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Representative system characteristics and examples of evaluating interference into receiving earth stations in the radionavigation-satellite service (space-to-Earth) from spaceborne synthetic aperture radar sensors in the Earth exploration-satellite (active) service in the 1 215-1 300 MHz band

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REPORT ITU-R RS.2537-0

Representative system characteristics and examples of evaluating interference into receiving earth stations in the radionavigation-satellite service (space-to-Earth) from spaceborne synthetic aperture radar sensors in the Earth exploration-satellite (active) service in the 1 215-1 300 MHz band

(Question ITU-R 234/7)

(2023)

Scope

Recommendation ITU-R RS.2160 recommends that the methodology of Recommendation ITU-R M.2030 be used for performing a preliminary evaluation of the interference from one of the planned and future Earth exploration-satellite service (active) (EESS (active)) spaceborne synthetic aperture radars (SARs) to the receiving earth stations in the radionavigation-satellite service (RNSS) (space-to-Earth) operating in the frequency band 1 215-1 300 MHz. This Report presents examples of applying the methodology of Recommendation ITU-R M.2030 in a preliminary evaluation of the interference from one of the spaceborne synthetic aperture radars in the EESS (active) into receiving earth stations in the RNSS (space-to-Earth) operating in the 1 215-1 300 MHz frequency band. This Report has not been evaluated for application to RNSS (space-to-space) receivers on board spacecraft. Annex 1 contains technical characteristics for representative EESS spaceborne SARs and characteristics and protection criteria for RNSS receiving earth stations based on Recommendation ITU-R M.1902. Annex 2 presents examples of applying the individual interference evaluation methodology for representative spaceborne SARs of Annex 1 with representative RNSS receivers. When the studies on scatterometers operating in the 1 215-1 300 MHz band are complete, relevant material could be included in a revision to this Report.

NOTE – Because there has been an increased number of satellite networks within the EESS (active) in recent years in the frequency band 1 215-1 300 MHz, including systems consisting of multiple, simultaneously-operating EESS (active) satellites, it is reasonable in future to continue the studies in order to take into account the influence of the aggregate interference from EESS (active) sources which can simultaneously affect the RNSS receiver. The need to take aggregate EESS (active) emissions' impact on RNSS receivers into account is recognized in and essential to Recommendation ITU-R RS.2160, and study results on resolving potential or actual cases of aggregate interference from EESS (active) SAR sensors at levels that exceed the relevant RNSS degradation allowances can be reflected in a future revision to this Report. In the meantime, Report ITU-R M.2305, addressing consideration of aggregate radio frequency interference event potentials from multiple Earth exploration-satellite service systems on radionavigation-satellite service receivers operating in the frequency band 1 215-1 300 MHz, could be consulted for guidance.

Keywords

EESS, pulsed RF interference, RNSS, spaceborne active sensor, spaceborne synthetic aperture radar, scatterometer

Abbreviations/glossary

GPS	(NAVSTAR) Global positioning system
GLONASS	Global navigation satellite system
QZSS	Quasi-Zenith satellite system
SAR	Synthetic aperture radar
SBAS	Satellite-based augmentation system

Related ITU Recommendations, Reports

Recommendation ITU-R RS.1347 – Feasibility of sharing between radionavigation-satellite service receivers and the Earth exploration-satellite (active) and space research (active) services in the 1 215-1 260 MHz band

Recommendation ITU-R RS.2160 – Evaluation of the potential for pulsed interference from new spaceborne synthetic aperture radar sensors in the earth exploration-satellite (active) service to radionavigation-satellite service receivers in the 1 215-1 300 MHz band

Recommendation ITU-R M.1318 – Evaluation model for continuous interference from radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz bands

Recommendation ITU-R M.1787 – Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

Recommendation ITU-R M.1901 – Guidance on ITU-R Recommendations related to systems and networks in the radionavigation-satellite service operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz

Recommendation ITU-R M.1902 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz

Recommendation ITU-R M.2030 – Evaluation method for pulsed interference from relevant radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

Recommendation ITU-R RS.2105 – Typical technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 432 MHz and 238 GHz

Report ITU-R M.2220 – Calculation method to determine aggregate interference parameters of pulsed RF systems operating in and near the frequency bands 1 164-1 215 MHz and 1 215-1 300 MHz that may impact radionavigation satellite service airborne and ground-based receivers operating in those bands

Report ITU-R M.2305 – Consideration of aggregate radio frequency interference event potentials from multiple Earth exploration-satellite service systems on radionavigation-satellite service receivers operating in the 1 215-1 300 MHz frequency band

1 Introduction

The frequency band 1 215-1 300 MHz is allocated to the radionavigation-satellite service (RNSS) and is used by several systems including the Navstar Global Positioning System (GPS), the Global Navigation Satellite System (GLONASS-M), Galileo, QZSS, and COMPASS. The 1 215-1 300 MHz band is also allocated on a primary basis to the EESS (active) for spaceborne active microwave sensors subject to the limitations of Nos. **5.332** and **5.335A** of the Radio Regulations (RR). The types of spaceborne active sensors requiring use of this band include synthetic aperture radars (SAR) and scatterometers.

This Report contains material that may be useful for evaluation of pulsed interference from planned and future EESS (active) SAR sensors to RNSS receivers in the 1 215-1 300 MHz band per *recommends* 1 to 4 of Recommendation ITU-R RS.2160. Annex 1 contains representative technical characteristics for EESS spaceborne active SAR sensors and characteristics (including protection criteria) of RNSS receiving earth stations based on Recommendation ITU-R M.1902. Annex 1 also includes in § 4 the methodology of Recommendation ITU-R M.2030 for evaluating pulsed radio frequency interference (RFI) from spaceborne active sensors to RNSS receivers along with pulsed

RFI protection criteria for RNSS receivers.[1] Annex 2 presents examples of the interference analysis for representative spaceborne SARs provided in Annex 1 with representative RNSS receivers.

Annex 1

Representative technical characteristics of EESS (active) spaceborne synthetic aperture radar sensors and receiving earth stations in the RNSS and a general analytic method used in evaluating the potential for pulsed radio frequency interference to receiving earth stations in the RNSS in the 1 215-1 300 MHz band

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1 Introduction

This Annex presents characteristics of representative spaceborne SARs in § 2, and characteristics of some RNSS earth station receiver types in § 3, based on Recommendation ITU-R M.1902. It also includes in § 4 the methodology of Recommendation ITU-R M.2030 for evaluating pulsed radio frequency interference (RFI) from spaceborne SARs to RNSS receivers along with pulsed RFI protection criteria for RNSS receivers.[2]

In addition, it must be noted that the evaluation of the potential for pulsed interference from an EESS (active) sensor to an RNSS receiver should also consider the cumulative impact of multiple spaceborne active sensors that may simultaneously illuminate the RNSS receivers. One means of

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[1] Note that the set of RNSS receivers whose characteristics are provided in Recommendation ITU-R M.1902 does not include every type of RNSS receiver that may be deployed in this band. Additional studies are required to determine the potential of interference from EESS (active) systems into other RNSS receiver types.

[2] Note that the set of RNSS receivers whose characteristics are provided in Recommendation ITU-R M.1902 does not include every type of RNSS receiver that may be deployed in this band. Additional studies are required to determine the potential of interference from EESS (active) systems into other RNSS receiver types.

mitigating the potential aggregate interference from multiple spaceborne active sensors is through operational collaboration by EESS (active) operators of such sensors.

2 Representative technical characteristics of EESS spaceborne SARs

The technical characteristics for six spaceborne SARs which operate in the 1 215-1 300 MHz band are given in Table 1. The antenna gain pattern equations for standard SAR1 through SAR6 are given in Tables 2 through 6 respectively. The parameters of these systems offer a range of possible characteristics that are representative for operational SARs. The characteristics chosen for the analysis in this Report are those which would result in the worst-case interference to the considered RNSS receiver.

