UAS CNPC Satellite Link Performance – Sharing Spectrum with Terrestrial Systems

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Abstract—**In order to provide for the safe integration of unmanned aircraft systems into the National Airspace System, the control and non-payload communications (CNPC) link connecting the ground-based pilot with the unmanned aircraft must be highly reliable. A specific requirement is that it must operate using aviation safety radiofrequency spectrum. The 2012 World Radiocommunication Conference (WRC-12) provided a potentially suitable allocation for radio line-of-sight (LOS), terrestrial based CNPC link at 5030-5091 MHz. For a beyond radio line-of-sight (BLOS), satellite-based CNPC link, aviation safety spectrum allocations are currently inadequate. Therefore, the 2015 WRC will consider the use of Fixed Satellite Service (FSS) bands to provide BLOS CNPC under Agenda Item 1.5. This agenda item requires studies to be conducted to allow for the consideration of how unmanned aircraft can employ FSS for BLOS CNPC while maintaining existing systems. Since there are terrestrial Fixed Service systems also using the same frequency bands under consideration in Agenda Item 1.5 one of the studies required considered spectrum sharing between earth stations on-board unmanned aircraft and Fixed Service station receivers. Studies carried out by NASA have concluded that such sharing is possible under parameters previously established by the International Telecommunications Union. As the preparation for WRC-15 has progressed, additional study parameters Agenda Item 1.5 have been proposed, and some studies using these parameters have been added. This paper examines the study results for the original parameters as well as results considering some of the more recently proposed parameters to provide insight into the complicated process of resolving WRC-15 Agenda Item 1.5 and achieving a solution for BLOS CNPC for unmanned aircraft.**

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1. INTRODUCTION

Many potential applications for civil use of unmanned aircraft system (UAS) have been identified, with additional use concepts emerging almost daily. However, the ability of UAS to operate in the National Airspace (NAS), in particular in non-segregated airspace, faces many obstacles. Among a number of technical barriers that must be overcome to meet this goal is the absence of standard, certifiable communications links supplying the control and non-payload communications (CNPC) function, essentially providing the link over which a pilot on the ground can control the unmanned aircraft (UA). The International Civil Aviation Organization (ICAO) has determined that the CNPC link must operate over protected aviation spectrum. Therefore protected aviation spectrum must be allocated for this function, approved through the processes of the International Telecommunications Union Radiocommunication Sector (ITU-R).

Spectrum requirements have been established for both line-of-sight (LOS) and beyond-line-of-sight (BLOS) CNPC. Actions taken at the ITU's 2012 World Radiocommunication Conference (WRC) have established sufficient spectrum resources to meet the LOS spectrum requirement. The BLOS spectrum requirement remains unfulfilled. As a result, the UAS community has been searching for a solution to meet the BLOS CNPC needs.

It has been proposed to use existing Fixed Service Satellites (FSS), of which many operate in several bands, to provide BLOS CNPC. Given the size of most unmanned aircraft, higher frequency bands are preferred in order to have antennas small enough to mount on the aircraft. Therefore the use of FSS in Ku-Band (12-18 GHz) and Ka-Band (26.5-40.0 GHz) for BLOS CNPC has been proposed. Military UAS operations successfully using satellite links for CNPC in these bands have been cited as demonstrating the feasibility of this approach. Agenda Item 1.5 for the 2015 WRC was established to study this proposal and the associated regulatory requirements necessary to allow such an application in those bands.

As studies on the sharing of the Ku- and Ka-Band between existing services and CNPC for UAS have progressed, alternative viewpoints have been expressed regarding methods to ensure that terrestrial services sharing the proposed FSS bands are not subject to unacceptable interference levels. These methods can take the form of specific transmit power limitations, specification of antenna characteristics, co-frequency transmission limitations, coordination distances, and EIRP and/or power flux density limitations. Analyses have been prepared to examine some of these methods and the alternative system parameters. The results provide interesting possibilities in terms of assuring all interested parties that the terrestrial system can be properly protected while still enabling the required level of CNPC satellite link performance. For example, several variations of power flux density limits have been developed that would require UA using satellite communication links to employ specific transmit power limits, antenna pattern performance, and operational location limitations to avoid exceedance.

This paper will expand upon previous UAS CNPC satellite sharing study results to examine possible methods of specifying ways to ensure acceptable sharing with in-band terrestrial systems. The impact of system parameters and operational constraints vs. power density limitations will be explored and possible solutions presented.

