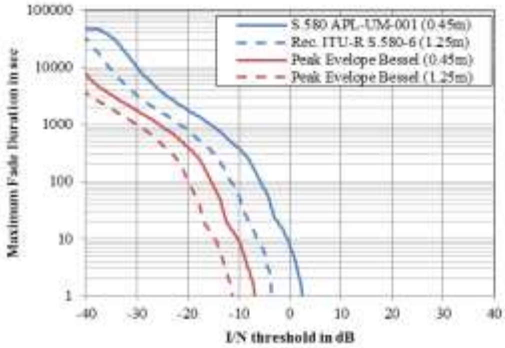
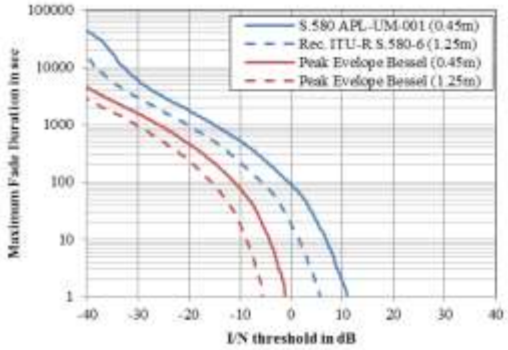
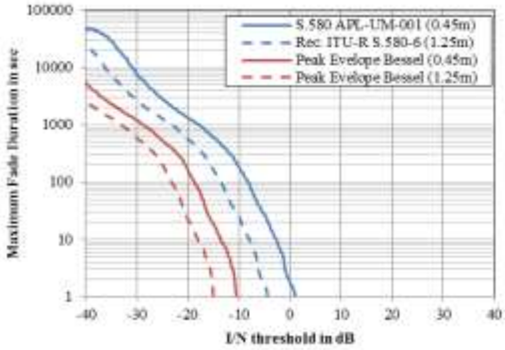
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-50

Maximum fade duration maximum ground speed (250 kts)

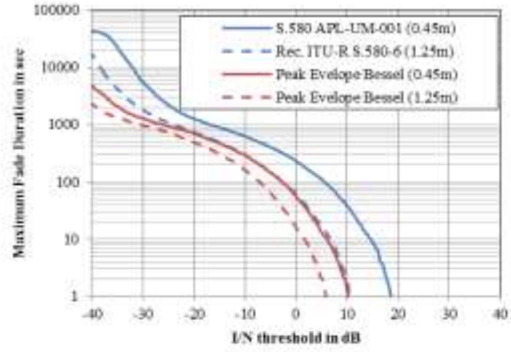
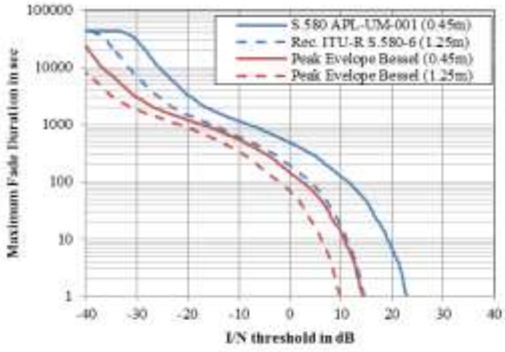
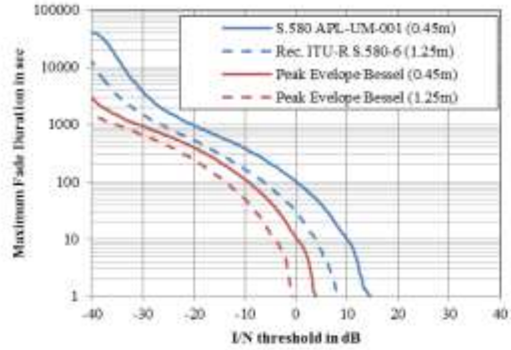
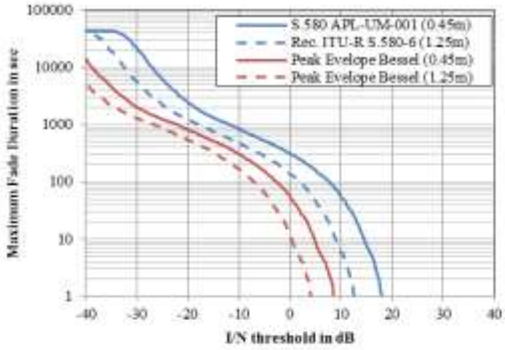
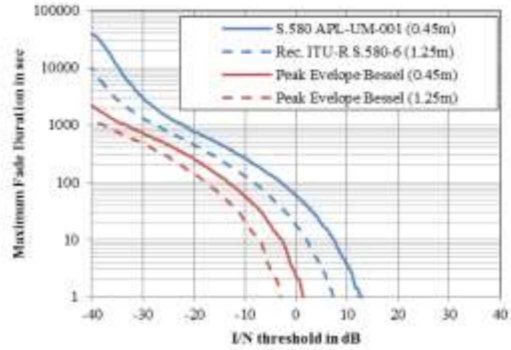
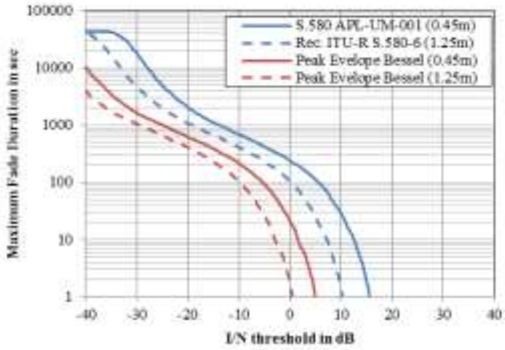
<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td></td><td></td></tr>
<tr><td>20°</td><td></td><td></td></tr>
<tr><td>30°</td><td></td><td></td></tr>
</table>

TABLE A6-51

Aggregate fade duration minimum ground speed (80 kts)

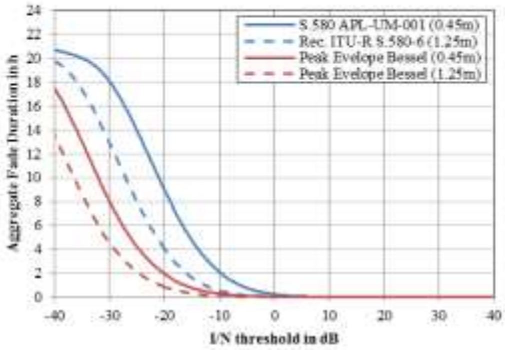
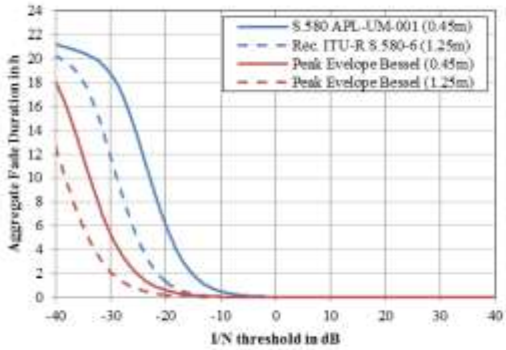
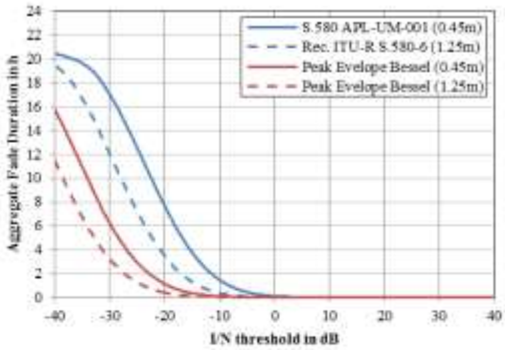
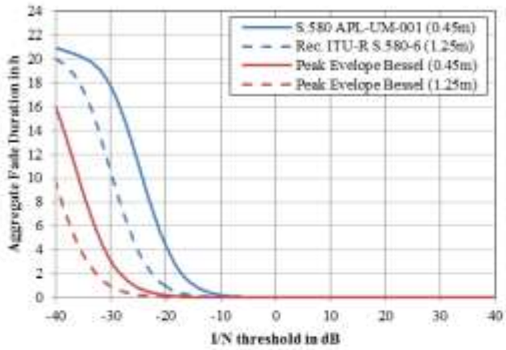
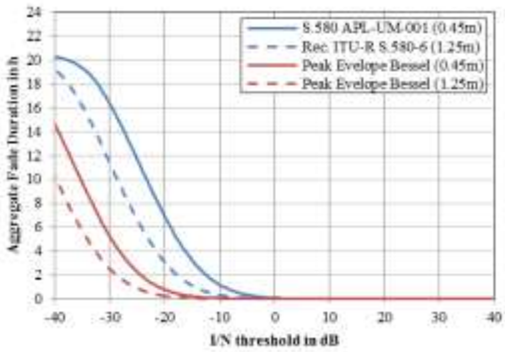
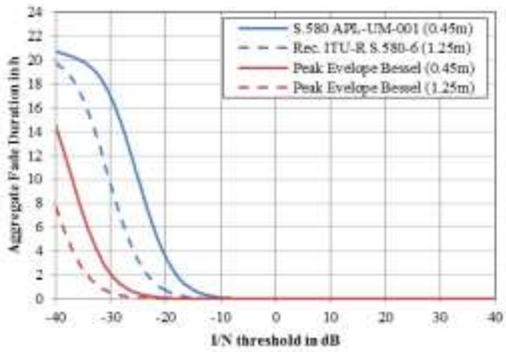
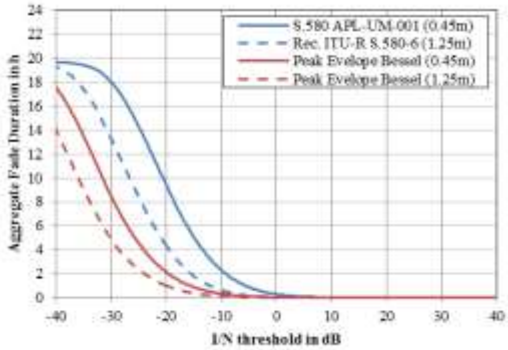
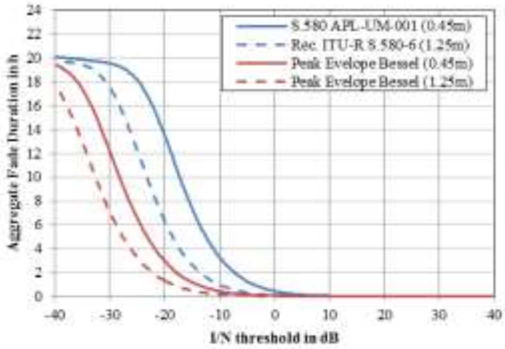
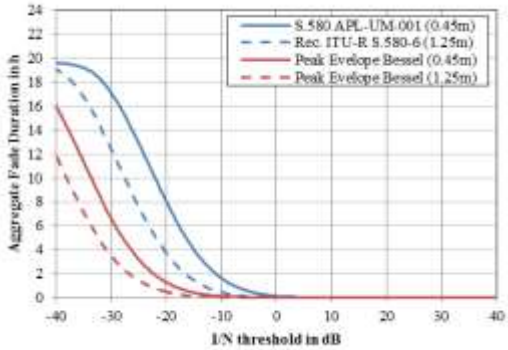
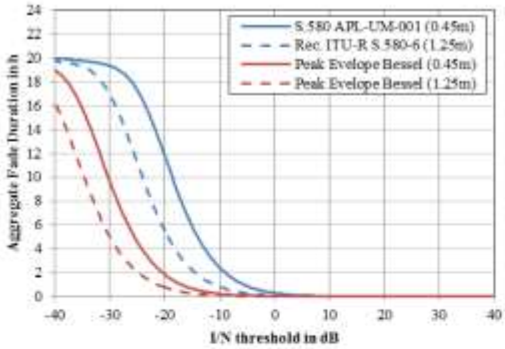
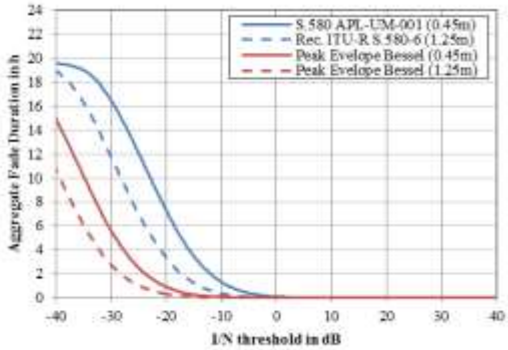
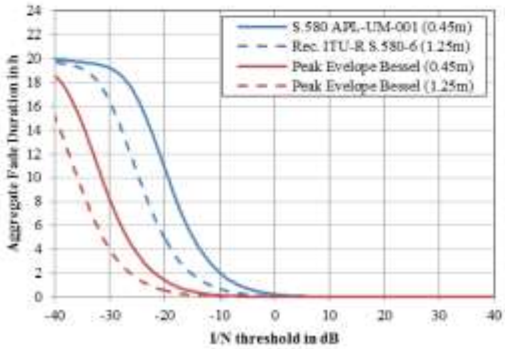
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-52

Aggregate fade duration maximum ground speed (250 kts)

Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

A6-6.4.2.1.3 Interfade duration

TABLE A6-53

Average interfade duration minimum ground speed (80 kts)

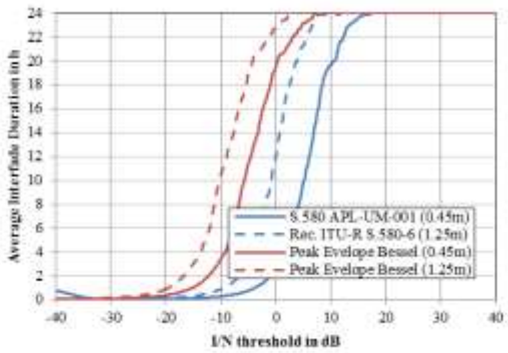
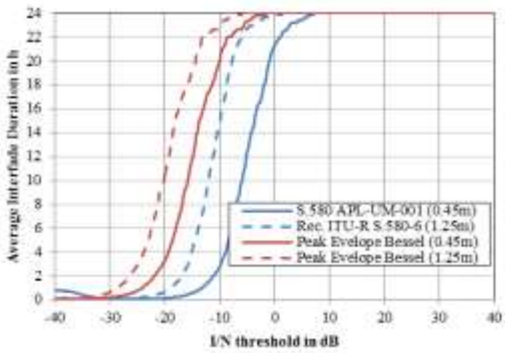
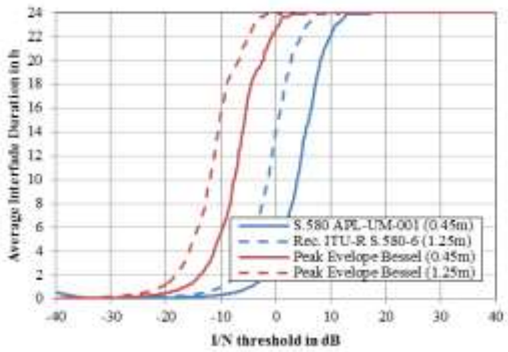
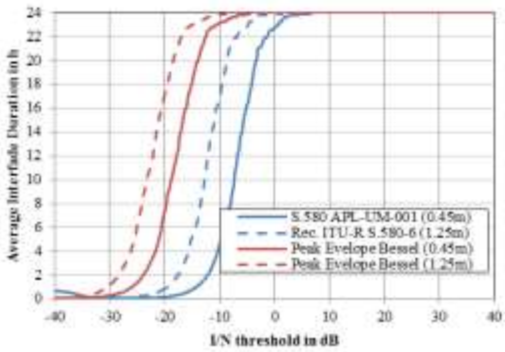
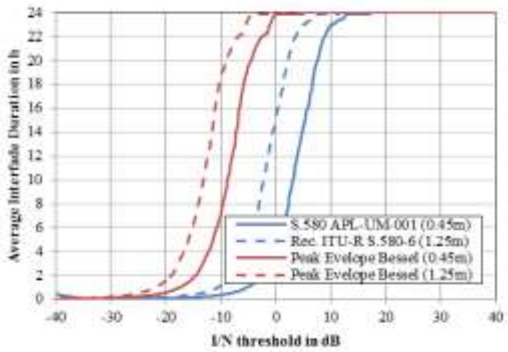
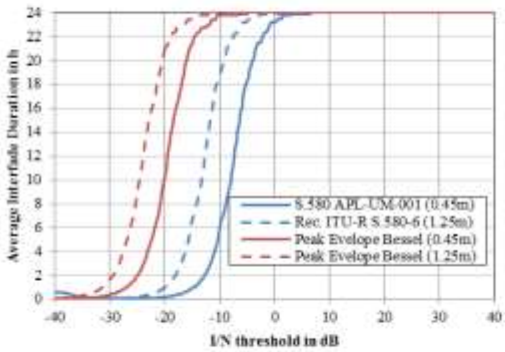
<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-54

Average interfade duration maximum ground speed (250 kts)

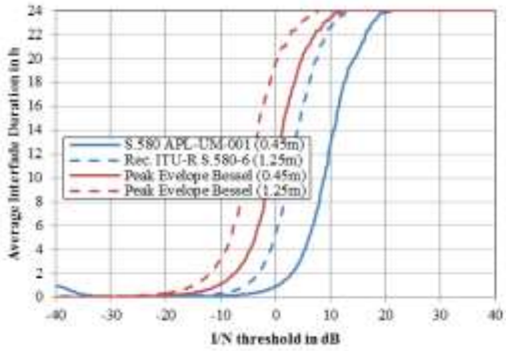
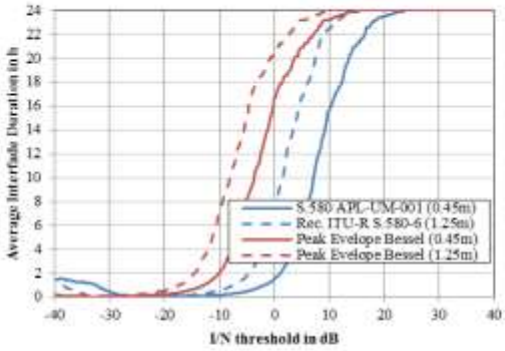
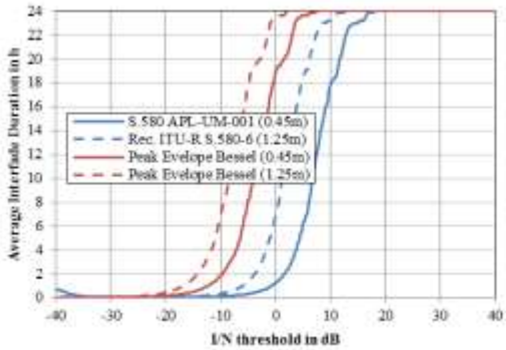
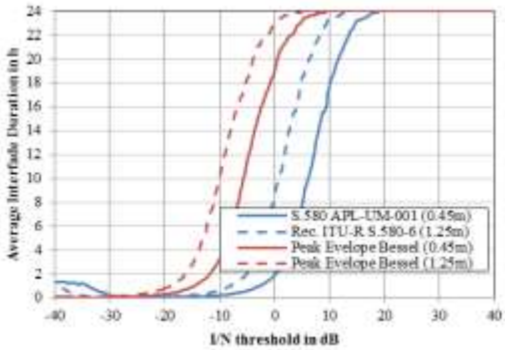
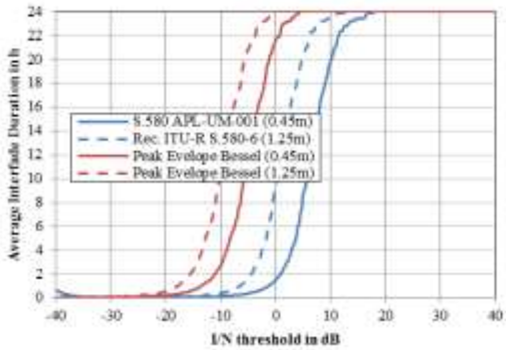
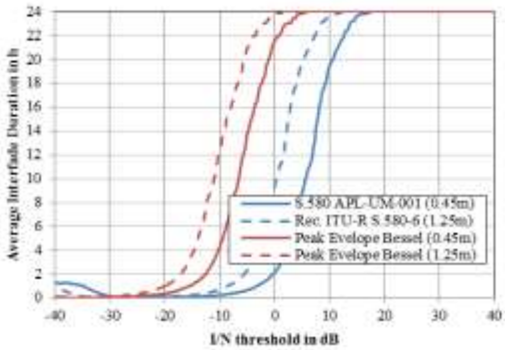
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-55

Aggregate interfade duration minimum ground speed (80 kts)

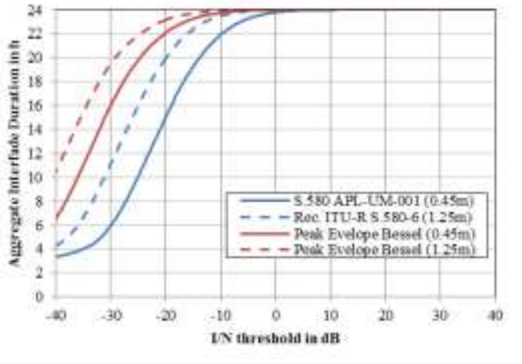
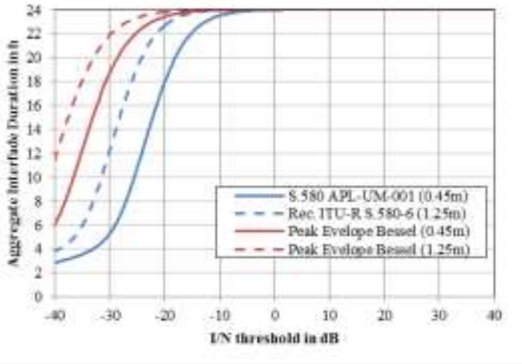
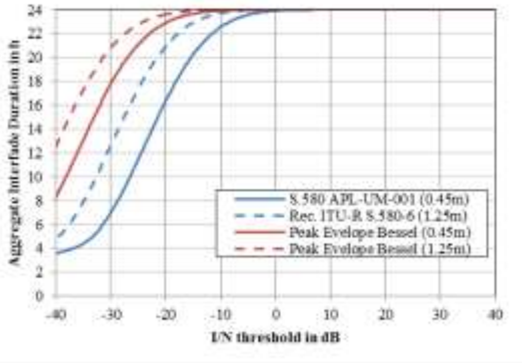
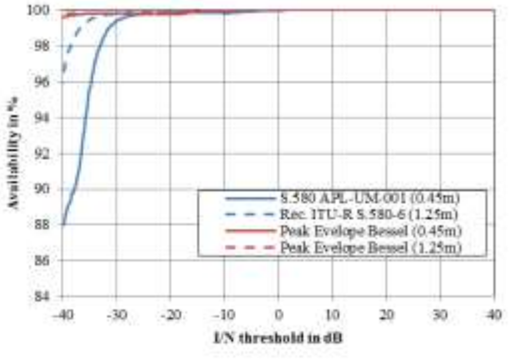
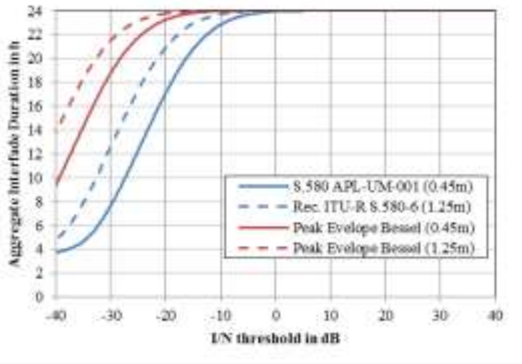
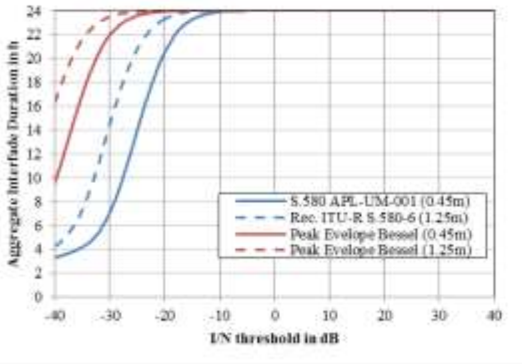
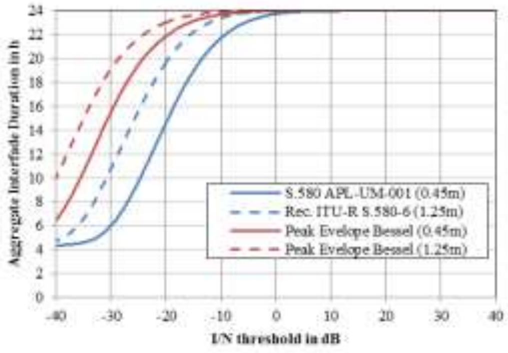
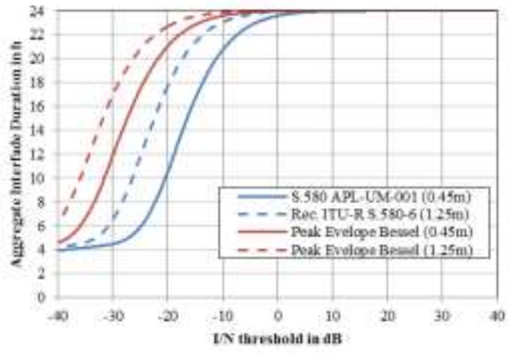
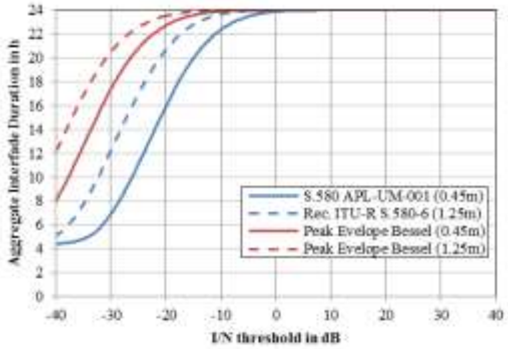
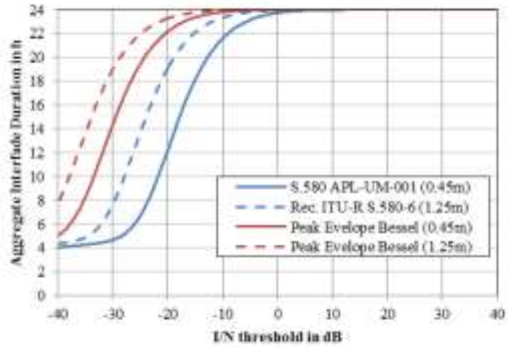
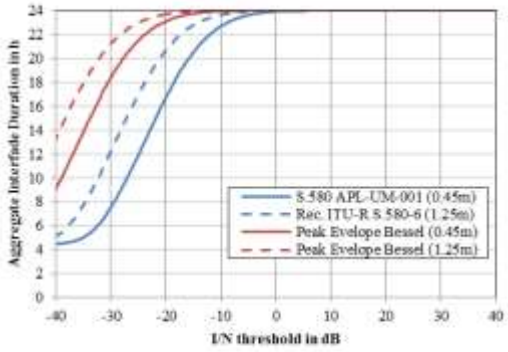
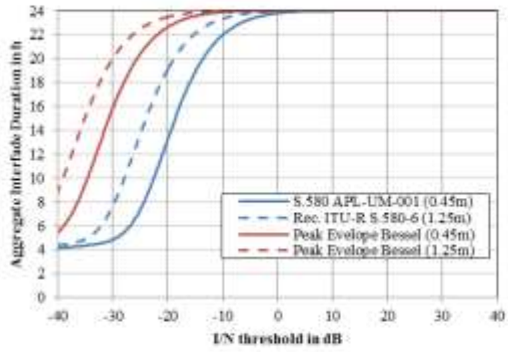
<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td></td><td></td></tr>
<tr><td>20°</td><td></td><td></td></tr>
<tr><td>30°</td><td></td><td></td></tr>
</table>

TABLE A6-56

Aggregate interfade duration maximum ground speed (250 kts)

Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

A6-6.4.2.2 Simulation Case 2

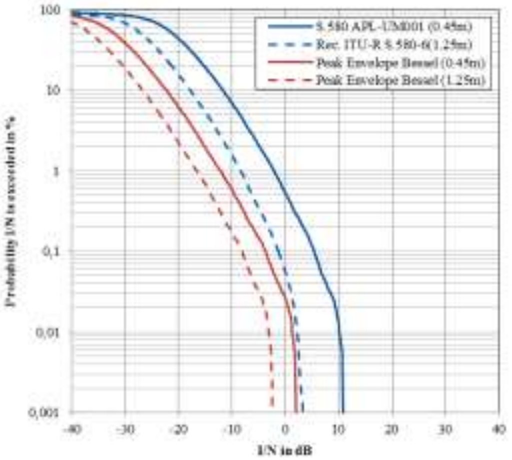
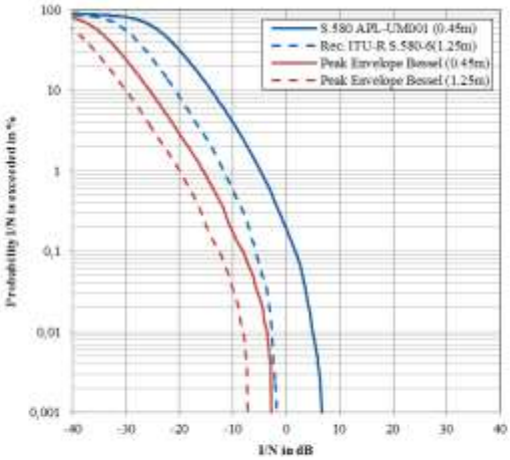
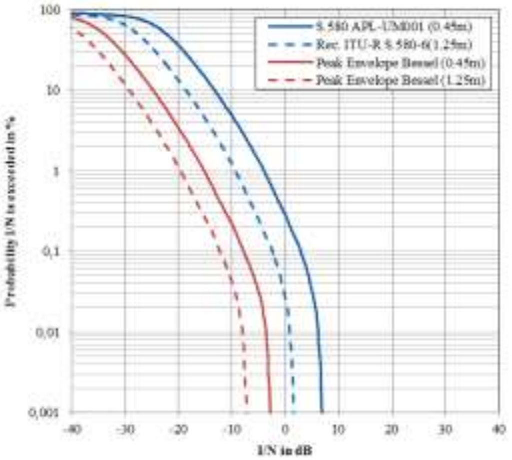
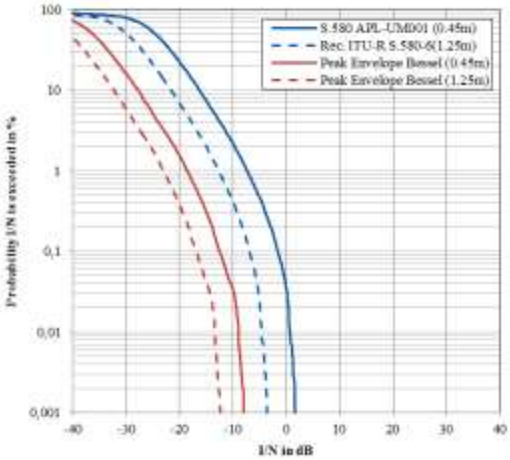
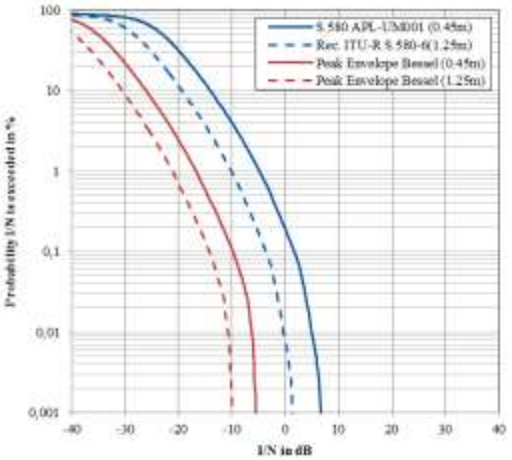
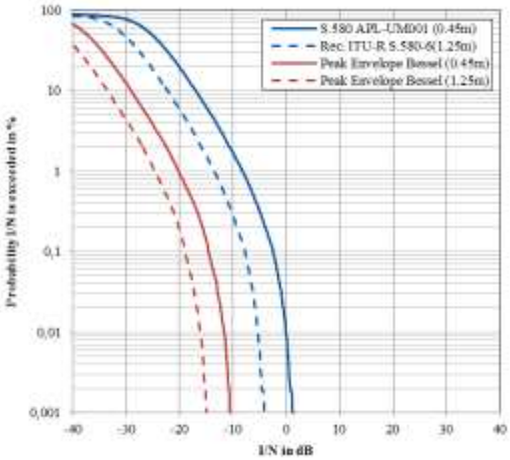
The following diagrams show the CDF, fade and inter-fade durations for simulation scenario 2 (flight height 19 000 ft up to 30 000 ft) for *I/N* thresholds from -40 dB up to 40 dB in comparison with the maximum possible peak I/N without any mitigation according to section A6-2-2.

All diagrams show compliance with the thresholds including large margins, all interference effects can be covered.

