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Sharing conditions between space research service proximity operations links and fixed and mobile service links in the 410-420 MHz band

SA Series

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1 Introduction

WARC-92 allocated the band 410-420 MHz to the space research service (SRS) on a secondary basis to allow for extra-vehicular activity (EVA) communications in the vicinity of Earth orbiting manned space vehicles. RR No. **651A** (WARC-92) was applied to the SRS allocation specifying that use of the band by the SRS is limited to EVA operation within 5 km of orbiting manned space vehicles. WRC-97 upgraded the allocation to the SRS in the band 410-420 MHz to primary status with the conditions given in RR No. **5.268**, which include a set of power flux-density (pfd) limits to assure protection of the fixed and mobile services based on ITU studies and the previously agreed to RR No. **651A** distance and EVA operation limitations. WRC-15 agenda item 1.13 proposes for consideration an examination of RR No. **5.268** to remove or relax the 5 km distance limitation without modifying the existing pfd limits and SRS (space-to-space) uses beyond extra-vehicular activities in the band 410-420 MHz.

The band 410-420 MHz is used today for communications by astronauts conducting EVA operations in the immediate vicinity of the international space station (ISS). The physical construction of a manned space vehicle is typically of material and design not necessarily optimized for radio-frequency communication (such as the ISS); hence the use of this band for proximity operations by vehicles approaching manned space vehicles would be advantageous as the propagation and physical properties of this frequency range enable comparable coverage performance in the highly multipath environment.

The 5 km limit was agreed during WARC-92 when the use of the band was envisioned for free floating astronauts working in the near vicinity of a manned space vehicle. The addition of pfd limits by WRC-97 assures the protection of systems operating in the fixed and mobile services. Vehicles approaching the ISS, whether manned or robotic, need to communicate over somewhat longer distances to ensure safe operations and docking manoeuvres. It is therefore necessary to modify RR No. **5.268** to remove the 5 km limitation while maintaining the current pfd limits. Similarly, this will allow proximity operations with orbiting vehicles and not solely limit the use of the band for extra-vehicular activities.

Resolution **652 (WRC-12)**, *recognizing c)*, states that "power flux-density (pfd) limits contained in RR No. **5.268** ensure the protection of terrestrial stations operating in the fixed and mobile services independent of the distance from, or the source of, space-to-space communications in the SRS". In accordance with WRC-15 agenda item 1.13, this Report presents a description of proximity link operations and typical communication characteristics for SRS (space-to-space) systems communicating in proximity with orbiting manned space vehicles and analyses to demonstrate space vehicle links operating in the 410-420 MHz band, around a manned vehicle beyond 5 km, can meet the pfd limits in RR No. **5.268**.

2 Space research service (space-to-space) proximity operations

As discussed above, the band 410-420 MHz is advantageous for proximity operations between vehicles approaching one another in a space-to-space environment. Currently, most proximity operations occur when a visiting vehicle is set to rendez-vous with the ISS. The ISS uses capabilities of different space vehicles to resupply consumables, transfer crew, launch flight elements, and provide systems for assembly, repair or replacement. As other permanent space facilities are developed and implemented in the future, the needs and requirements for proximity links between two space vehicles will increase in order to support space operations and exploration activities.

Visiting vehicles to orbiting space facilities, such as the ISS, can be manned spacecraft able to provide manual control for rendez-vous or can be autonomous space vehicles that are able to rendez-vous and dock with the space facility without human intervention. In either case, the procedure for the docking manoeuvre is a highly delicate process with no margin for error. The two spacecraft must be in constant, high quality communications, to assure a successful rendez-vous without any damage to the spacecraft or any danger to human life.

As a visiting vehicle approaches an orbiting space facility such as the ISS, two primary and reliable communications functions will need to be established for a successful rendez-vous of the two vehicles. The first function is a direct means of communications between the crew on the ISS and the crew on the visiting vehicle (for manned visiting vehicles only). The second function is a direct means of data communication between the two vehicles. These two functions are essential to provide timely and accurate information such as range, speed, and any other essential rendez-vous information that can be communicated to the observing crew or onboard systems. Also, in the case of an autonomous rendez-vous operation, the base station crew should be able to send critical commands to the approaching spacecraft. Reliable operations of these communications links between a visiting vehicle and a manned space station is required to ensure safe rendez-vous operations. The nominal communication range of the proximity link for rendez-vous with the ISS is between 23 km and 30 km, depending on the approach trajectory, in order for the approaching space vehicle to determine a navigational solution and to assure required accuracy and precision for a successful approach and rendez-vous.