2. Spectrum Environment for UAS CNPC

Spectrum requirements have been derived for both radio line-of-sight (LOS) and beyond radio line-of-sight (BLOS) CNPC, as described in [1]. Spectrum allocation for LOS CNPC were addressed at the 2012 World Radiocommunication Conference (WRC-12) by adding an Aeronautical Mobile (Route) Service (AM(R)) allocation to the 5030-5091 MHz band, augmenting other AM(R)S allocations in the 960-1164 MHz band. AM(R)S is a terrestrial aeronautical safety communications service which provides protection for safety critical aeronautical communications.

BLOS CNPC spectrum requires a similar type of allocation for satellite aeronautical safety communications, Aeronautical Mobile Satellite (Route) Service (AMS(R)S). Current AMS(R)S allocations are inadequate to meet the projected spectrum requirements for BLOS CNPC. Although there are several such allocations, they are either nearly saturated with existing uses, or as in the case of the AMS(R)S allocation in the 5030-5091 MHz band, there are no on-orbit systems in place to enable use of the band for AMS(R)S. In addition, as noted above this band also has an AM(R)S allocation to support LOS CNPC, and so has to be shared between the two services.

To address this lack of BLOS CNPC spectrum, WRC-12 adopted Resolution 153: "To consider the use of frequency bands allocated to the fixed-satellite service (FSS) not subject to Appendices 30, 30A and 30B for the control and non-payload communications of unmanned aircraft systems in non-segregated airspaces" [2]. This resolution essentially creates an agenda item for the 2015 World Radiocommunication Conference (WRC-15), known as Agenda Item 1.5, to consider, based on the results of the ITU-R studies, possible regulatory actions to support the use of FSS frequency bands for the UAS CNPC links, and invites ITU-R, ICAO and other administrations and organizations to conduct the necessary studies leading to technical, regulatory and operational recommendations to WRC-15 to enable it to decide on the usage of FSS for the CNPC links for the operation of UAS.

So, in the absence of adequate AMS(R)S spectrum and operational systems to support BLOS CNPC, it has been proposed to allow CNPC operations using the certain bands in the FSS, that is, using commercial satellite service. Since these bands do not have an AMS(R)S allocation to support what has been deemed to be an aeronautical safety service, a number of provisions must be accepted to enable CNPC communications links of sufficient quality to support a safety service while not placing an additional burden on the existing FSS services and operators in those bands. The development of the necessary provisions has been a difficult and lengthy process and is outside the scope of this paper. Instead here we are focused on a portion of the studies called for by WRC-12 Resolution 153.

Under WRC-15 Agenda Item 1.5, the bands being considered for UAS BLOS CNPC are in the Ku-Band and Ka-Band:

- 10.7-12.75 GHz – Ku-Band downlink from the satellite to the UA.
- 14.0-14.5 GHz – Ku-Band uplink from the UA to the satellite.
- 17.3-20.2 GHz – Ka-Band downlink from the satellite to the UA.
- 27.5-30.0 GHz – Ka-Band uplink from the UA to the satellite.

The studies required to support Agenda Item 1.5 look at interference and sharing/compatibility issues between the UAS, other FSS systems, and other services in the bands. Figure 1 shows the compatibility scenario, in which interference among the various entities must be analyzed [3].

Three types of sharing studies result. First, interference between the UA Control Station (UACS), an FSS earth station on the ground accessing the FSS satellite being used for CNPC, and other FSS satellites (links 1 and 4 in Figure 1), and between the FSS earth station on the UA and other FSS satellites (links 2 and 3 in Figure 1). Second, interference between in-band terrestrial system transmitters and the UA earth station receivers (link 2s in Figure 1). Third, interference from the UA earth station transmitter and in-band terrestrial system receivers (link 3s in Figure 1).

Although several types of terrestrial services have allocations in the bands under study, system characteristics and protection criteria exist only for the Fixed Service (FS allocation, so the second and third sharing studies involve only the UA FSS earth station and FS stations.

This paper focuses on the third type of sharing studies, interference from the UA earth station transmitter and in-band terrestrial system receivers.

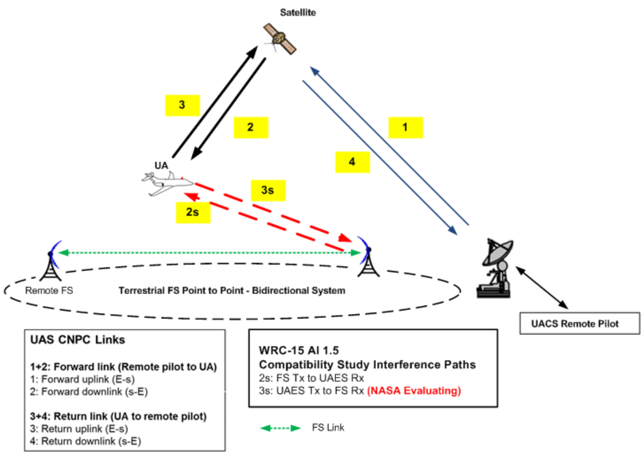


Figure 1 – Compatibility scenario for UAS BLOS CNPC in FSS bands.