A6-6.4.2.2.1 Cumulative distribution function

TABLE A6-57

CDF Simulation Case 2

<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.2.2.2 Fade durations

TABLE A6-58

Average fade duration minimum ground speed (100 kts)

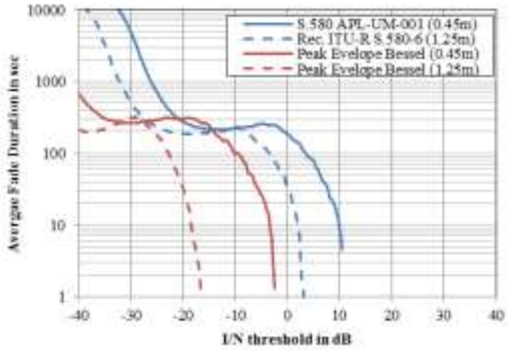
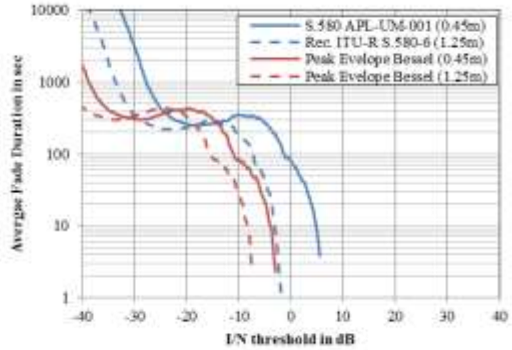
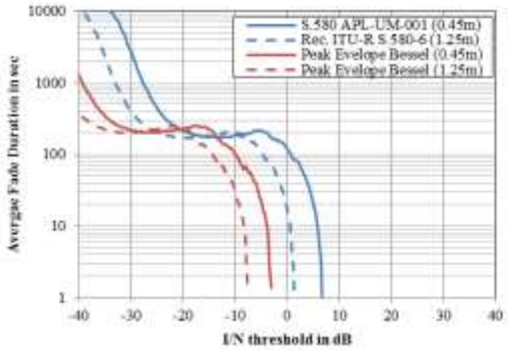
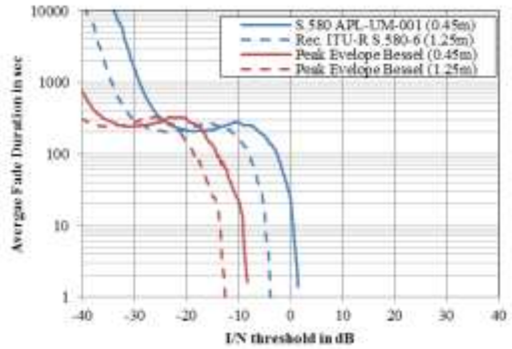
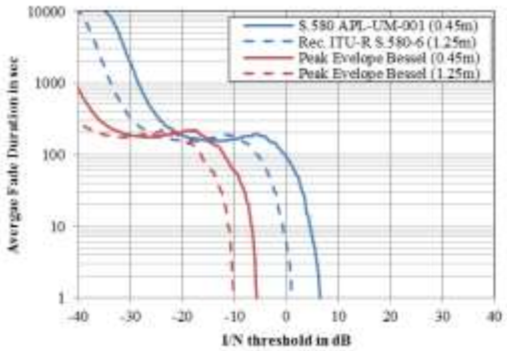
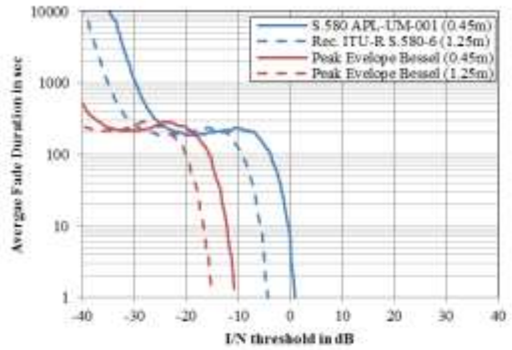
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-59

Average fade duration maximum ground speed (300 kts)

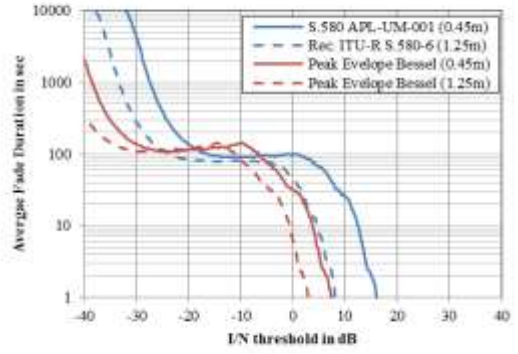
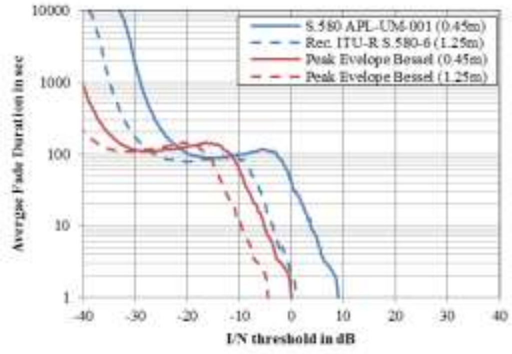
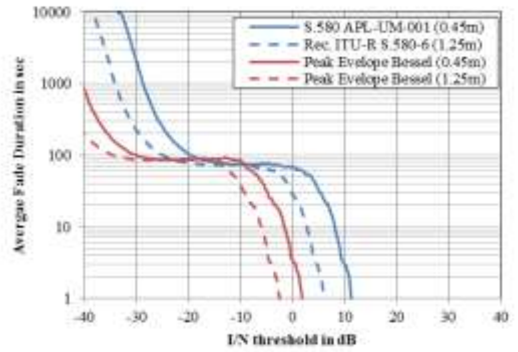
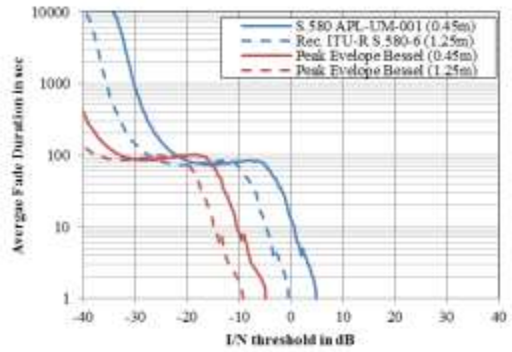
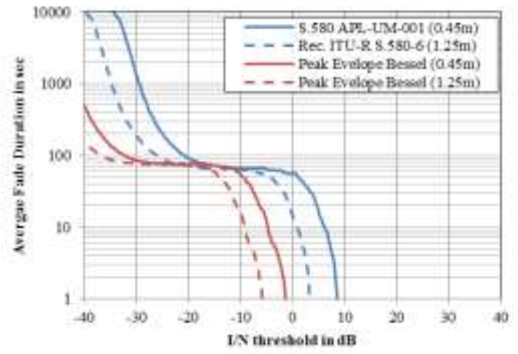
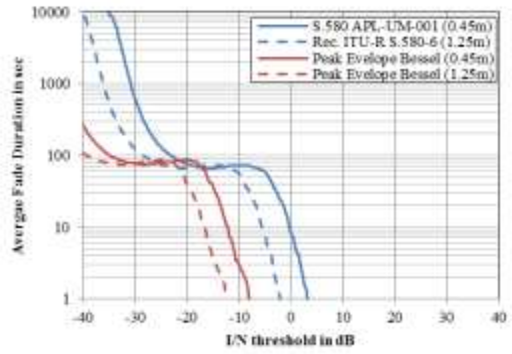
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-60

Maximum fade duration minimum ground speed (100 kts)

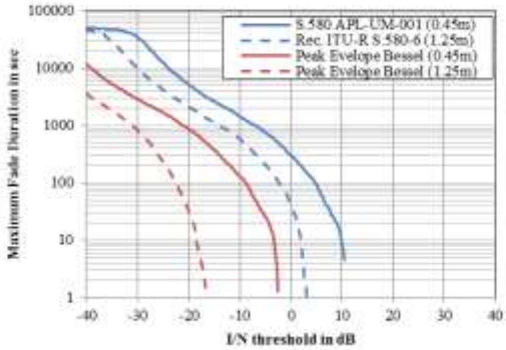
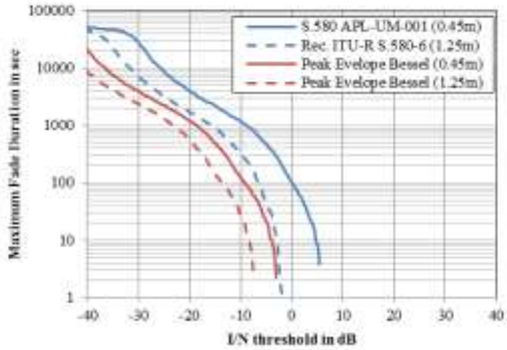
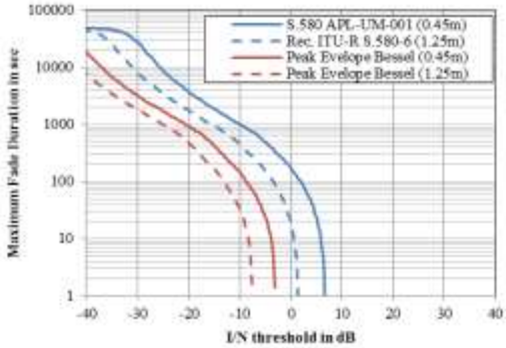
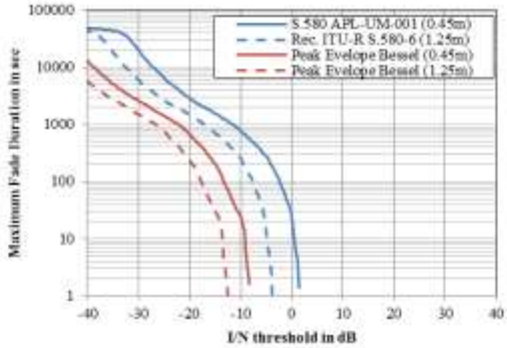
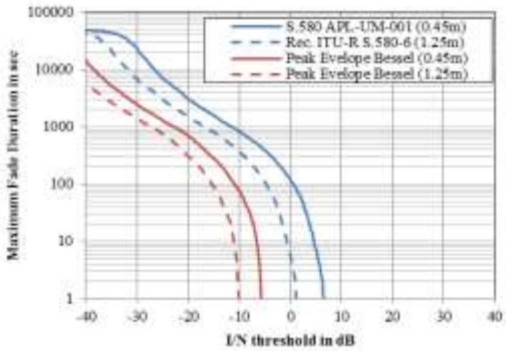
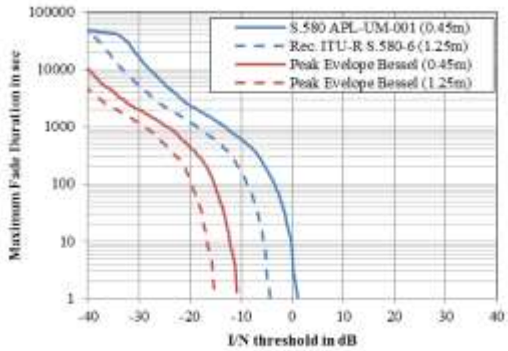
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-61

Maximum fade duration maximum ground speed (300 kts)

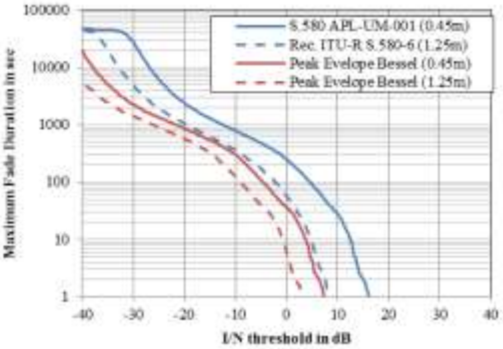
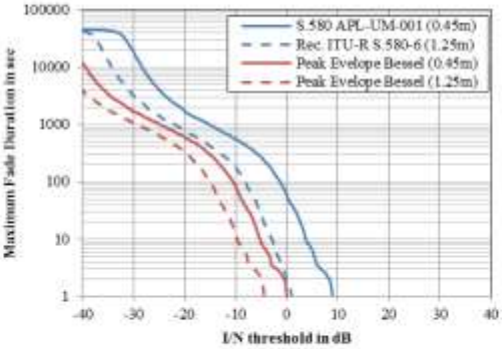
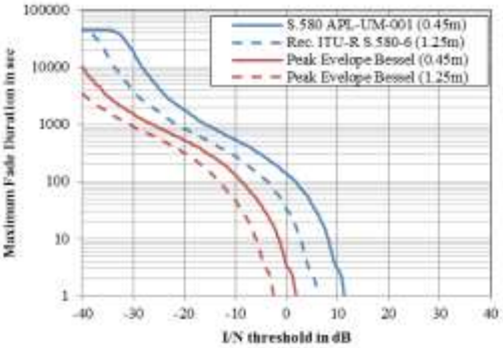
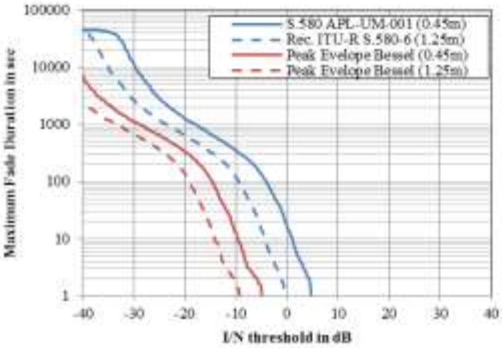
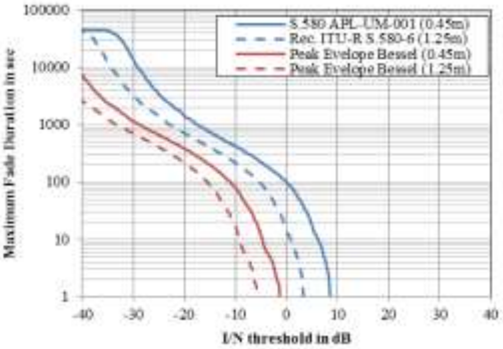
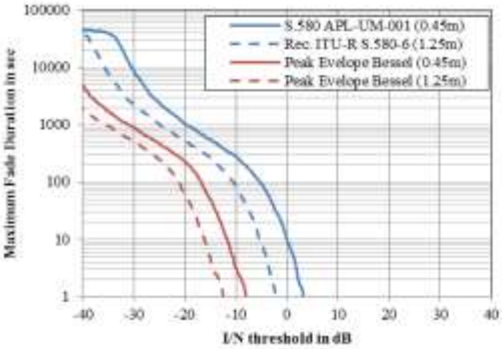
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-62

Aggregate fade duration minimum ground speed (100 kts)

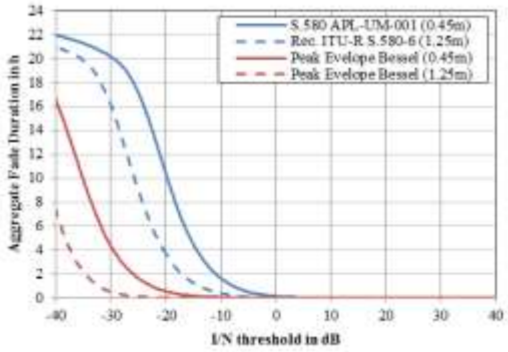
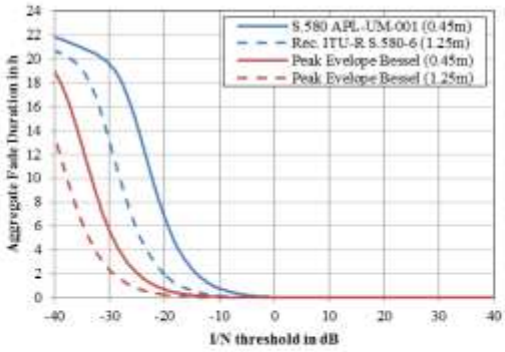
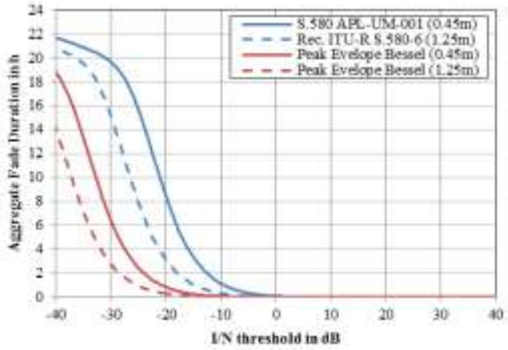
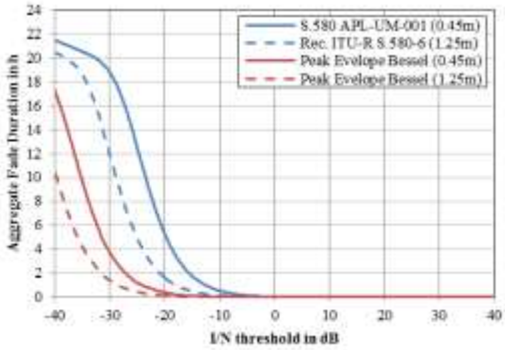
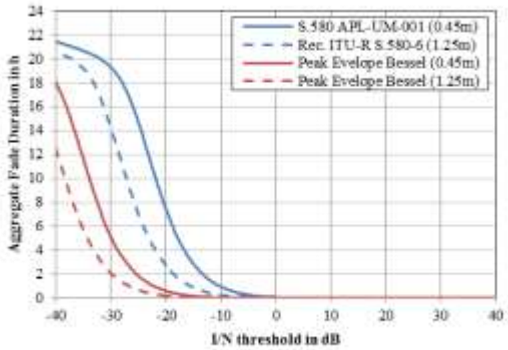
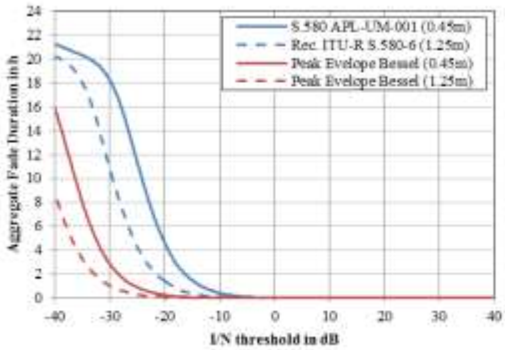
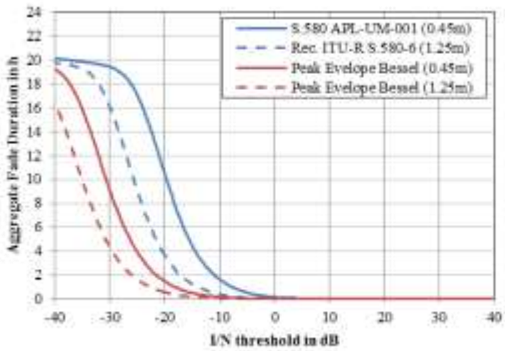
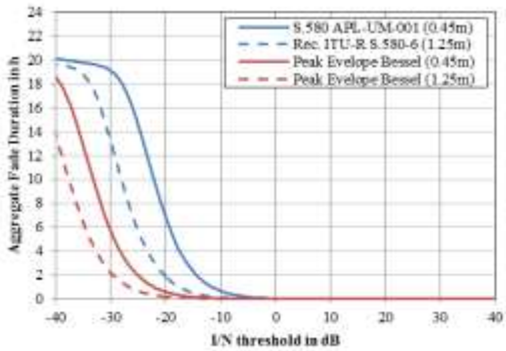
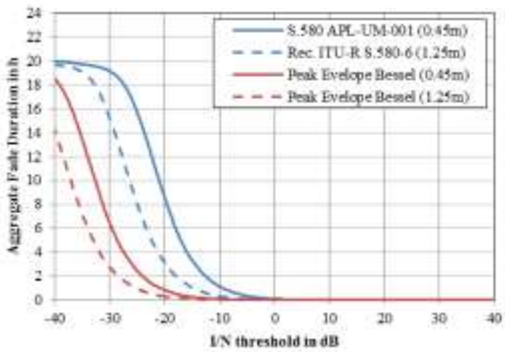
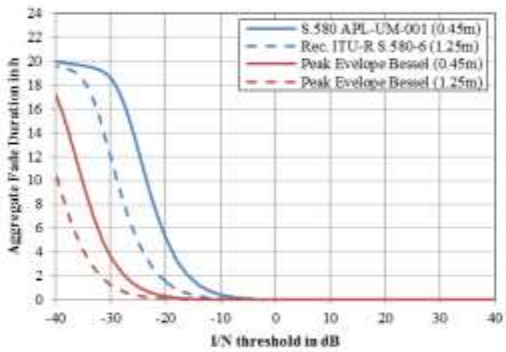
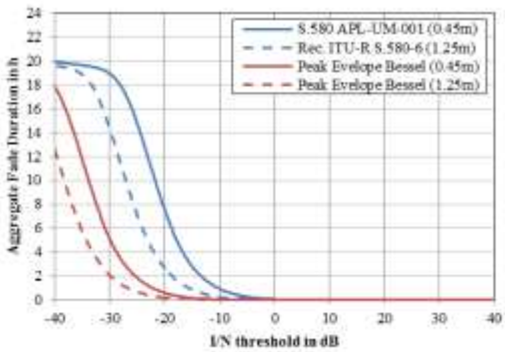
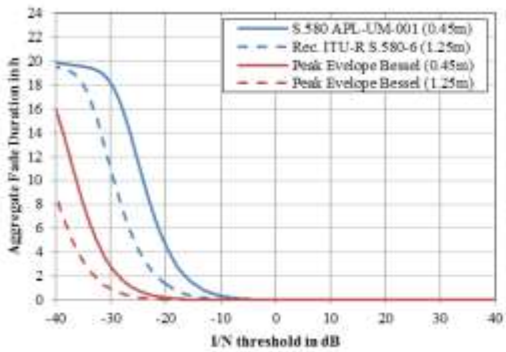
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-63

Aggregate fade duration maximum ground speed (300 kts)

<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

A6-6.4.2.2.3 Interfade duration

TABLE A6-64

Average interfade duration minimum ground speed (100 kts)

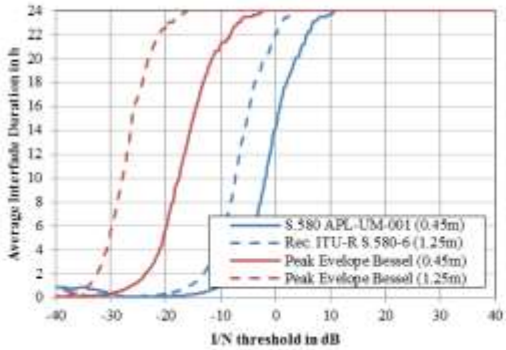
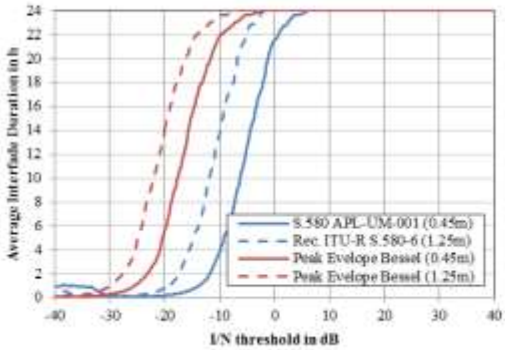
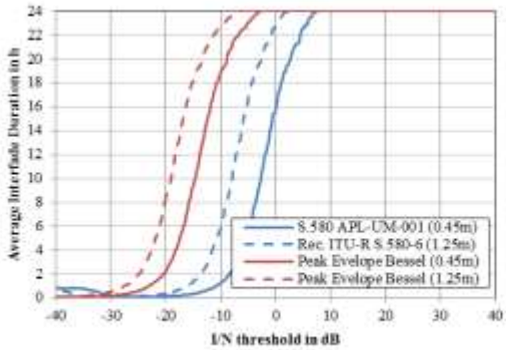
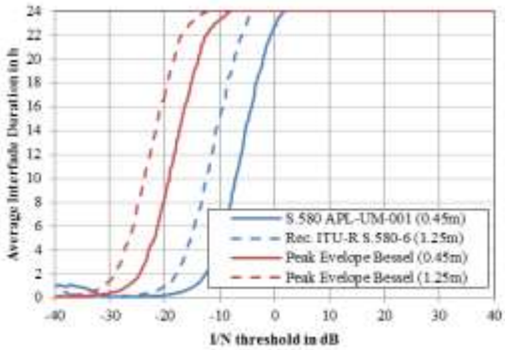
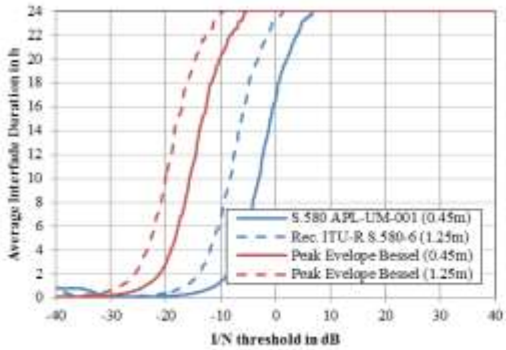
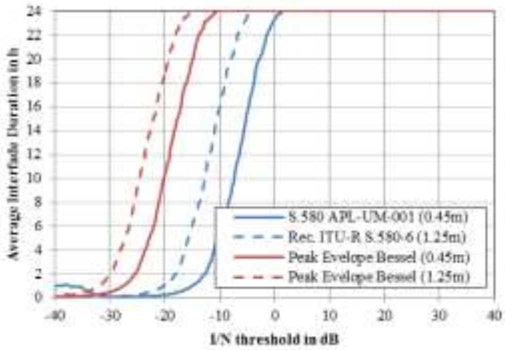
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-65

Average interfade duration maximum ground speed (300 kts)

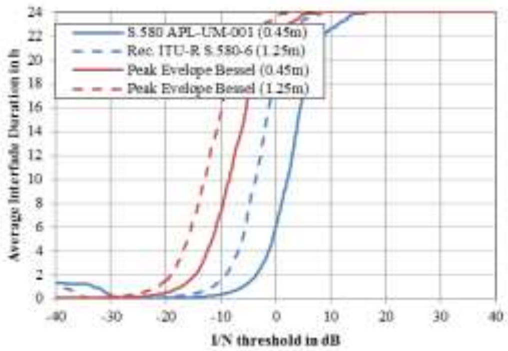
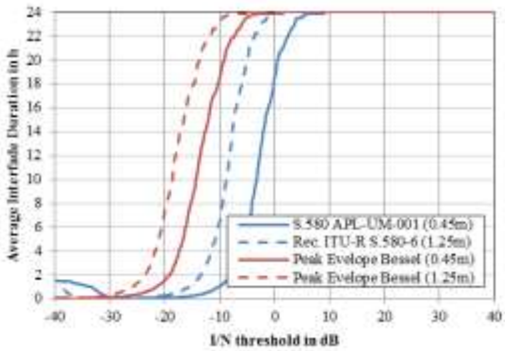
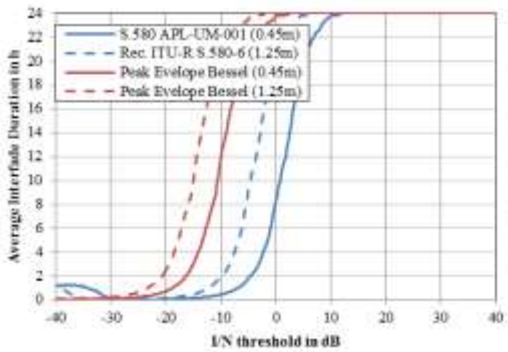
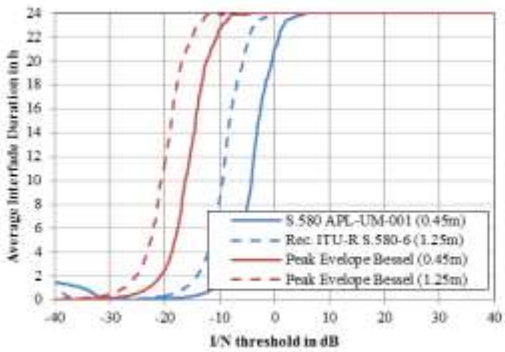
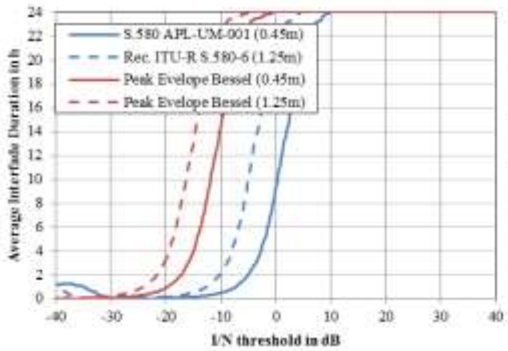
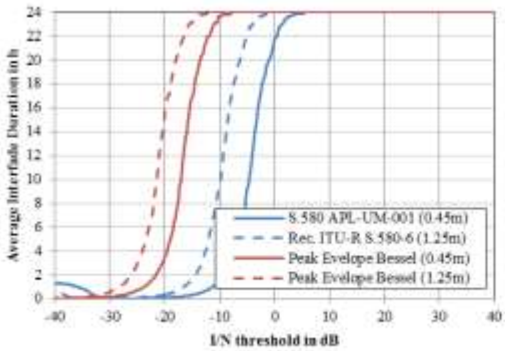
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-66

Aggregate interfade duration minimum ground speed (100 kts)

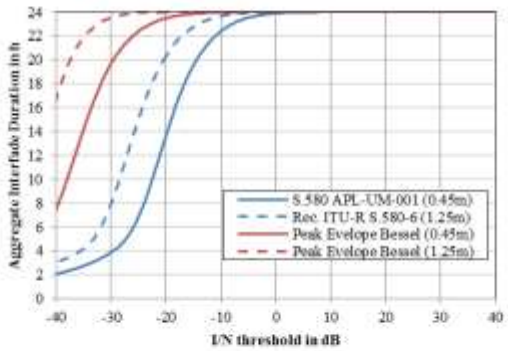
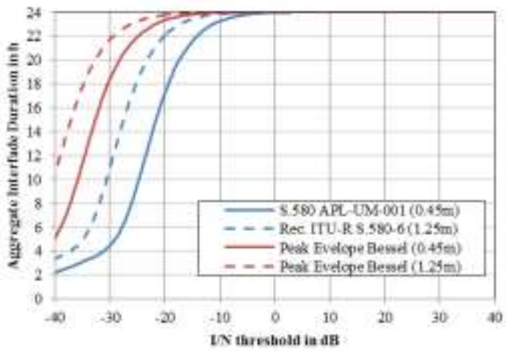
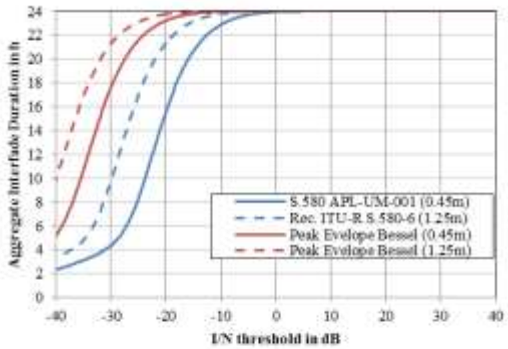
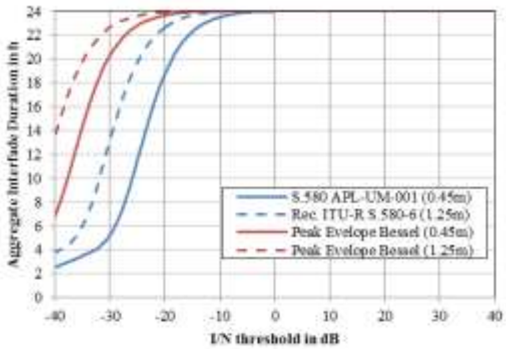
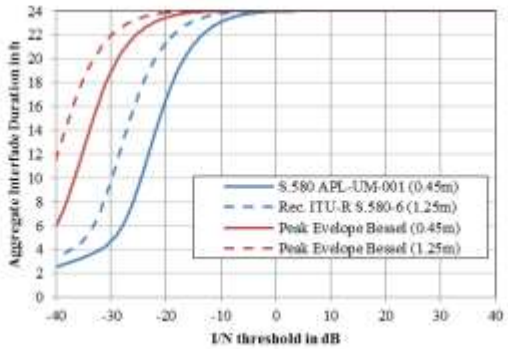
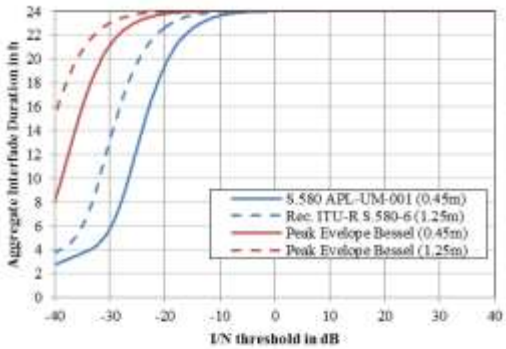
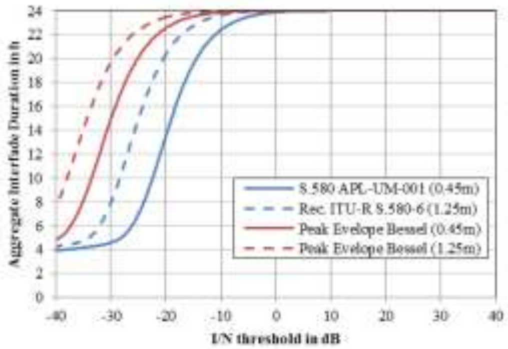
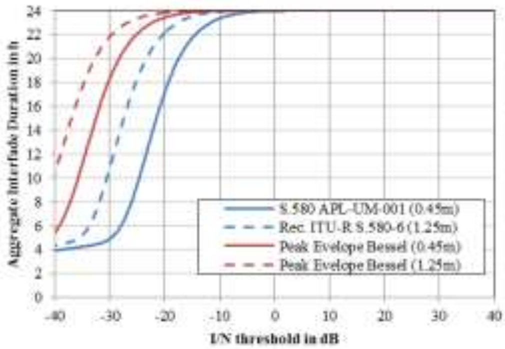
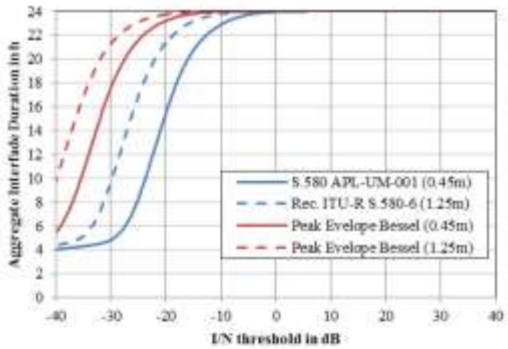
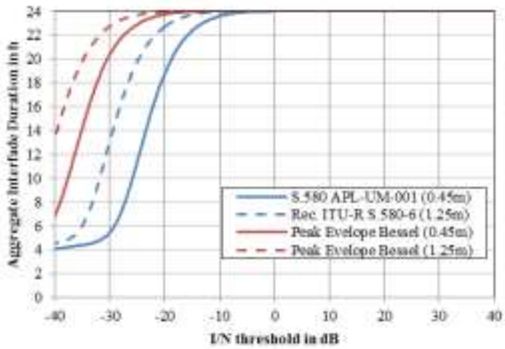
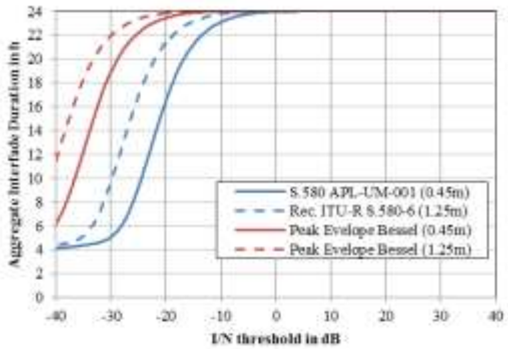
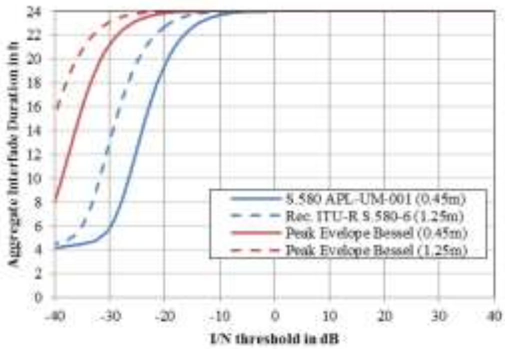
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-67

Aggregate interfade duration maximum ground speed (300 kts)

Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

A6-6.5 Availability performance with respect to interference from fixed service stations

The same availability considerations are applied as in Appendix 2, Section A6-5.5. It is based on the definition of availability and unavailability of the radio path as given by Recommendation ITU-R M.828-1.

$$Availability = \frac{(scheduled\ operation\ time) - (duration\ of\ circuit\ interruption)}{(scheduled\ operation\ time)}$$

$$Unavailability = 100\% - Availability$$

A6-6.5.1 Link availability for 11 GHz links

A6-6.5.1.1 Simulation Case 1

TABLE A6-68

Average availability minimum ground speed (80 kts)

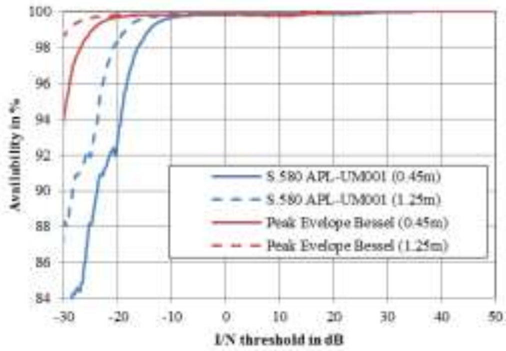
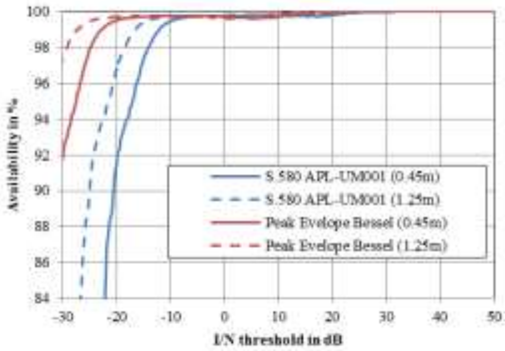
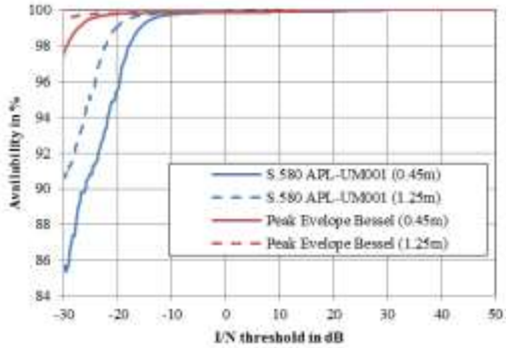
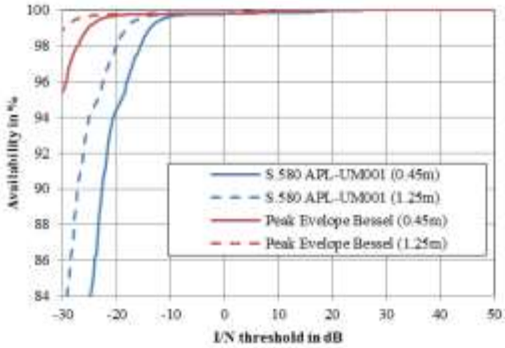
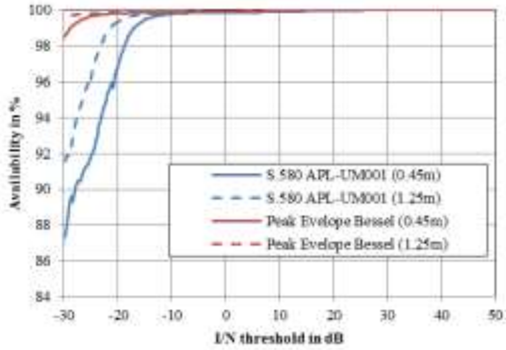
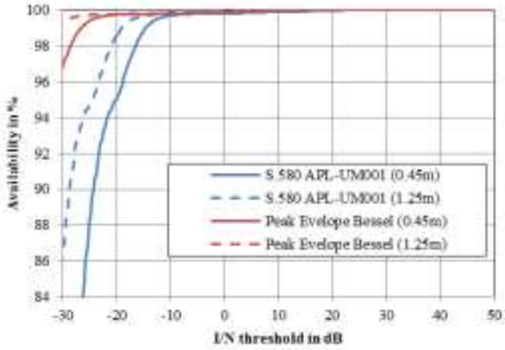
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-69