TABLE 1

Technical characteristics of spaceborne synthetic aperture radars in the 1 215-1 300 MHz band

Parameters	**Standard SAR1**	**Standard SAR2**	**Standard SAR3 [SAR-B1]**	**Standard SAR4 [SAR-B2]**	**Standard SAR5 [SAR-B2]**	**Standard SAR6 [SAR-B2]**
Type of orbit	Sun-synchronous	Sun-synchronous	Sun-synchronous	Sun-synchronous	Sun-synchronous	Sun-synchronous
Altitude (km)	400	568	757	628	628	628
Inclination (degrees)	57	97.7	98	97.9	97.9	97.9
Eccentricity	circular	circular	circular	Circular	Circular	Circular
Ascending node	NSS	6:00	18:00	12:00	12:00	12:00
Transmit peak power (W)	3 200	1 200	3 200	3 950	6 120	6 120
Antenna type	Planar array 2.9 m × 12.0 m	Planar array 2.2 m × 12.0 m	Offset-feed parabolic 15 m diameter, linear array feed	Planar array 2.9 m × 6.0 m	Planar array 2.9 m × 9.9 m	Planar array 2.9 m × 9.9 m
Antenna peak transmit gain (dBi)	36.4	33	35	34.7	36.6	36.6
e.i.r.p. (peak) (dBW)	71.5	63.8	68.4	70.7	74.5	74.5
Antenna elev. beamwidth (degrees)[3]	4.9	6	20.9	4.3	4.6	4.6
Antenna azimuth beamwidth (degrees)	1	1	0.89	2.1	1.3	1.3
RF centre frequency (MHz)	1 257.5	1 257.5	1 215-1 300	1 257.5	1 236.5, 1 257.5, 1 278.5, selectable	1 236.5, 1 257.5, 1 278.5, selectable
Polarization	Dual linear H and V	Linear H	Dual/quad, linear H and V	H and V	H and V	H, V, Circular and 45 degrees linear
Pulse modulation	Linear FM	Linear FM	Linear FM	Linear FM	Linear FM	Linear FM
RF bandwidth, maximum (MHz)[4]	40	15	78	84	14, 28	28
RF pulse width (μs)	33.8	35	78	43-71	37-67	18-43

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[3] The values in Table 1 are the minimum requirement for the −3 dB beamwidth. See Tables 5 and 6 for antenna pattern equations to be used in interference analysis.

[4] NOTE – The "Maximum RF bandwidth" value shown is the *occupied bandwidth* for SAR4, SAR5 and SAR6, while for SAR1, SAR2 and SAR3 it is the *resolution bandwidth*.

TABLE 1 (*end*)

Parameters	**Standard SAR1**	**Standard SAR2**	**Standard SAR3 [SAR-B1]**	**Standard SAR4 [SAR-B2]**	**Standard SAR5 [SAR-B2]**	**Standard SAR6 [SAR-B2]**
Pulse repetition frequency maximum (Hz)	1 736	1 607	2 400	1 620-2 670	1 050-1 860	1 550-3 640
Transmit average power (W)	187.8	67.5	598.4	454.3	428.4	428.4
e.i.r.p. average (dBW)	59.1	51.3	61.2	61.3	62.9	62.9
Chirp rate (MHz/µs)				1.18 to 1.95	14 MHz: 0.21 to 0.38 28 MHz: 0.42 to 0.76	0.65 to 1.56
Transmit duty cycle (%)[5]	5.87	5.62	18.7	11.5	7	6.8
Azimuth scan rate (rpm)	0	0	0	0	0	0
Antenna beam transmit look angle (degrees)	20-55	35	30	7.2 to 59	7.2 to 59	7.2 to 59
Antenna beam transmit azimuth angle (degrees)	0	0	0	±3.5	0	0
NOTE	Transmits beam orthogonal to flight path (az angle of 0 degrees) at selectable look angle 20 to 55 degrees	Transmits beam orthogonal to flight path (az angle of 0 degrees) at fixed look angle 35 degrees	Transmits wide beam in elevation, receives with multiple narrow beams in elevation during receive interval.	Transmits beam orthogonal to flight path (azimuth angle of ±3.5 degrees for spotlight SAR observation) at selectable look angle 7.2 to 59 degrees	Transmits beam orthogonal to flight path (azimuth angle of 0 degrees; ScanSAR) at selectable look angle 7.2 to 59 degrees	Transmits beam orthogonal to flight path (azimuth angle of 0 degrees; Strip map SAR) at selectable look angle 7.2 to 59 degrees

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[5] NOTE – For a given EESS transmitter, the transmit duty cycle value is fixed across the range of PRF values shown above. This is done by reducing the RF pulse-width as the PRF is increased.

All six spaceborne SARs in Table 1 transmit linear FM pulses with pulse widths and pulse repetition frequencies as shown in the Table resulting in a range of pulse-to-pulse, or static, duty cycle values from 5% to 18.7%. They transmit on antenna beams orthogonal to the flight path (azimuth angle of 0 degrees) at either a selectable look angle for the pass or at a fixed look angle for the mission.

TABLE 2

Standard SAR1 antenna gain equations

Pattern	**Gain $G(\theta)$ (dBi) as a function of off-axis angle θ (degrees)**	**Angle range**
Vertical (elevation)	$G_v(\theta_v) = 36.4 - 0.478(\theta_v)^2$ $G_v(\theta_v) = 33.8 - 1.0\,\theta_v$ $G_v(\theta_v) = -11$	$0° < \lvert\theta_v\rvert < 3.6°$ $3.6° \le \lvert\theta\rvert < 45°$ $\lvert\theta_v\rvert \ge 45°$
Horizontal (azimuth)	$G_h(\theta_h) = 0.0 - 19.6(\theta_h)^2$ $G_h(\theta_h) = -24.5 - 0.47\,\theta_h$ $G_h(\theta_h) = -30.5$	$0° < \lvert\theta_h\rvert < 1.13°$ $1.13° \le \lvert\theta_h\rvert < 12.7°$ $\lvert\theta_h\rvert \ge 12.7°$
Beam pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h), -11\}$ max	-

TABLE 3

Standard SAR2 antenna gain equations

Pattern	**Gain $G(\theta)$ (dBi) as a function of off-axis angle θ (degrees)**	**Angle range**
Vertical (elevation)	$G_v(\theta_v) = 33.0 - 0.320(\theta_v)^2$ $G_v(\theta_v) = 30.4 - 0.818\,\theta_v$ $G_v(\theta_v) = -11$	$0° < \lvert\theta_v\rvert < 4.4°$ $4.4° \le \lvert\theta_v\rvert < 50.6°$ $\lvert\theta_v\rvert \ge 50.6°$
Horizontal (azimuth)	$G_h(\theta_h) = 0.0 - 19.6(\theta_h)^2$ $G_h(\theta_h) = -24.5 - 0.47\,\theta_h$ $G_h(\theta_h) = -30.5$	$0° < \lvert\theta_h\rvert < 1.13°$ $1.13° \le \lvert\theta_h\rvert < 12.7°$ $\lvert\theta_h\rvert \ge 12.7°$
Beam pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h), -11\}$ max	-