3. PARAMETERS OF THE SHARING STUDY

Sharing study parameters are based upon approved ITU-R documents which detail such things as typical system characteristics, interference protection criteria, and analysis methodologies. ITU-R expert groups are consulted for advice as to which ITU-R documents provide the appropriate information for a particular sharing study.

For the sharing study between UAS and FS that is the subject of this study, ITU-R Working Party 5C provided recommendations as to the appropriate FS technical characteristics and protection criteria to apply. For the UA earth station, an ITU-R document detailing technical characteristics is still in development and has not yet been approved. The UA technical characteristics are therefore based upon the document currently under development and undergoing the ITU-R approval process.

The UA earth station transmit parameters are based on link budgets developed to meet the UA link requirements while operating within normal FSS system parameters. Since UA can vary considerably in size, three UA antenna diameters are defined for both KU-band and Ka-Band: 0.45 m, 0.8 m, and 1.25 m. Based upon measurements of typical existing UA antennas, a Bessel function antenna patterns is used to model these antennas. EIRP densities corresponding to these antenna sizes are 43.78, 53.78 and 57.68 dBW/250 kHz for Ku-Band, and 42.38, 44.48 and 48.08 dBW/kHz for Ka-Band, respectively. The reference bandwidth of 250 kHz is chosen to approximately correspond to transmit data rates of a maximum of 320 kbps.

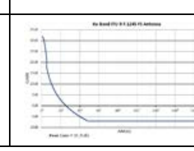
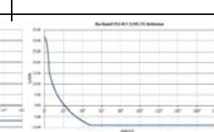
Of importance in studying interference scenarios for the sharing study is the expected density of UA. ITU-R has established expected peak UA densities for small, medium and large UA [4]. Only medium and large UA are large enough to be fitted with satellite antennas, so the UA densities used in the sharing study do not include small UA. Table 1 shows the medium and large UA peak densities. Due to antenna pointing limitations, UA using geostationary satellites for BLOS CNPC is not considered feasible at very high latitudes, therefore sharing studies are conducted considering only latitude from 0^0 to 70^0.

Table 1. UAS Peak Traffic Distribution

Type	Altitude	UA/km^2	UA/10,000km^2
Medium	300 – 5500m	0.000195	1.950
Large	>5500m	0.000044	0.440

FS station receive parameters are defined in [5]. The key parameters include antenna gain and efficiency, antenna pattern and receiver noise figure. The values for both bands are shown in Table 2. ITU-R Working Party 5C recommended analyzing FS antenna elevation angels of -5 to +5 degrees.

Table 2. Fixed Service Receive Parameters

	Units	14.0-14.5 GHz	27.5-29.5 GHz
Antenna Gain	dB	31.9	31.5
Antenna efficiency	%	60	60
Noise Figure	dB	8	8
Antenna pattern			

The final key sharing study parameter is the protection criteria, which is calculated to protect both long-term and short-term performance of the FS link from an unacceptable level of deterioration. As recommended by Working Party 5C, these criteria are described in [6] and [7] and summarized in Table 3. The interference criteria are defined in terms of received interference-to-noise power.

Table 3. Fixed Service Protection Criteria

Parameter	Frequency	Value	Comments
Long-Term I/N (dB)	14.0-14.5 GHz 27.5-29.5 GHz	-10 dB	Not to exceed for more than 20% of the time
Short-Term I/N (dB)	14.0-14.5 GHz	+20 dB	Not to exceed for more than $1x10^{-4}$ % of the time.
Short-Term I/N (dB)	27.5-29.5 GHz	+14 dB	Not to exceed for more than 0.01% of the time in any month.
Short-Term I/N (dB)	27.5-29.5 GHz	+18 dB	Not to exceed for more than 0.0003% of the time in any month.
Short-Term I/N (dB)	27.5-29.5 GHz	+9 dB	Not to exceed for more than 0.001% of the time.

4. RESULTS FOR THE GENERAL CASE

Sharing studies considered the general, or average case where the FS station can vary in its configuration, such that the FS antenna can be pointing in azimuth over a range of $\pm180^0$ and the antenna elevation angle can vary over a range of $\pm 5^0$. The process employed for the sharing study analyses is described in [3].