Average availability maximum ground speed (250 kts)

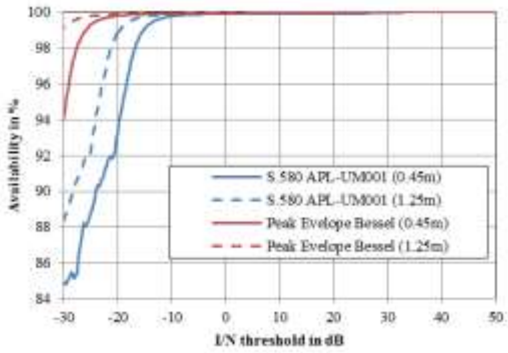
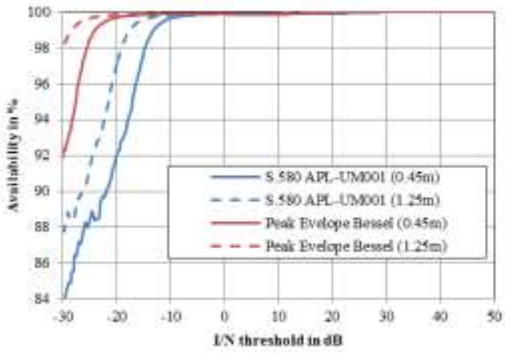
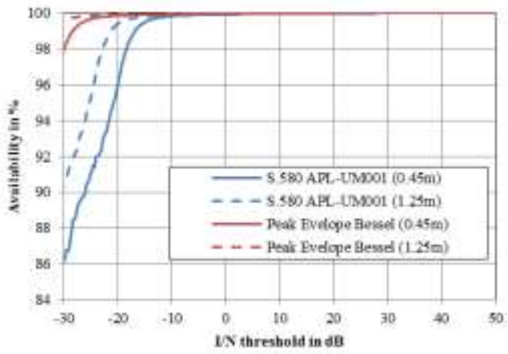
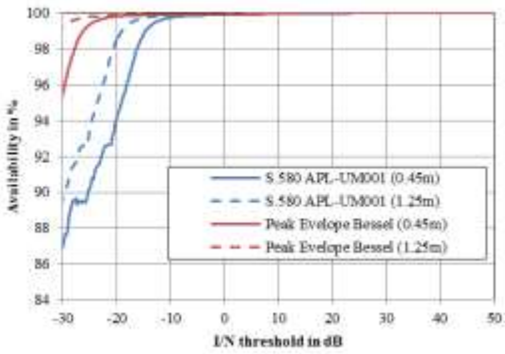
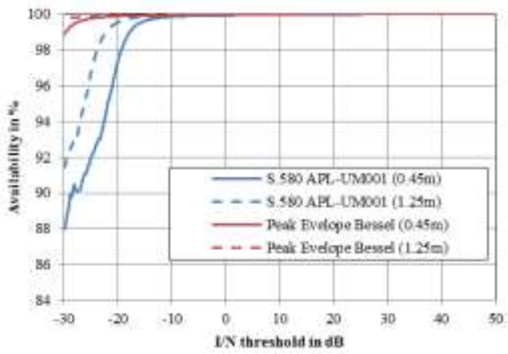
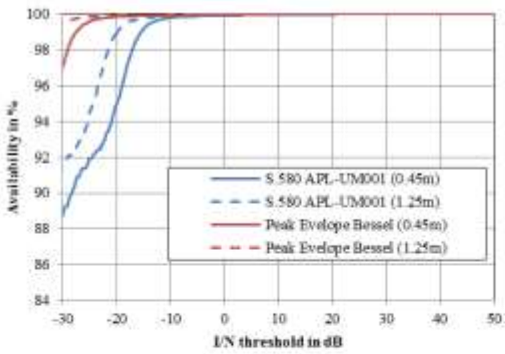
Elevation	1 500 m (5 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-70

Average unavailability minimum ground speed (80 kts)

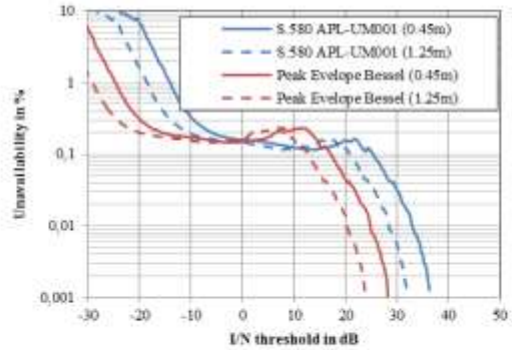
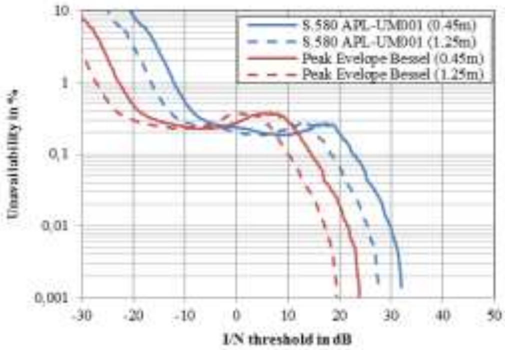
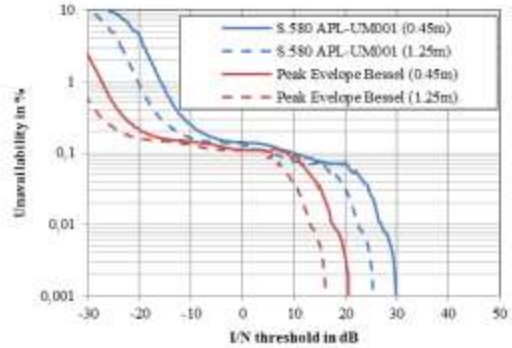
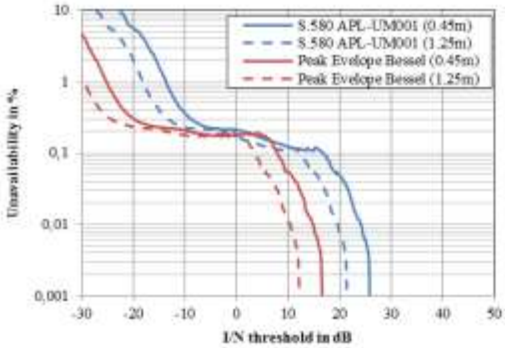
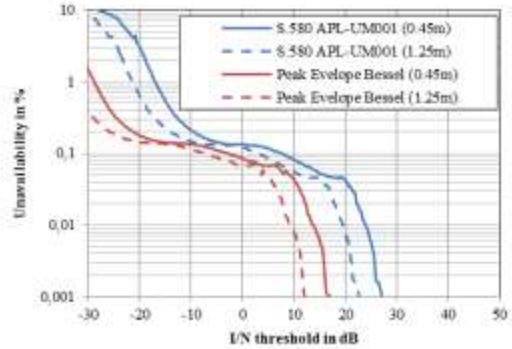
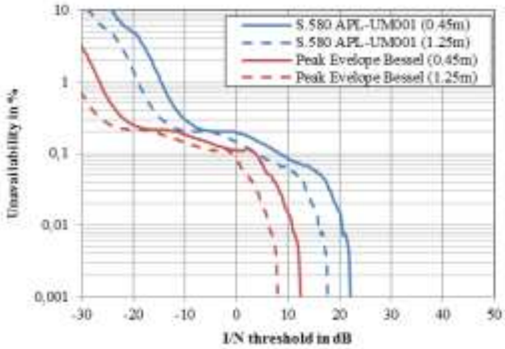
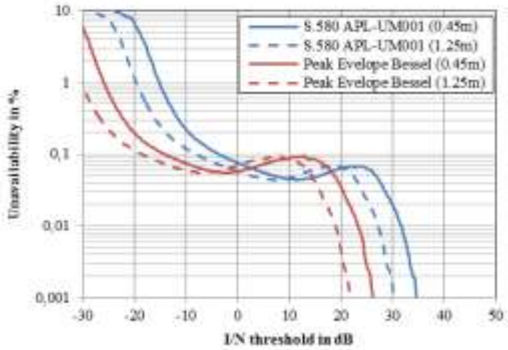
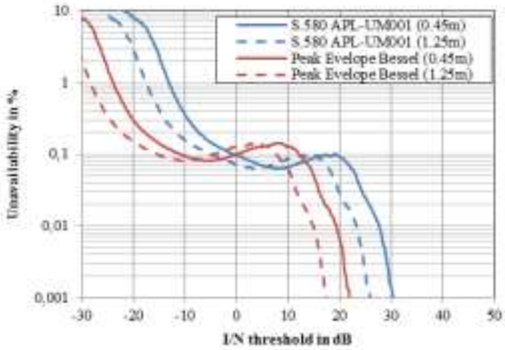
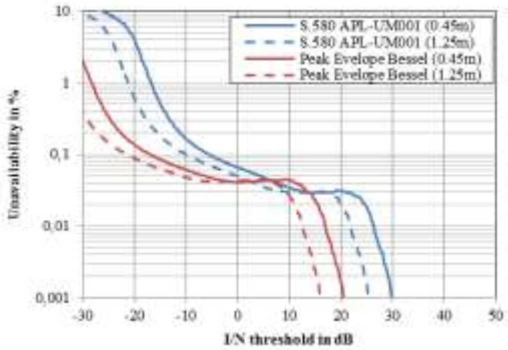
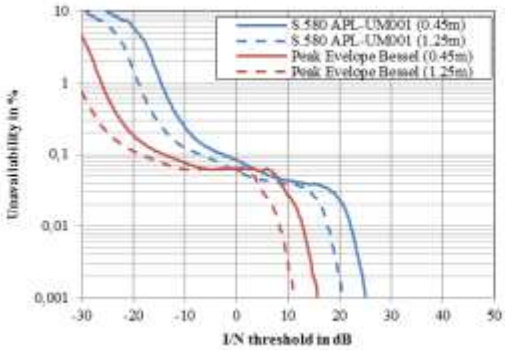
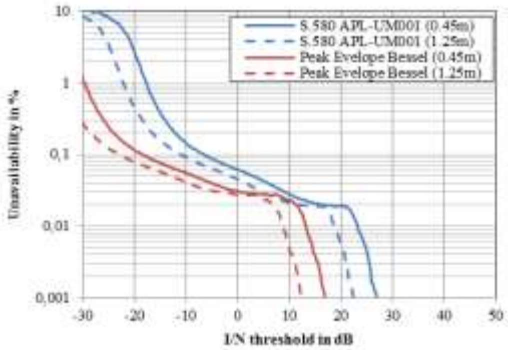
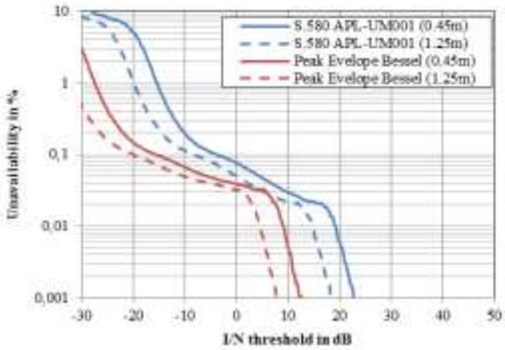
<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-71

Average unavailability maximum ground speed (250 kts)

<table>
<tr><th>Elevation</th><th>1 500 m (5 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td></td><td></td></tr>
<tr><td>20°</td><td></td><td></td></tr>
<tr><td>30°</td><td></td><td></td></tr>
</table>

A6-6.5.1.2 Simulation Case 2

TABLE A6-72

Average availability minimum ground speed (100 kts)

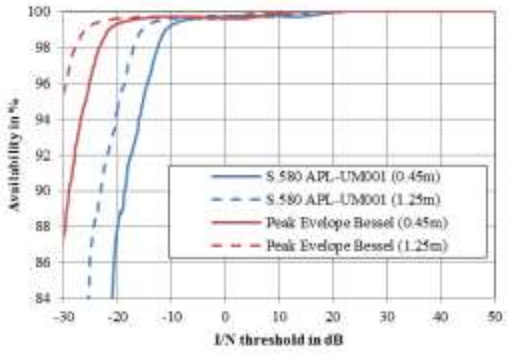
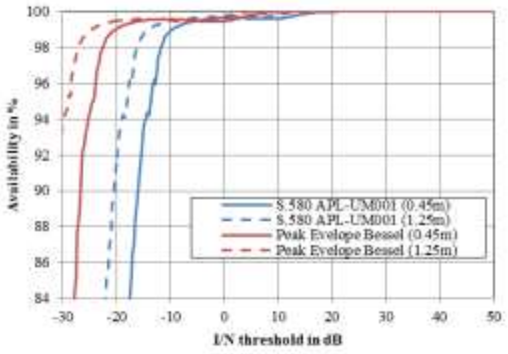
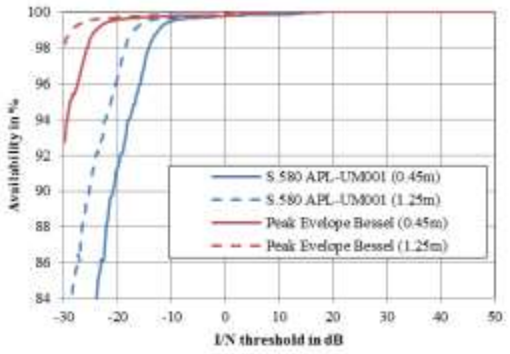
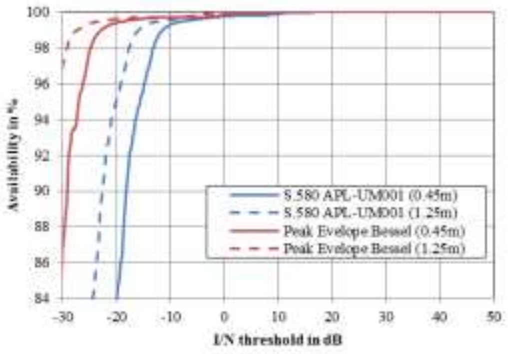
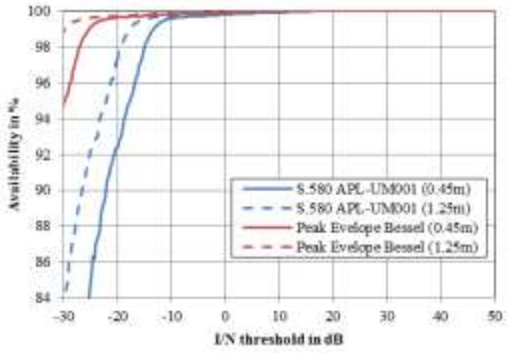
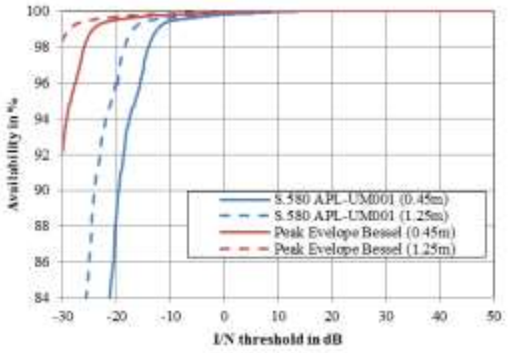
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-73

Average availability maximum ground speed (300 kts)

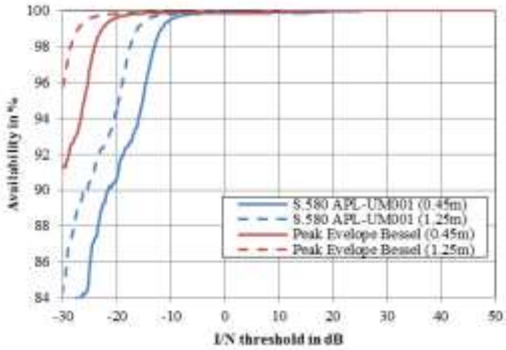
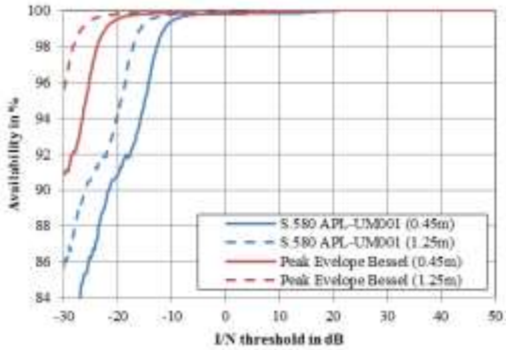
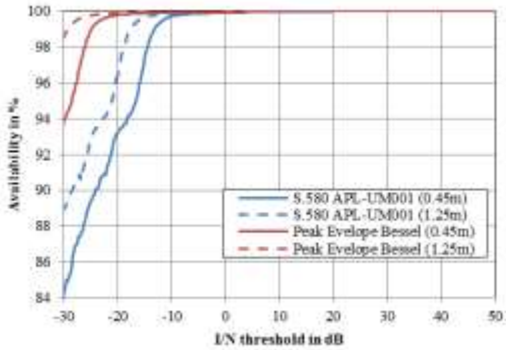
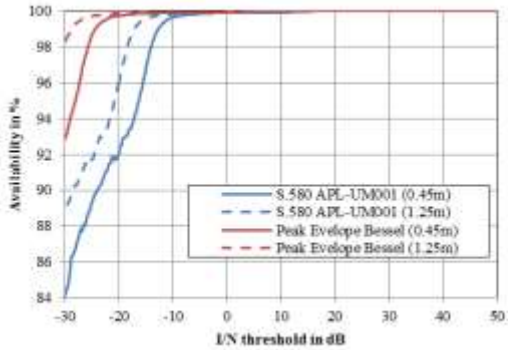
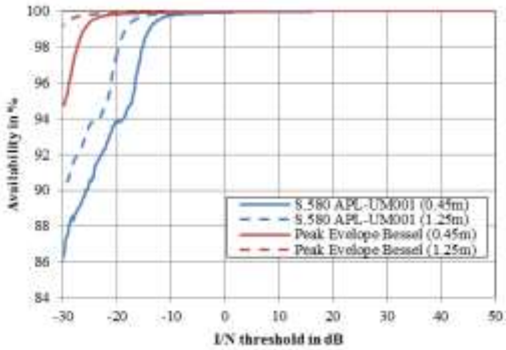
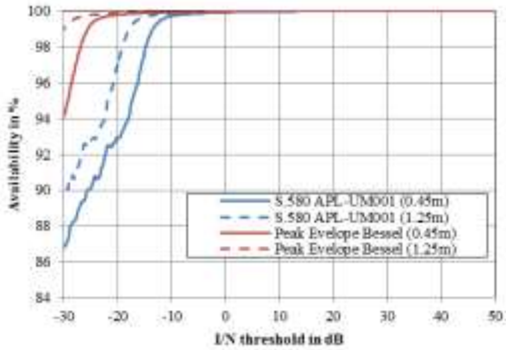
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-74

Average unavailability minimum ground speed (100 kts)

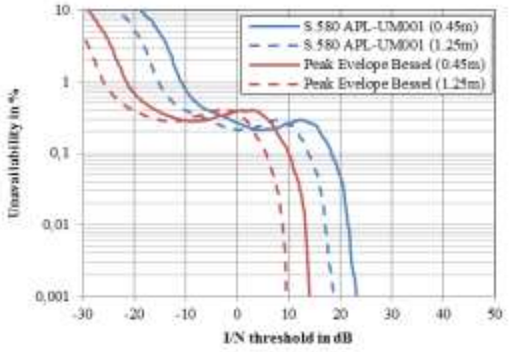
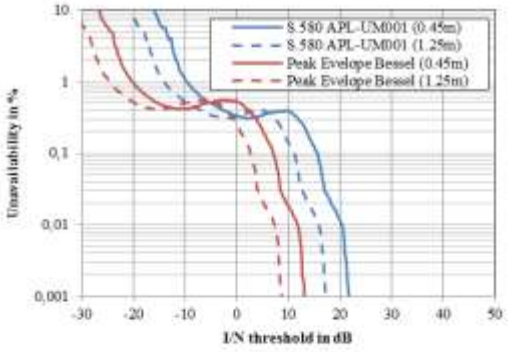
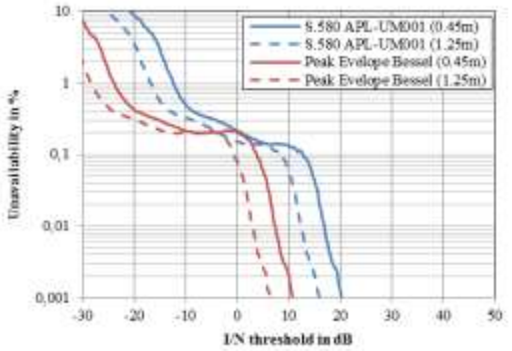
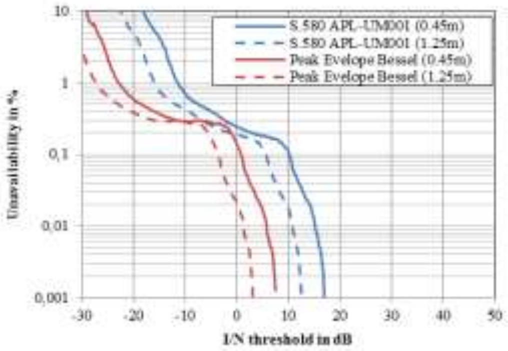
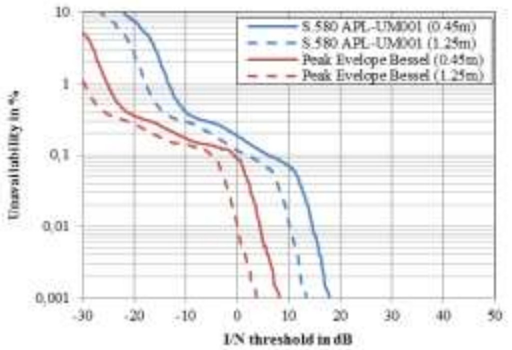
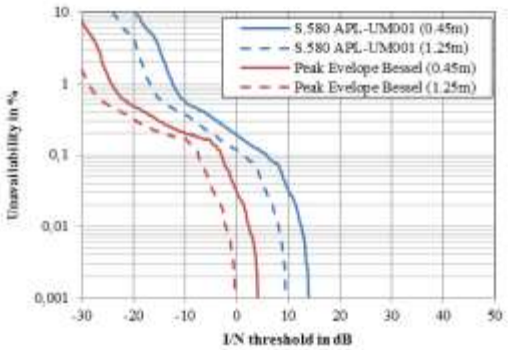
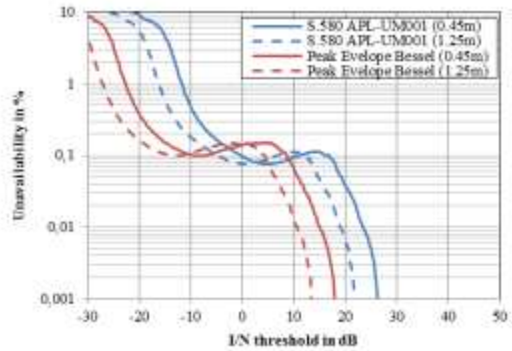
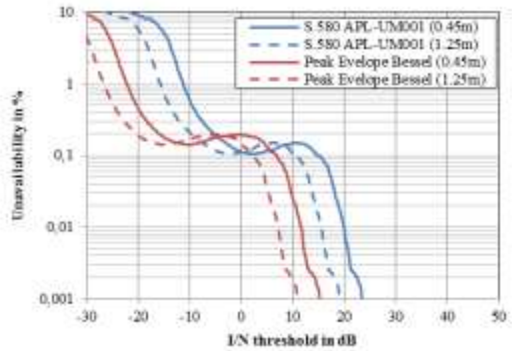
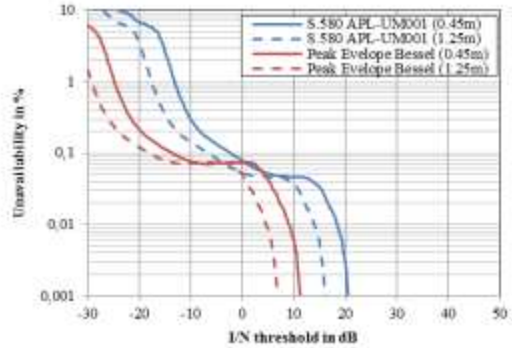
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

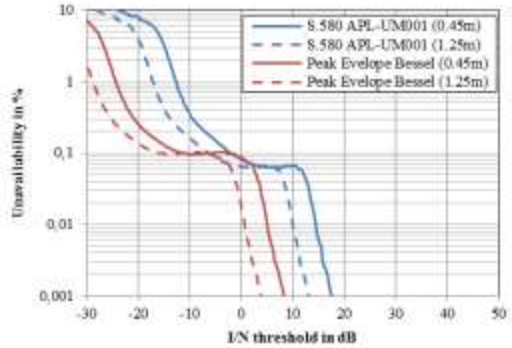
TABLE A6-75

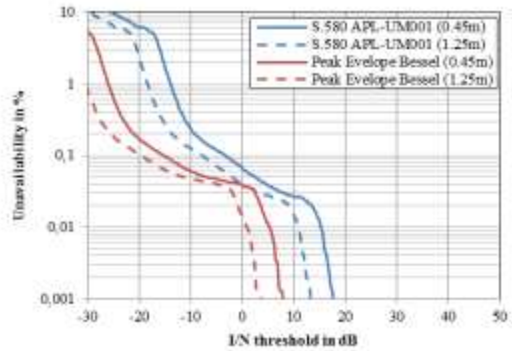
Average unavailability maximum ground speed (300 kts)

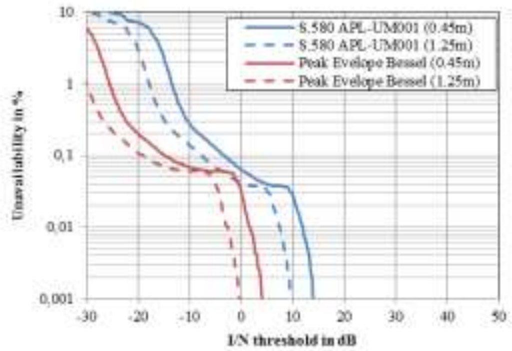
<table>
<tr><th>Elevation</th><th>6 000 m (19 000 ft)</th><th>9 000 m (30 000 ft)</th></tr>
<tr><td>10°</td><td>


</td><td>


</td></tr>
<tr><td>20°</td><td>


</td><td>


</td></tr>
<tr><td>30°</td><td>


</td><td>


</td></tr>
</table>

A6-6.5.2 Link availability for 19.7 GHz links

A6-6.5.2.1 Simulation Case 1

TABLE A6-76

Average availability minimum ground speed (80 kts)

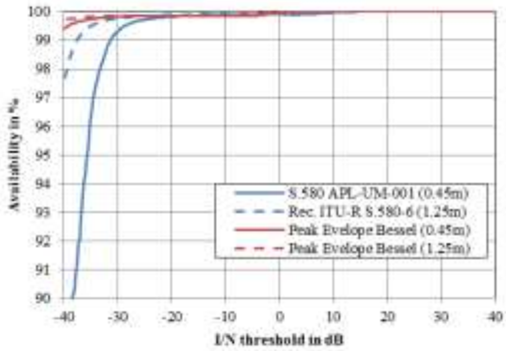
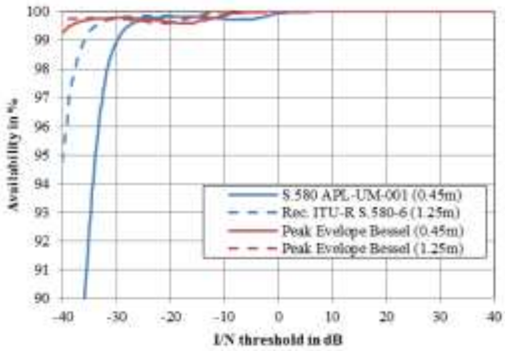
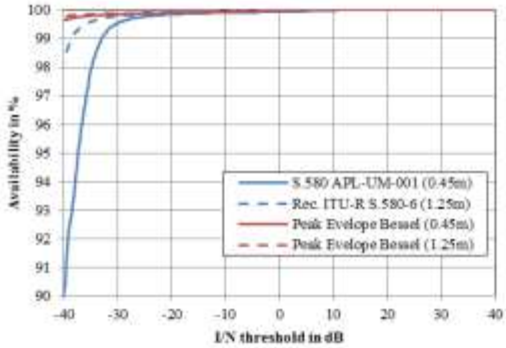
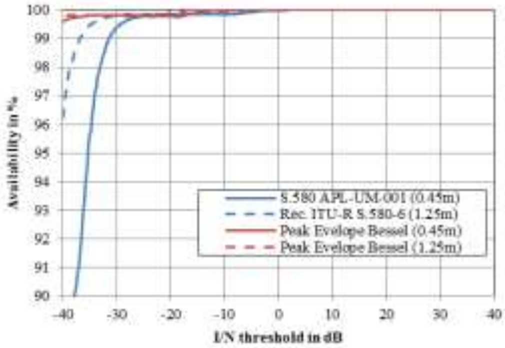
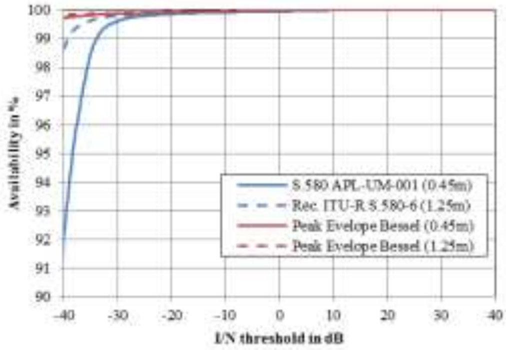
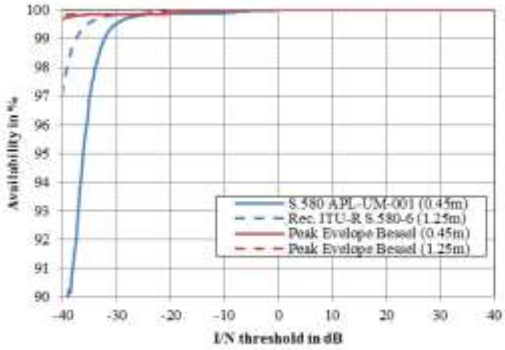
<table>
<tr><th>Elevation</th><th>914 m (3 000 ft)</th><th>3 000 m (10 000 ft)</th></tr>
<tr><td>10°</td><td>
</td><td>
</td></tr>
<tr><td>20°</td><td>
</td><td>
</td></tr>
<tr><td>30°</td><td>
</td><td>
</td></tr>
</table>

TABLE A6-77

Average availability maximum ground speed (250 kts)

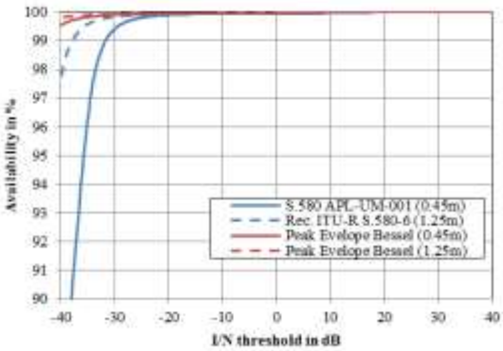
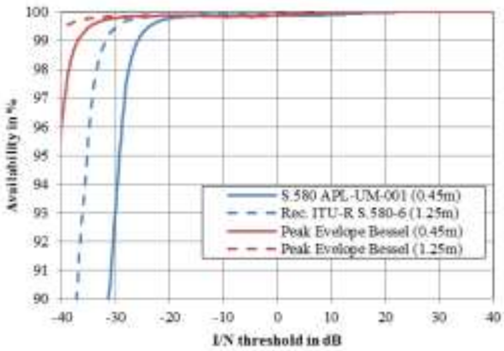
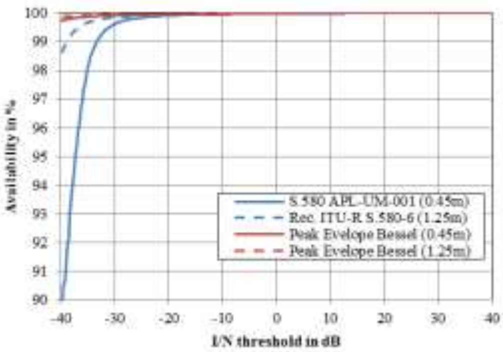
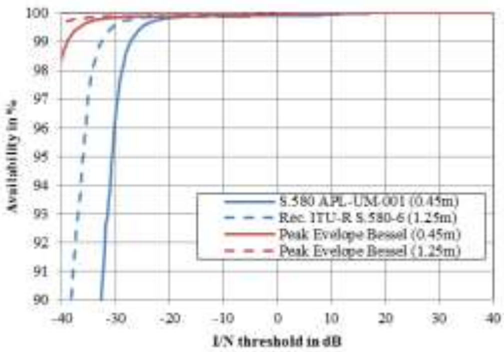
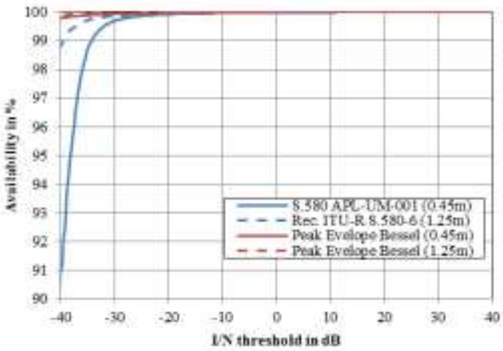
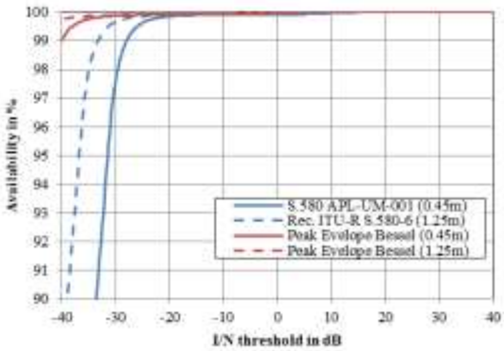
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-78

Average unavailability minimum ground speed (80 kts)