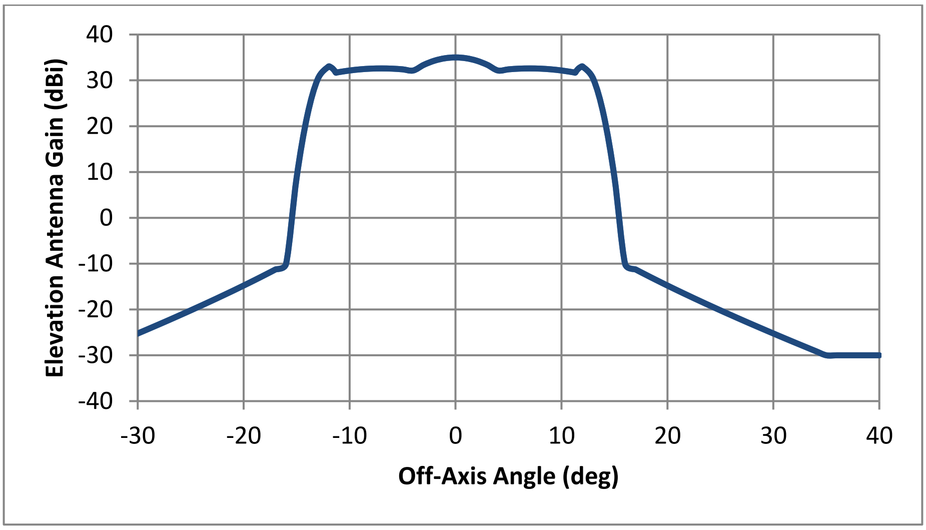
TABLE 4

Standard SAR3 antenna gain equations

Pattern	**Gain $G(\theta)$ (dBi) as a function of off-axis angle θ (degrees)**	**Angle range**
Vertical (elevation)	$G_v(\theta_v) = 35.0 - 0.18(\theta_v)^2$ $G_v(\theta_v) = 32.6 - 0.05(\lvert\theta_v\rvert - 7)^2$ $G_v(\theta_v) = 33.0 - 2.69(\lvert\theta_v\rvert - 12)^2$ $G_v(\theta_v) = 15.0 - 20.8\log(\lvert\theta_v\rvert) - 0.68(\lvert\theta_v\rvert - 16)$ $G_v(\theta_v) = -30$	$\lvert\theta_v < 4.0°$ $4.0° \leq \lvert\theta_v\rvert < 11.3°$ $11.3° \leq \lvert\theta_v\rvert < 16.0°$ $16.0° \leq \lvert\theta_v\rvert < 35.0°$ $\lvert\theta_v\rvert \geq 35°$
Horizontal (azimuth)	$G_h(\theta_h) = 0.0 - 15.0(\theta_h)^2$ $G_h(\theta_h) = -18.0$ $G_h(\theta_h) = -13.55 - 23\log\lvert\theta_h\rvert$ $G_h(\theta_h) = -36.5$	$\lvert\theta_h\rvert < 1.1°$ $1.1° \leq \lvert\theta_h\rvert < 1.7°$ $1.7° \leq \lvert\theta_h\rvert < 10.0°$ $\lvert\theta_h\rvert \geq 10.0°$
Beam pattern	$G(\theta) = \{G_v(\theta_v) + G_h(\theta_h)\}$	

FIGURE 1

a) Standard SAR3 antenna elevation transmit gain pattern model



b) Standard SAR3 antenna azimuth transmit gain pattern model

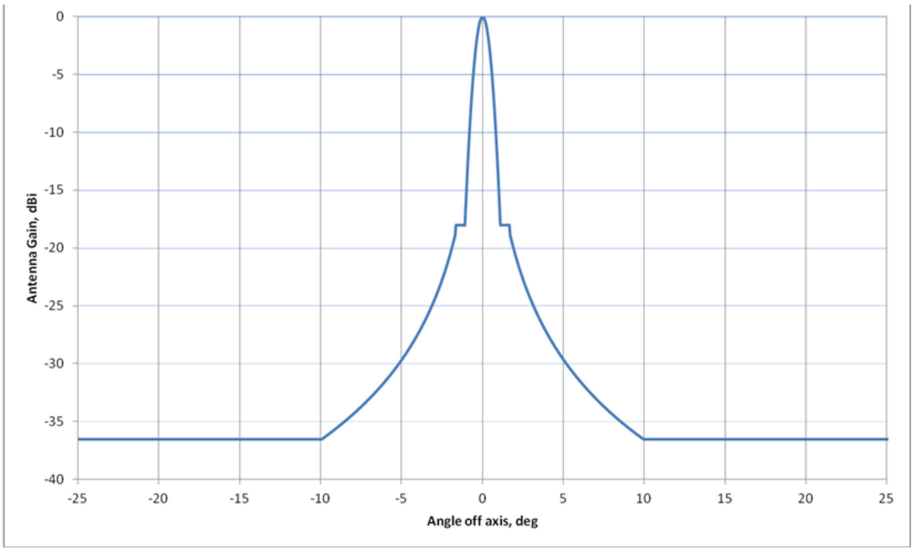


TABLE 5

Standard SAR4 antenna gain equations

Pattern	Gain $G(\theta)$ (dBi) as a function of off-axis angle θ (degrees)	Angle range
Vertical (elevation)	$G_v(\theta_v) = 0.0 - 0.38(\theta_v)^2$ $G_v(\theta_v) = 0.0 - 0.544\theta_v - 8.5$ $G_v(\theta_v) = -22.0$	$0^\circ < \lvert\theta_v\rvert < 5.5^\circ$ $5.5^\circ \leq \lvert\theta_v\rvert < 24.75^\circ$ $\lvert\theta_v\rvert \geq 24.75^\circ$
Horizontal (azimuth)	$G_h(\theta_h) = 34.7 - 2.7(\theta_h)^2$ $G_h(\theta_h) = 34.7 - 0.95\,\theta_h - 10.65$ $G_h(\theta_h) = 34.7 - 23.0$ $G_h(\theta_h) = 34.7 - 23.0 - 35\log(\theta_h/38)$ $G_h(\theta_h) = 34.7 - 36.1$	$0^\circ < \lvert\theta_h\rvert < 2.17^\circ$ $2.17^\circ \leq \lvert\theta_h\rvert < 13.0^\circ$ $13.0^\circ \leq \lvert\theta_h\rvert < 38.0^\circ$ $38.0^\circ \leq \lvert\theta_h\rvert < 90.0^\circ$ $\lvert\theta_h\rvert \geq 90.0^\circ$
Beam pattern	$G(\theta) = G_v(\theta_v) + G_h(\theta_h)$	–

NOTE – These equations cover the worst-case envelope patterns with the maximum electric beam steering angle range in both elevation and azimuth directions. As the result, these equations contain some margins against actual antenna patterns. Therefore, the −3 dB beamwidth derived from these equations can be slightly different from the beamwidth (−3 dB) specified in Table 1.

TABLE 6

Standard SAR5 and SAR6 antenna gain equations

Pattern	**Gain $G(\theta)$ (dBi) as a function of off-axis angle θ (degrees)**	**Angle range**
Vertical (elevation)	$G_V(\theta_V) = 0.0 - 0.30(\theta_V)^2$ $G_V(\theta_V) = 0.0 - 0.69\,\theta_V - 7.24$ $G_V(\theta_V) = -26.0$	$0° < \lvert\theta_V\rvert < 6.20°$ $6.20° \le \lvert\theta_V\rvert < 27.00°$ $\lvert\theta_V\rvert \ge 27.00°$
Horizontal (azimuth)	$G_h(\theta_h) = 36.6 - 7.0(\theta_h)^2$ $G_h(\theta_h) = 36.6 - 1.43\,\theta_h - 12.83$ $G_h(\theta_h) = 36.6 - 25.0$ $G_h(\theta_h) = 36.6 - 25.0 - 34\log(\theta_h/40)$ $G_h(\theta_h) = 36.6 - 36.98$	$0° < \lvert\theta_h\rvert < 1.46°$ $1.46° \le \lvert\theta_h\rvert < 8.47°$ $8.47° \le \lvert\theta_h\rvert < 40.0°$ $40.0° \le \lvert\theta_h\rvert < 90.0°$ $\lvert\theta_h\rvert \ge 90.0°$
Beam pattern	$G(\theta) = G_V(\theta_V) + G_h(\theta_h)$	–

NOTE – These equations cover the worst-case envelope patterns with the maximum electric beam steering angle range in both elevation and azimuth directions. As the result, these equations contain some margins against actual antenna patterns. Therefore, the −3 dB beamwidth derived from these equations can be slightly different from the beamwidth (−3 dB) specified in Table 1.

3 Characteristics of RNSS receivers

The following ITU-R documents provide the characteristics and description of the several systems to be used in assessing compatibility between RNSS earth station receivers and other services in the frequency band 1 215-1 300 MHz:

- Recommendation ITU-R M.1902 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz;
- Recommendation ITU-R M.1787 – Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz.

In addition, the following Recommendation gives definitions for receiver and signal parameters used in the above set of RNSS characteristics' Recommendations.

- Recommendation ITU-R M.1901 – Guidance on ITU-R Recommendations related to systems and networks in the radionavigation-satellite service operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz.