Sharing studies considering the long-term FS protection criteria were carried out for UA altitudes of 3000 ft and 19000 ft, with FS stations located at latitudes of 10^0, 40^0 and 70^0. For both frequency ranges, the small (0.45 m diameter) and large (1.25 m diameter) antennas were used in the analysis. Each combination of these parameters was simulated, resulting in data used to create cumulative distribution functions of the probability of exceeding the protection criteria. The results showed that for all cases, the long-term protection criteria was met – the received I/N did not exceed -10 dB for more than 20% of the time. This result applied to both frequency ranges under study.

Figures 2 through 5 show example results for the small and large Ku-Band and Ka-Band antennas at three latitudes of operation. In all of these cases the UAS was flying at an altitude of 3000 ft. The analyses at 19000 ft in all cases resulted in lower probabilities than the corresponding 3000 ft. cases. The protection criteria is shown as a red diamond at the intersection of -10 dB (x-axis) and 20% (y-axis). The cdf curves lying below this point indicate that the protection criterion has been met. Examination of many simulation results supports the key conclusion that while the long-term protection criteria threshold of 10 dB can be exceeded by UA in many circumstances, the expected peak density of UA is not sufficient to allow this threshold to be exceeded 20% of the time.

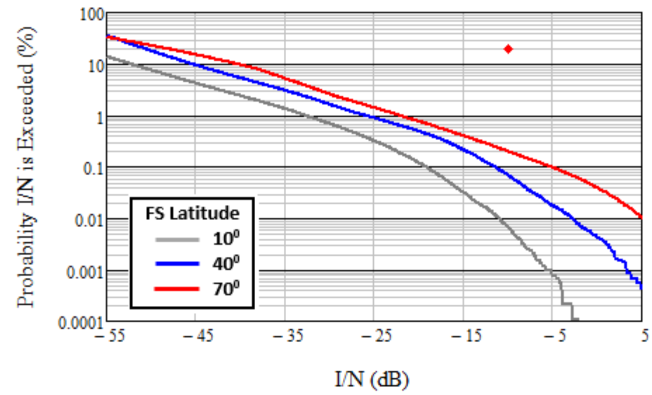


Figure 2 – Long-term analysis results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna

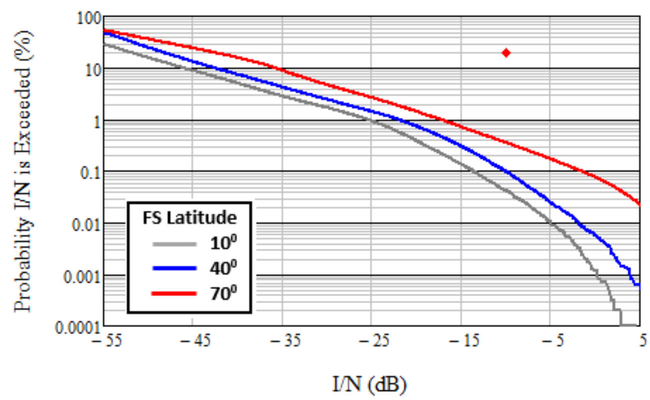


Figure 3 – Long-term analysis results for 14.4 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna

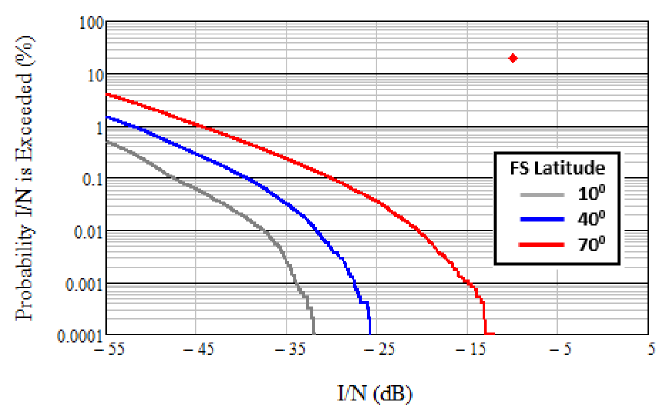


Figure 4 – Long-term analysis results for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, small UA antenna

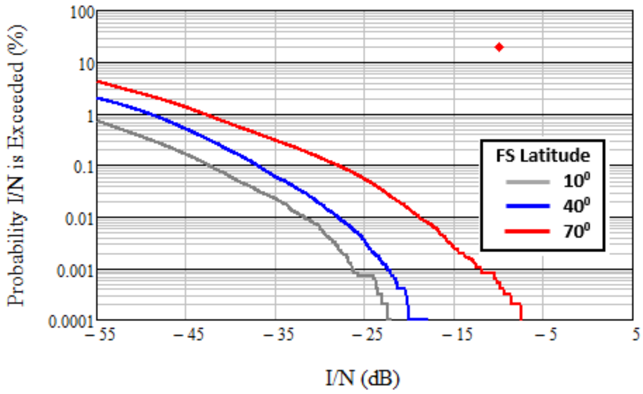


Figure 5 – Long-term analysis for 28.5 GHz with FS station at 10^0, 40^0, and 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna

The analysis approach for the short-term protection criteria is described in [3]. The short term criteria is much more stringent in terms of the amount of time in which the criteria can be exceeded, although the I/N threshold is higher. This higher I/N threshold results in a much smaller area in which a UA cause and exceedance of the protection criteria. Figure 6 shows an example of how this exceedance area can vary with altitude.