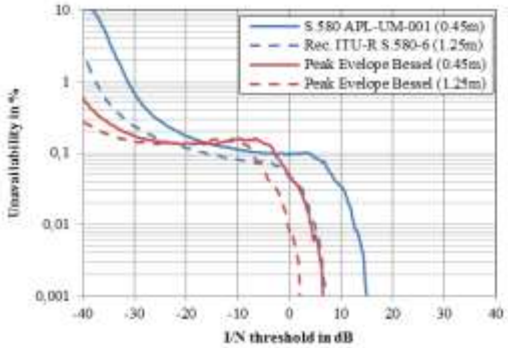
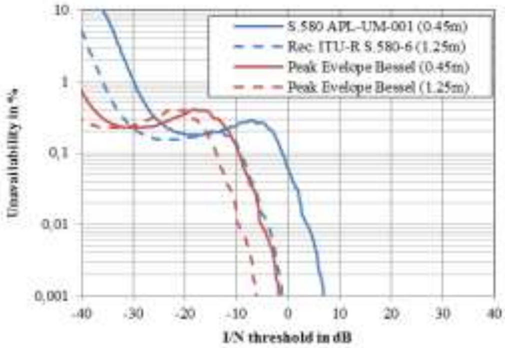
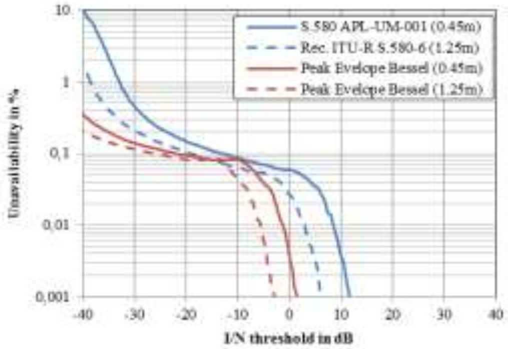
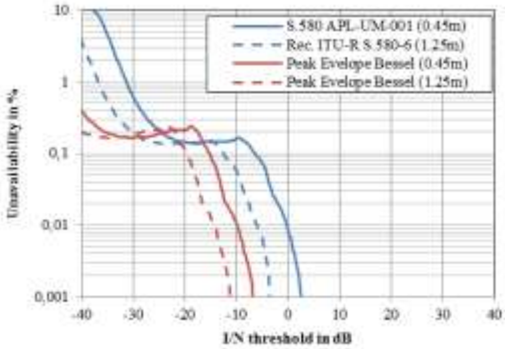
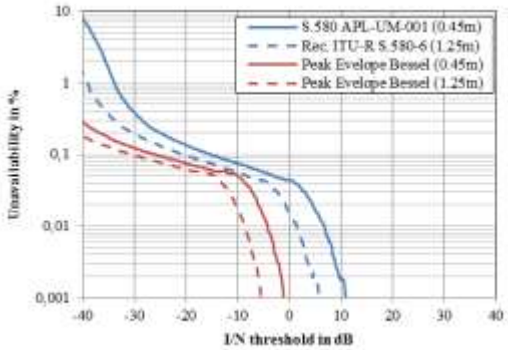
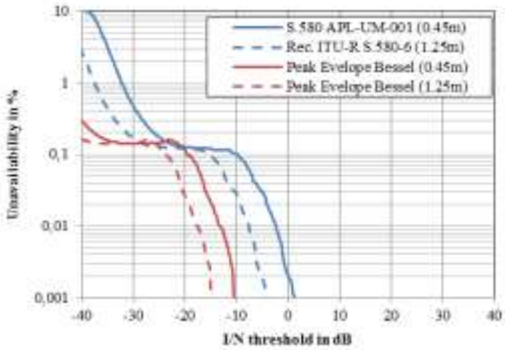
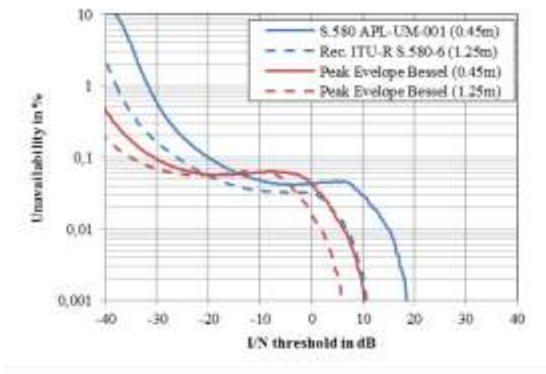
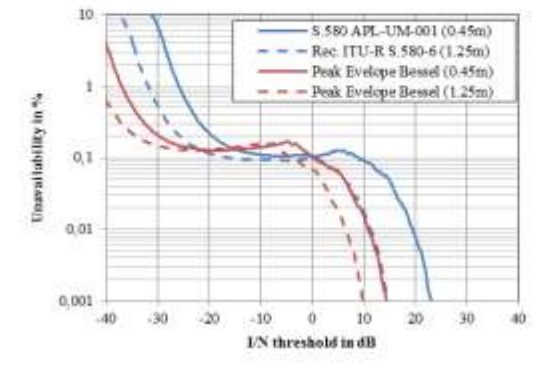
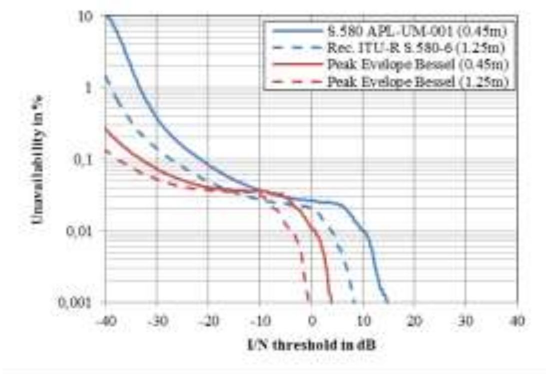
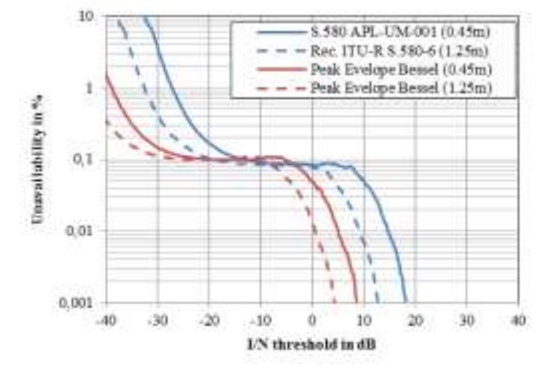
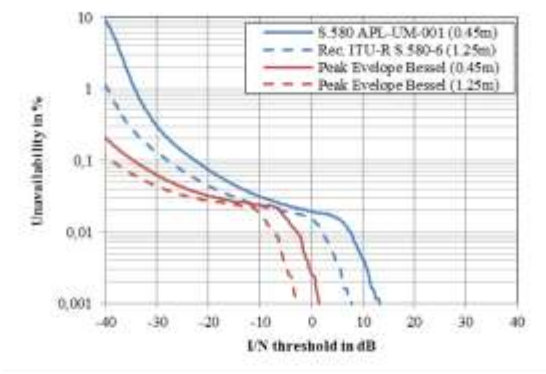
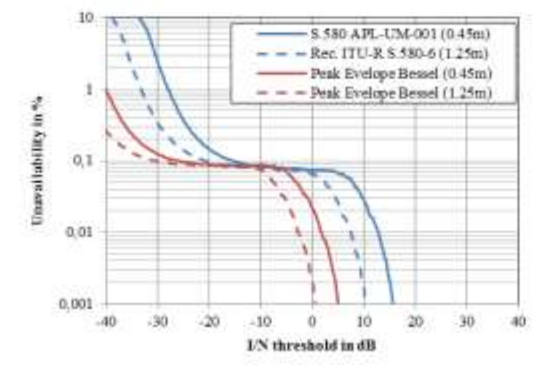
Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

TABLE A6-79

Average unavailability maximum ground speed (250 kts)

Elevation	914 m (3 000 ft)	3 000 m (10 000 ft)
10°		
20°		
30°		

A6-6.5.2.2 Simulation Case 2

TABLE A6-80

Average availability minimum ground speed (100 kts)

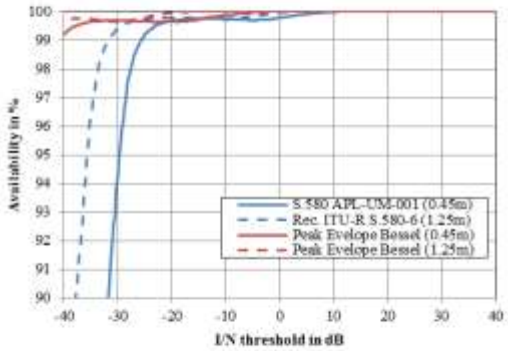
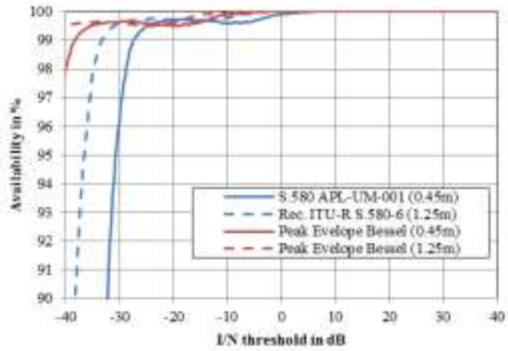
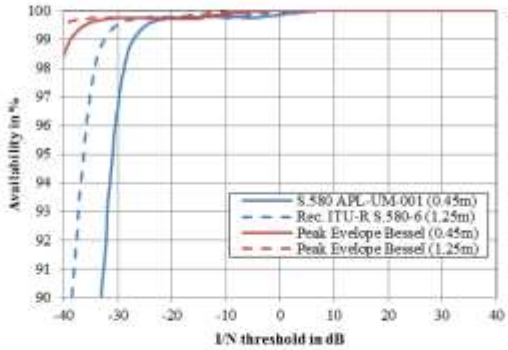
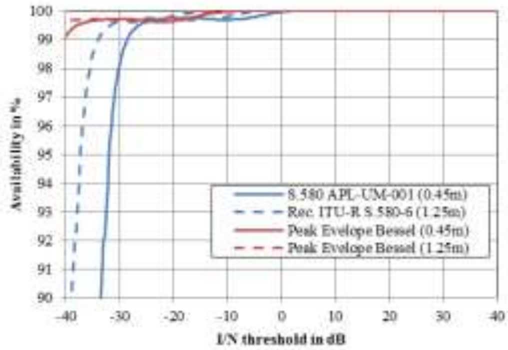
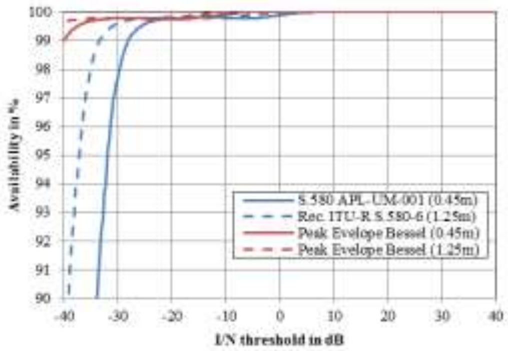
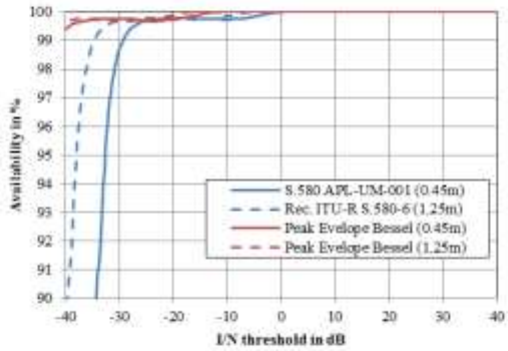
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-81

Average availability maximum ground speed (300 kts)

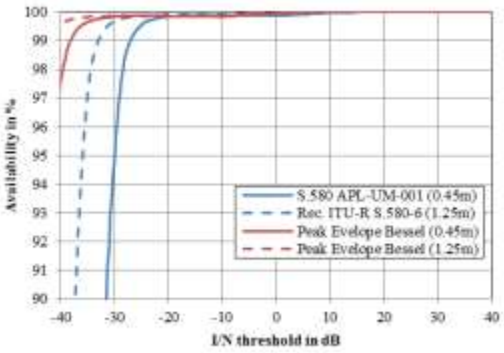
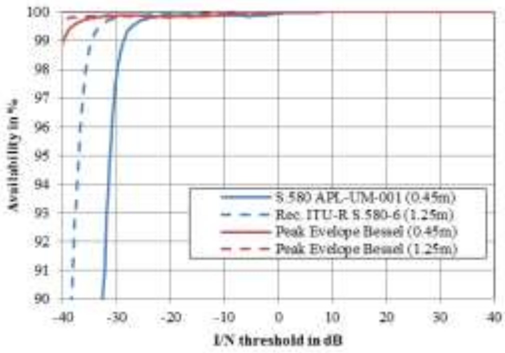
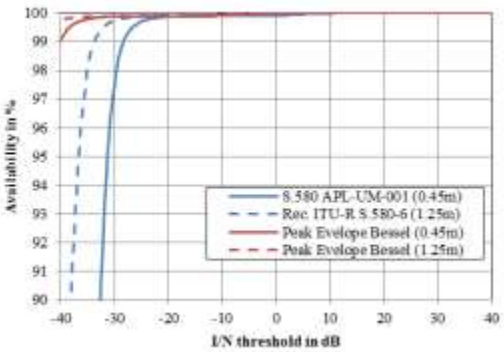
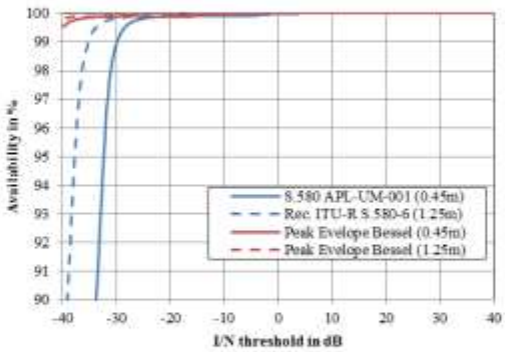
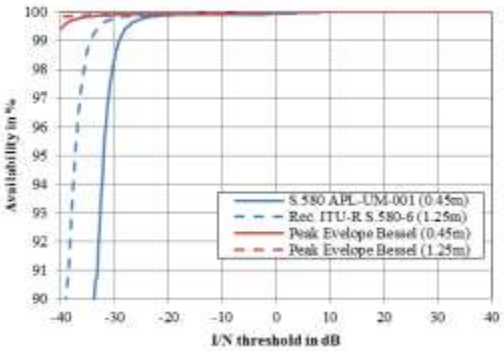
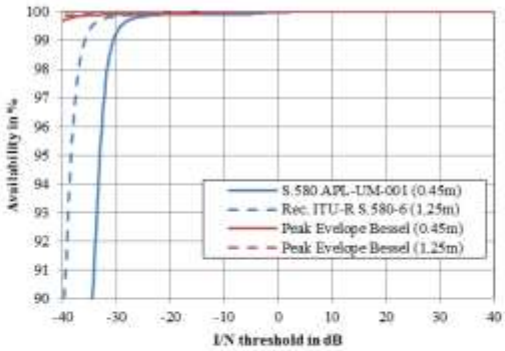
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-82

Average unavailability minimum ground speed (100 kts)

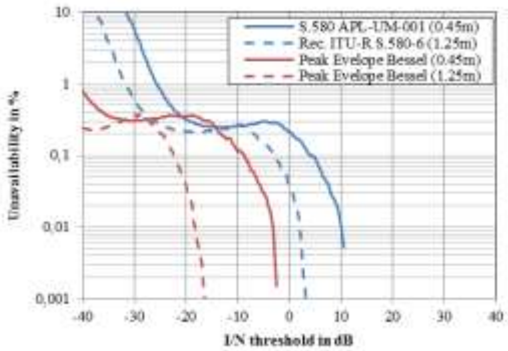
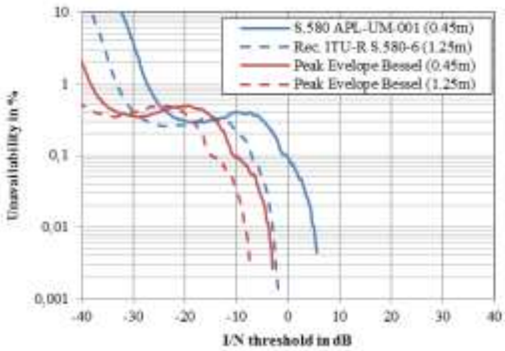
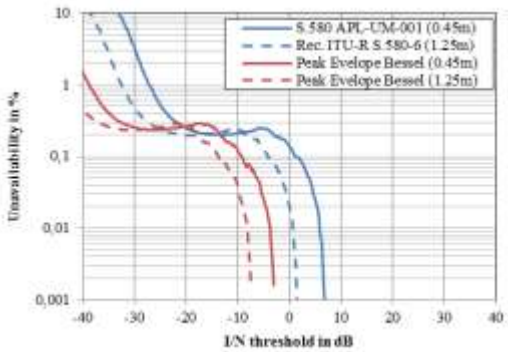
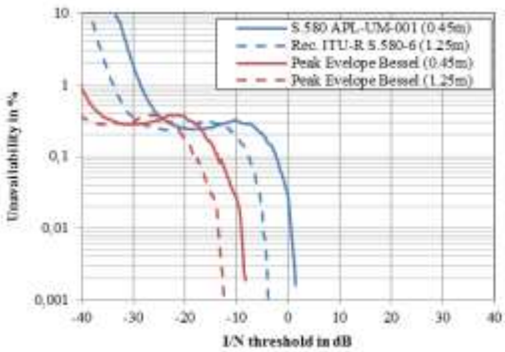
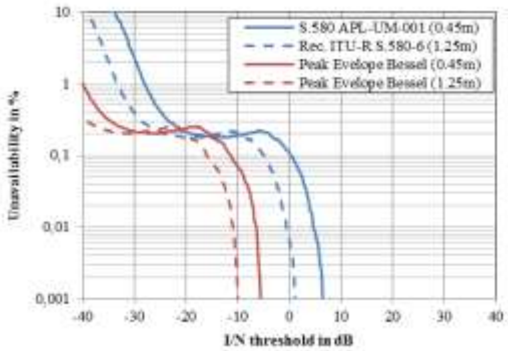
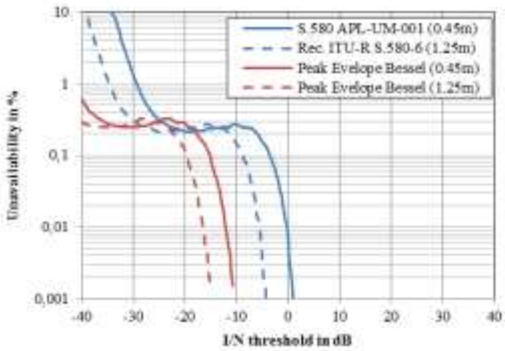
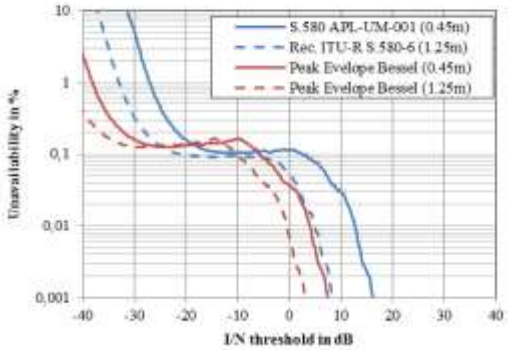
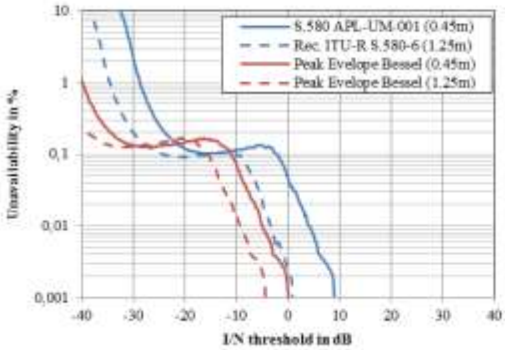
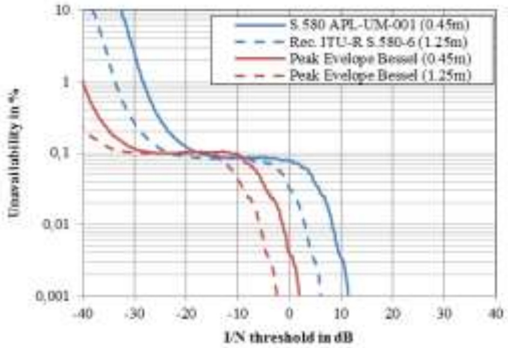
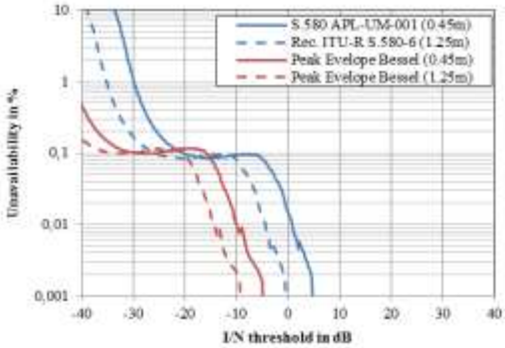
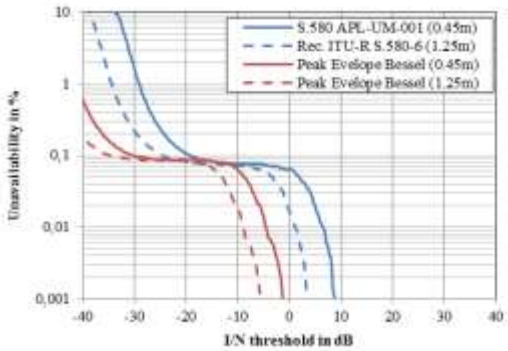
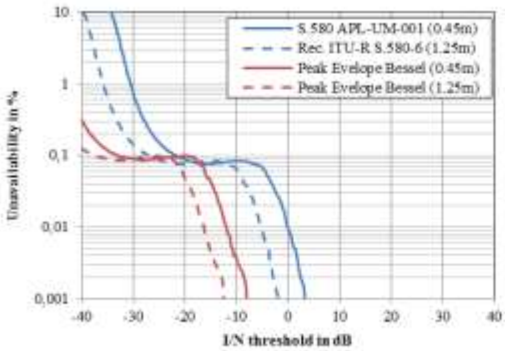
Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

TABLE A6-83

Average unavailability maximum ground speed (300 kts)

Elevation	6 000 m (19 000 ft)	9 000 m (30 000 ft)
10°		
20°		
30°		

APPENDIX 3

A6-7 Short term and long term effects into unmanned aircraft receiver caused by a mix of high and low fixed service densities

A6-7.1 Summary

Appendix 3 contains the sharing studies to assess the potential interference caused by FS into UA (CNPC link 2) operating in the FSS, both for the short and long term, using the same methodology as in Appendix 2 and 2A but with different input parameters. The major differences are:

- Antenna pattern side and back lobes are limited to -10 dBi
- The feeder loss for FS stations in the 19 GHz frequency range is limited to only 0 and 2 dB compared to Recommendation ITU-R F.758
- The “No FS” category size is fixed independent of flight speed compared to Appendix 2A

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. It can be noted that the interference levels received by the UA in the 19 GHz frequency range is significantly lower than the levels received in the 11 GHz range.

A6-7.2 Introduction

This appendix determines the statistics corresponding to the aggregate I/N ratios in order to assess the level of interference from fixed service towards the UA receiver.

For the long term interference assessment, the protection criterion corresponding to “an I/N ratio of -10 dB not to be exceeded for more than 20% of the samples analyzed” can be applied.

In the absence of protection criterion associated with short term interference, the link margin *M* (being derived from the link budget analyses in Annex 2 of this report) could be considered for the mitigation of interference from stations operating in incumbent services. The respective maximum possible peak I/N from Section A6-5.2 are used in this analysis.

A6-7.3 Interference simulation

The applied analysis setup is identical to A6-5.3. In addition I/N levels are calculated each second over the total 24 h flight duration. As 100 Monte Carlo draws are performed per simulation, the total number of samples analysed is equal to:

$$\text{number of samples analysed} = 24 \text{x} 3600 \text{x} 100 = 8\ 640\ 000 \text{ samples}$$

This large number of samples ensures that all possible configurations are met.

A6-7.4 Fixed service parameters

A6-7.4.1 Fixed service characteristics

The performance parameters of the FS stations are taken from Annex 4. Whenever some parameter is not given by this Annex, reliable sources are used to complete the needed set of information. The parameters of the FS station are reminded in the following table including the source of origin.

TABLE A6-84

Fixed service parameters used in simulation

	Unit	Distribution	11 GHz frequency range	20 GHz frequency range	Source
Antenna diameter	M	Uniform Discrete	0.54; 1.25; 3.5 [(1)]	0.08; 0.89; 1.7 [(1)]	Rec. ITU-R F.758
Azimuth	degrees	Uniform	0-360	0-360	
Elevation	degrees	Normal	N(-5°, +5°)	N(-5°, +5°)	
Height	M	Uniform	Between 10 and 100	Between 10 and 100	Annex 4
Tx power density	dBW/MHz	Uniform	Between -16 and -12.8	Between -45.4 and -19	Rec. ITU-R F.758
FS co-frequency	%	none	7.2	5.9	Appendix 1
Feeder loss	dB	Uniform	Between 0 and 9.5	Between 0 and 2	Rec. ITU-R F.758

(1) These values are calculated from Rec. ITU-R F.758 and represent the largest, average and smallest antenna diameter of the antenna gain range with an antenna efficiency of 65%.

A6-7.4.2 Fixed service densities

Same fixed service density categories as in Section A6-6.3.4 are applied.

Each category corresponds to an area of a specific size associated with a specific FS density. Values used in the simulations are shown in Table A6-85. These values have been applied over the whole visible area seen from the UA during the complete simulation time of 24h.

TABLE A6-85

Definition of FS densities per category and frequency band

Density category	Apportionment of simulations area	Size of the area (degree x degree)	Size of the area (km x km)	Density 11 GHz	Density 19.7 GHz
No FS	10 %	0.7 x 0.7	77.9 x 77.9	0 FS/km^2	0 FS/km^2
Rural	79.99 %	N/A	N/A	0.002 FS/km^2	0.016 FS/km^2
Suburban	10%	0.1 x 0.1	11.1 x 11.1	0.07 FS/km^2	0.07 FS/km^2
Urban	0.01%	0.02 x 0.02	2.2 x 2.2	3.8 FS/km^2	3.8 FS/km^2

A6-7.4.3 Unmanned aircraft station parameters

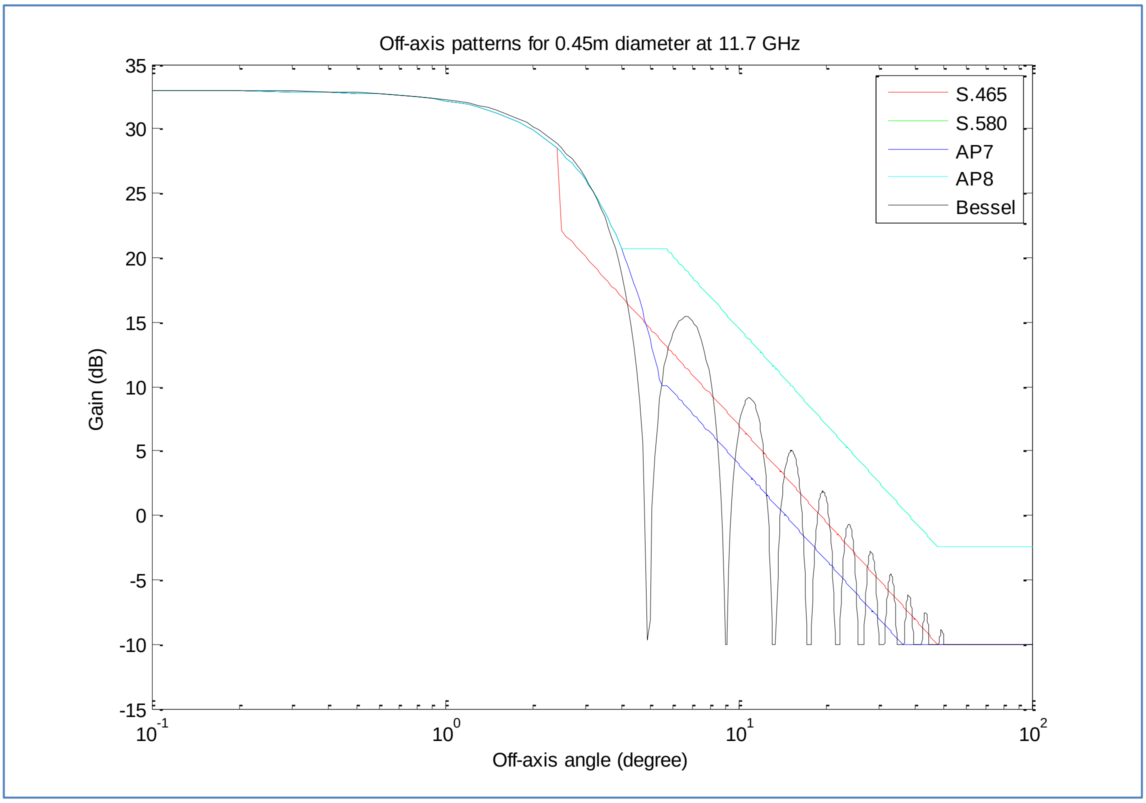
UA parameters are taken from Annex 1 to this Report. In the simulations, only the small (0.45m diameter) and the large (1.25m diameter) antenna sizes are considered. In addition, as the UA antenna pattern is an influencing element, several patterns have been considered:

- The referenced antenna pattern listed in Annex 1 is based on Rec. ITU-R S.580,
- For information, others antenna patterns are considered based on the Rec. ITU-R S.465, AP7 and AP8,
- For information, a "Bessel" pattern, similar to the one considered in Appendix 1 to this Annex, but limited to the level of -10 dB for the far side lobes is also considered.

These patterns are represented in the figures below:

FIGURE A6-64

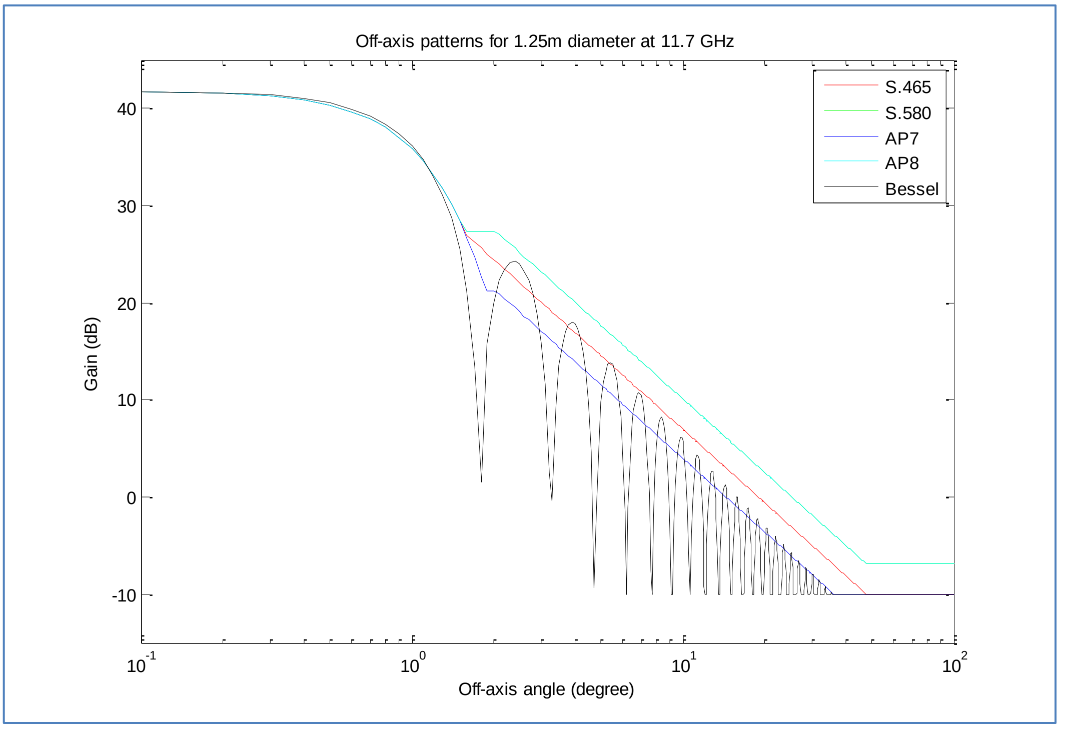
0.45m UA receiver antenna patterns at 11.7 GHz



Note: in this configuration, patterns for Rec. ITU-R S.580 and for AP8 are identical

FIGURE A6-65

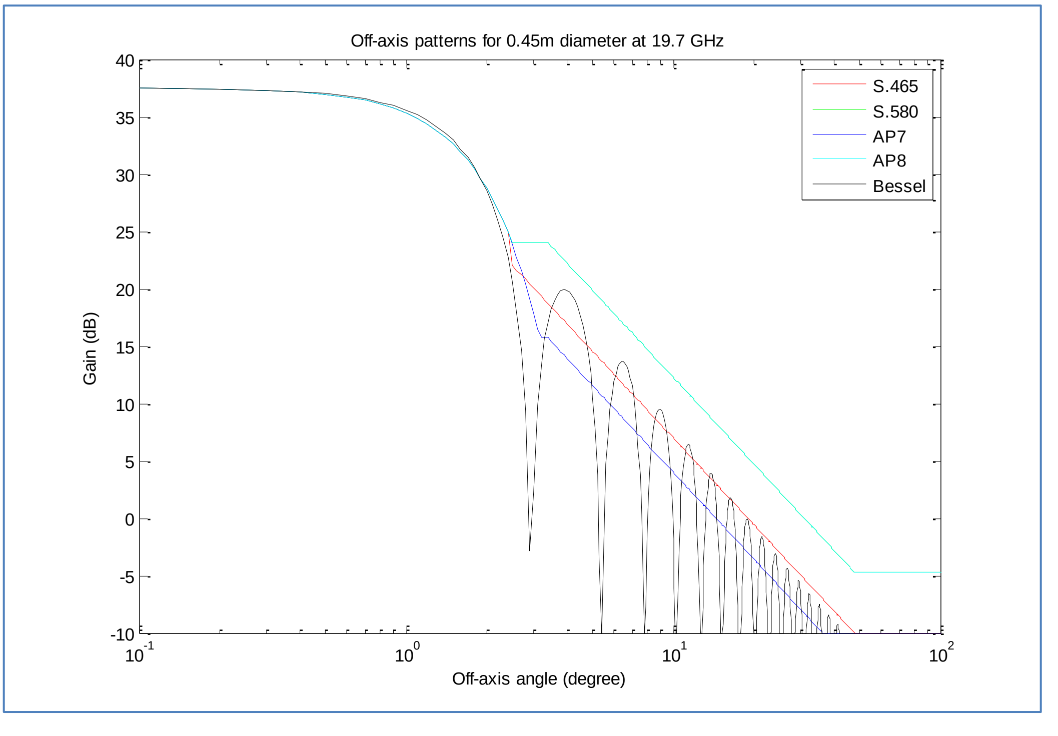
1.25m UA receiver antenna patterns at 11.7 GHz



Note: in this configuration, patterns for Rec. ITU-R S.580 and for AP8 are identical

FIGURE A6-66

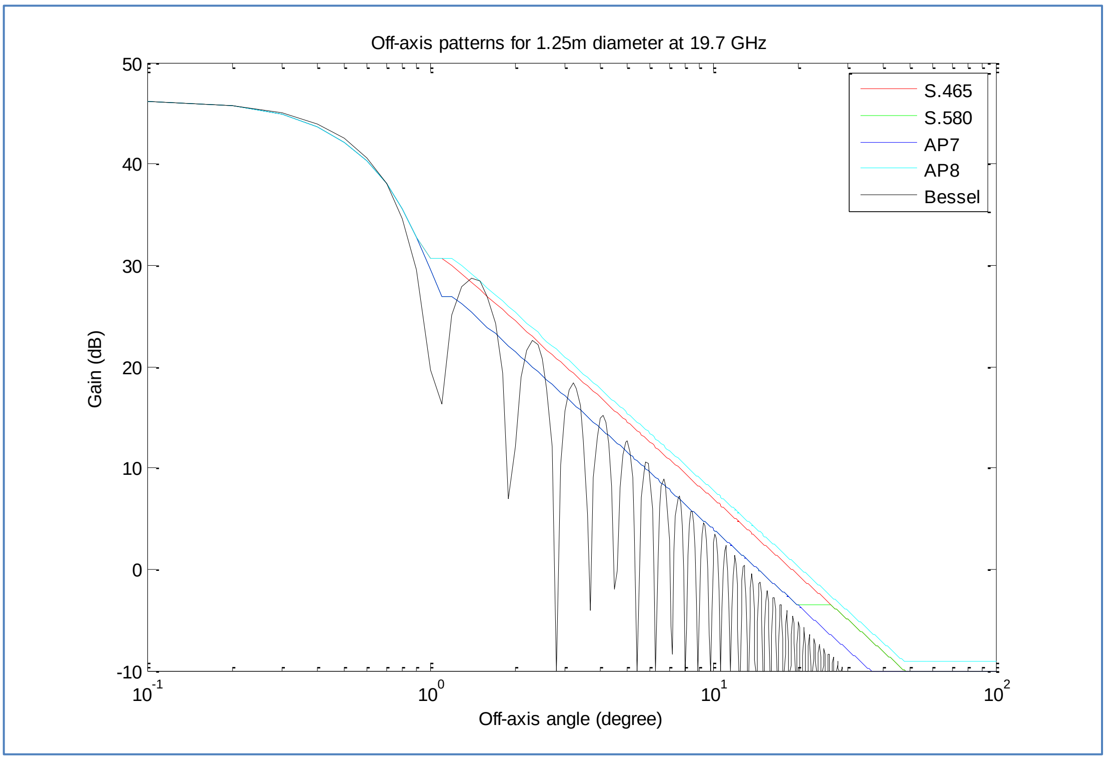
0.45m UA receiver antenna patterns at 19.7 GHz



Note: in this configuration, patterns for Rec. ITU-R S.580 and for AP8 are identical

FIGURE A6-67

1.25m UA receiver antenna patterns at 19.7 GHz



A6-7.5 Study results

For the representative flight scenarios 2 and 4, the cumulative distribution functions (CDF) of the aggregate I/N level at UA receiver are provided in the following sections, for both the 14/11 GHz and the 30/20 GHz bands.