The RNSS receivers may encounter both pulsed and continuous interference[6] during both signal acquisition and tracking phases. In the case of potential interference from the SAR spaceborne active sensors included in Table 1 above, the interference falls into the category of pulsed interference. Pulsed interference can affect an RNSS receiver in two ways: either by causing receiver saturation, or by causing receiver front-end burnout. The principal interference effect is that the pulsed interference causes saturation in the receiver. This occurs when a signal level is received that is strong enough to cause gain reduction or saturation at some point in the receiver. When this saturation occurs, the relatively low-level desired signal would be blocked during the transmission pulse period and any recovery time that is necessary for the RNSS receiver. However, if this period of lost signal is short enough, there should be no appreciable impact on the performance of the receiver.

The other possible interference effect occurs when either the peak or average RF power level is high enough to cause receiver front-end component damage. The relevant technical characteristics for the RNSS systems are summarized in Table 7. The saturation power level (receiver input saturation level) and the input survival power level are also given in Table 7.

A pulsed signal received power level that is below the input saturation level of an RNSS receiver is assumed to have less detrimental effect on the performance of the receiver if the spaceborne active sensor transmitted pulse width is relatively short compared to the RNSS information bit length and the spaceborne active sensor transmitter duty cycle is low. This lessor detrimental impact is in comparison to pulsed signals with longer durations and/or higher duty cycle. See § 4 for more details.

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[6] *Pulsed interference* results from RF transmitted signals that are modulated on/off at some *pulse repetition frequency* (usually identified in Hz). The duration of the "on" period is called the *pulse duration* (given in units of time, e.g. microsecond). The product of the pulse duration and the pulse repetition frequency is the *pulse duty cycle* (a unit-less quantity). An interference signal is considered *pulsed RFI* if the pulse duration is much shorter than the integration time of a victim receiver. On the other hand, *continuous* RFI is used here to mean interference from sources of fairly constant power that is generally present at all times.

TABLE 7

Technical characteristics and protection criteria for RNSS receivers (space-to-Earth) operating in the band 1 215-1 300 MHz

	1	**2**	**3**	**3a**	**3b**		**4**		**5**				**6**			
Parameter	SBAS ground reference receiver*	High-precision semi-codeless receiver*	High-precision receiver using L2C*	High-precision receiver using B3 and B3A	High-accuracy and authentication receiver using E6-BC/L6		Air-navigation receiver (Note 10)		Indoor positioning				General purpose			
Signal frequency range (MHz)	1 227.6 ± 15.345	1 227.6 ± 15.345	1 227.6 ± 15.345	1 268.52 ± 12	1 278.75 ± 21		1 246 + 0.4375*K ± 5.11, where K = –7, …, +6 (Note 8)	1 248,06 ± 7.7	1 227.6 ± 12	1 246 + 0.4375*K ± 5.11 where K = –7, …,	1 248,06 ± 7.7	1 268.52 ± 12	1 227.6 ± 12	1 246 + 0.4375*K ± 5.11 where K= –7,..,+6	1 248,06 ± 7.7	1 268.52 ± 12
Maximum receiver antenna gain in upper hemisphere (dBi)	–2.0 circular (Note 3)	3.0 circular	3.0 circular	3.0 circular	3 circular		7 circular (Note 11)		6			3	6			3
Maximum receiver antenna gain in lower hemisphere (dBi)	–5.0 circular (see Note 3)	–7 linear (< 10° elev.)	–7 linear (< 10° elev.)	–7 linear (< 10° elev.)	–6 circular (Note 15)		–10 circular		6 (Note 12)			–9	6 (Note 12)			-10
RF filter 3 dB bandwidth (MHz)	24.0	24.0	24.0	24.0	40.92 (Note 18)	42.0 (Note 18)	30		32	30		24	32	30		24
Pre-correlation filter 3 dB bandwidth (MHz)	20.46	20.46	20.46	20.46	40.92 (Note 18)	42.0 (Note 18)	20	25	2	20	25	20.46	2	20	25	20.46
Receiver system noise temperature (K)	513	513	513	513	722 (Note 18)	645 (Note 18)	400		645			330	645			330
Thresholds for continuous interference																
Tracking mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	–137.5 (P(Y)) (Note 1)	–137.4 (P(Y)) (Note 1)	–151.4 (Note 1)	–157.4 (Note 2)	–134.5 (Note 16)		–149 (Note 1) (Note 9)		–193 (Note 1)			–193 (Note 2)	−158 (Note 1)			−150 (Note 2)
Acquisition mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	See Note 4	See Note 5	–157.4 (Note 1)	–157.4 (Note 2)	See Note 17		–155 (Note 1) (Note 9)		–199 (Note 1)			–199 (Note 2)	−164 (Note 1)			−156 (Note 2)

TABLE 7 (*end*)

	1	2	3	3a	3b	4	5		6	
Parameter	SBAS ground reference receiver*	High-precision semi-codeless receiver*	High-precision receiver using L2C*	High-precision receiver using B3 and B3A	High-accuracy and authentication receiver using E6-BC/L6	Air-navigation receiver (Note 10)	Indoor positioning		General purpose	
Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–147.5 (P(Y)) (Note 1)	–147.4 (P(Y)) (Note 1)	–147.4 (Note 1)	–147.4 (Note 2)	–140 (Note 16)	–140 (Note 1) (Note 9)	–150 (Note 1)	–145 (Note 2)	–139 (Note 1)	−140 (Note 2)
Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	See Note 4	See Note 5	–147.4 (Note 1)	–147.4 (Note 2)	See Note 17	–146 (Note 1) (Note 9)	–156 (Note 1)	–151 (Note 2)	–145 (Note 1)	−146 (Note 2)
Thresholds for pulsed interference (see Note 14)										
Receiver input saturation level (dBW) (Note 14)	–135.0 (Note 6) (Note 13)	–120 (Note 6)	–120 (Note 6)	–120 (Note 6)	–120 (Note 6)	–80	–70	–100	–70	–100
Receiver survival level (dBW) (Note 14)	−10.0 (Note 7)	–20	–20	–20	–20	−1	−20	–17	−20	–17
Overload recovery time (s) (Note 14)	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	$(1 \text{ to } 30) \times 10^{-6}$	30×10^{-6}		30×10^{-6}	

* These columns cover characteristics and thresholds for RNSS receivers that operate in the 1 215-1 300 MHz band. (Receivers of this type operate with the signals described in Annex 2 to Recommendation ITU-R M.1787.) For characteristics and protection criteria for the receiver operation in the bands 1 559-1 610 MHz and/or 1 164-1 215 MHz, refer also to the associated table columns in Recommendations ITU-R M.1903 and/or ITU-R M.1905, respectively.

Note 1: For P(Y) signal processing, including that using semi-codeless techniques, narrow-band interference is considered to have less than a 100 kHz bandwidth and wideband interference has greater than a 1 MHz bandwidth. For L2C signal processing, narrow-band interference is considered to have less than a 1 kHz bandwidth and wideband interference has greater than a 1 MHz bandwidth. For FDMA and CDMA (carrier frequency 1 248.06 MHz) signals processing, narrow-band continuous interference is considered to have less than a 1 kHz bandwidth, and wideband continuous interference is considered to have greater than a 500 kHz bandwidth. Thresholds for interference bandwidths between 100 kHz (for P(Y)) or 1 kHz (for L2C and FDMA/CDMA (carrier frequency 1 248.06 MHz)) to 1 MHz (or for FDMA to 500 kHz) are undefined and may require further study.

Note 2: Narrow-band continuous interference is considered to have a bandwidth less than 700 Hz. Wideband continuous interference is considered to have a bandwidth greater than 1 MHz. Thresholds for interference bandwidths between 700 Hz and 1 MHz may require further study.

Note 3: The listed maximum upper hemisphere gain value applies for 30° elevation (i.e. maximum expected RFI arrival angle). The listed maximum lower hemisphere gain value applies for 5° elevation.

Note 4: Signal acquisition is performed using the L1 C/A signal. See the appropriate acquisition threshold row in Recommendation ITU-R M.1903 Annex 2, Table 2-2, “SBAS Ground Reference Receiver” column.

Note 5: Signal acquisition is performed using the L1 C/A signal. See the appropriate acquisition threshold row in Recommendation ITU-R M.1903 Annex 2, Table 2-2, “High-precision” column.

Note 6: These receiver input saturation levels apply over the corresponding RF filter 3-dB bandwidth.