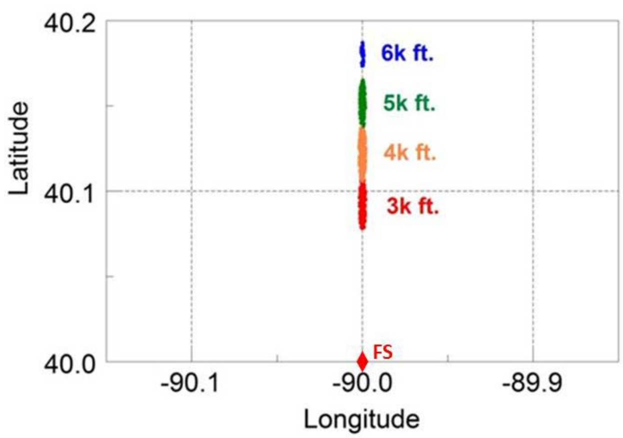


Figure 6 - Areas in which unmanned aircraft at altitudes of 3 000, 4 000, 5 000, and 6 000 ft need to reside in order to produce an I/N greater than 20 dB, for an FS station at 40^0 N.

To gain the required level of simulation resolution, the simulation area was greatly reduced in order to develop cdf curves having the required accuracy at low probabilities. Figure 7 is an example showing how the closely the short-term protection criteria for the Ku-Band case is met at the highest latitude. The red diamond indicates the short-term protection criteria.

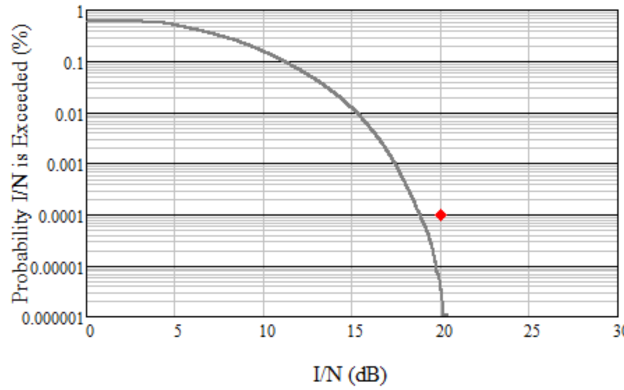


Figure 7 – Short-term analysis for 14.45 GHz with FS station at 70^0 latitude, UA at 3 000 ft above ground level, large UA antenna

5. STUDIES FOR ADDITIONAL PARAMETERS

After the results above were completed, additional study parameters were proposed by some ITU-R member administrations. In addition, Working Party 5C made additional recommendations on sharing study parameters, less than four months prior to the opening of WRC-15. This left very little time to prepare additional studies based on these new parameters, but it was considered that such information would still be useful. So some additional studies were carried out.

First, it was suggested that the Bessel function antenna was not an appropriate antenna model for the UA antenna because, although UA manufacturers claimed that it was an accurate representation of a real UA antenna, the Bessel function pattern was not included in the ITU-R catalog of antenna patterns applicable to the FSS. An antenna pattern designated by ITU as S.580-APL-UM001 was suggested to be used, as applicable to an FSS earth station. Figure 8 compares a peak-envelope Bessel function pattern and the S.580-APL-UM001.

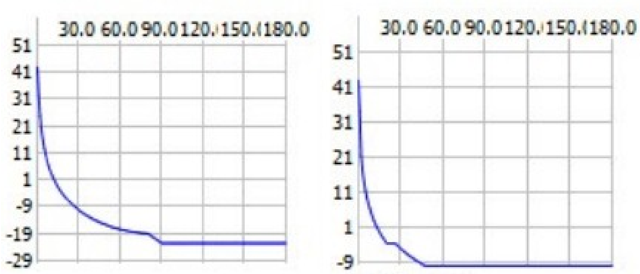


Figure 8 – Antenna patterns for sharing study analyses, peak-envelope Bessel function (left) and S.580-APL-UM001 (right)

It was further suggested that a study concentrating on the worst possible interference scenario be conducted to assess the potential operational bounds for a UA using satellite communications for BLOS CNPC.A study was therefore conducted to ascertain the worst case study parameters. This was presented in [8], with the resulting worst case parameters: the FS and FSS satellite at which the UA is pointing are at the same longitude; the FS antenna azimuth is 0^0 (i.e. pointing North); the is FS located at 70^0 N latitude; the UA is flying at the minimum analyzed altitude of 3000 ft altitude; and the FS elevation angle is $+5^0$. Consequently these input parameters were applied to the compatibility analyses under FS long-term and short-term protection criteria.