For each of the two scenarios considered, CDF are computed with small (0.45m) and large (1.25m) diameter antenna for the UA receiver. In order to assess the impact for the elevation angle of the UA antenna, the simulation has been performed both for an elevation of 10 degrees and of 60 degrees. The analysis of the curves obtained with these two elevations shows that only far side-lobes of the UA pattern influence the results for 60 degrees elevation, whereas closer side-lobes have larger impact to the results for 10 degrees elevation.

Regarding long term interference, results show that 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.

Regarding short term interference, the range of I/N levels obtained is to consider in comparison with the maximum possible peak I/N according to section A6-3-2. 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. It can be noted that the interference levels received by the UA in the 19 GHz frequency range is significantly lower than the levels received in the 11 GHz range.

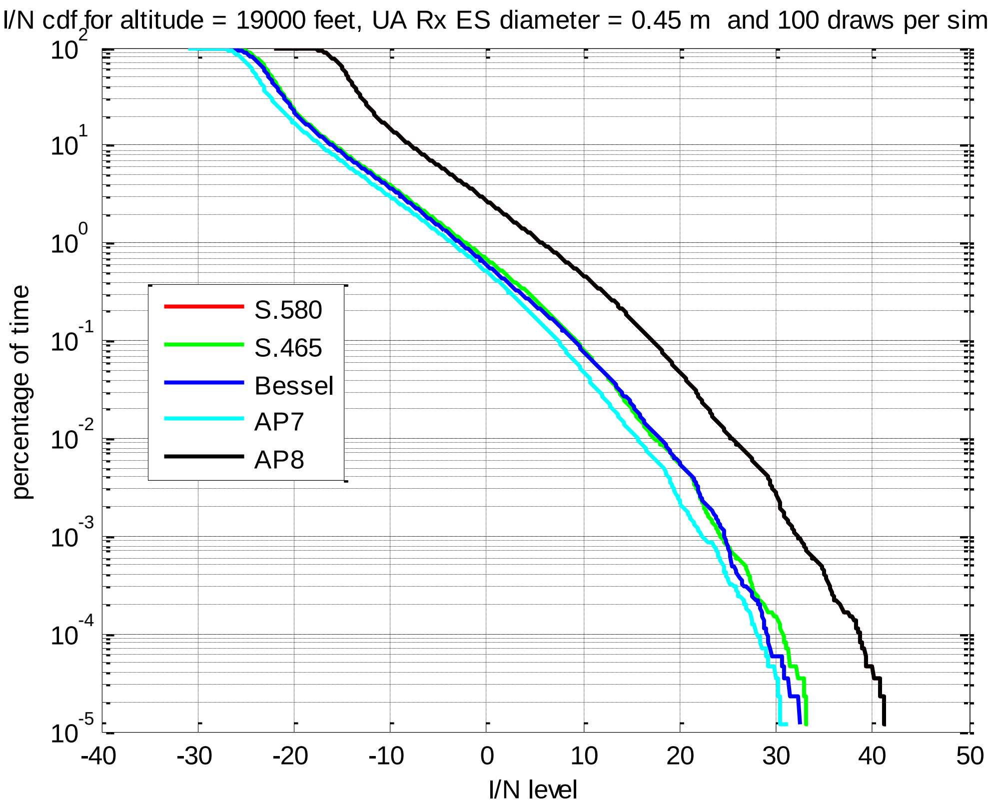
A6-7.5.1 Simulations results for 11 GHz

A6-7.5.1.1 Flight scenario 2

The following diagrams show the CDF corresponding to flight scenario 2 (flight height 19 kft) for *I/N* ratios at UA receiver with small (0.45m) and large (1.25m) diameter antenna, both for an elevation of 10 degrees and of 60 degrees.

FIGURE A6-68

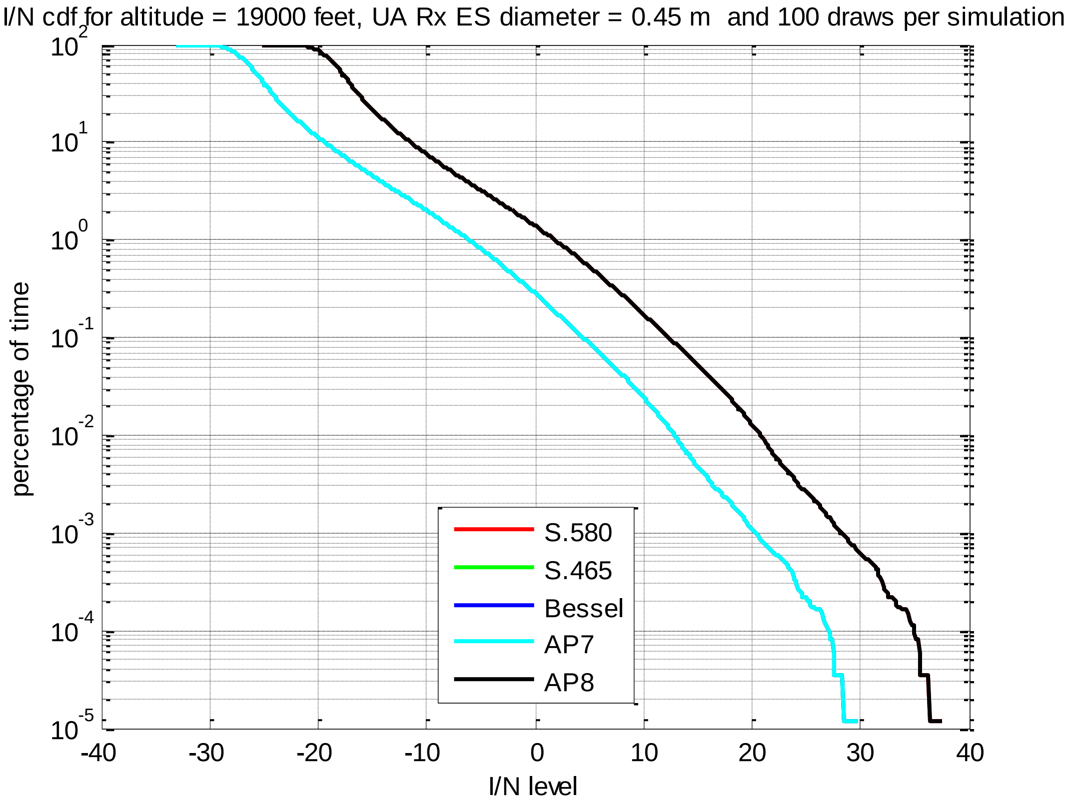
I/N CDF for Scenario 2 at 11.7 GHz with 10 degrees elevation for 0.45m UA antenna



Note: in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

FIGURE A6-69

I/N CDF for Scenario 2 at 11.7 GHz with 60 degrees elevation for 0.45m UA antenna

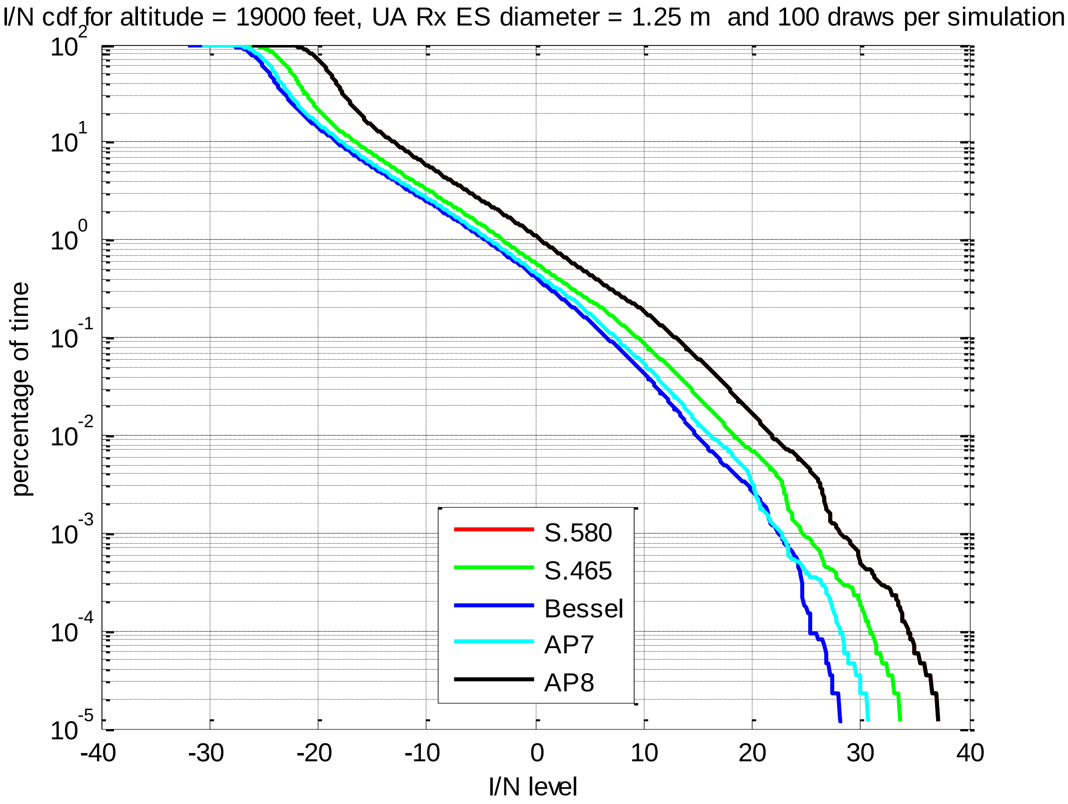


Note 1: in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2: in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

FIGURE A6-70

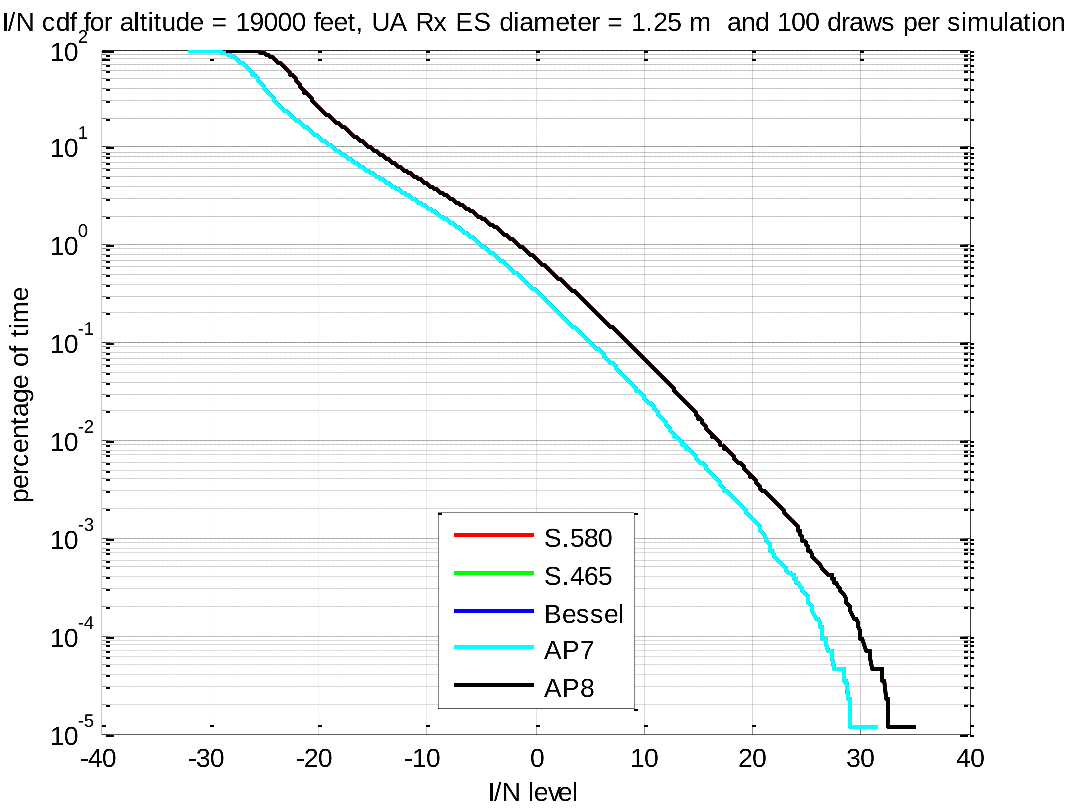
I/N CDF for Scenario 2 at 11.7 GHz with 10 degrees elevation for 1.25m UA antenna



Note: in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

FIGURE A6-71

I/N CDF for Scenario 2 at 11.7 GHz with 60 degrees elevation for 1.25m UA antenna



Note 1: in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

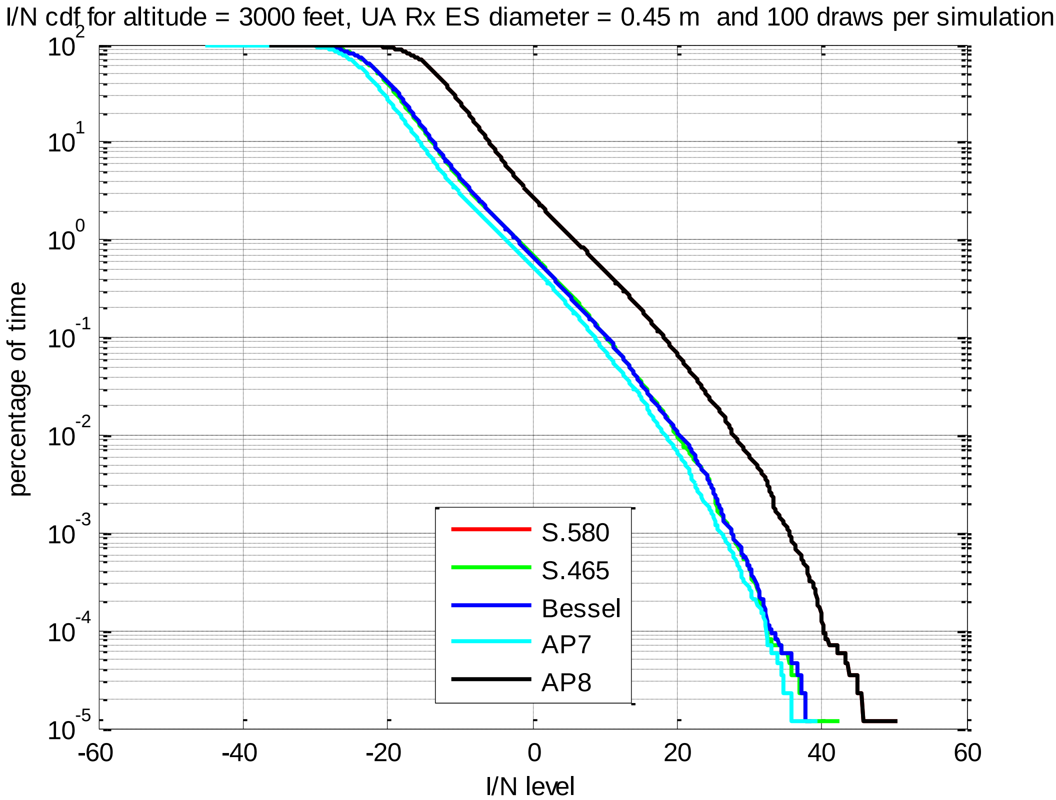
Note 2: in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

A6-7.5.1.2 Flight scenario 4

The following diagrams show the CDF corresponding to flight scenario 4 (flight height 3 000 ft) for *I/N* ratios at UA receiver with small (0.45m) and large (1.25m) diameter antenna, both for an elevation of 10 degrees and of 60 degrees.

FIGURE A6-72

I/N CDF for Scenario 4 at 11.7 GHz with 10 degrees elevation for 0.45m UA antenna

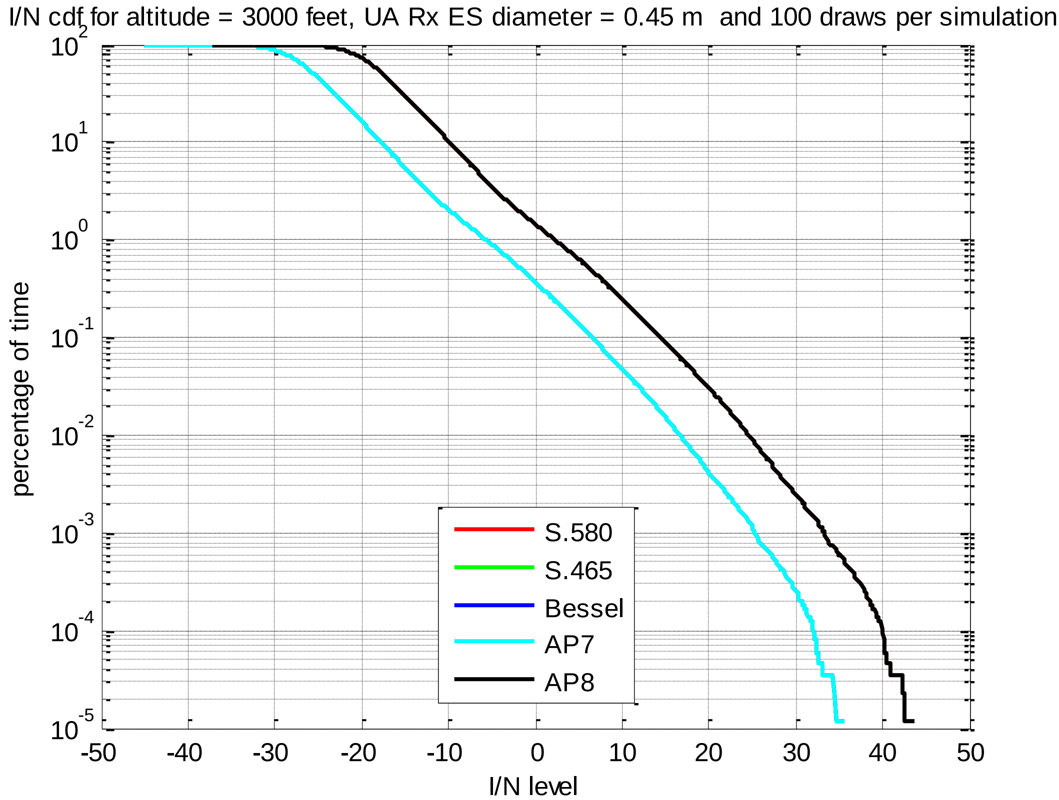


Note 1 : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2 : in this configuration, CDF obtained with Rec. ITU-R S.465 and with Bessel antenna patterns are identical;

FIGURE A6-73

I/N CDF for Scenario 4 at 11.7 GHz with 60 degrees elevation for 0.45m UA antenna

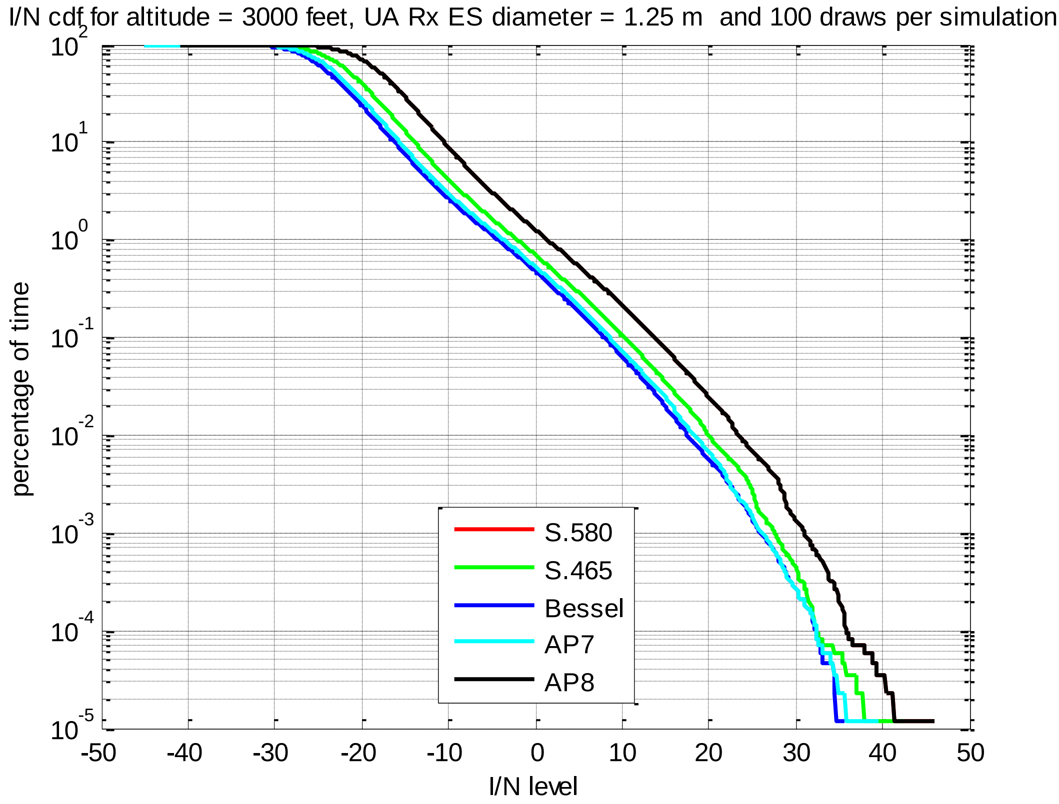


Note 1 : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2 : in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

FIGURE A6-74

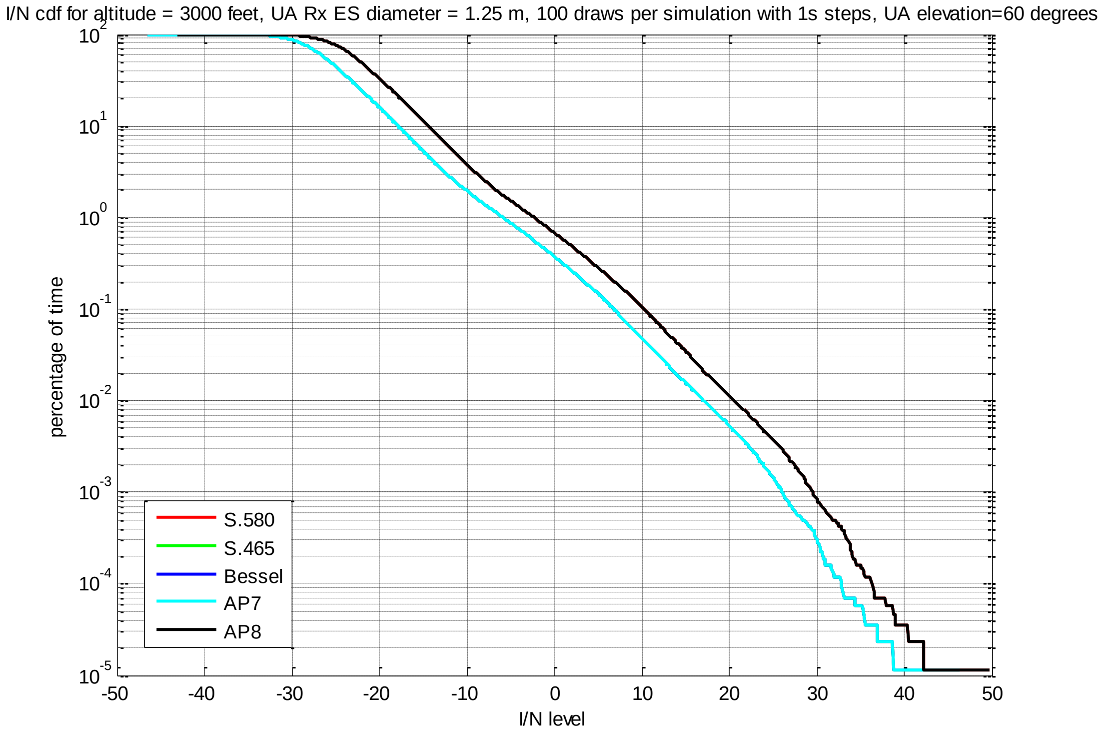
I/N CDF for Scenario 4 at 11.7 GHz with 10 degrees elevation for 1.25m UA antenna



Note : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical

FIGURE A6-75

I/N CDF for Scenario 4 at 11.7 GHz with 60 degrees elevation for 1.25m UA antenna



Note 1 : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2 : in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

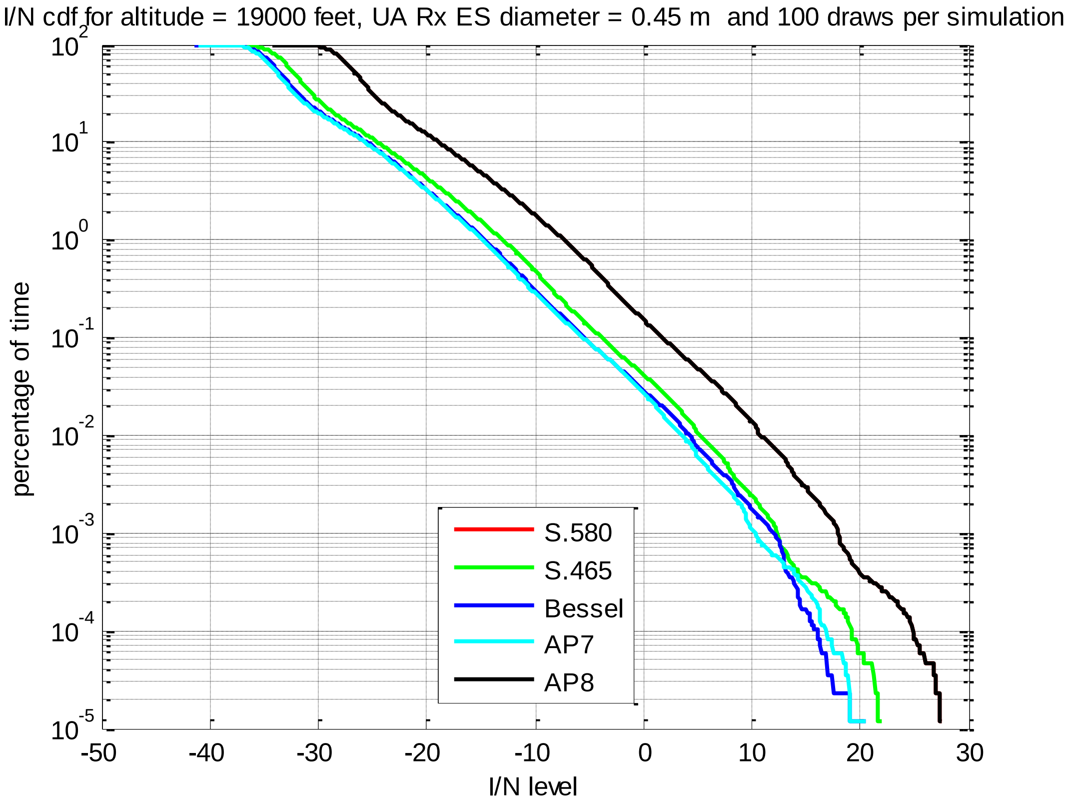
A6-7.5.2 Simulations results for 19.7 GHz

A6-7.5.2.1 Flight scenario 2

The following diagrams show the CDF corresponding to flight scenario 2 (flight height 19 000 ft) for *I/N* ratios at UA receiver with small (0.45m) and large (1.25m) diameter antenna, both for an elevation of 10 degrees and of 60 degrees.

FIGURE A6-76

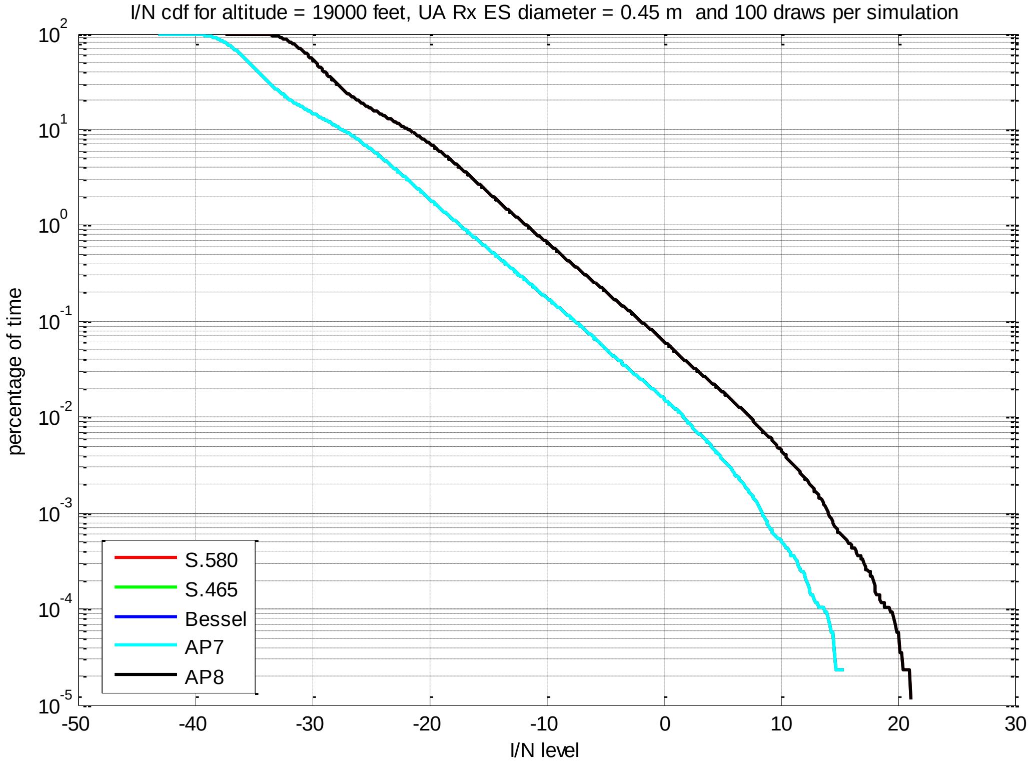
I/N CDF for Scenario 2 at 19.7 GHz with 10 degrees elevation for 0.45m UA antenna



Note : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

FIGURE A6-77

I/N CDF for Scenario 2 at 19.7 GHz with 60 degrees elevation for 0.45m UA antenna



Note 1 : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2 : in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

FIGURE A6-78

I/N CDF for Scenario 2 at 19.7 GHz with 10 degrees elevation for 1.25m UA antenna

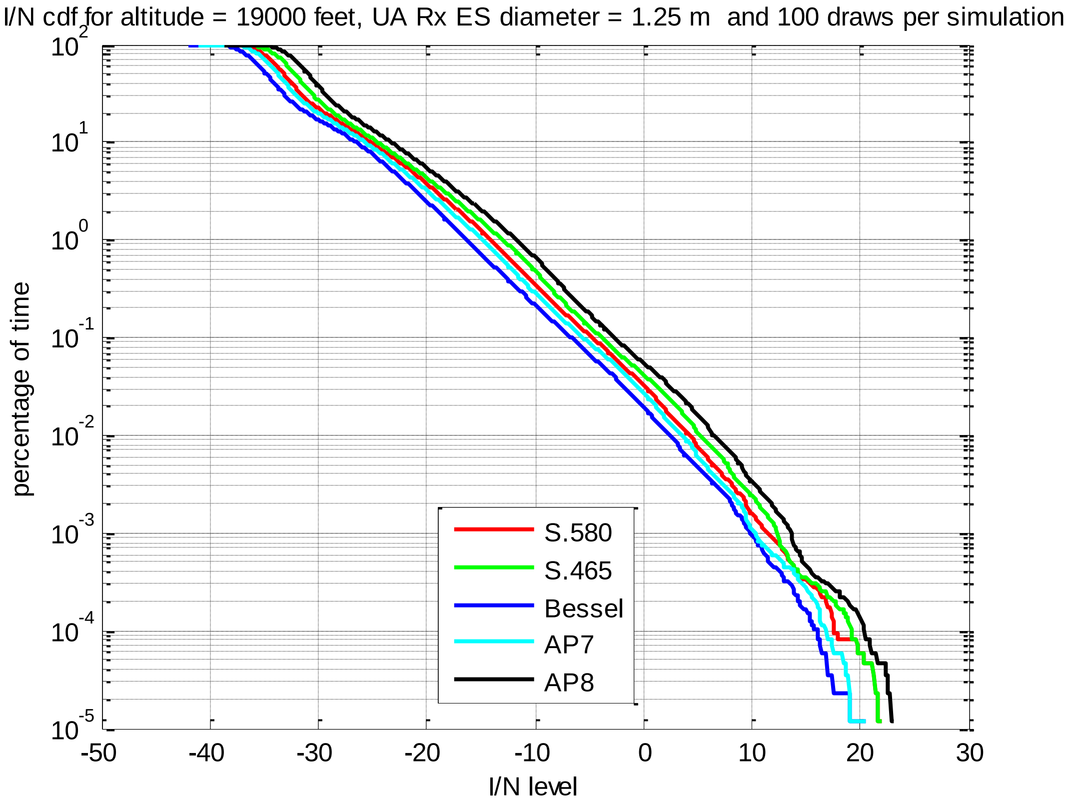
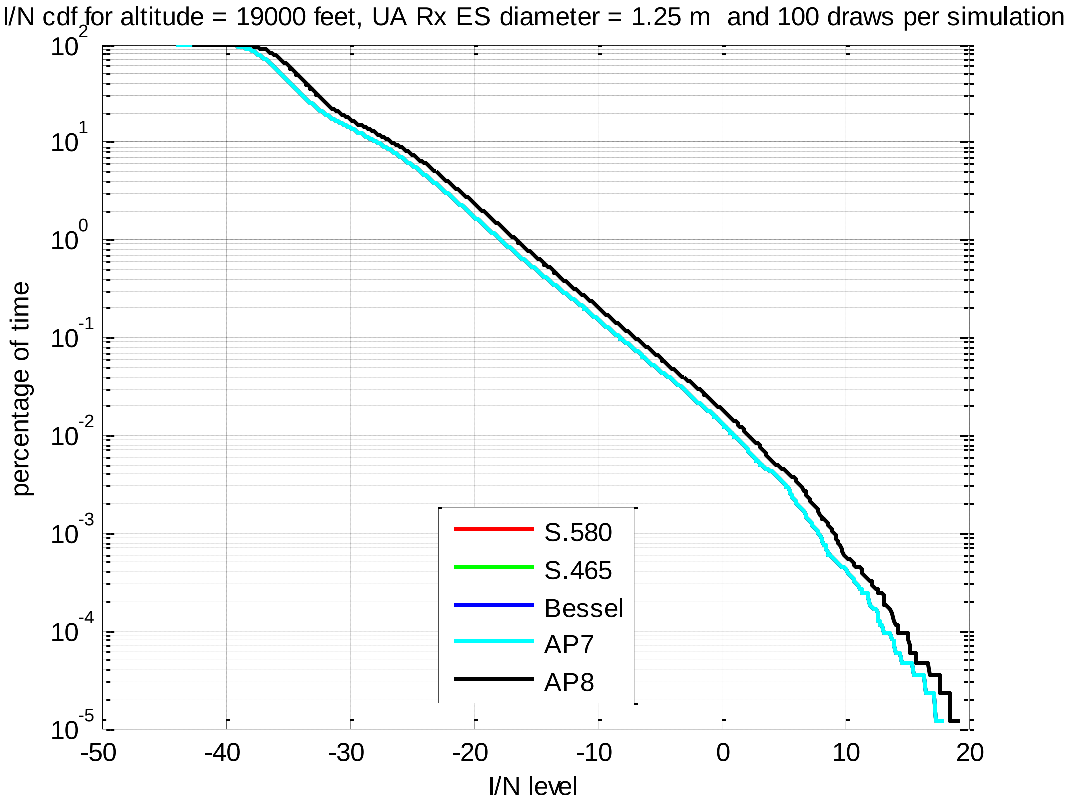


FIGURE A6-79

I/N CDF for Scenario 2 at 19.7 GHz with 60 degrees elevation for 1.25m UA antenna



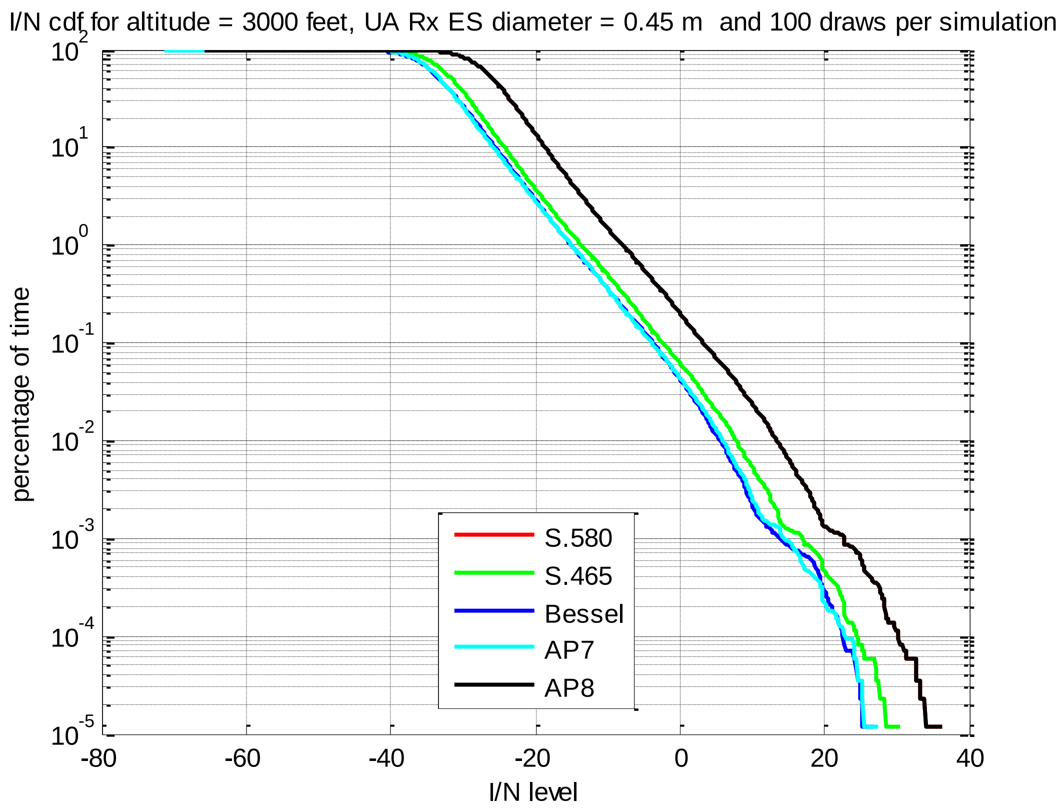
Note: in this configuration, CDF obtained with Rec. ITU-R S.465, with Rec. ITU-R S.580, with AP7, and with Bessel antenna patterns are identical;

A6-7.5.2.2 Flight scenario 4

The following diagrams show the CDF corresponding to flight scenario 4 (flight height 3 000 ft) for *I/N* ratios at UA receiver with small (0.45m) and large (1.25m) diameter antenna, both for an elevation of 10 degrees and of 60 degrees.