Note 7: This survival level is the peak power level for a pulsed signal with a 10% maximum duty factor.

Note 8: This receiver type operates on several RNSS signal carrier frequencies simultaneously. The carrier frequencies are defined by f_c (MHz) = 1 246.0 + 0.4375 K, where $K = -7$ to $+6$.

Note 9: This threshold should account for the aggregate power of all interference. The threshold value does not include any safety margin.

Notes relative to Table 7:

Note 10: Given values represent typical characteristics of receivers. Under certain conditions more rigid values for some parameters could be required (e.g. recovery time after overload, threshold values of aggregate interference, etc.).

Note 11: Minimum receiver antenna gain at 5 degrees elevation angle is −5.5 dBic.

Note 12: Because the antenna in some RNSS receiver applications could potentially be pointed in almost any direction, the maximum antenna gain in the lower hemisphere could (under worst-case conditions) be equal to that for the upper hemisphere.

Note 13: This receiver input saturation level is for power in a 1 MHz bandwidth.

Note 14: The values in these rows are to be used for assessment of interference from pulsed sources in conjunction with the methodology

Note 15: The maximum lower hemisphere gain value applies for 5° elevation angle.

Note 16: Narrow-band continuous interference is considered to have a bandwidth less than 128 kHz. Wideband continuous interference is considered to have a bandwidth greater than 1 MHz. Thresholds for interference with a bandwidth between 128 kHz and 1 MHz may require further study.

Note 17: For E6-BC, signal acquisition is performed using the E1-BC signal. See the appropriate acquisition threshold row in Recommendation ITU-R M.1903 Annex 2, Table 2-2, “High-precision” column. For L6 signal, some receivers perform signal acquisition using the signals in L1 band and other receivers are expected to have 6 dB smaller threshold for the acquisition mode than for the tracking mode.

Note 18: Bandwidth of 40.92 MHz is for E6-BC receiver and that of 42.0 MHz is for L6 receiver. Noise temperature of 722 K is for E6-BC receiver and that of 645 K is for L6 receiver.

4 Analytic evaluation method for pulsed RFI from spaceborne SARs to RNSS receivers

4.1 Assessment of potential for RNSS receiver damage or saturation

The first step in analysing the interference potential from a spaceborne SAR to a RNSS receiver is to determine if the peak signal power from the spaceborne active sensor is great enough to cause front-end component damage within the RNSS receiver. The maximum interfering signal power levels received from a spaceborne active sensor occur when an RNSS receiver is located in the main beam of the spaceborne active sensor antenna (no RNSS receiver filtering assumed). The peak interfering signal power levels from active sensors into an RNSS receiver may be calculated using a template shown in Table 8. The calculations assume co-frequency operation. The template is applied to each of the RNSS receiver types, and the results are first compared with the particular receiver input survival levels listed in Table 7 to assure none exceed the limits.

TABLE 8

Maximum RNSS received RFI power calculation template

Parameters (units)	SAR1	SAR2	SAR3	SAR4	SAR5	SAR6
Centre frequency (MHz)[7]	1 257.5	1 257.5	1 215.0- 1 300.0	1 257.5	1 215.0- 1 300.0	1 215.0- 1 300.0
Peak transmitter power (dBW)	35.1	30.8	35.1	36.0	37.9	37.9
Transmitter antenna gain (dB)	36.4	33.0	33.4	34.7	36.6	36.6
Distance (km)	427.5	710.8	898.5	637.8	636.65	639.53
Free space loss (dB)	147.0	151.5	153.4	150.5	150.5	150.6
Receive antenna gain (dB)	–	–	–	–	–	–
Polarization mismatch loss (dB)(1)	1.46	1.46	1.46	1.46	1.46	0.0(2)
Max. received RFI power (peak) (dBW)	–	–	–	–	–	–
Receiver input saturation point (dBW)	–	–	–	–	–	–
Receiver input survival level (dBW)						

(1) Polarization mismatch loss is defined in section 2.2.3 of Appendix **8 (Rev.WRC-03)** of the Radio Regulations (Edition 2004).

(2) SAR6 capable of transmitting the circular polarization (RHCP or LHCP is selectable by command), so the worst-case polarization loss for the RHCP receive antenna is assumed to be 0.0 dB.

Then, if the results from the assessment template indicate the peak received pulsed power from the spaceborne active sensor is below the survival level but above a level of 15 dB below the RNSS receiver input saturation point, the RNSS receiver degradation ratio should be computed as described in § 4.2.

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[7] Centre frequency of active sensor can vary within the given range. For calculation of free space loss, a centre frequency of 1 250 MHz is assumed. For sensor waveforms which overlap a particular RNSS receiver −3 dB RF bandwidth, the loss at the RNSS signal centre frequency should be used instead.

4.2 Assessment of potential for RNSS receiver performance degradation

It is noted that RNSS receivers operating in the 1 215-1 300 MHz band can be subjected to continuous interference from a variety of sources, including RNSS space stations. In addition, they can be subjected to in-band and adjacent band pulsed RF interference from radiolocation radars and ARNS transmitters as well as spaceborne EESS active sensors. The presence of continuous RFI from other sources reduces the amount of pulsed RFI that the affected RNSS receiver can tolerate. The presence of an existing baseline amount of pulsed RFI reduces the amount of additional pulsed RFI that the affected RNSS receiver can tolerate from a new source. The amount of pulsed RFI to be considered depends on the number of pulsed sources within the radio horizon of the considered RNSS receive antenna.

4.2.1 RNSS receiver effective noise density general formula

The effects of both pulsed and continuous RFI for a saturating RNSS receiver can be quantified by defining an effective post-correlator noise power spectral density, $N_{0,EFF}$, which combines all the pulsed RFI effects on thermal noise density, wideband continuous RFI density, and RNSS signal loss. It is given by:

$$N_{0,EFF} = \frac{N_0\left[\left(1+\frac{I_{0,WB}}{N_0}+R_I\right)\left(1+\frac{{N_{LIM}}^2 PDC}{(1-PDC)}\right)\right]}{(1-PDC)} \tag{1}$$

where:

$$R_I = \left(\frac{1}{N_0 \times BW}\right)\sum_{i=1}^{N} P_i \times dc_i \tag{2}$$

In the above equations:

N_0:	receive system thermal noise power spectral density in Watts/Hz (= kT_{SYS})
PDC:	fractional duty cycle (unitless ratio) of all pulses exceeding the specific peak power threshold (blanking or saturation)
R_I:	ratio (unitless) of average power density of below-threshold pulsed RFI to receiver thermal noise spectral density, N_0
$I_{0,WB}$:	total wideband equivalent continuous RFI power spectral density (Watts/Hz)
N_{LIM}:	ratio (unitless) of receiver analogue-to-digital (A/D) saturation level to 1σ noise voltage established by automatic gain control (AGC)
BW:	pre-correlator RF/IF bandwidth (Hz)
P_i:	received peak power (Watts) of the *i*-th pulsed RFI source (referenced to antenna output) with peak level below the specific threshold
dc_i:	*i*-th below-threshold pulse source duty cycle (unitless ratio), and
N:	number of pulsed emitters with signals below the specific peak power threshold (blanking or saturation).

All the noise and interference terms in equations (1) and (2) are referenced to the receive system passive antenna terminals. The parameter N_{LIM} is a non-negative receiver parameter that is determined by the A/D conversion implementation (Note that $N_{LIM} = 0$ for a pulse blanking receiver). For the simplest RNSS receiver with a “1-bit” quantizer (hard-limiting), N_{LIM} = unity.

The total pulsed RFI parameter, *PDC*, is built out of components from the separate heterogeneous pulsed transmitter systems (or individual sources) “*a*”, “*b*” and “*c*” as follows:

$$PDC = 1 - \left(1 - PDC_a\right)\left(1 - PDC_b\right)\left(1 - PDC_c\right) \tag{3}$$

where:

PDC_a : above-threshold pulse duty cycle for system “*a*” pulses (e.g. radiolocation)

PDC_b : above-threshold pulse duty cycle for system “*b*” pulses (e.g. ARNS), and

PDC_c : above-threshold pulse duty cycle for system “*c*” pulses (e.g. EESS).