The same methodology was applied to the long-term and short term analyses as for the previous studies, except that the FS was studied only at 70^0 latitude and the FS antenna was fixed in azimuth and elevation, and the UA was studied only at an altitude of 3000 ft. Both the Bessel function antenna and the S.580-APL-UM001 were used in this study, and the small and large diameter antennas were analyzed. Figures 9 and 10 show the results for the long-term FS protection criteria study, for Ku-Band and Ka-Band, respectively. The red diamond again indicates the protection criteria.

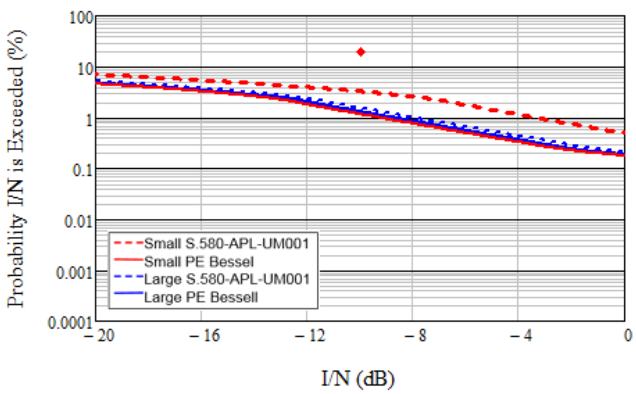


Figure 9 – Long-term analysis for 14.4 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes.

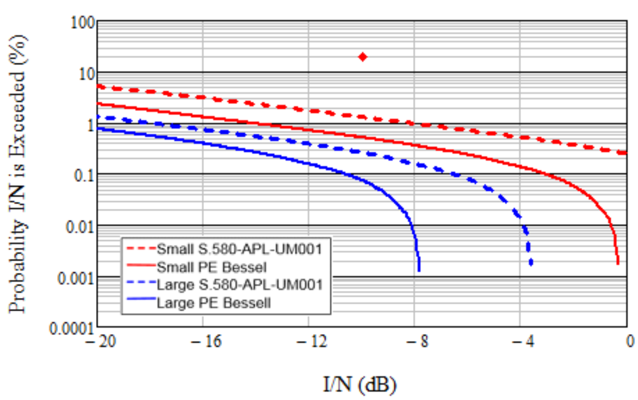


Figure 10 – Long-term analysis for 28.5 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes.

Under the worst case conditions, the long-term criteria are met for both frequency bands regardless of the antenna pattern analyzed.

To analyze the short-term protection criteria at the worst case conditions, it was suggested to consider only whether the short-term protection criteria was exceeded, rather than the percent of time the exceedance occurred. This was to take into account the uncertainty of UA velocity, considering the very small time intervals involved in defining the protection criteria, which could be as small as 3 seconds in one month.

This changed the sharing study analysis to a search for UA operational conditions where the I/N threshold could never be exceeded, rather than developing a cdf to compare to the criteria. Tables 4 and 5 show the results for the worst case conditions, analyzing both antenna patterns and the small and large antenna diameters, for Ku-Band and Ka-Band respectively. The tables show the minimum UA altitude at which the I/N threshold is not exceeded when operating in the vicinity of an FS located at 70^0 latitude, and the maximum latitude at which an UA can operate as low as 3000 ft without exceeding the I/N threshold.

Table 4. Results of short term FS protection criteria analyses for 14.4 GHz

Antenna size	Antenna pattern	Min altitude at 70^0	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

Table 4. Results of short term FS protection criteria analyses for 28.5 GHz

Antenna Size	Antenna Pattern	Min altitude at 70^0	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

The analyses show that for the Ka-Band case the short term protection criteria are still met even regardless of the antenna pattern and very strict application of the protection criteria. However for the Ku-Band case, these conditions result in operational restrictions for the UA. Either the UA must always maintain an altitude of 5000 ft or higher in order to operate at latitudes up to 700, or must operate at lower latitudes in order to fly as low as 3000 ft, in order to avoid any possibility of exceeding the short-term I/N threshold.