FIGURE A6-80

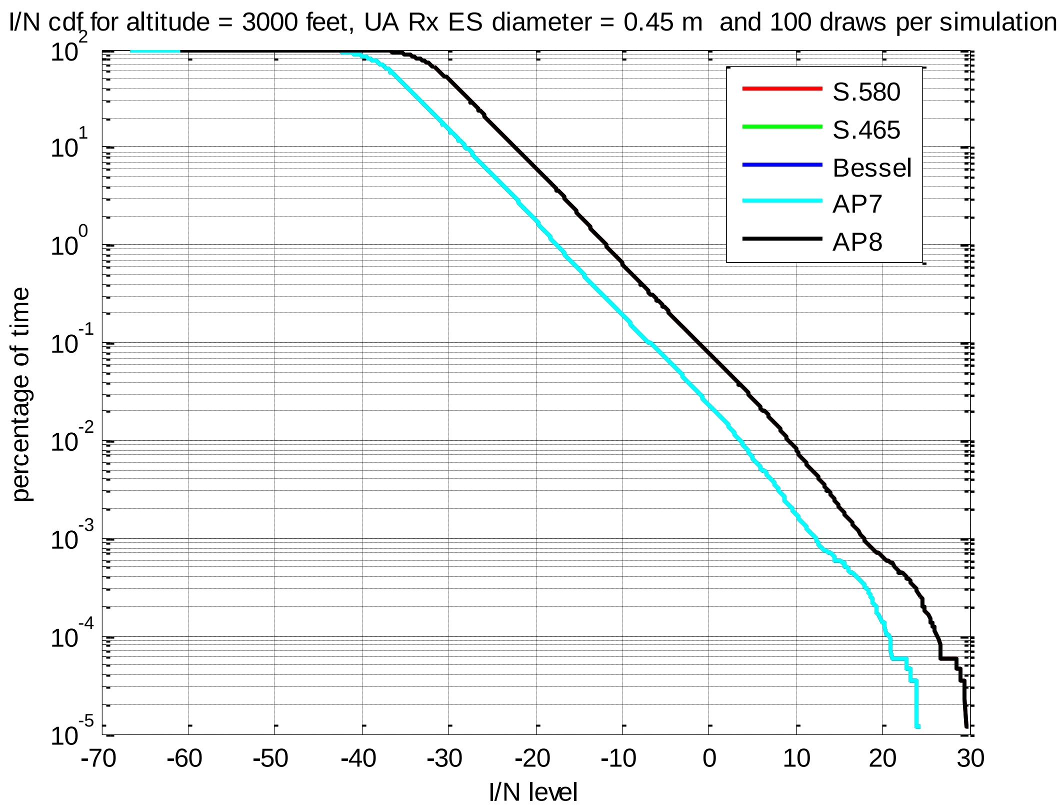
I/N CDF for Scenario 4 at 19.7 GHz with 10 degrees elevation for 0.45m UA antenna



Note : in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

FIGURE A6-81

I/N CDF for Scenario 4 at 19.7 GHz with 60 degrees elevation for 0.45m UA antenna



Note 1: in this configuration, CDF obtained with Rec. ITU-R S.580 and with AP8 antenna patterns are identical;

Note 2: in this configuration, CDF obtained with Rec. ITU-R S.465, with AP7, and with Bessel antenna patterns are identical;

FIGURE A6-82

I/N CDF for Scenario 4 at 19.7 GHz with 10 degrees elevation for 1.25m UA antenna

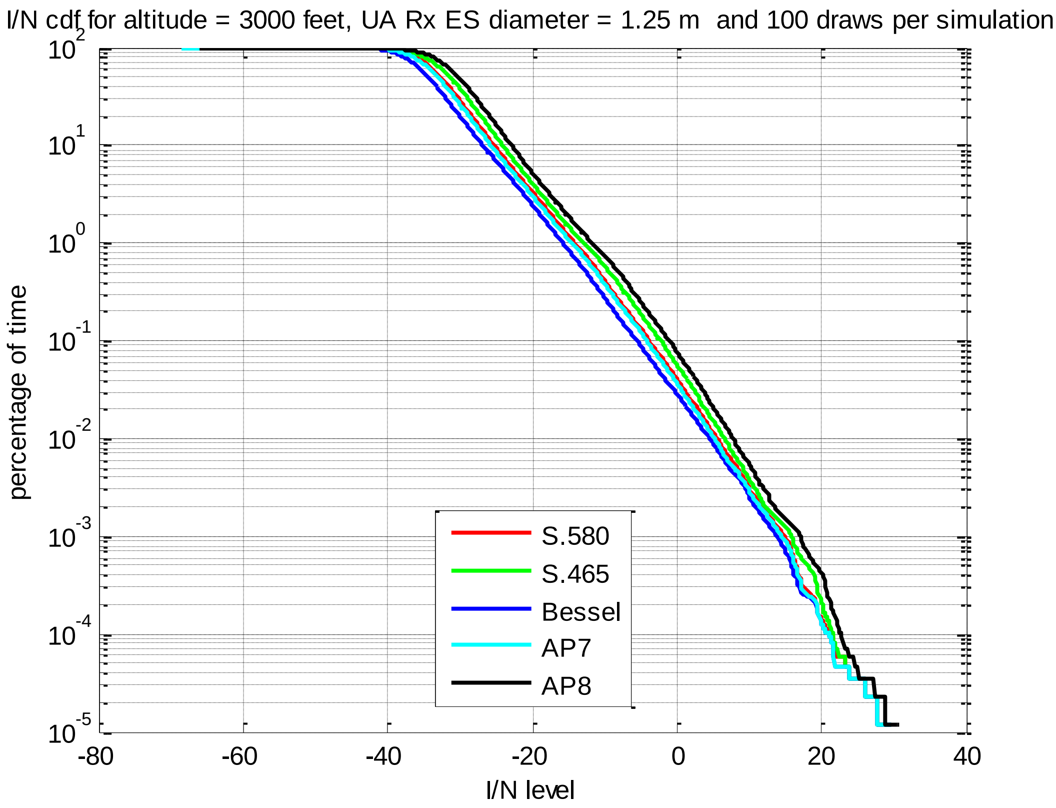
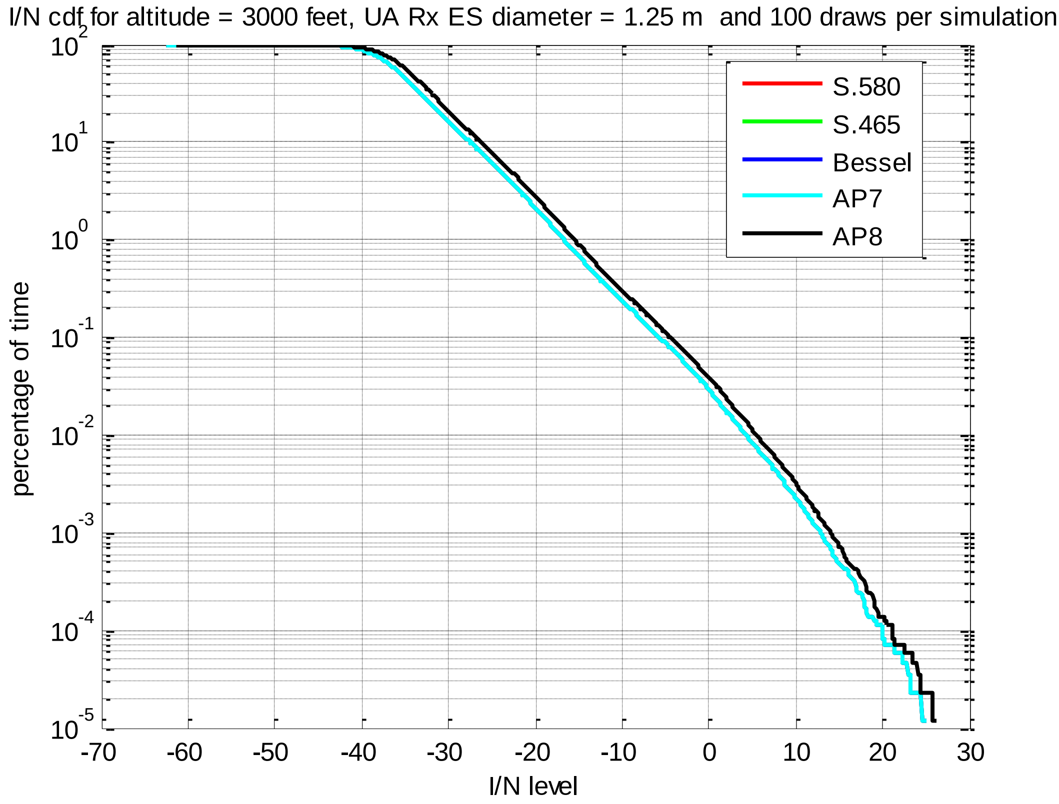


FIGURE A6-83

I/N CDF for Scenario 4 at 19.7 GHz with 60 degrees elevation for 1.25m UA antenna



Note: in this configuration, CDF obtained with Rec. ITU-R S.465, with Rec. ITU-R S.580, with AP7, and with Bessel antenna patterns are identical.

ANNEX 7 TO REPORT ITU-R M.[UAS-FSS]

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

Summary

Annex 7 contains the compatibility studies to assess the potential interference caused by UA operating in the FSS into FS. This analysis includes methods, systems characteristics, assumptions, results and conclusions. No compatibility studies are conducted with systems other than the FS, since there are no detailed system characteristics available for any other system. Studies are conducted against long-term and short-term FS protection criteria using study parameters identified in Annexes 1, 2 and 4 of this report for the UA earth station and by WP5C through liaison 5B/164-E (15 November 2012) and 5B/880-E (15 July 2015).

Appendix 1 provides the study parameters applicable to both the long-term and short-term protection criteria studies. Appendix 2 provides the parameters, methodologies and results specific to the long-term protection criteria study for the general (non-worst) case. Appendix 3 provides the parameters, methodologies and results specific to the short-term protection criteria study for the general (non-worst) case.

Appendix 4 provides complementary study results for worst-case scenario analysis specific to the long-term protection criteria. Appendix 5 provides complementary study results for worst-case scenario analysis specific to the short-term protection criteria and contains a proposed power flux density mask to protect the FS stations against exceedance of the short-term protection criteria, as the studies show that the long-term protection criteria is never exceeded.

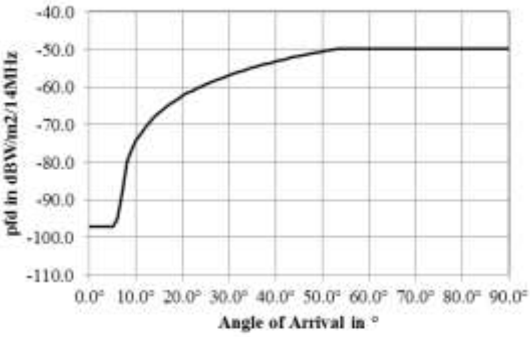
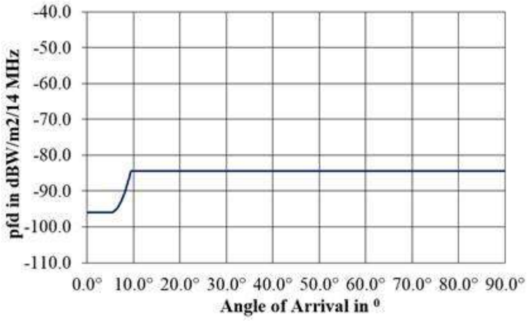
The analyses show: the long-term protection criterion of Rec. ITU-R F.758-5 is met in all cases studied for both frequency ranges studied; the short-term protection criteria of Rec. ITU-R F.1495-2 and Rec. ITU-R SF.1719 are met for all cases for the 27.5-29.5 GHz frequency range; the short-term protection criterion of Rec. ITU-R F.1494-0 is met for all cases for the 14.0-14.47 GHz frequency range with UA operating at altitudes ≥9 000 ft. To assure short-term protection criteria are met, a power flux density mask is derived in Appendix 5 for both frequency ranges.

Table A7-1lists the relevant FSS bands where the FS is allocated on a primary basis either by footnote or table allocation and thus is entitled to be protected.

From the results of the analysis, the conclusions shown in Table A7-1 are drawn.

TABLE A7-1

Summary of conclusions of the sharing studies on emissions from fixed satellite service earth station transmitters on-board unmanned aircraft into incumbent terrestrial services for link 3

Fixed service frequency band range (GHz)	Analysis conclusions
14.0-14.47	UA FSS transmitters do not cause FS protection criteria to be exceeded at altitudes ≥ 9 000 ft AGL and latitudes up to 70 degrees. 
27.5-29.5	UA FSS transmitters do not cause FS protection criteria to be exceeded at altitudes ≥ 3 000 ft AGL and latitudes up to 70 degrees. 

APPENDIX 1

Sharing study parameters applicable to long-term and short-term fixed service protection criterion studies

A7.1 Introduction

This Annex contains the compatibility studies between the earth station transmitters on unmanned aircraft and the FS receivers including methodology and results. Appendix 1 presents the study parameters applied to each of the studied frequency bands applied against long-term and short-term protection criteria.

A7.2 Sharing studies on 14.0-14.47 GHz and 27.5-29.5 GHz frequency ranges in the uplink, unmanned aircraft earth station to satellite (Link 3) direction

Figure 1 of this Report depicts the communications links involved in beyond line of sight control and non-payload communications for an unmanned aircraft system. Annex 7 examines the sharing scenario between Link 3, the return uplink (Earth-to-space), in this case the UA transmit, and fixed terrestrial services in the frequency bands 14.0-14.47 GHz and 27.5-29.5 GHz.

A7.3 Services to be included in the sharing study, 14.0-14.47 GHz

The terrestrial services allocated to the frequency band 14.0-14.47 GHz in ITU Regions 1, 2 and 3 (including pertinent footnotes) are found in Annex 4 of this report. As indicated in Annex 4, system characteristics and protection criteria are available for FS only, therefore the study for the frequency band 14.0-14.47 GHz covers sharing between UA transmitters and FS receivers. There are no records in the ITU Master Registry indicating use of the radionavigation allocation in the frequency band 14.0-14.3 GHz by any administration. No additional information was obtained on radionavigation use of the frequency band as a result of inquiries by former ITU-R Study Groups

A7.4 Services to be included in the sharing study, 27.5-29.5 GHz

The terrestrial services allocated to the frequency band 27.5-29.5 GHz in ITU Regions 1, 2 and 3 (including pertinent footnotes) are found in Annex 4 of this report. As indicated in Annex 4, system characteristics and protection criteria are available for FS only, therefore the study for the frequency band 27.5-29.5 GHz covers sharing between UA transmitters and FS receivers.

A7.5 Flight scenarios

Relevant UAS flight scenarios have been defined in Section 2.3 of the report. Based on the flight scenario descriptions, scenarios 2 and 4 identify the altitudes for the sharing studies (19,000 ft above mean sea level for scenario 2 and 3,000 ft above mean sea level for scenario 4). 3,000 feet above mean sea level is the minimum altitude considered for this study. Long-term protection criteria studies are carried out at 3000 ft (914 meters) and 19000 ft (5 791 meters). Short-term protection criteria studies also consider several altitudes between these altitudes.

A7.6 Distribution of unmanned aircraft

The number and distribution of UA are defined in ITU-R M.2171. The UA density projections for the 2030 time-frame based on estimated UAS usage rates in both the commercial and government sectors are described in Table A7-2. Based on the flight scenarios that will be studied, the total of the medium and large UA densities are considered, since small UA operate only below 3,000 ft. In this study it is assumed all UA are using satellite-based BLOS CNPC within the frequency band being considered (14.0-14.47 GHz or 27.5-29.5 GHz).

For the sharing studies, UA are randomly distributed in an area bounded by the radio horizon using the relative densities shown in the table.

TABLE A7-2

Unmanned aircraft traffic density

Type	Altitude	UA/km^2	UA/10,000km^2	UA/Spot Beam	UA/Regional Coverage Beam
Small	<300 m	0.000803	8.031	385	0
Medium	300-5 500 m	0.000195	1.950	93	1 515
Large	>5 500 m	0.000044	0.440	21	341

A7.7 Fuselage attenuation

The effects of fuselage attenuation as described in Annex 10 are not included in the sharing studies.

A7.8 Unmanned aircraft earth station transmit study parameters

The transmit parameters of Earth stations on board unmanned aircraft used in this study are shown in Table A7-3. The following are the input parameters and general assumptions made for the UA transmit frequency bands 14.0-14.47 GHz, and 27.5-29.5 GHz.

a) small and large antenna UA sizes are evaluated.

b) the reference transmit frequencies (channel bandwidth of 250 kHz) are randomly assigned within the respective bands under study.

c) e.i.r.p. density (dBW/Hz) from Annex 1 and converted to dBW/250 kHz.

d) the UA antenna tracks a GSO satellite that is in same longitude as the center of the FS station's antenna main beam.

e) locations at several latitudes from 10 to 70 degrees are evaluated.

f) UA altitudes evaluated range from 914 meters (3 000 feet) to 5 791 meters (19 000 feet) from [Provisional] UAS ICAO scenarios 2 and 4.

g) UA antenna orientation is always pointing towards the GSO.

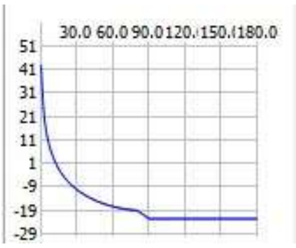
h) all UA are assumed to be at the same altitude for a given computation in order to reduce computation time, except where a more precise computation was required as noted.

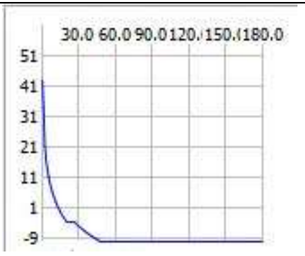
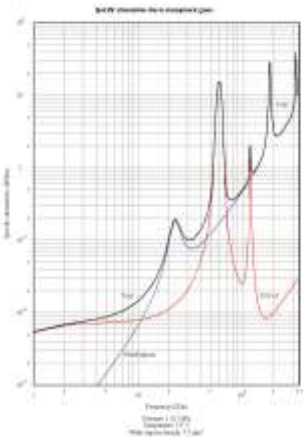
i) all UA are using satellite-based BLOS CNPC within the frequency band being considered (14.0-14.47 GHz or 27.5-29.5 GHz).)

System characteristics in Table A7-3 are taken from Annex 1, and transmit e.i.r.p. densities are based on the UA-to-FSS link budgets described in Annex 2 of this report.

TABLE A7-3

Unmanned aircraft earth station transmit study parameters in the frequency bands 14.0-14.47 and 27.5-29.5 GHz

Parameter	**Units**	**Frequency band(s)**	**Value**	**Source**
Telemetry Data Rate	Kbps	Both	320	Annex 1
Antenna Diameters	M	Both	Small = 0.45 Medium = 0.80 Large = 1.25	Annex 1 Only small and large antenna studied.
Tx Channel bandwidth	kHz	Both	250	
Tx frequency range (evaluation)	GHz	14.0-14.47	14.4	
Tx frequency range (evaluation)	GHz	27.5-29.5	28.5	
e.i.r.p. density	dBW/250 kHz	14.0-14.47 GHz	S,M,L = 43.78, 53.78, 57.68	Only small and large antenna studied as defined in Annex 1
e.i.r.p. density	dBW/250 kHz	27.5-29.5 GHz	S,M,L = 42.38, 44.48, 48.08	Only small and large antenna studied as defined in Annex 1
3 dB beamwidth	Degrees	14.0-14.47 GHz	Antenna Size S,M,L = 3.26, 1.97, 1.2	Only small and large antenna studied as defined in Annex 1
3 dB beamwidth	Degrees	27.5-29.5 GHz	Antenna Size S,M,L = 1.52, 0.86, 0.52	Only small and large antenna studied as defined in Annex 1
Antenna efficiency	%	Both	55	Annex 1
Radome loss	dB	Both	1	
Antenna patterns		Peak-envelope Bessel Function Antenna	 $G(\varphi)=G_{max} - 30\log(D/\lambda \sin\varphi) - 0.86$ dBi for $10° \leq \varphi \leq 90°$ $G(\varphi)=G_{max} - 30\log(D/\lambda) - 10.86$ dBi for $90° \leq \varphi \leq 180°$	Applied in Appendix 2, 3, 4 4 and 5.
		S.580-APL-UM001	Rec. S.580 for D/Lambda >= 100; BR-IFIC APL APEREC015V01 for D/Lambda < 100;	Applied in Appendix 4 and 5.

Parameter	Units	Frequency band(s)	Value	Source
				
Altitude	Feet AGL	Both	3,000’ (914 meters) and 19,000’ (5 791 meters) AGL for long-term; Various altitudes ≥3,000’ at 1000’ increments as required for short-term.	ICAO Scenarios 2 and 4
Polarization loss	dB	Both	0	Worst-case: no polarization mismatch loss assumed.
Atmospheric gas attenuation	dB	Both		ITU-R P.676-9

A7.9 Fixed service receive study parameters (Table A7-4)

The fixed service receive study parameters are shown in Table A7-4.

The following are the input parameters and general assumptions made for the FS receive frequency bands in the frequency ranges of 14.0-14.47 GHz, and 27.5-29.5 GHz.

a) FS antenna elevation angle is uniformly randomized over ±5 degrees in the long term study, and randomized over a normal distribution with mean value of -0.040 and standard deviation of 0.850 limited to ±5 degrees in the short term study, for the general (non-worst) case studies in Appendix 2 and 3. FS antenna elevation angle is fixed at the determined worst case angle for the worst-case studies in Appendix 4 and 5.

b) FS station locations at several latitudes from 10 to 70 degrees are evaluated, with fixed longitude.

c) FS antenna height fixed at 10 m AGL.

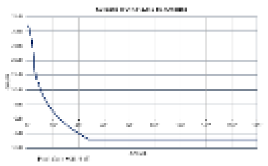
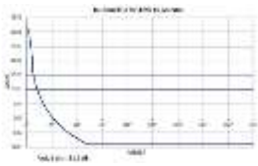
d) FS receiver bandwidth from Recommendation ITU-R F.758-5. Maximum specification for each band is evaluated.

e) FS antenna pattern from Recommendation ITU-R F.1245-2.

f) Results are compared to the long-term and short-term protection criteria shown in Table A7-5.

TABLE A7-4

Fixed service receive parameters in the frequency bands 14.0-14.47 and 27.5-29.5 GHz

Fixed service	Units	14.0-14.47 GHz Parameter	27.5-29.5 GHz Parameter	Comment
Frequency	GHz	14.4	28.5	FS receive band fixed
Bandwidth	MHz	28	56	ITU-R Rec. F.758-5
Line loss	dB	6	0	ITU-R Rec. F.758-5
Antenna Gain	dB	31.9	31.5	ITU-R Rec. F 758-5
Antenna efficiency	%	60	60	
Antenna azimuth orientation	Degrees	+/-180	+/- 180	
Antenna elevation angle	Degrees	-5 to +5	-5 to +5	5B/164-E
Locations - latitude		Locations at several latitudes from 10 to 70 degrees are evaluated.	Locations at several latitudes from 10 to 70 degrees are evaluated.	
Antenna pattern for average antenna gain				Rec. ITU-R F.1245 Antenna pattern. fixed for all FS

A7.10 Fixed Service protection criteria

Protection criteria for the FS including both long-term and short-term protection are shown in Table A7.5.

TABLE A7-5

Protection criteria for the fixed service in the frequency bands 14.0-14.47 and 27.5-29.5 GHz

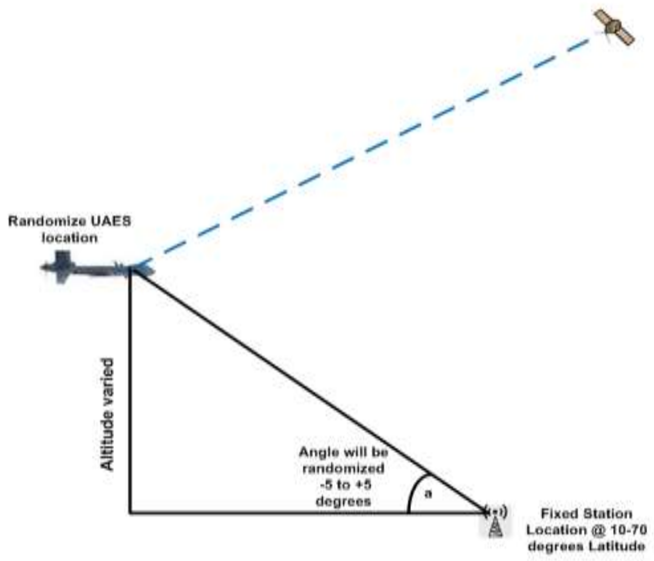
Parameter	Frequency Range	Value	ITU-R Source Document	Comments
I/N (Long Term)	Both14.0-14.47 GHz	-10 dB	ITU-R Rec. F.758-5	Not to exceed for more than 20% of the time
I/N (Short Term)	14.0-14.47 GHz	+20 dB	ITU-R Rec. F.1494-0	Not to exceed for more than $1x10^{-4}$ % of the time.
I/N (Short Term)	27.5-29.5 GHz	+14 dB	ITU-R Rec. F.1495-2	Not to exceed for more than 0.01% of the time in any month.
I/N (Short Term)	27.5-29.5 GHz	+18 dB	ITU-R Rec. F.1495-2	Not to exceed for more than 0.0003% of the time in any month.
I/N (Short Term)	27.5-29.5 GHz	+9 dB	ITU-R Rec. SF.1719	Not to exceed for more than 0.001% of the time.

A7.11 Analysis set-up

For analysing both the long-term and short-term protection criteria, the physical characteristics of the study, UA input parameters, and FS input parameters are the same. The physical characteristics of the study are depicted in Figure A7-1. UA input parameters for the study are shown in Table A7-3 and FS input parameters are in Table A7-4.

FIGURE A7-1

Physical characteristics of study



APPENDIX 2

Study of the long-term protection criteria for systems operating in the fixed service

Introduction

Appendix 2 contains the compatibility studies between the earth station transmitters on unmanned aircraft and the FS receivers, including methodology and results for the long-term FS protection criteria case. The study in this appendix considers the general (non-worst) case where FS stations may operate over a range of latitudes (N10^0, 40^0 and 70^0 are studied), antenna elevation angles and antenna azimuth. Study results and conclusions are presented for each of the studied bands.

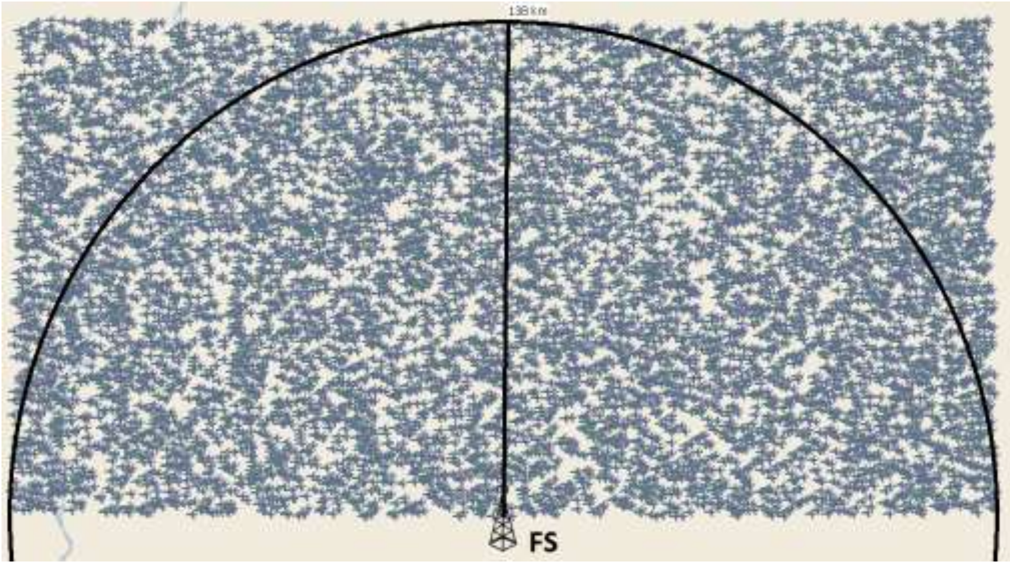
A7.12 Long-term protection criterion analysis – 14.0-14.47 GHz frequency range

A7.12.1 Analysis set-up

Each analysis scenario is set up with one fixed service station at one of three separate latitude positions of N10^0, 40^0 and 70^0 and a longitude of W90^0 for each case. The FS antenna elevation is uniformly randomized +/- 5^0 from the horizon. The FS antenna azimuth is randomized in all directions +/-180^0. Two UA flight altitudes of 3 000 ft (914 meters) and 19 000 ft (5 791 meters) are studied. At 14.4 GHz with the UA distribution at 3 000 ft and the FS at 10 m AGL, the radio horizon is at 138 km. With the UA distribution at 19 000 ft, the horizon is at 327 km for the same scenario. Figure A7.2 depicts an example showing the distribution of 10,000 UA data samples at latitude N40^0 with the FS azimuth fixed at 0^0. The aggregate interference (I/N) at the FS from all UA is computed for every time sample and a cumulative distribution function (cdf) is then generated to compare to the long-term protection criteria threshold (Table A7.5).

FIGURE A7-2

Distribution example - 3,000'altitude case
fixed service fixed at 0^0 azimuth
14.0-14.47 GHz



A7.12.2 Long-term sharing analysis in the 14.0-14.47 GHz frequency range

The analysis show that the probability that the aggregate I/N interference levels do not exceed -10 dB for greater than 20%. Figures A7-3 through A7-6 show 12 cases covering: small UA antenna and large UA antenna; 3,000 ft altitude and 19 000 ft altitude; and FS station location at 10^0, 40^0 and 70^0 N latitude.