The total pulsed RFI parameter, R_I, is built out of components from the separate heterogeneous pulsed transmitter systems (or individual sources), for example, “*a*”, “*b*” and “*c*” as follows:

$$R_I = R_a + R_b + R_c \tag{4}$$

where R_a, R_b, and R_c are the below-threshold average pulse power density ratios for systems “*a*”, “*b*” and “*c*” respectively. These ratios are calculated without regard to the presence of any other pulses that overlap in time from the various individual pulsed RFI sources.

The pulsed RFI parameter, PDC_j, for strong (above-threshold) pulses from a given (j-th) source is:

$$PDC_j = \left(PW_{j,eff} + \tau_r\right)PRF_j \tag{5}$$

where $PW_{i,eff}$ and PRF_j are, respectively, the effective pulse width (in seconds) and pulse repetition frequency (Hz) for the j-th RFI source, and τ_r is the RNSS receiver overload recovery time (in seconds). Similarly, the duty cycle, dc_k, for weak (below-threshold) pulses from the k-th RFI source, used in computing the pulsed RFI parameter R_k, for that source is determined by:

$$dc_k = PW_{k,eff}\ PRF_k \tag{6}$$

Intra-pulse frequency chirp is typically employed by the spaceborne active sensors considered in this Report. In some cases the chirp may be wide enough that a portion of the full transmit pulse width falls outside the RNSS receiver passband and does not impact receiver performance. In equations (5) and (6) the effective pulse width, PW_{eff}, is related to the full RFI source transmit pulse width, PW, by $PW_{eff} = PW \cdot (\Delta f\ /\ Chirpwidth)$, where Δf is the portion of the full chirp width that falls within the receiver pre-correlation passband[8] (see Table 7)[9].

It should be noted that a bandwidth greater than the pre-correlator −3 dB filter bandwidth of RNSS receivers has to be taken into consideration. However, this value should not be greater than the RF −3 dB filter bandwidth which is contained in Recommendation ITU-R M.1902.

4.2.2 RNSS receiver performance degradation computation

Define the baseline environment to have pulsed RFI present (i.e. baseline PDC and/or $R_I > 0$). If an additional pulse source group Y is introduced, the new composite RNSS pulsed RFI parameters, PDC_{base+Y} and R_{I+Y}, can be defined by extension of equations (3) and (4) as:

$$(1 – PDC_{base+Y}) = (1 – PDC_{base})(1 – PDC_Y) \text{ and } R_{I+Y} = R_I + R_Y$$

---

[8] When $PW_{EFF} = 0$ due to zero bandwidth overlap ($\Delta f = 0$), the associated PDC is identically 0.

[9] Report ITU-R M.2220 does not indicate the RNSS receiver bandwidth associated with the necessary attenuation level for the pre-correlator filter that should be used to calculate the overlap bandwidth factor ($\Delta f\ /\ Chirpwidth$). This level depends on the technical implementation of RNSS receivers. Because this information is lacking, a worst-case assumption is used for GLONASS air navigation receivers in Table 9. For those receivers lacking sufficient information, a unity overlap bandwidth factor value should be used in equations (5) and (6) for preliminary evaluations using the methodology of Recommendation ITU-R M.2030. However, any increase of the estimation of interference from spaceborne active sensors resulting from the use of a unity overlap bandwidth factor should be taken into account when performing more detailed analyses specified in the Recommendation.

where PDC_{base} and R_I represent the baseline environment pulsed RFI parameters and PDC_Y and R_Y represent the additional source group pulsed RFI parameters. The degradation ratio is then defined by extension using equation (1) as:

$$\begin{aligned} {N_{0,EFF+Y}}\big/{N_{0,EFF}} &= \frac{N_0\left(1+\frac{I_{0,WB}}{N_0}+R_{I+Y}\right)\left(1+\frac{{N_{LIM}}^2 PDC_{base+Y}}{\left(1-PDC_{base+Y}\right)}\right)\left(1-PDC_{base}\right)}{N_0\left(1+\frac{I_{0,BW}}{N_0}+R_I\right)\left(1+\frac{{N_{LIM}}^2 PDC_{base}}{\left(1-PDC_{base}\right)}\right)\left(1-PDC_{base+Y}\right)} \\ &= \frac{1}{\left(1-PDC_Y\right)}\left[1+\frac{R_Y}{\left(1+\frac{I_{0,WB}}{N_0}+R_I\right)}\right]\left[1+\left(\frac{{N_{LIM}}^2 PDC_Y}{\left(1-PDC_Y\right)\left[1+PDC_{base}\left({N_{LIM}}^2-1\right)\right]}\right)\right] \end{aligned} \qquad (7)$$

If in addition, the RNSS receiver is a hard-limiting style, $N_{LIM} = 1$ and $R_I = R_Y \cong 0$, then the degradation ratio in equation (7) simplifies to:

$${N_{0,EFF+Y}}\big/{N_{0,EFF}} = \frac{1}{\left(1-PDC_Y\right)^2} \qquad (8)$$

4.2.3 Allowable RNSS receiver degradation and associated model parameters

Table 9, taken from Recommendation ITU-R M.2030, Annex 1, Table 2, lists baseline model parameters and allowable degradation ratios[10] to be used for a preliminary evaluation of the potential for pulsed interference from an active spaceborne sensor (EESS or SRS) to an RNSS system or network operating in the 1 215-1 300 MHz band. RNSS receiver types in the table are taken from Recommendation ITU-R M.1902. The listed baseline model pulse RFI model parameters, PDC and R_I, and continuous parameter, $I_{0,WB}/N_0$, are to be used in the appropriate degradation ratio equation (either (7) or (8) as determined by the N_{LIM} parameter). The equation result for the actual degradation ratio in dB ($10 \cdot \log_{10}(N_{0,EFF+Y}/N_{0,EFF})$) is compared to the allowable degradation ratio value in Table 9. If the allowable degradation ratio of an RNSS receiver in Table 9 is exceeded, then a more detailed analysis of the impact of the pulsed interference should be conducted to determine whether or not the pulsed interference is acceptable to the victim RNSS receiver.

Report ITU-R M.2220 provides a methodology for computing received pulsed RFI model parameters, PDC and R_I for both baseline and new pulsed sources and background on the continuous parameter, $I_{0,WB}/N_0$. Computation examples are given in § 4 of that Report.

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[10] The allowable degradation ratio is the upper limit for the RFI effect of new planned pulsed sources not in the baseline RFI condition. It is determined from consideration of the overall RFI, including the baseline parameters, that the receiver can tolerate and still meet required performance.

TABLE 9

Baseline pulsed RFI model parameters and allowable degradation ratios for RNSS receivers (space-to-Earth) operating in the band 1 215-1 300 MHz *

Receiver type	N_{LIM} (unitless) (1)	Baseline PDC (unitless) (2)	Baseline R_I (unitless) (2)	Baseline $I_{0,WB}/N_0$ ratio (unitless)	Allowable degradation ratio for pulsed sources (3) (dB)
SBAS[11] ground reference receiver	1	0.0793 (4)	0	0.3925	0.2
High-precision semi-codeless receiver	2	0.0765 (4)	0	0.3983	0.2
Air navigation receiver (FDMA)	1	0.1327 (4)	0	0.455	0.1
Air navigation receiver (FDMA)	1	0.1723 (5)	0	0.455	0.1

* Parameter values for other RNSS receiver types are yet to be developed. The degradation ratio equations in § 4.2 of this Annex can be used to predict the general nature of the pulsed interference effects on RNSS receiver types for which no parameters are listed.

(1) A receiver with pulse blanking has an N_{LIM} value of zero.

(2) The parameters for the baseline pulsed sources given in this Table are considered to be the worst-case values. It is expected that, in most actual environments, there may be various types of pulsed interference sources with lower individual values for PDC and the therefore the aggregate baseline pulsed interference PDC would be less than given in the Table. These actual conditions should be taken into account when performing more detailed analyses.

(3) The allowable degradation ratio for new pulsed sources not in the baseline RFI condition requires consideration of the cumulative impact on an RNSS receiver from multiple pulsed sources that simultaneously illuminate the RNSS receiver.

(4) Based on a 1-µs overload recovery time.

(5) Based on a 30-µs overload recovery time.