Working Party 5C recommended studying additional FS parameters in the Ka-Band frequency range as an outcome of their July 2015 meeting. Parameters for four different types of FS stations, designated as FS1, FS2, FS3, and FS4 are shown in Table 5.

Table 5 - Additional FS station parameters for the 27.5-30.0 GHz range

Parameter	FS1	FS2	FS3	FS4
Receiver Noise Figure, dB	6	6	6	6
Antenna Elevation Angle	0^0	5^0	10^0	0^0
Antenna Gain, dBi	45	43	35	18

With very little time remaining to complete additional studies in time for WRC-15, the previous analysis methodologies were applied for both the long-term and short-term FS protection criteria.

The results for the long-term studies, which applied the worst case conditions using the small and large diameter antennas and the two antenna patterns along with the FS station parameters FS1, FS2, FS3 and FS4 are shown in figures 11-14, respectively.

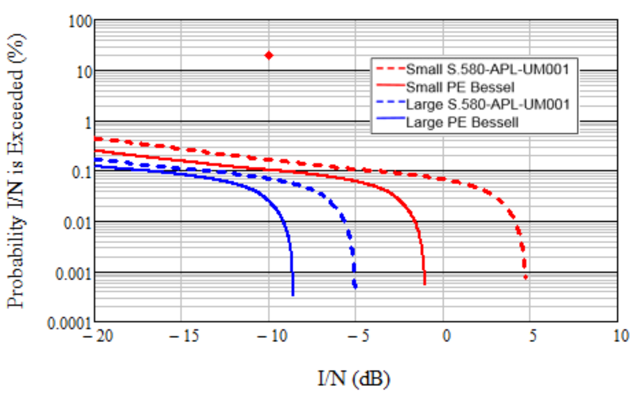


Figure 11 – Long-term analysis for 28.5 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes for FS1.

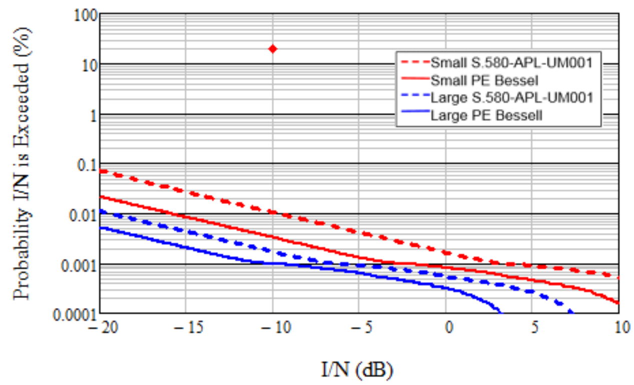


Figure 12 – Long-term analysis for 28.5 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes for FS2.

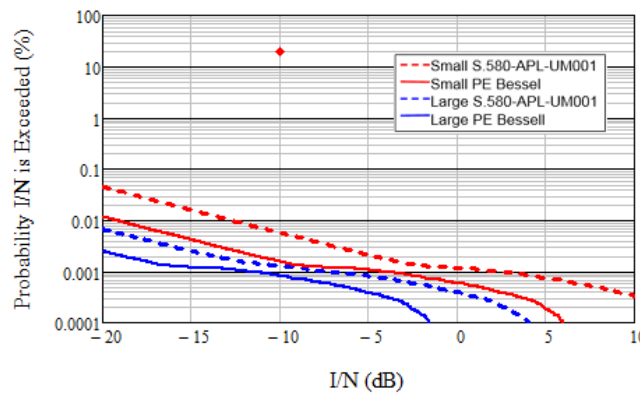


Figure 13 – Long-term analysis for 28.5 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes for FS2.

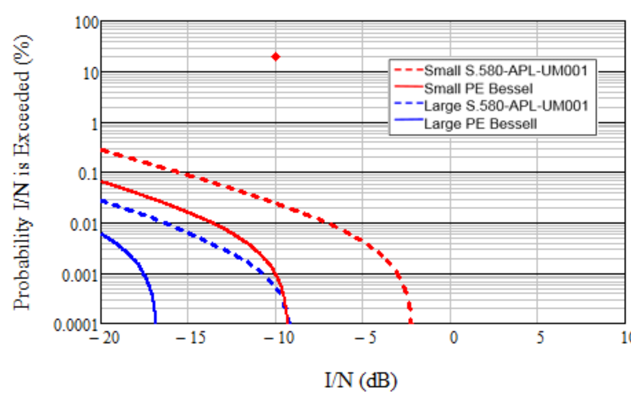


Figure 14 – Long-term analysis for 28.5 GHz with worst-case study parameters, for two antenna patterns and two antenna sizes for FS2.