FIGURE A7-3

Long term analysis
Results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna

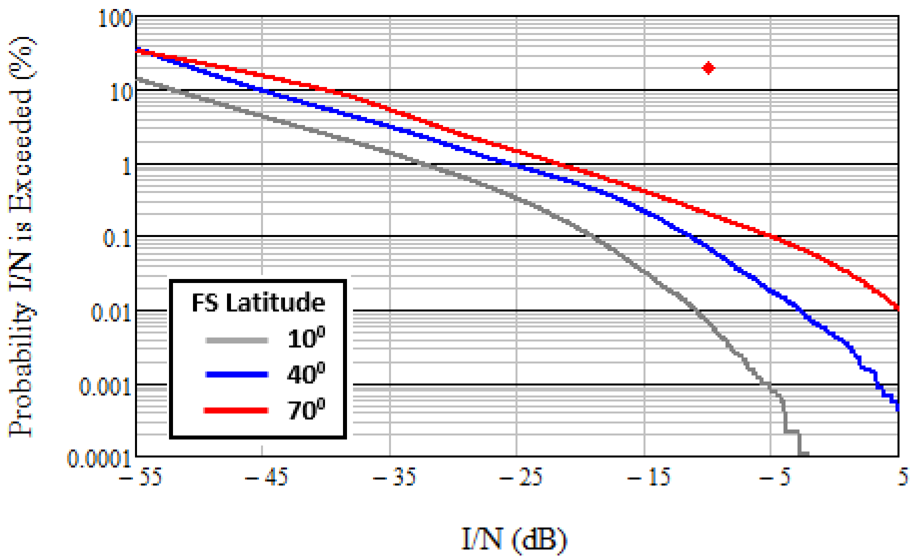


FIGURE A7-4

Long term analysis
Results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna

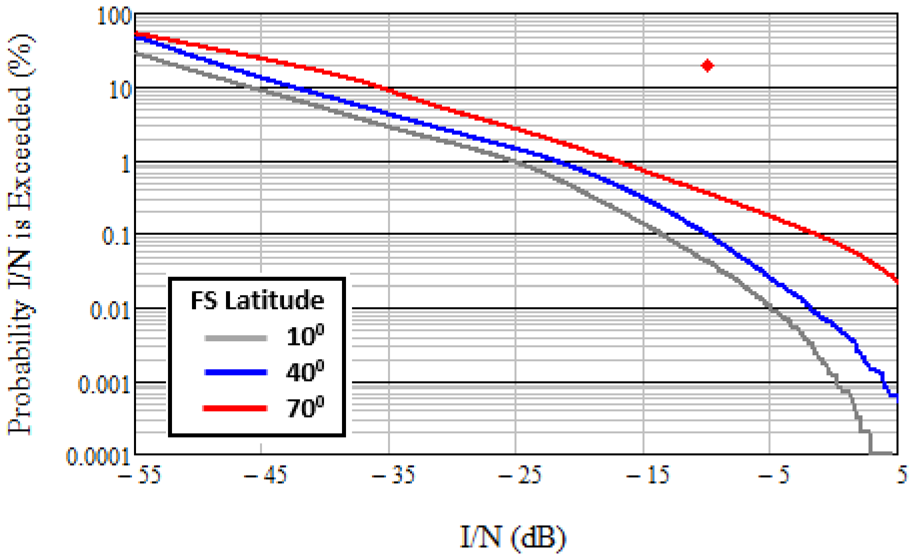


FIGURE A7-5

Long term analysis
Results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 19 000 ft above ground level, small UA antenna

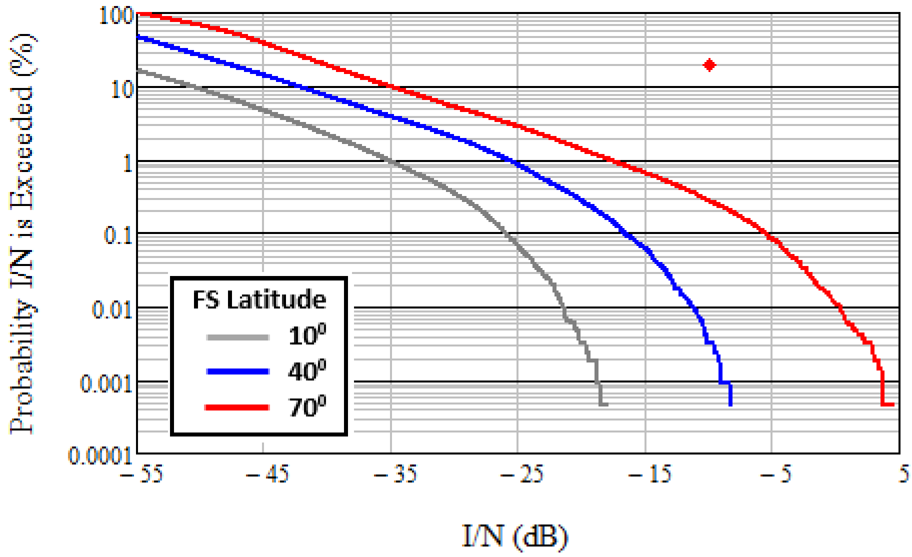
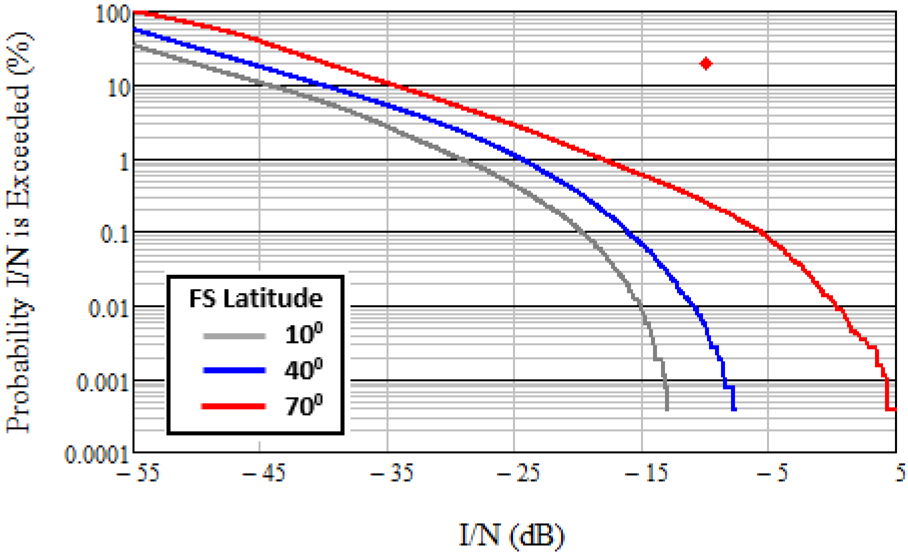


FIGURE A7-6

Long term analysis
Results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 19 000 ft above ground level, large UA antenna



A7.12.3 Conclusions for long-term criterion for the frequency range 14.0-14.47 GHz

Under the conditions stated, the analysis carried out indicates the required long term FS I/N protection criteria is met for altitudes of 3000 ft and above for all latitudes up to and including 70^0.

A7.13 Long-term protection criterion analysis - 27.5-29.5 GHz frequency range analysis

A7.13.1 Analysis Set-up

The analysis set-up for the long-term protection criterion study for the 27.5-29.5 frequency range is the same as for the 14.0-14.47 GHz range, described in section 7.12.1.

A7.13.2 Long-term results for analysis in the 27.5-29.5 GHz frequency range

Under the conditions stated, the analysis results show that the aggregate I/N interference levels do not exceed -10 dB for greater than 20%. Figures A7-7 through A7-10 show the results for 12 cases varying: Small UA antenna and large UA antenna; 3 000 ft altitude and 19 000 ft altitude; and FS station location at 10^0, 40^0 and 70^0 N latitude.

FIGURE A7-7

Long term analysis
Results for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna

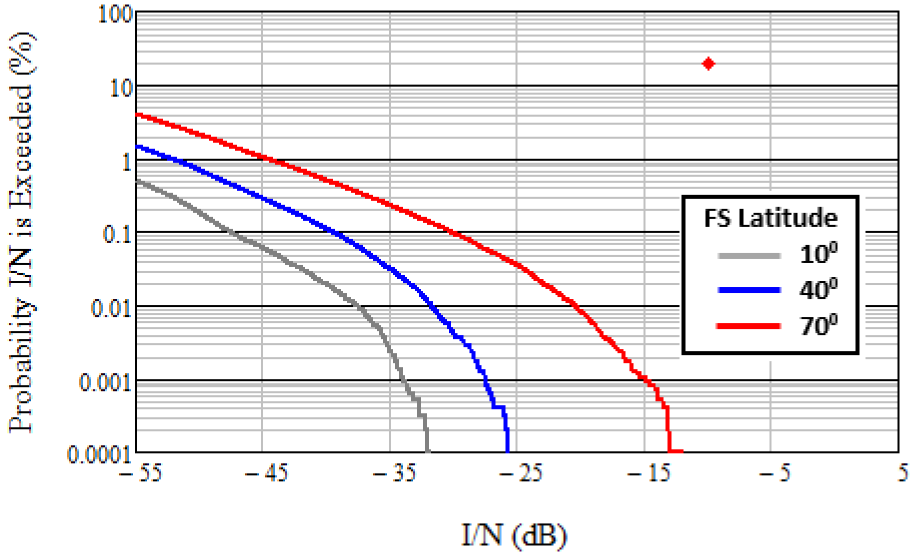


FIGURE A7-8

Long term analysis
Results for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna

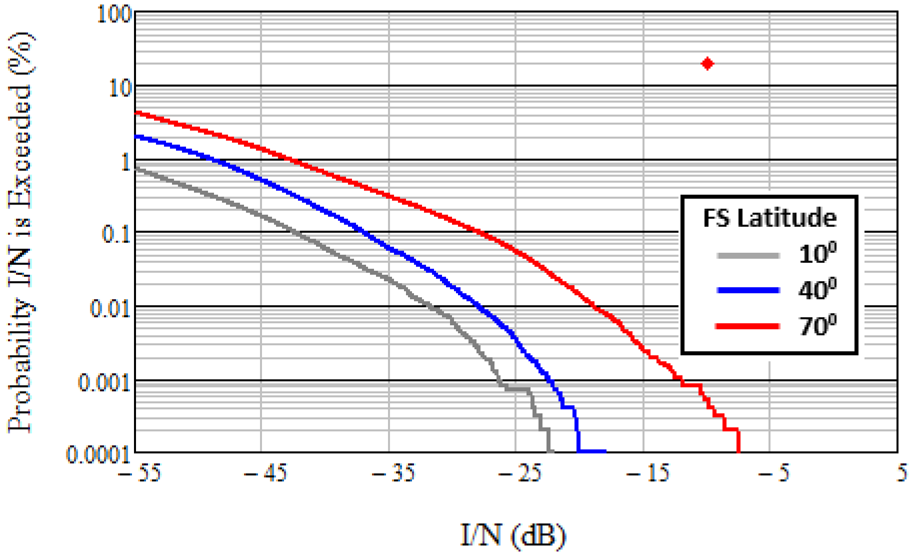


FIGURE A7-9

Long term analysis
Results for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 19 000 ft above ground level, small UA antenna

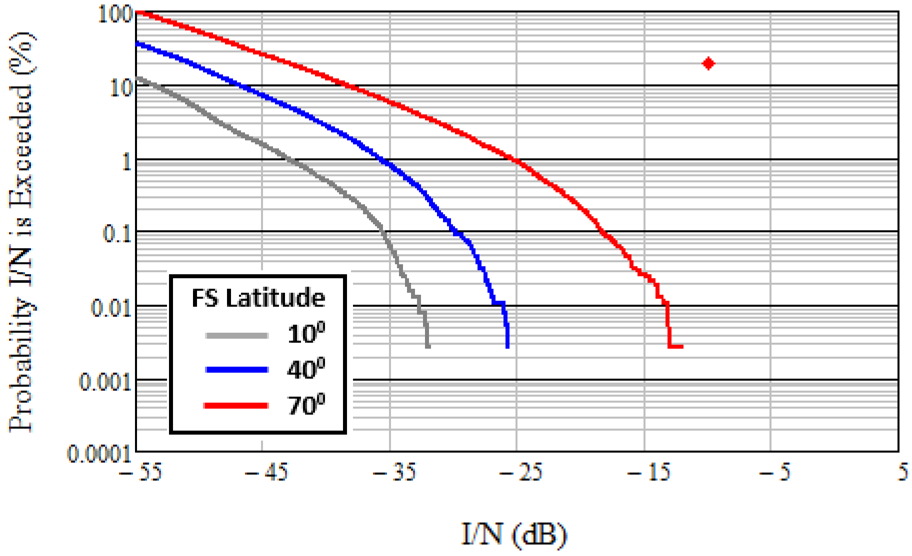
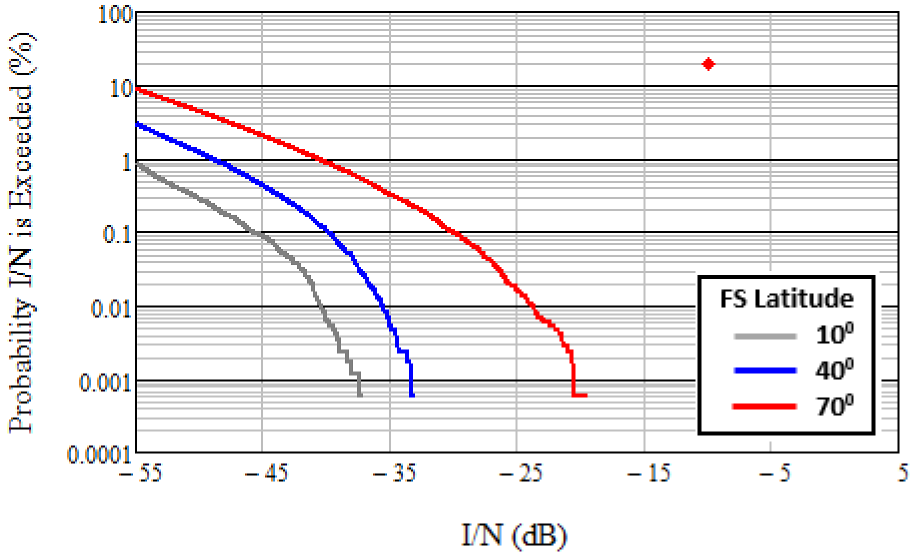


FIGURE A7-10

Long term analysis
Results for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 19 000 ft above ground level, large UA antenna



A7.13.3 Conclusions for the long-term criterion for the frequency range 27.5-29.5 GHz

Under the conditions stated, the analysis carried out indicates the required long term FS I/N protection criteria is met for altitudes of 3 000 ft and above for all latitudes up to and including 70^0.

APPENDIX 3

Study of the short-term protection criteria for systems operating in the fixed service

Introduction

Appendix 3 contains the compatibility studies between the unmanned aircraft earth station (UA) transmitters and the FS receivers, including methodology and results for the short-term FS protection criteria case. The study in this appendix considers the general (non-worst) case where FS stations may operate over a range of latitudes (N10^0, 40^0 and 70^0 are studied), antenna elevation angles and antenna azimuth. Study results and conclusions are presented for each of the studied bands.

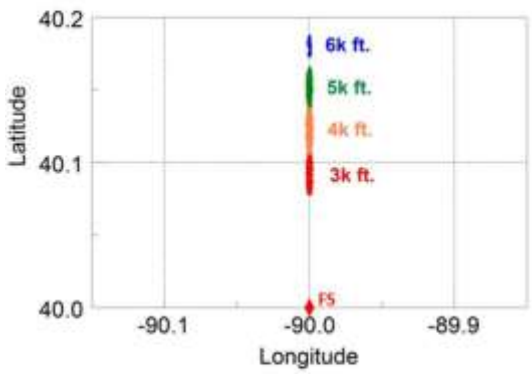
A7.14 Short-term protection criterion analysis – 14.0-14.47 GHz frequency range

A7.14.1 Short-term analysis set-up

In the short-term interference calculations, the FS is placed at specific locations and the surrounding airspace is populated with 1,000,000 randomly located UA's. This high 'computational' density of UA is used to determine the area relative to the FS in which a UA needs to reside so that it produces an I/N > 20 dB at the FS. An example is shown in Figure A7-11 for an FS at 40N with an elevation angle of 5^0 and UA with large 14 GHz antennas at altitudes from 3k to 6k feet. The area (in km^2) of each coloured area is computed and multiplied by the projected UA density of 2.39/10,000 km^2 to obtain the probability that a UA exists in that area at any given time. The result is multiplied by 28 MHz/ 500 MHz = 0.056 to account for the probability that a UA is transmitting within the 28 MHz bandwidth of the FS. The result multiplied by 100% is the percentage of time that the short term interference criterion is expected to be exceeded.

FIGURE A7-11

Areas in which unmanned aircraft at altitudes of 3 000, 4 000, 5 000, and 6 000 ft pointing at a satellite located at 90^0 W need to reside in order to produce an I/N greater than 20 dB, for an FS station at 40^0 N, 90^0 W with an antenna elevation angle of 5^0 and azimuth angle of 0^0.



A7.14.2 14.0-14.47 GHz frequency range short-term interference analysis

The FS elevation angle has a significant impact on the results. Analysis has shown that high FS elevation angles (e.g. 5^0) produce the highest levels of I/N. However study of the statistics of actual

FS stations in operation shows that the majority of FS operate at elevation angles at or near 0^0. Based on the actual operational FS station data, a normal distribution with mean value -0.04^0 and standard deviation of 0.85^0 provides an accurate description of the distribution of FS station elevation angles. Therefore, this distribution has been applied to the short-term interference study.

Simulations were performed at FS latitudes from 10^0 N to 70^0 N in 10^0 intervals and at UA altitudes of 3 000 ft.

A7.14.3 Results for short-term protection criteria analysis in the 14.0-14.47 GHz frequency range

Under the conditions stated above, the results of simulations show that the short-term protection criteria can be met at the minimum altitude of 3000 ft at latitudes up to 70^0 N. The cdf for the case of 3000 ft and 70^0 N is shown in Figure A7-12 for the small UA antenna and in Figure A7-13 for the large UA antenna. Results for lower latitudes at 3000 ft fall below the cdfs shown in these figures and therefore meet the protection criteria by a greater margin.

FIGURE A7-12

Short term analysis
I/N results for 14.4 GHz with FS station at 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna

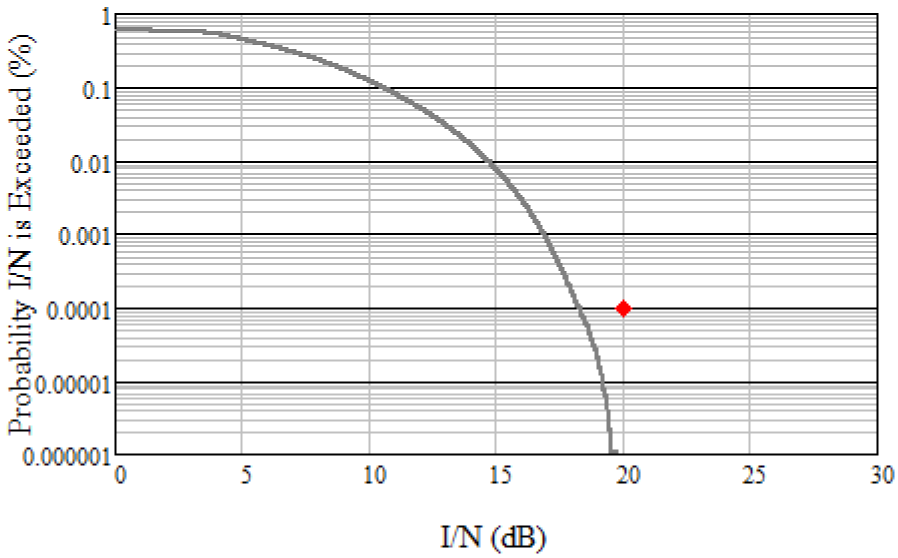
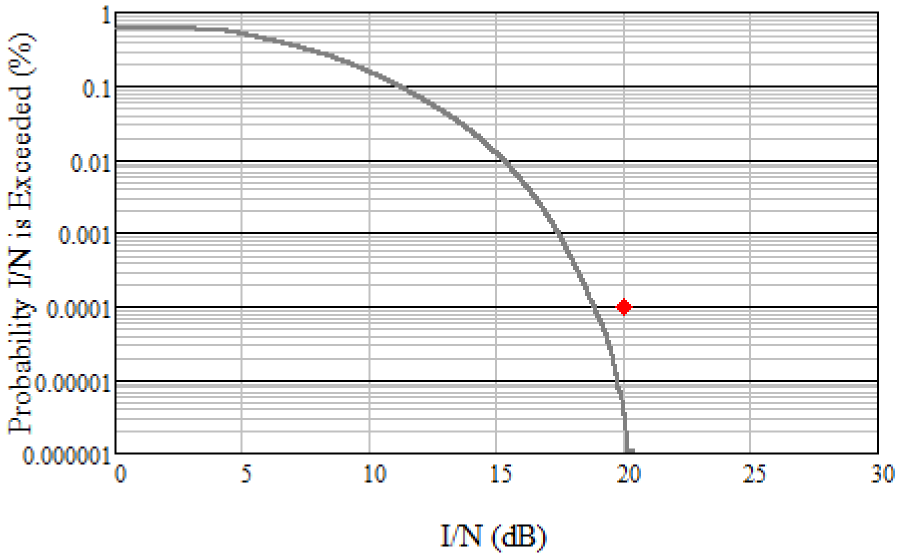


FIGURE A7-13

Short term analysis
I/N results for 14.4 GHz with FS station at 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna



A7-14.4 Short-term protection criteria analysis conclusions for the frequency range 14.0-14.47 GHz

Under the conditions stated, the analyses presented show that in the frequency range 14.0-14.47 GHz UA can operate at altitudes ≥ 3 000 ft at latitudes up to 70^0 when using the either the small or large 14 GHz antenna without causing the short-term FS protection criterion to be exceeded.

A7.15 Short-term protection criterion analysis – 27.5-29.5 GHz frequency range

A7.15.1 Short-Term Analysis Set-up

The analysis set-up for the long-term protection criterion study for the 27.5-29.5 GHz frequency range is the same as for the 14.0-14.47 GHz range, described in section A7.14.1.

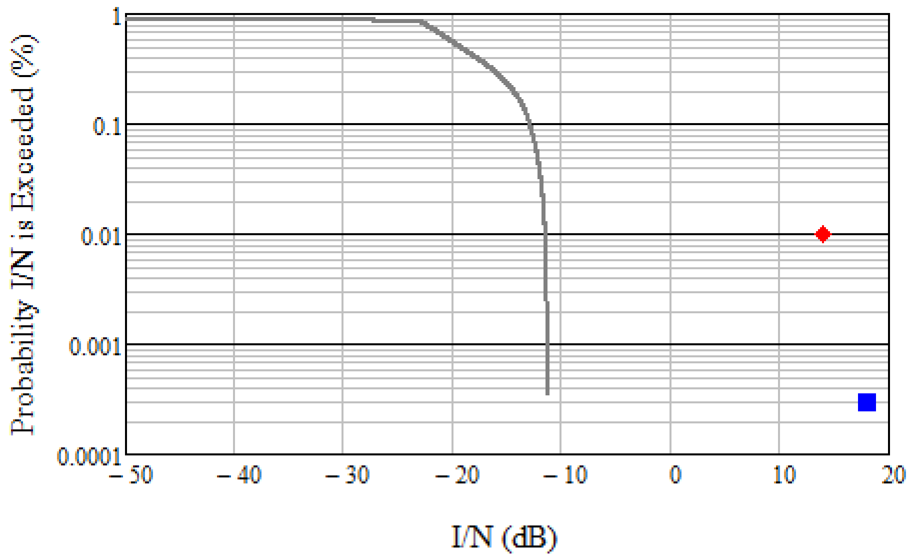
A7.15.2 Results for short-term protection criteria analysis in the 27.5-29.5 GHz frequency range.

Under the conditions stated, in all simulations performed in the 27.5-29.5 GHz range, the I/N at the FS is found to be well below both short term criteria for all latitudes and UA altitudes of 3 000 ft and above for both large and small antennas.

Figure A7-14 shows the cdf for at UA altitude of 3 000 ft at an FS latitude of 70^0, which is the worst case latitude, for the small 28 GHz antenna, which is the worst case antenna size. The analyses for all other altitudes, latitudes and antenna sizes produce I/N results lower than that shown in Figure A7-14 so only the small antenna case is shown.

FIGURE A7-14

Short term analysis
I/N results for 28.5 GHz with FS station at 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna



A7.15.3 Short-term protection criteria analysis conclusions for the frequency range 27.5-29.5 GHz

Under the conditions stated, the analyses presented show that in the frequency range 27.5-29.5 GHz UA can operate at altitudes ≥ 3 000 ft at latitudes up to 70^0 without causing the short-term FS protection criterion to be exceeded.

APPENDIX 4

Worst case compatibility analyses under long-term FS protection criteria

A7.16 Introduction

Studies in addition to those in Appendix 2 have been carried out to assess UA performance in meeting long term FS protection criteria. These studies include analyses with additional antenna models and some different performance parameters as described below, and are carried out for the UA antenna sizes: 0.45 m (Small) and 1.25 m (Large).

In the studies described in Appendix 4 the antenna of the FSS earth station on-board the UA is modelled in two ways, either using Recs. ITU-R S.580 antenna model based on BR-IFIC APEREC015V01 Document: APL-UM-001 Version 1.1.7 Date: 2007-05-28 (heretofore referred to as “S.580-APL-UM001”) or using a peak-envelope Bessel function antenna model (as used in Appendix 2 general (non-worst) case study). These studies use the same performance parameters described in Appendix 1. In addition, several other FS station parameter sets suggested by one administration for the 27.5-29.5 GHz range are also studied (see Table A7-6).

In order to ensure the study of the worst case conditions, the sensitivity of several input parameters were analysed to establish the worst case situation for these parameters. The input parameters studied were:

- FS antenna azimuth
- Relative position of satellite and FS
- FS latitude
- UA altitude
- FS antenna elevation angle

The long term FS protection criteria applied in this study for both 14.0-14.47 GHz and 27.5-29.5 GHz are $I/N \leq -10$ dB, not to be exceeded for more than 20% of the time (from Recommendation ITU-R F.758-5 as recommended by the liaison statement from WP 5C 5B/164-E).

A7.16.1 Worst case input parameters

The following are the results for the study to determine the worst case input parameters listed in the introduction. These results were derived for the 14.0-14.47 GHz case but are considered equally applicable to the 27.5-29.5 GHz studies as well.

FS antenna azimuth and relative position of satellite and FS

Simulations were performed to determine the worst case for FS antenna azimuth position, performed with the FS located at 70^0 N latitude and the UA at an altitude of 3 000 ft. These simulations were repeated for several relative satellite locations: with the FS station located at 90^0 W longitude, simulations were performed with the geostationary satellite at locations of 90^0, 95^0, 100^0 and 105^0 W.

The results of these simulations demonstrate that maximum I/N results are found when the relative offset between the FS and the satellite is equal to the FS antenna azimuth position. For example, when the FS and satellite are both located at the same longitude (i.e. 90^0 W), the maximum I/N occurs with an FS azimuth of 0^0. When the satellite longitude is separated by 15^0 degrees from the FS longitude, the maximum I/N occurs at an FS azimuth of 15^0 degrees. Therefore it is concluded that using an FS azimuth position of 0^0 and a satellite location at the same longitude as the FS is representative of the worst case for these two parameters.

FS latitude

Simulations were performed to determine the worst case for FS latitude. With the FS and satellite at the same longitude and the UA at an altitude of 3 000 ft, the maximum I/N at the FS receiver was recorded at latitudes of 10^0, 20^0, 30^0, 40^0, 50^0, 60^0, and 70^0. 70^0 – corresponding to approximately 10° elevations – is the highest latitude analysed for UA operations with geostationary satellites. Above this latitude UA operations with geostationary satellites are not expected to be viable because of the low UA antenna elevations involved.

The results of these simulations demonstrate that I/N increases with latitude. The worst case I/N occurs at a latitude of 70^0 N. As expected this corresponds to the lowest UA antenna elevation angle resulting in the maximum UA antenna gain pointing at the FS.

UA Altitude

Simulations were performed to determine the worst case for UA altitude. With the FS and satellite at the same longitude and the FS located at 70^0 N latitude, the UA altitude was varied from 3 000 ft to 19,000 ft in 2 000 ft increments.

The results of these simulations demonstrated that I/N decreases with increasing UA altitude since the UA antenna gain in the direction of the FS is lower as the UA altitude increases. Therefore a UA altitude of 3 000 ft is the worst case.

FS Antenna Elevation Angle

Simulations were performed to determine the worst case for FS antenna elevation angle. With the FS and satellite at the same longitude, the FS located at 70^0 N latitude, and the UA altitude at 3 000 ft, the FS elevation angle was varied between -5^0 and $+5^0$.

The results of these simulations demonstrate that the highest I/N occurs at an FS elevation angle of $+5^0$ where the FS antenna is pointing more directly towards the UA.

Worst Case Input Parameters – Conclusion

The simulations conducted to determine worst case input parameters resulted in the following conclusion. The interference into the FS should be analysed under the following conditions: FS and satellite at the same longitude; FS antenna azimuth of 0^0; FS located at 70^0 N latitude; UA at 3 000 ft altitude; FS elevation angle of $+5^0$.

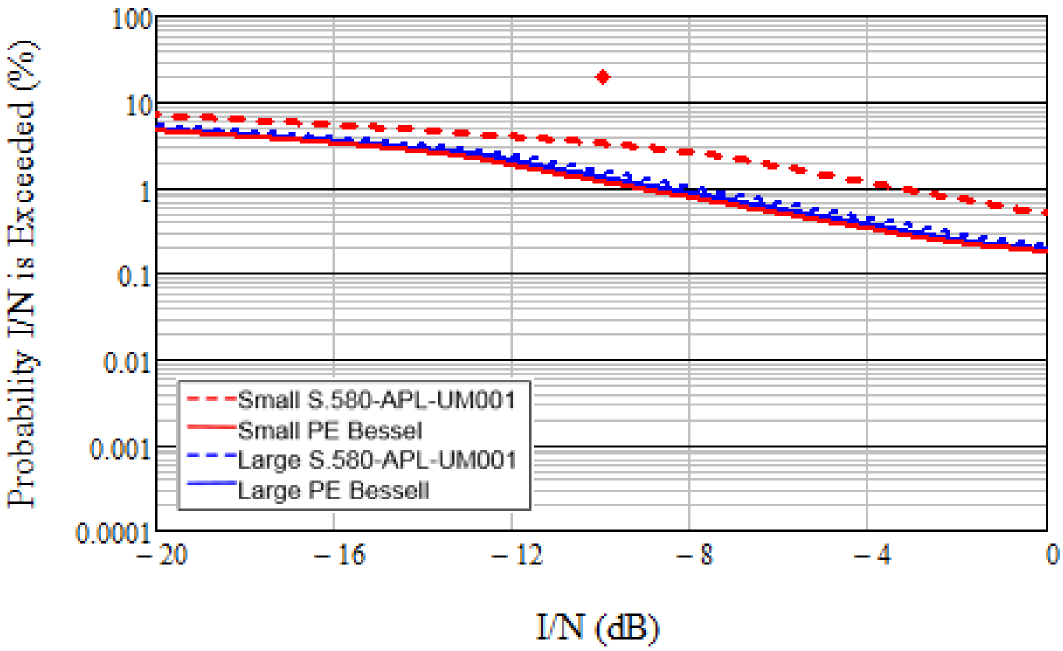
Consequently these input parameters were applied to the compatibility analyses under FS long-term protection criteria.

A7.16.2 Results for the compatibility analyses under long-term FS protection criteria – 14.0-14.47 GHz

Simulations following the same methodology as defined in Appendix 2 were performed for the worst case input parameters identified in A7.16.1 with the UA antenna modelled in four configurations: small peak-envelope Bessel; small S.580-APL-UM001; large peak-envelope Bessel; and large S.580-APL-UM001. Figure A7-15 shows the cdfs resulting from these simulations.

FIGURE A7-15

Long term FS protection criteria results for 14.0-14.47 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel



A7.16.3 Conclusions for the compatibility analyses under long-term FS protection criteria – 14.0-14.47 GHz

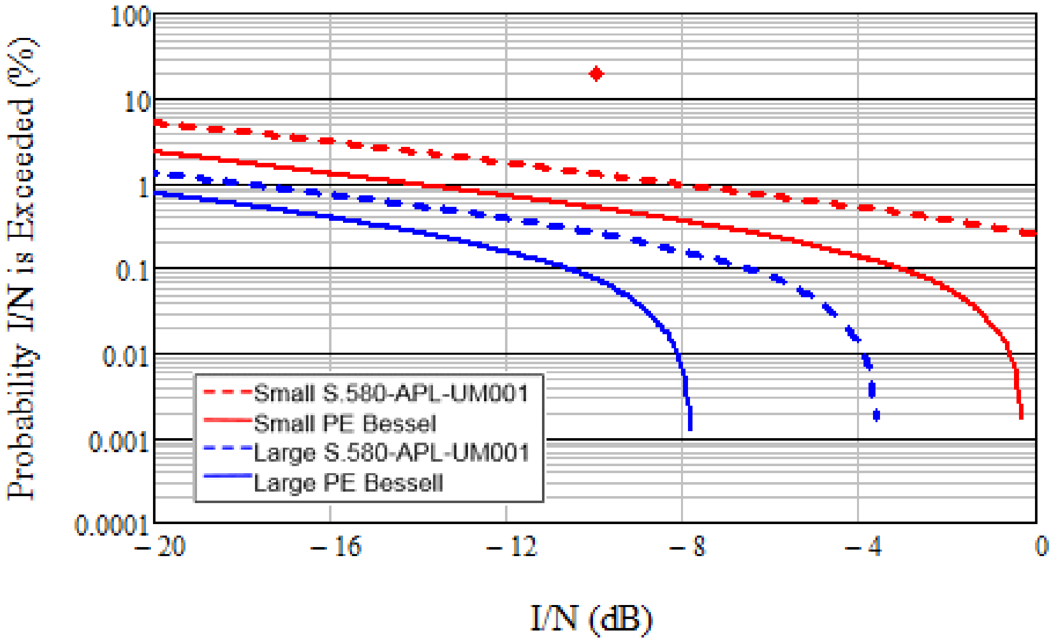
The above analysis shows that the long-term FS protection criterion is not exceeded under the worst case conditions.

A7.16.4 Results for the compatibility analyses under long-term FS protection criteria – 27.5-29.5 GHz

Simulations following the same methodology as defined in Appendix 2 were performed for the worst case input parameters identified in A7.16.1 with the UA antenna modelled in four configurations: small peak-envelope Bessel; small S.580-APL-UM001; large peak-envelope Bessel; and large S.580-APL-UM001. Figure A7-16 shows the CDFs resulting from these simulations, indicating that the long-term protection criteria is not exceeded for these cases.

FIGURE A7-16

Long term FS protection criteria results for 27.5-29.5 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel



A7.16.5 Results for the compatibility analyses under long-term FS protection criteria – 27.5-29.5 GHz - alternative FS parameters

A set of additional FS parameters were proposed for the 27.5-29.5 GHz by one administration, based on SF.1719. Although not referenced in any ITU-R document, the long-term FS protection criteria study described above in this appendix was repeated for these parameters, which are shown in Table A7-6. The additional parameters represent four possible FS station configurations, designated as FS1, FS2, FS3, and FS4.

TABLE A7-6

Additional FS station parameters for 27.5-29.5 GHz

Parameter	**FS1 (Point to Point)**	**FS2 (Point to Point)**	**FS3 (Point to Point)**	**FS4 (Point-Multi-Point)**
Receiver noise figure, F	6 dB	6 dB	6 dB	6 dB
N (dBW)	-126.5	-126.5	-126.5	-126.5
RX elevation angle	0°	5°	10°	0°
RX peak gain	45 dBi	43 dBi	35 dBi	18 dBi

Simulations following the same methodology as defined in Appendix 2 were performed using the worst case input parameters identified in A7.16.1 with the UA antenna modelled in four configurations: small peak-envelope Bessel; small S.580-APL-UM001; large peak-envelope Bessel; and large S.580-APL-UM001, and applying the FS station parameters in Table A7-6. Figures A7-17 through A7-20 provide the results for these simulations for the four additional FS configurations. These results show that the long-term FS protection criterion is not exceeded under the worst case conditions for the small and large UA antennas.