From an orbital dynamics viewpoint, a visiting vehicle spacecraft typically approaches the ISS either in-line with the flight path of the spacecraft (V-bar approach) or perpendicular to the flight path along the line of the radius of the orbit (R-bar approach). The visiting vehicles, in this case the active or chaser, approaches the ISS from behind and below. Thus, the orientation and pointing of the communication antenna will direct the main beam of the visiting vehicle antenna towards the ISS and away from the surface of the Earth.

Proximity communications between a visiting vehicle and the ISS can occur at multiple data rates to fulfil the minimum requirements for reliable rendez-vous operations. As an example, rendez-vous manoeuvres between a visiting vehicle and the ISS, commands to and receipt acknowledgements can be sent at low rates for operations at specific checkpoints outside of 30 km, between 30-10 km and higher rates between 10-0 km. Power management schemes on board both the visiting vehicle and the ISS, in combination with techniques such as spread spectrum technology, coding to reduce required E_b/N_0, advanced modulation, and spacecraft attitude management can assure compliance with the pfd. Table 1 presents typical data rate variation and the expected usage based on the distance of the visiting vehicle from the ISS.

TABLE 1

Data rate change for SRS (space-to-space) proximity operations

Data rate (kbps)	Range from ISS (km)
10	Greater than 10.0
50	10.0 – 2.5
250	2.5 – 0.0

3 Protection of fixed and mobile service

RR Footnote No. **5.268** provides for the primary use of the band 410-420 MHz by the SRS and specifies the pfd limits to protect existing allocated terrestrial users in the 410-420 MHz band.

The pfd limits specified by RR No. **5.268** are that the pfd at the surface of the Earth produced by emissions from extra-vehicular activities shall not exceed:

– -153 dB(W/m^2) for $0° \leq \delta \leq 5°$

– $-153 + 0.077\ (\delta-5)$ dB(W/m^2) for $5° \leq \delta \leq 70°$

– -148 dB(W/m^2) for $70° \leq \delta \leq 90°$

where δ is the angle of arrival of the radio-frequency wave and the reference bandwidth is 4 kHz.

4 Transmission parameters and maximum pfd levels

Equation (1) gives the expression for the calculation of the pfd level at the Earth's surface.

$$pfd = \frac{P_t G}{4\pi}\left[\frac{1}{\frac{h}{\cos\theta}}\right]^2 \; W/m^2 \qquad (1)$$

where:

pfd: power flux-density level at the Earth's surface (W/m^2)

P_t: transmit power (W)

G: antenna gain (dBi)

h: orbital altitude (m)

θ: incidence angle (degrees).

Using equation (1), the maximum pfd incident on the surface of the Earth can be calculated from the transmit parameters of the visiting vehicle and the ISS.

Tables 2 and 3 present typical communication characteristics of SRS (space-to-space) proximity operations during the final 2.5 km of a rendez-vous operation. The higher data rate requirement is driven by the need for more frequent updates of telemetry during the final approach for GO/NOGO decisions during this critical period. Spread spectrum technology of at least 6 MHz and as high as

10 MHz in the 410-420 MHz supports the increased data rate requirement while assuring compliance to the pfd limit.

TABLE 2

SRS 2.5 km – 0.0 km proximity operations characteristics using spread spectrum technology of 6 MHz

	Visiting vehicle	**Base vehicle**
Transmitter power (dBW)	10	4
Transmitter line losses (dB)	–3	–13
Maximum antenna gain towards the surface of the Earth (dBi)	–14	5
Bandwidth (MHz)	6	6
Orbital altitude (km)	390	390
pfd (dBW/m^2/4 kHz)	–161.56	–158.57

TABLE 3

SRS 2.5 km – 0.0 km proximity operations characteristics using spread spectrum technology of 10 MHz

	Visiting vehicle	**Base vehicle**
Transmitter power (dBW)	10	4
Transmitter line losses (dB)	–3	–13
Maximum antenna gain towards the surface of the Earth (dBi)	–14	5
Bandwidth (MHz)	10	10
Orbital altitude (km)	390	390
pfd (dBW/m^2/4 kHz)	–163.80	–160.79

Using the SRS proximity parameters presented in Table 2, the worst-case unwanted field strength (expressed in terms of pfd incident at the surface of the Earth) is found to be –161.56 dBW/m^2/4 kHz for links from a visiting vehicle to the ISS and –158.57 dBW/m^2/4 kHz for links from the ISS to a visiting vehicle for a spread spectrum system of 6 MHz. Using the SRS proximity parameters presented in Table 3, the worst-case unwanted field strength (expressed in terms of pfd incident at the surface of the Earth) is found to be –163.80 dBW/m^2/4 kHz for links from a visiting vehicle to the ISS and –160.79 dBW/m^2/4 kHz for links from the ISS to a visiting vehicle for a spread spectrum system of 10 MHz. These values meet the protection criteria for all elevation cases given by RR No. **5.268**.