The sharing study results for the worst case conditions using the additional FS station parameters show that the long-term protection criteria is still met. This reflects the previous conclusion that the density of UA is insufficient to cause the long-term I/N threshold to be exceeded more than 20% of the time.

Table 6 - Results of short term FS protection criteria analyses for 28.5 GHz

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

For the additional FS station parameters, short term analyses were conducted in the same manner as described for the worst case short-term analyses above, using the small S.580-APL-UM001 and the small and large S.580-APL-UM001 and peak-envelope Bessel antenna patterns. The results of these analyses are shown in Table 6 along with the previous result using the FS parameters from [5].

The results show that for FS1 and FS 4 the short-term criteria are met without any constraints on UA operation. For FS 3, use of the small S.580-APL-UM001constrains the UA operation to 6000 ft altitude and above, or to 57^0 latitude and below if operating at 3000 ft altitude. For FS2, use of both the small and large S.580-APL-UM001 antennas impose an altitude and/or latitude constraint – 5000 ft for the small antenna and 4000 ft for the large antenna, or 57^0 for the small antenna at 3000 ft or 68^0 for the large antenna at 3000 ft.

6. Conclusion

WRC-15 Agenda Item 1.5 requires the completion of several sharing studies to ascertain the conditions under which UA may be able to make use of satellites in the FSS, in both Ku-Band and Ka-Band frequency ranges, to support BLOS CNPC. Among these sharing studies is an investigation of the potential interference from a UA earth station transmitter into an FS receiver. Protection criteria defined in approved ITU recommendations are applied to determine whether the potential interference si within acceptable levels.

Characteristics of the UA earth station have been proposed, although they are not yet available in an approved ITU publication. Characteristics of the FS receiver are available in ITU publications recommended by the ITU-R expert group Working Party 5C.

Sharing studies completed before 2015, based on Working Party 5C recommendations, showed that the FS protection criteria could be met considering UA earth station technical characteristics currently under development, in the ITU expert group Working Party 5B.

However, since those studies were completed, some ITU member administrations proposed that additional parameters and characteristics also be studies, and Working Party 5C also recommended additional FS parameters less than four months before the start of WRC-15.

Additional studies performed suing these more recent study parameters indicate that there are conditions under which the FS protection criteria may not be met. However, although they may place some constraints on UA operations, these constraints do not appear to be severe, and it remains possible that satellite operating under the FSS can support UA BLOS CNPC. However, WRC-15 will make that determination.

Overall, we can see that the sharing studies are sensitive to variations in the study parameters, which is not unexpected. Agreement on the proper study parameters to apply is crucial in arriving at an internationally harmonized outcome for WRC-15 Agenda Item 15.

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BIOGRAPHIES

Robert J. Kerczewski *has been involved with research and development of satellite and aeronautical communications systems and applications for the Analex Corporation (1982-1986) and NASA (1986-present). He holds a BEE degree from Cleveland State University (1982) and an MSEE degree from Case Western Reserve University (1987). He is currently the Spectrum Element Manager for the NASA's Unmanned Aircraft Systems Integration in the National Airspace System (UAS in the NAS) Communications Sub Project.*

Jeffrey D. Wilson *received the B.S. degree in physics magna cum laude from Bowling Green State University in 1976, and the M.S. and Ph.D. degrees in physics from the University of Illinois at Urbana-Champaign in 1978 and 1983, respectively. Since 1983, Dr. Wilson has been associated with the vacuum electronics microwave amplifier research group at NASA Glenn Research Center, Cleveland, Ohio. He spent the 1984-1985 academic year in postdoctoral study with the Air Force Thermionic Electronics Research (AFTER) Program at the University of Utah. His research efforts have focused on computational techniques to enhance the power, efficiency, and performance of coupled-cavity, helical, and terahertz wave traveling-wave tubes (TWT's), the electromagnetic properties of metamaterials, and interference issues in RF communications systems. Dr. Wilson is a Senior Member of IEEE.*

William D. Bishop is currently involved with the research, design and development of Unmanned Aircraft Systems (UAS) Control Non-Payload Communications (CNPC) Systems at NASA in the Datalink and Spectrum Sub-Project areas (2010-present). He also has extensive, comprehensive wireless industry experience (commencing in 1986) in the RF design, optimization and management of wireless networks supporting all U.S. carriers in all currently deployed voice and data technologies. His early efforts include the design, development and practical use of the Dual-Cell Concept (FOA - GTE Mobilnet, 1987), which increased offered load capacity in congested areas within a traditional reuse plan. He holds a BEE degree from Cleveland State University - Fenn College of Engineering (1998), as well as an FCC General Radiotelephone License (1986).