FIGURE A7-17

Long term FS protection criteria results for 27.5-29.5 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel for FS1

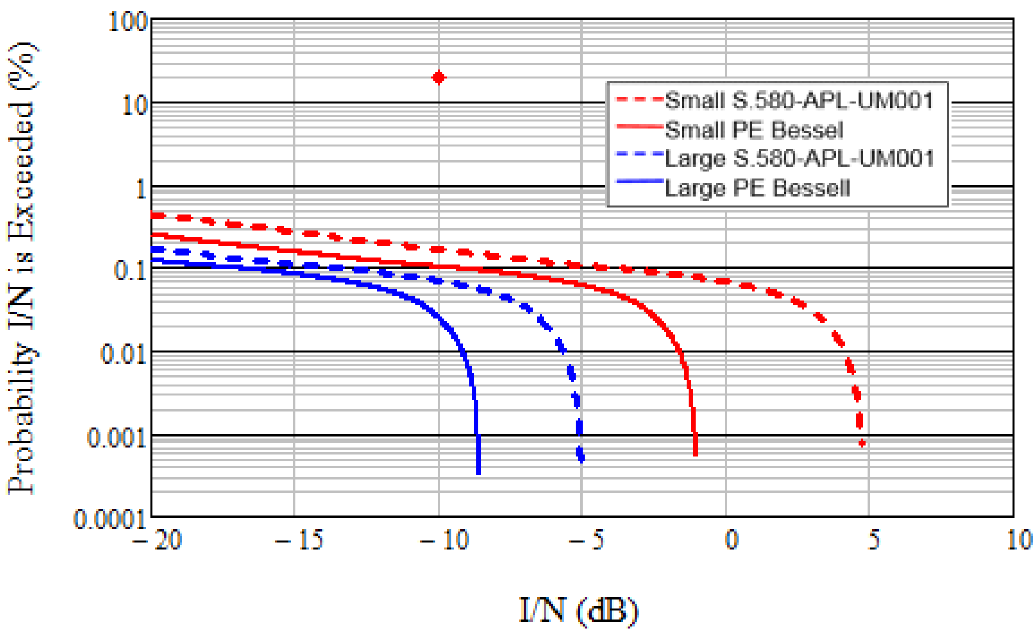


FIGURE A7-18

Long term FS protection criteria results for 27.5-29.5 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel for FS2

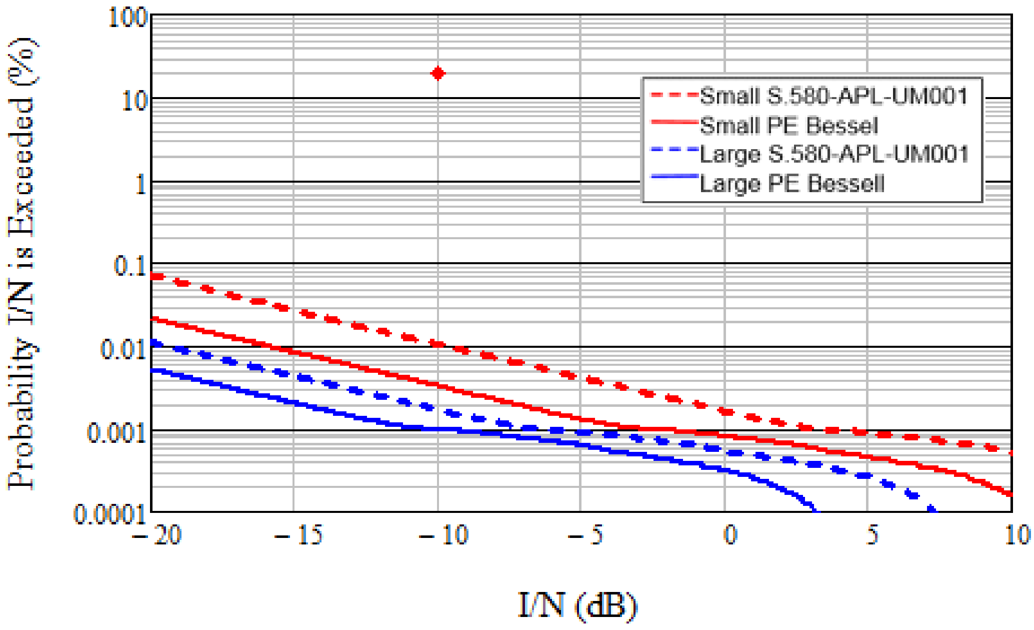


FIGURE A7-19

Long term FS protection criteria results for 27.5-29.5 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel for FS3

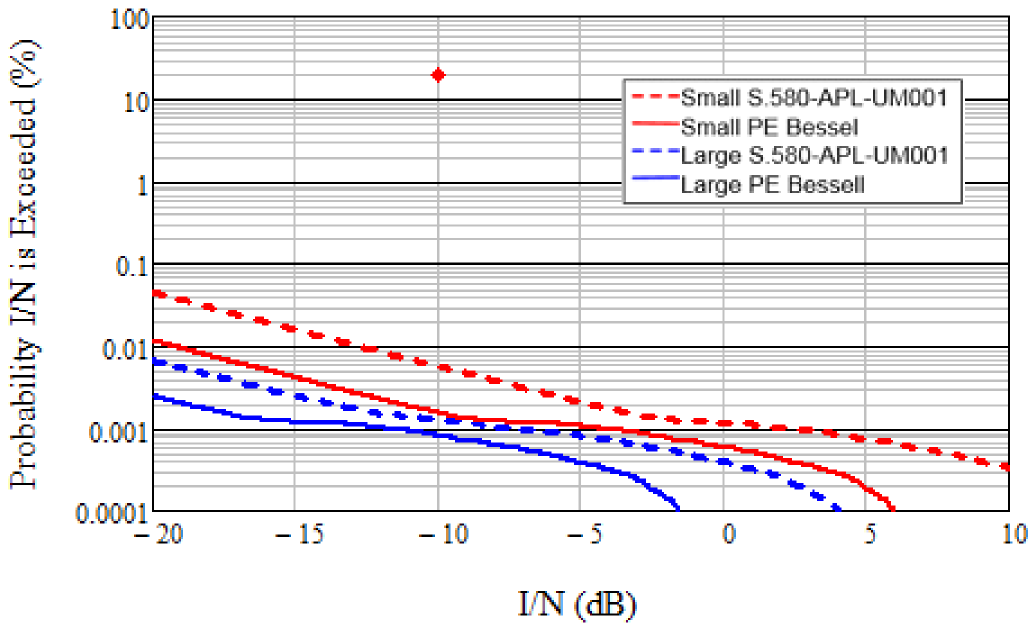
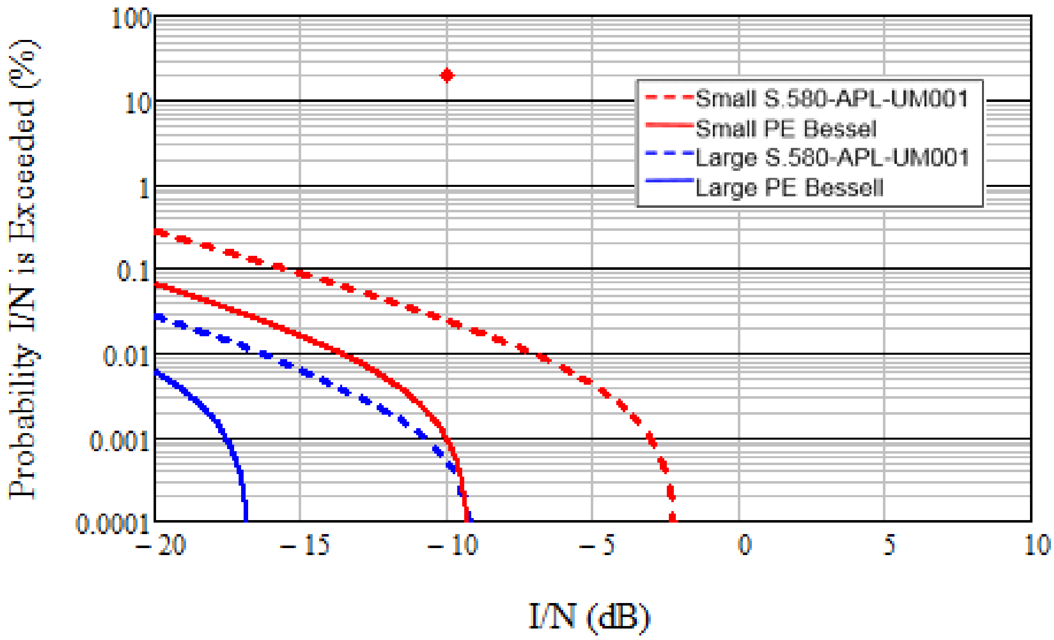


FIGURE A7-20

Long term FS protection criteria results for 27.5-29.5 GHz under worst case conditions for the small and large UA antennas modelled as S.580-APL-UM001 and peak-envelope Bessel for FS4



A7.16.6 Conclusions for the compatibility analyses under long-term FS protection criteria – 27.5-29.5 GHz

The above analyses shows that the long-term FS protection criterion is not exceeded under the worst case conditions.

APPENDIX 5

Worst case compatibility analyses under short-term FS protection criteria

A7.17 Introduction

Studies in addition to those in Appendix 3 have been carried out to assess UA performance in meeting short term FS protection criteria. These studies include analyses with additional antenna models and some different performance parameters as described below, and are carried out for the UA antenna sizes: 0.45 m (Small) and 1.25 m (Large).

In the studies described in this Appendix the antenna of the FSS earth station on-board the UA is modelled in two ways, either using Recs. ITU-R S.580 antenna model based on BR-IFIC APEREC015V01 Document: APL-UM-001 Version 1.1.7 Date: 2007-05-28 (heretofore referred to as “S.580-APL-UM001”) or using a peak-envelope Bessel function antenna model. These studies use the same performance parameters described in Appendix 1. In addition, several other FS station parameter sets suggested by one administration for the 27.5-29.5 GHz range are also studied (see Table A7-6).

The short term protection criteria for the FS are (from Recs. ITU-R F.1494 and F.1495-2 as recommended by liaison from WP 5C 5B/164-E, 15 November 2012):

- 14.0-14.47 GHz Protection Criterion: cannot exceed I/N +20 dB for more than 0.0001% of the time/month.
- 27.5-29.5 GHz Protection Criteria: cannot exceed I/N +14 dB for more than 0.01% of the time/month, +18 dB for more than 0.0003% of the time/month.

An additional liaison from WP 5C (5B/880-E, 15 July 2015), recommended application of short term protection criteria based on ITU-R FS.1719 for the 27.5-29.5 GHz range:

- 27.5-29.5 GHz Protection Criteria: cannot exceed I/N +9 dB for more than 0.001% of the time.

The time intervals for these protection criteria are relatively small, for example less than 3 seconds per month for the 14 GHz protection criterion. Therefore, for the purposes of this study it is assumed the short FS term I/N criteria must never be exceeded.

In addition to the studies of the short-term FS protection criteria, compliance of all UA CNPC emissions with Recommendation ITU-R S.524 is shown through a power flux density (pfd) mask, derived as a function of the angle above the horizon as seen from the FS station.

A7.17.1 Results for the compatibility analyses under short-term FS protection criteria – 14.0-14.47 GHz

Simulations following the same methodology as defined in Appendix 3 were performed under the worst case input parameters identified in A7.16.1 but with FS latitude and UA altitude varied in order to determine the minimum conditions under which the FS protection criterion is not exceeded. The UA antenna was modelled in four configurations: small peak-envelope Bessel; small S.580-APL-UM001; large peak-envelope Bessel; and large S.580-APL-UM001.
Results of the simulations are shown in Table A7-7. The third column of the table indicates the minimum altitude at which the short term FS I/N protection criterion is not exceeded at a latitude of 70^0. In the fourth column the maximum latitude at which the short term FS I/N protection criteria is not exceeded with the UA at 3000 ft. altitude is shown.

TABLE A7-7

Results of compatibility analyses under short-term FS protection criteria 14.0-14.47 GHz

Antenna size	Antenna pattern	Min altitude at 70^0 latitude	Max latitude at 3 000 ft
Small	Peak-envelope Bessel	5 000 ft	66^0
Small	S.580-APL-UM001	9 000 ft	48^0
Large	Peak-envelope Bessel	5 000 ft	65^0
Large	S.580-APL-UM001	5 000 ft	54^0

A7.17.2 Conclusions for the compatibility analyses under short-term FS protection criteria – 14.0-14.47 GHz

Considering all cases, the maximum latitude at which the UA can operate without exceeding the short term FS I/N protection criterion at altitudes of 3 000 ft and above is 48^0 and the minimum altitude at which the UA can operate at all latitudes up to 70^0 is 9 000 ft.

A7.17.3 Results for the compatibility analyses under short-term FS protection criteria – 27.5-29.5 GHz

Simulations following the same methodology as defined in Appendix 3 were performed under the worst case input parameters identified in A7.16.1 but with FS latitude and UA altitude varied in order to determine the minimum conditions under which the FS protection criterion is not exceeded. The UA antenna was modelled in four configurations: small peak-envelope Bessel; small S.580-APL-UM001; large peak-envelope Bessel; and large S.580-APL-UM001. These simulations applied the short-term protection criteria from ITU-R F.1495-2 of: cannot exceed I/N +14 dB for more than 0.01% of the time/month, +18 dB for more than 0.0003% of the time/month.

Results of the simulations are shown in Table A7-8. The third column of the table indicates the minimum altitude at which the short term FS protection criterion is not exceeded at a latitude of 70^0. In the fourth column the maximum latitude at which the FS short term protection criteria is not exceeded with the UA at 3 000 ft. altitude is shown.

TABLE A7-8

Results of short term FS protection criteria analyses for 27.5-29.5 GHz (ITU-R F.1495-2)

Antenna Size	Antenna Pattern	Min altitude at 70^0 latitude	Max latitude at 3000 ft
Small	Peak-envelope Bessel	3 000 ft	70^0
Small	S.580-APL-UM001	3 000 ft	70^0
Large	Peak-envelope Bessel	3 000 ft	70^0
Large	S.580-APL-UM001	3 000 ft	70^0

A7.17.4 Results for the compatibility analyses under short-term FS protection criteria – 27.5-29.5 GHz based on ITU-R FS.1719 and alternative FS parameters

The more recent liaison from WP5C (5B/880-E, 15 July 2015) recommended application of short term protection criteria based on ITU-R FS.1719: I/N not to exceed +9 dB for more than 0.001% of the time. Simulations applying this short-term criterion were completed.

A set of additional FS parameters were proposed for the 27.5-29.5 GHz by one administration, shown in Table A7-6. Although not referenced in any ITU-R document, the short-term FS protection criteria study described above in this appendix was repeated for these parameters, which are shown in Table A7-6. The additional parameters represent four possible FS station configurations, designated as FS1, FS2, FS3, and FS4. Simulations applying these additional parameter sets and the short term protection criteria based on ITU-R FS.1719 were also completed.

Results of the simulations are shown in Table A7-9. The results for simulations applying the FS parameters based on ITU-R F.758-5 are shown in the two columns with the heading F.758-5. The cases for the additional parameters are shown in the columns with the headings FS1, FS2, FS3, and FS4. Columns 3 through 7 of the table indicates the minimum altitude at which the short term FS protection criterion is not exceeded at a latitude of 70^0. Columns 8 through 12 indicate the maximum latitude at which the FS short term protection criteria is not exceeded with the UA at 3 000 ft. altitude is shown.

TABLE A7-9

Results of short term FS protection criteria analyses for 27.5-29.5 GHz (ITU-R SF.1719)

Antenna Size	Antenna Pattern	Min altitude at 70^0 latitude					Max latitude at 3000 ft				
FS parameter set		FS1	FS2	FS3	FS4	F.758-5	FS1	FS2	FS3	FS4	F.758-5
Small	S.580-APL-UM001	3000 ft	5000 ft	6000 ft	3000 ft	3000 ft	70^0	57^0	57^0	70^0	70^0
Large	S.580-APL-UM001	3000 ft	4000 ft	3000 ft	3000 ft	3000 ft	70^0	68^0	70^0	70^0	70^0
Large	Peak-envelope Bessel	3000 ft	3000 ft	3000 ft	3000 ft	3000 ft	70^0	70^0	70^0	70^0	70^0

A7.17.5 Conclusions for the compatibility analyses under short-term FS protection criteria – 27.5-29.5 GHz

Considering the cases for which the FS short term protection criteria based on ITU-R F.758-5 is applied, the maximum latitude at which the UA can operate without exceeding the short term FS I/N protection criteria at altitudes of 3 000 ft and above is 70^0 and the minimum altitude at which the UA can operate at all latitudes up to 70^0 is 3 000 ft.

Considering the cases of FS parameters not included in ITU-R documentation, that is FS1 through FS 4, UA can operate at altitudes of 6000 ft and above up to 70^0.

A7.17.6 Power flux density requirements related to the protection of the fixed service

All UA CNPC emissions will comply with Recommendation ITU-R S.524.

Additionally, for protection of the Fixed Service, a pfd mask has been derived as a function of the angle above the horizon as seen from the FS station.

This mask for the 14.0-14.47 GHz and 27.5-29.5 GHz frequency ranges is based on

- the FS characteristics stipulated in Recommendation ITU-R F.758 with the noise power of -136 BW/1MHz for both frequency ranges;
- the short term protection criteria for the FS at the respective frequency ranges from recommendation ITU-R F.1494 and ITU-R SF.1719 for the on-axis direction of the FS
    - valid for angles above the horizon at the FS of up to 5 degrees
    - Ku band: I/N = +20 dB
    - Ka band: I/N = +9 dB

- the FS off-axis antenna pattern characteristics of Recommendation ITU-R F.1245 using the antenna parameters to the antenna type mentioned in Recommendation ITU-R F.758.

Up to angles above the horizon at the FS of 5 degrees the on-axis FS protection criteria is applied, at higher angles above the horizon the allowed pfd level can be increased because the off-axis gain of the FS antenna decreases.

In the 14-14.47 GHz frequency band as used by fixed service networks, within line-of-sight of the territory of an administration where fixed service networks are operating in this band, the maximum pfd produced at the surface of the Earth by emissions from a single UA should not exceed:

-97	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$\theta \leq 5°$
$-97 + 2.1 \cdot (\theta - 5°)^2$	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$5° < \theta \leq 7.5°$
$-91.7 + 25 \cdot \log_{10} (\theta - 5°)$	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$7.5° < \theta \leq 53°$
-49.7	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$53° < \theta \leq 90°$

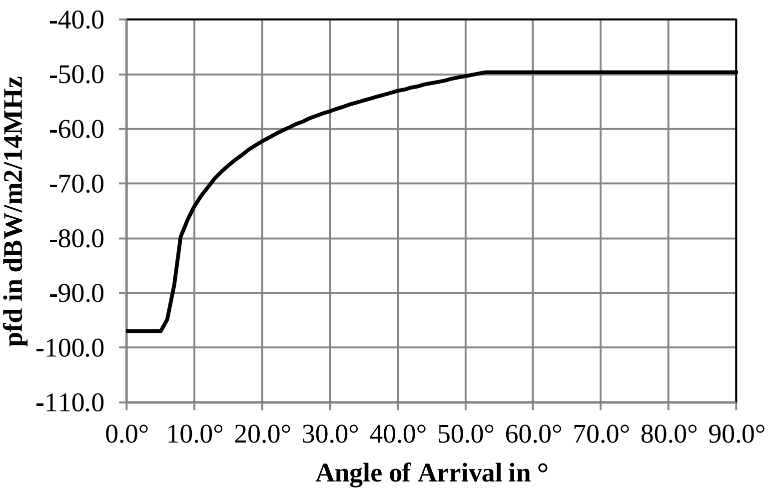
where θ is the angle of arrival of the radio-frequency wave (degrees above the horizon at the FS).

NOTE 1 The aforementioned limits relate to the pfd and angles of arrival that would be obtained under free-space propagation conditions.

Figure A7-21 shows the pfd mask for the frequency range 14.0-14.47 GHz.

FIGURE A7-21

PFD mask as function of angle of arrival for 14.0-14.47 GHz



In the 27.5-29.5 GHz frequency band as used by fixed service networks, within line-of-sight of the territory of an administration where fixed service networks are operating in this band, the maximum pfd produced at the surface of the Earth by emissions from a single UA should not exceed:

-96	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$\theta \leq 5°$
$-96 + 0.6 \cdot (\theta - 5°)^2$	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$5° < \theta \leq 9.4°$
-84.4	$\text{dB}(\text{W}/(\text{m}^2 \cdot 14\text{MHz}))$	for	$9.4° < \theta \leq 90°$

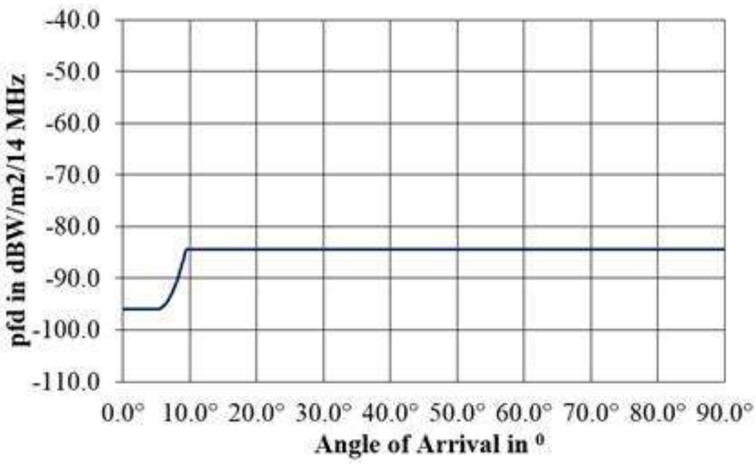
where θ is the angle of arrival of the radio-frequency wave (degrees above the horizon at the FS).

NOTE 1 The aforementioned limits relate to the pfd and angles of arrival that would be obtained under free-space propagation conditions.

Figure A7-22 shows the pfd mask for the frequency range 27.5-29.5 GHz.

FIGURE A7-22

PFD mask as function of angle of arrival for 27.5-29.5 GHz



ANNEX 10

Physical environment of unmanned aircraft

A10-1 Introduction

The physical environment of UA relevant for the CNPC assessments are mainly determined by the antenna pointing error on one side (mainly affecting the own link budgets) and the losses due to the fuselage obstructions (mainly affecting the links to / from fixed services, i. e. sharing cases).

The sections which follow analyse each of the potential impairments above.

A10-2 Antenna tracking and pointing error

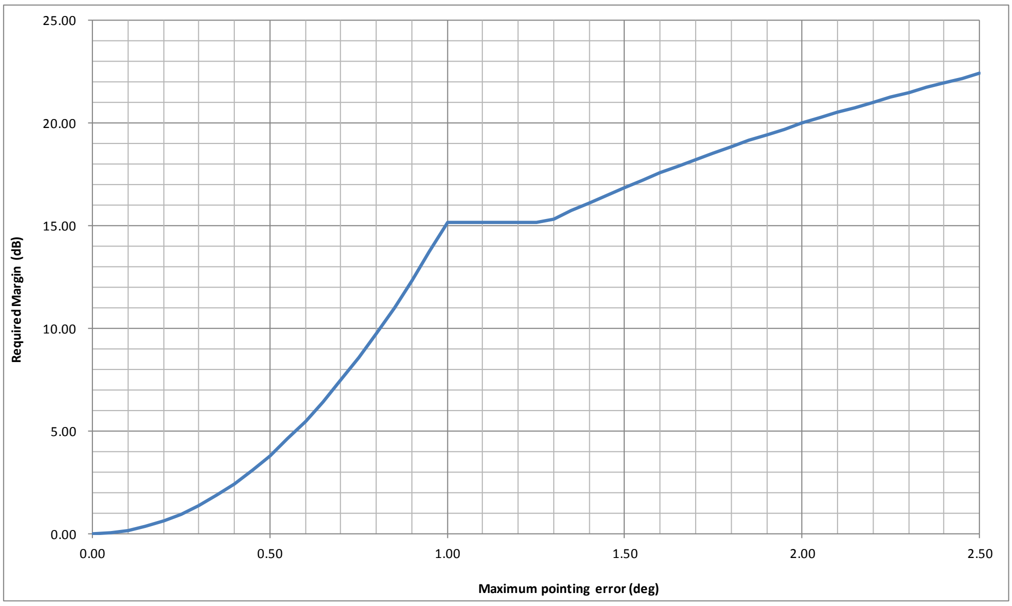
A degradation of the link performance could be caused by a temporary mis-pointing of the antennas used by the UAS (both that used by the UACS and that used by the UA). Being mobile by nature, particular concern might arise from the consideration of the terminal on board the UA. Any such terminal shall have the capability of automatically tracking the wanted satellite, modifying its azimuth and elevation taking into account the satellite longitude, the UA location on Earth (latitude and longitude), its altitude and its *pitch*, *roll* and *yaw* angles. Such performance can today be achieved by multiple-axis stabilized antennas, which provide a very precise pointing even when the antenna orientation needs to be adjusted following sudden and sharp manoeuvres of the aircraft.

Furthermore, such antennae are generally driven by an Antenna Control Unit (ACU) that continuously optimizes the pointing of the wanted satellite by maximizing the power of the received "beacon" signal or any other pre-determined carrier through strong and effective algorithms.

Although such systems are today extensively used in many civil applications, a mis-pointing error is always possible; the design of the link between the UAS and the FSS satellite should therefore take into account an appropriate margin to make sure that the link is kept "alive" even when such pointing error events would occur.

The magnitude of such margin depends on the terminal characteristics – mainly by the radiation pattern of its antenna. Knowing which is the maximum pointing error α that is not exceeded for a given percentage of time A_a, the margin can be therefore opportunely dimensioned and taken into account in the link design. As an example, the following Figure A10-1 illustrates the magnitude of the additional margin required depending on the maximum pointing error α for an antenna with a diameter of 80 cm, whose radiation pattern is compliant with Annex III of RR Appendix **8** and operating at 29.25 GHz.

FIGURE A10-1



A10-3 Impacts of unmanned aircraft fuselage

Determination of fuselage attenuation is needed for sharing studies between UA and FS (in both directions).

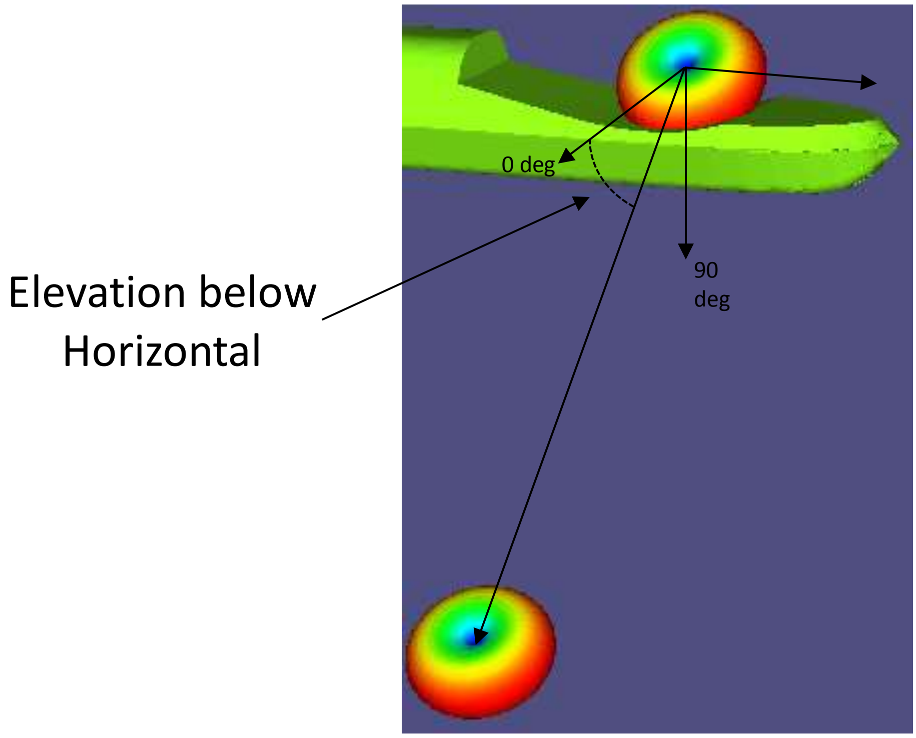
A10-3.1 Software Simulation used for calculations of fuselage attenuation

The UA fuselage attenuation is applicable to all interference scenarios from/to the UA. The placement of the FSS antenna that must operate effectively on an aircraft fuselage is an application that requires the use of professional Computational Electromagnetic (CEM) software. Fuselage attenuation was calculated using a shooting and bouncing rays simulation that is well suited to analysis of models of many wavelengths and aircraft dimensions. The simulation uses high-density ray tracing to determine surfaces currents induced in the fuselage by the antennas. These currents then reradiate to create the scattered fields that are added to the direct fields from the antennas. This simulation approach accurately predicts blockage, reflection and diffraction as well as creeping waves. The software employed has been used for many applications including the optimization and performance evaluation of the installed performance antennas placed on the fuselages of many aircraft.

The specific model used represented a typical medium to large size UA and consisted of an approximately one meter diameter tubular cross-section fuselage that was truncated horizontally across its diameter, see Figure A10-2, with the 14/11 GHz or 30/20 GHz antenna located high enough above the flat part of the fuselage so that no fuselage attenuation occurred up to 20 degrees antenna elevation below horizontal as would be required to accommodate 20 degrees of aircraft roll while pointing at a satellite low on the horizon. No aerodynamic radome was included in the simulation as it is effectively transparent at these frequencies.

FIGURE A10-2

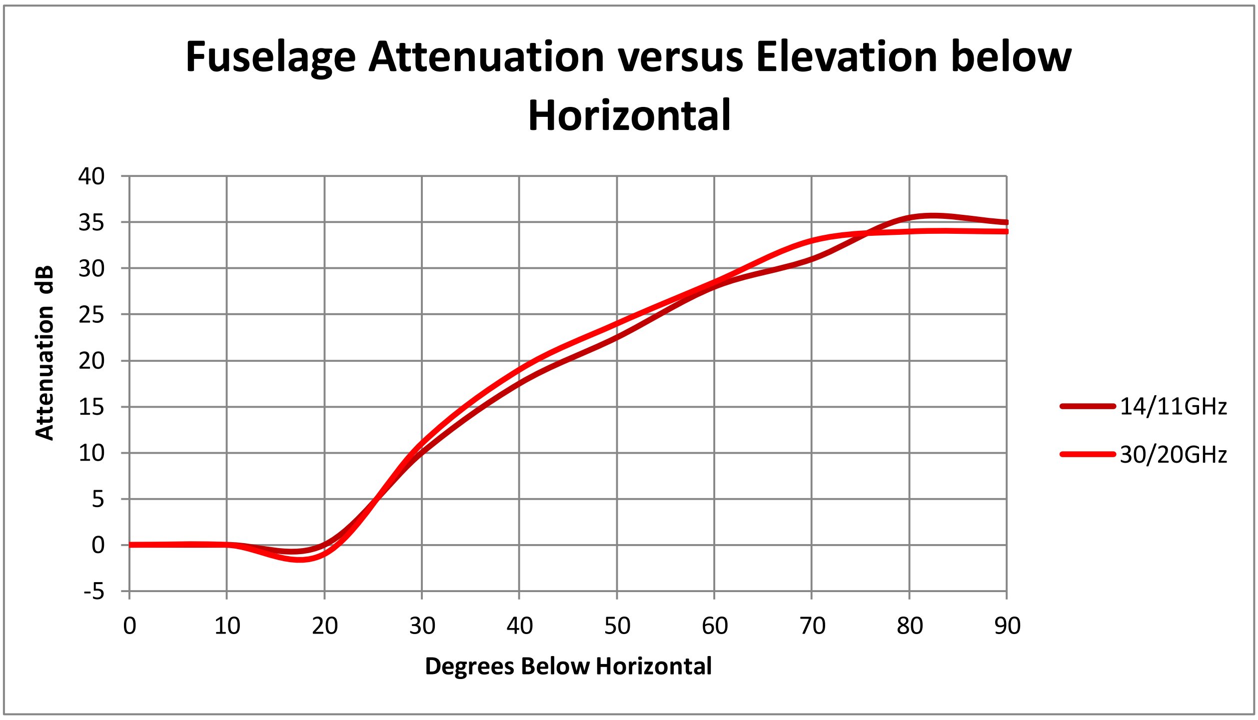
Antennas at 50 degrees elevation below horizontal



The fuselage attenuation was calculated by placing antennas greater than their near-filed distance apart to first calculate the free space path loss between them and then the path loss between the antennas was again calculated with the two antennas still pointing at each other but set at various elevation angles below horizontal relative to the fuselage, see Figure A10-2 showing an example at 50 degrees below horizontal. The difference between the free-space path loss and the path loss with the fuselage is plotted as fuselage attenuation versus elevation below horizontal in Figure A10-3 below.

FIGURE A10-3

Off-axis attenuation for unmanned aircraft in the frequency bands (14/11 and 30/20 GHz)

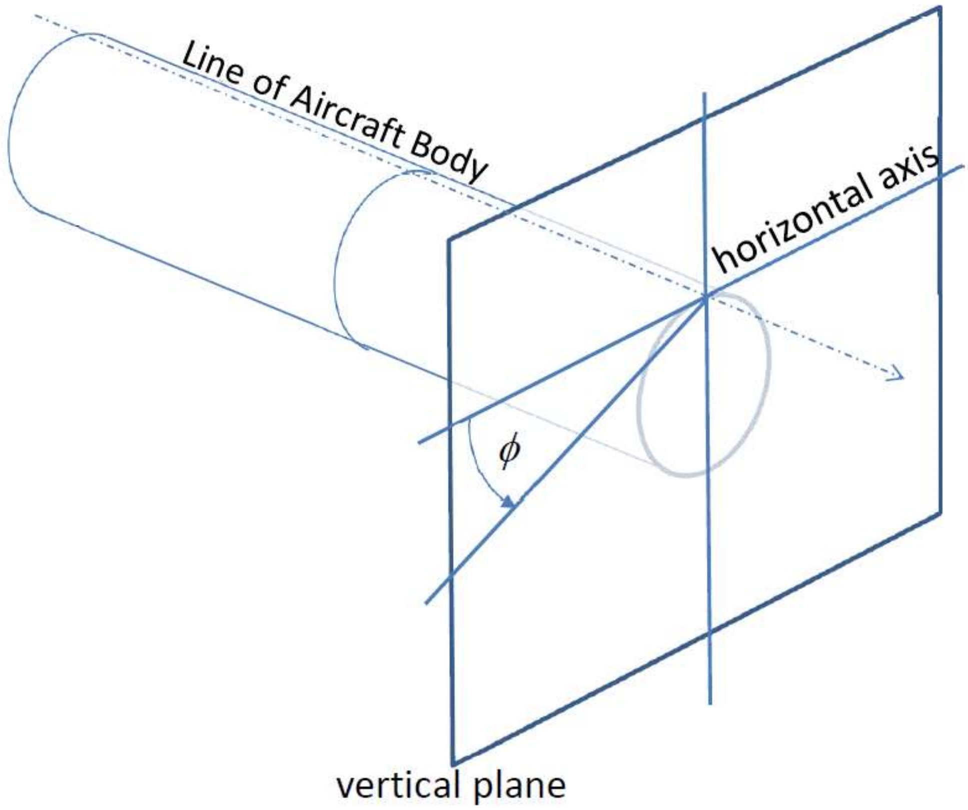


A10-3.2 Commercial Aircraft Fuselage Attenuation

Report ITU-R M.2221 (10/2011), Feasibility of MSS operations in certain frequency bands, contains data on a measurement campaign, run by an aeronautical Internet Service Provider. In that particular study, the attenuation due to the aircraft body on the roll-plane (i.e. for azimuth = 90°) has been measured when an antenna was mounted on top of a full cylinder with radius of curvature approximately equal to that of a Boeing 737 fuselage.

FIGURE A10-4

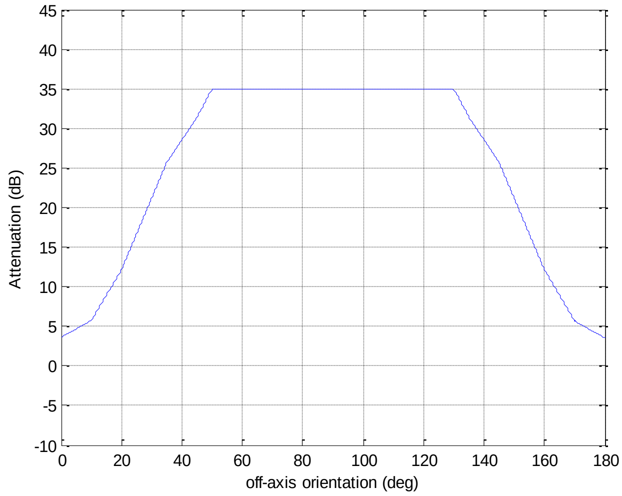
Reference coordinates of the fuselage of the aircraft



The following Figure shows the path loss over the roll plane; Φ = 0 = 180° is the aircraft horizontal axis.

FIGURE A10-5

Attenuation due to the fuselage of the aircraft



Although all of the measurements were made at 14.2 GHz the results will not be narrow band and can be extended to at least the 14/11 GHz band and possibly the 30/20 GHz band as well. More importantly the measurements agree very well with the simulation results from Section 3.1 of this Annex providing validation of that data across the frequencies (14/11 GHz and 30/20 GHz) included in the Section 3.1simulation.

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