5 Summary

Annex 1 presents representative characteristics of spaceborne active SAR sensors and characteristics and pulsed RFI protection criteria for RNSS earth station receivers based on Recommendation ITU-R M.1902. Annex 1 also includes in § 4 the methodology of Recommendation ITU-R M.2030 for evaluating pulsed RFI from spaceborne active sensors to RNSS receivers along with pulsed RFI protection criteria for RNSS receivers.[12]

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[11] Satellite-based augmentation system (SBAS) ground reference receiver, a semi-codeless type receiver.

[12] Note that the set of RNSS receivers whose characteristics are provided in Recommendation ITU-R M.1902 does not include every type of RNSS receiver that may be deployed in this band. Additional studies are required to determine the potential of interference from EESS (active) systems into other RNSS receiver types.

Annex 2

Analytic method application examples of evaluating the potential for one spaceborne synthetic aperture radar pulsed radio frequency interference to RNSS Earth station receivers operating in the 1 215-1 300 MHz band

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1 Introduction

The 1 215-1 300 MHz frequency band is allocated to the radionavigation-satellite service (RNSS) and is used by several systems including the Navstar Global Positioning System (GPS), the Global Navigation Satellite System (GLONASS-M), Galileo, QZSS, and COMPASS. The 1 215-1 300 MHz band is allocated on a primary basis to the EESS (active) for spaceborne active microwave sensors. According to RR No. **5.332**, in the band 1 215-1 260 MHz, active spaceborne sensors in the Earth exploration-satellite shall not cause harmful interference to, claim protection from, or otherwise impose constraints on operation or development of the radionavigation-satellite service and other services allocated on a primary basis.

The types of active sensors requiring use of this band include the synthetic aperture radar (SAR) and scatterometers. This Annex presents the worst-case interference evaluation analyses of some representative spaceborne SARs (Annex 1) in regard to three RNSS receivers and presents a performance degradation evaluation analysis example between a SAR and the GPS SBAS ground reference receiver and between a SAR and the GLONASS receiver.

In addition, it must be noted that the evaluation of the potential for pulsed interference from an EESS (active) sensor to an RNSS receiver should also consider the cumulative impact of multiple spaceborne active sensors that may simultaneously illuminate the RNSS receivers, wherever relevant. One means of mitigating the potential aggregate interference from multiple spaceborne active sensors is through operational collaboration of such sensors.

2 RNSS received power damage and saturation level example calculations

The levels for spaceborne active sensor maximum peak or average power at the receiver input of an RNSS receiver are likely to be well below the −20 to −1 dBW levels that would cause front end burnout. Thus, the emissions from a spaceborne active sensor will likely not cause burnout or damage to a RNSS receiver. The interfering signal level at the RNSS receiver input which will compress the receiver and cause a temporary loss of signal is −80 to −70 dBW in all cases except for the GPS SBAS ground reference receiver for which the level is −135 dBW. As an example, the worst-case received peak power configuration for three types of receivers is depicted as follows:

– CDMA (QZSS) indoor positioning receiver: Table 10;

– (GPS) SBAS ground reference receiver: Table 11;

– GLONASS air navigation receiver: Table 12.

TABLE 10

Maximum received peak RFI power for CDMA (QZSS) indoor positioning receivers

Parameter	**SAR1**	**SAR2**	**SAR3**	**SAR4**	**SAR5**	**SAR6**
Centre frequency (MHz)[13]	1 257.5	1 257.5	1 215.0- 1 300.0	1 257.5	1 215.0- 1 300.0	1 215.0- 1 300.0
Peak transmitter power (dBW)	35.1	30.8	35.1	36.0	37.9	37.9
Transmitter antenna gain (dB)	36.4	33.0	33.4	34.7	36.6	36.6
Distance (km)	427.5	710.8	898.5	637.8	636.65	639.53
Free space loss (dB)	147.0	151.5	153.4	150.5	150.5	150.6
Receiver antenna gain (dB)	6.0	6.0	6.0	6.0	6.0	6.0
Polarization mismatch loss (dB) (2)	1.46	1.46	1.46	1.46	1.46	0.0 (1)
Maximum received interference power (peak) (dBW)	–70.96	–83.16	–80.44	–75.29	–71.48	–70.05
Receiver input saturation level (dBW)	–70	–70	–70	–70	–70	–70
Receiver input survival level (dBW)	–20	–20	–20	–20	–20	–20

(1) SAR6 capable of transmitting the circular polarization (RHCP or LHCP is selectable by command), so the worst-case polarization loss for the RHCP receive antenna is assumed to be 0.0 dB.

(2) Polarization mismatch loss is defined in § 2.2.3 of Appendix **8 (Rev.WRC-03)** of the Radio Regulations (Edition 2004).

Since all the cells in the Table 10 row of maximum received interference peak power values are below the receiver input survival level, these representative systems do not exceed the allowable interference criteria from a peak power standpoint with the QZSS indoor positioning receiver. However, since all but one of the maximum received peak power results are within 15 dB of the QZSS receiver input saturation level, further interference evaluation analysis using the method of Annex 1, § 4.2, is warranted.

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[13] Centre frequency of active sensor can vary within the given range. For calculation of free space loss, a centre frequency of 1 250 MHz is assumed.

TABLE 11

Maximum received peak RFI power for (GPS) SBAS ground reference receivers

Parameter	**SAR1**	**SAR2**	**SAR3**	**SAR4**	**SAR5**	**SAR6**
Centre frequency (MHz)[14]	1 257.5	1 257.5	1 215.0- 1 300.0	1 257.5	1 215.0- 1 300.0	1 215.0- 1 300.0
Peak transmitter power (dBW)	35.1	30.8	35.1	36.0	37.9	37.9
Transmitter antenna gain (dB)	36.4	33.0	33.4	34.7	36.6	36.6
Distance (km)	427.5	710.8	898.5	637.8	636.65	639.53
Free space loss (dB)	147.0	151.5	153.4	150.51	150.5	150.6
Receiver antenna gain (dB)	–2.0	–2.0	–2.0	–2.0	–2.0	–2.0
Polarization mismatch loss (dB) (2)	1.46	1.46	1.46	1.46	1.46	0.0 (1)
Maximum received interference\power (peak) (dBW)	–78.96	–91.16	–88.36	–83.29	–79.48	–78.05
Receiver input saturation level (dBW)	–135	–135	–135	–135	–135	–135
Receiver input survival level (dBW)	–10	–10	–10	–10	–10	–10

(1) SAR6 capable of transmitting the circular polarization (RHCP or LHCP is selectable by command), so the worst-case polarization loss for the RHCP receive antenna is assumed to be 0.0 dB.

(2) Polarization mismatch loss is defined in § 2.2.3 of Appendix **8 (Rev.WRC-03)** of the Radio Regulations (Edition 2004).

Since all the cells in the Table 11 row of maximum received interference peak power values are below the receiver input survival level, these representative systems do not exceed the allowable interference criteria from a peak power standpoint with the SBAS ground reference receiver. However, since all of the maximum received peak power results are well above the receiver input saturation level, further interference evaluation analysis using the method of Annex 1, § 4.2 is needed. Section 3 below contains an example calculation.

TABLE 12

Maximum received peak RFI power for (GLONASS) air navigation receivers

Parameter	**SAR1**	**SAR2**	**SAR3**	**SAR4**	**SAR5 (3)**	**SAR6 (3)**
Centre frequency (MHz)	1 257.5	1 257.5	1 250	1 257.5	1 250	1 250
Peak transmitter power (dBW)	35.1	30.8	35.1	36.0	37.9	37.9
Transmitter antenna gain (dB)	36.4	33.0	33.4	34.7	36.6	36.6
Distance (km)	427.5	710.8	898.5	637.8	636.65	639.53
Free space loss (dB)	147.0	151.5	153.4	150.51	150.5	150.6

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[14] Centre frequency of active sensor can vary within the given range. For calculation of free space loss, a centre frequency of 1 250 MHz is assumed.