Table 2 presented the system characteristics of a visiting vehicle under worst-case, highest rate communications. As shown in Table 1, these characteristics are not constant over the full 23 km – 30 km rendez-vous communications range. At a further range of proximity operations, commands can be sent using low rate communications and at a lower transmit power. These low rate communications may not utilize spread spectrum technologies since the lower transmit power will meet the pfd limit of RR No. **5.268**. Tables 4 and 5 present the system characteristics of a visiting vehicle operating from 10.0 – 2.5 km and 30.0 – 10.0 km. The maximum bandwidth considered for these links is 338 kHz.

TABLE 4

SRS 10.0 km – 2.5 km proximity operations characteristics

	Visiting vehicle	**Base vehicle**
Transmitter power (dBW)	0	-8
Transmitter line losses (dB)	–3	–13
Maximum antenna gain towards the surface of the Earth (dBi)	–14	5
Bandwidth (kHz)	338	338
Orbital altitude (km)	390	390
pfd (dBW/m^2/4 kHz)	–159.06	–158.11

Using the SRS proximity parameters presented in Table 4, the worst-case unwanted field strength (expressed in terms of pfd incident at the surface of the Earth) is found to be –159.06 dBW/m^2/4 kHz for links from a visiting vehicle to the ISS and –158.11 dBW/m^2/4 kHz for links from the ISS to a visiting vehicle. This value meets the protection criteria for all elevation cases given by RR No. **5.268**.

TABLE 5

SRS greater than 10.0 km proximity operations characteristics

	Visiting vehicle	**Base vehicle**
Transmitter power (dBW)	–6	–14
Transmitter line losses (dB)	–3	–13
Maximum antenna gain towards the surface of the Earth (dBi)	–14	5
Bandwidth (kHz)	338	338
Orbital altitude (km)	390	390
pfd (dBW/m^2/4 kHz)	–165.06	–164.07

Using the SRS proximity parameters presented in Table 5, the worst-case unwanted field strength (expressed in terms of pfd incident at the surface of the Earth) is found to be –165.06 dBW/m^2/4 kHz for links from a visiting vehicle to the ISS and –164.07 dBW/m^2/4 kHz for links from the ISS to a visiting vehicle. This value meets the protection criteria for all elevation cases given by RR No. **5.268**.

The representative scenarios of rendez-vous operations between the ISS and a visiting vehicle demonstrate the ability to ensure the protection of the pfd limits in several ways. The first is through the use of pfd compliant communication link design as identified above. Requirement of rendez-vous operations demand that visiting vehicles resolve spacecraft altitude to within 0.1 degree (not during burns) and 0.5 degrees (during burns) in order to safely and effectively dock with the ISS. With the visiting vehicle holding to less than 0.5 degrees, the antenna gain will vary by less than 2 dB worst-case and less than 1 dB in most cases.

Additionally, the system will be disabled if the visiting vehicle attitude varies by more than 5 degrees off-nominal in any axis. The system can also be disabled manually from ground control or directly from the ISS. These combinations of systems and techniques will ensure that the pfd limit given in RR No. **5.268** will always be satisfied.

5 Conclusion

This Report presents the technical parameters and operational considerations for SRS (space-to-space) systems for proximity operations in the 410-420 MHz band. The maximum possible pfd levels are calculated based on the typical operational parameters presented in this Report. The analyses demonstrate that RR No. **5.268** pfd limits can be satisfied by using different modulation, spreading technologies, and power control schemes by proximity operations beyond 5 km. By keeping the pfd limit in RR No. **5.268** unchanged, the protection of fixed and mobile services is maintained regardless of the distance between the SRS space-to-space communications systems. Modern communications techniques can be employed to achieve compliance to pfd limits, independent of the placing restrictions on distance from, or the source of, space-to-space communications in the SRS.