TABLE 12 *(cont.)*

Parameter	SAR1	SAR2	SAR3	SAR4	SAR5 (3)	SAR6 (3)
Receiver antenna gain (dB)	7.0	7.0	7.0	7.0	7.0	7.0
Polarization mismatch loss (dB) (2)	1.46	1.46	1.46	1.46	1.46	0.0 (1)
Maximum received interference/power (peak) (dBW)	−69.96	−82.16	−79.36	−74.29	−70.48	−69.05
Receiver input saturation level (dBW)	−80	−80	−80	−80	−80	−80
Receiver input survival level (dBW)	−1	−1	−1	−1	−1	−1

(1) SAR6 capable of transmitting the circular polarization (RHCP or LHCP is selectable by command), so the worst-case polarization loss for the RHCP receive antenna is assumed to be 0.0 dB.

(2) Polarization mismatch loss is defined in in § 2.2.3 of Appendix **8 (Rev.WRC-03)** of the Radio Regulations (Edition 2004).

(3) The peak power is worst-case analysis, because the size of antenna aperture for SAR 5 and 6 will be small in actual.

Since all the cells in the Table 12 row of maximum received interference peak power values are below the receiver input survival level, these representative systems do not exceed the allowable interference criteria from a peak power standpoint with the GLONASS receiver. However, since almost all of the maximum received peak power results are above the receiver input saturation level, further interference evaluation analysis using the method of Annex 1, § 4.2 is needed. Section 3 below contains an example calculation.

3 RNSS receiver performance degradation calculation examples using the analytic evaluation method

3.1 SBAS ground reference receiver pulsed RFI evaluation case

One pulsed RFI analysis case chosen to illustrate the use of the analytic evaluation method is of an SBAS ground reference receiver illuminated by a single EESS SAR5 active sensor. The SBAS receiver is also assumed to be near a ground-based surveillance radar that produces a baseline pulsed RFI condition below the receiver's tolerance limit. Normally a dynamic link analysis would be done to find the actual time profile of peak received SAR5 power. The dynamic analysis would involve orbital simulation together with the satellite radiated power pattern and the RNSS receiver receive antenna pattern.

For this simpler example, however, it is assumed that for a certain nominal time period (at least a few minutes), the received SAR5 peak power is sufficiently above the SBAS ground reference receiver input saturation level so that the SBAS receiver is saturated during the pulse duration. With that worst-case assumption, the analytic method in Annex 1, § 4.2 can be applied to find the SBAS receiver pulsed RFI degradation.

3.1.1 Computation of the received effective pulsed RFI duty cycle parameter, PDC_{LIM}

The received peak SAR5 received power effective pulsed RFI duty cycle (PDC_{LIM}) is computed for the various SAR5 modes using equation (5):

$$PDC_{LIM,5} = \left(PW_{SAR5,eff} + \tau_r\right)PRF_{SAR5}$$

where:

$$PW_{SAR5,eff} = PW_{SAR5} \cdot \left(\frac{\Delta f}{Chirpwidth}\right)$$

From Table 1, it is noted that the transmit pulse width (PW_{SAR5}) and pulse repetition frequency (PRF_{SAR5}) vary over a stated range such that the transmit duty cycle is a constant (7%). The chirp width has two values (14 MHz and 28 MHz) and the chirp centre frequency has three values (1 236.5 MHz, 1 257.5 MHz, and 1 278.5 MHz). For this example, the effective received pulsed RFI duty cycle is computed for each centre frequency and chirp width (showing the SBAS receiver filtering effect) and two combinations of transmit pulse width and PRF. The assumed SBAS receiver recovery time (τ_R) for this example is 1.0 µs and the SBAS receiver pre-correlator filter bandwidth is 20.5 MHz (rectangular)[15] centred at 1 227.6 MHz. Tables 13 and 14 show the results for the 14 MHz and 28 MHz chirp width cases, respectively.

TABLE 13

SBAS ground reference receiver effective received pulse width and PDC for 14 MHz chirp width

Centre frequency (MHz)	Tx PRF (Hz)	Tx PW (µs)	BW overlap ratio	Eff. PW (µs)	PDC (%)
1 236.5	1 050	66.67	0.5964	39.760	4.280
	1 860	37.63	0.5964	22.445	4.361
1 257.5	1 050	66.67	0	0	0
	1 860	37.63	0	0	0
1 278.5	1 050	66.67	0	0	0
	1 860	37.63	0	0	0

TABLE 14

SBAS ground reference receiver effective received pulse width and PDC for 28 MHz chirp width

Centre frequency (MHz)	Tx PRF (Hz)	Tx PW (µs)	BW overlap ratio	Eff. PW (µs)	PDC (%)
1 236.5	1 050	66.67	0.5482	36.548	3.942
	1 860	37.63	0.5482	20.632	4.023
1 257.5	1 050	66.67	0	0	0
	1 860	37.63	0	0	0
1 278.5	1 050	66.67	0	0	0
	1 860	37.63	0	0	0

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[15] This bandwidth value is the estimated rectangular equivalent determined from the receiver design. It is slightly larger than the pre-correlator 3 dB bandwidth in Annex 1, Table 1-7.

3.1.2 SBAS ground reference receiver pulsed RFI degradation computation

The pulsed RFI degradation ratio for the SBAS receiver is computed from the PDC values in Tables 13 and 14 by using equation (8)[16]. The computation result is to be compared with an allowable degradation ratio limit (in dB) from Table 9. Using equation (8) in logarithmic form for the largest PDC value (0.04361) for 14 MHz chirp centred at 1 236.5 MHz from Table 13, the degradation ratio in dB is 10 log ($N_{0,EFF+Y}/N_{0,EFF}$) = -20log(1-PDC) = 0.387 dB. Similarly, the smallest PDC (0.03942) for 28 MHz chirp produces a 0.349 dB degradation ratio. Since both these results exceed the allowable degradation ratio limit of 0.2 dB, the preliminary evaluation shows SAR5 defined waveforms with 14 or 28 MHz chirp width at the 1 236.5 MHz centre frequency exceed the allowable interference criteria for the SBAS ground reference receiver. Therefore, a more detailed analysis should be performed. However, the preliminary analysis shows SAR5 defined waveforms at the higher two centre frequencies do not interfere since they do not overlap the SBAS receiver passband.

3.2 GLONASS receiver pulsed RFI evaluation cases

In this example, a single EESS SAR5 active sensor illuminates one GLONASS receiver. Normally a dynamic link analysis would be done to find the actual time profile of peak received SAR5 power. The dynamic analysis would involve orbital simulation together with the satellite radiated power pattern and the RNSS receiver receive antenna pattern. For this simpler example, however, it is assumed that for a certain nominal time period (at least a few minutes), the received SAR5 peak power is sufficiently above the GLONASS receiver input saturation level so that the GLONASS receiver is saturated during the pulse duration. With that basis, the analytic method in Annex 1, § 4.2 can be applied to find the GLONASS receiver pulsed RFI degradation.

3.2.1 Computation of the received effective pulsed RFI duty cycle parameter, PDC_{LIM}

As it was said in Annex 1, § 4.2.2, the estimation results depend on the pre-correlator filter bandwidth of RNSS receiver. Report ITU-R M.2220 does not indicate the RNSS receiver bandwidth associated with the necessary attenuation level for the pre-correlator filter that should be used to calculate the overlap bandwidth factor ($\Delta f/Chirpwidth$). This level depends on technical implementation of RNSS receivers. Because this information is lacking, a worst-case assumption may be used for GLONASS air navigation receivers in Table 9. However, the increase of the estimation of interference from spaceborne active sensors resulting from the use of a unity overlap bandwidth factor should be taken into account when evaluating the results of the more detailed analysis. Taking into account these circumstances, the following formula is used to define the worst-case pulse duty cycle for GLONASS system with respect to the pulsed interference from SAR signals:

PDC = (SAR pulse width + RNSS recovery time) * SAR pulse repetition frequency.

Values of the SAR5 pulse width and SAR5 pulse repetition frequency are presented in Table 1. There are GLONASS receivers with 1 µs as well as 30 µs of overload recovery time operating at the moment. Thus, both of these cases are presented in this example. The results of computation of the received PDC for the GLONASS receiver are presented in Table 15.

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[16] Equation (8) is used since the SBAS ground reference receiver N_{LIM} value = 1 (Table 9).

TABLE 15

GLONASS receiver PDC calculation results

Overload recovery time (µs)	**Tx PRF (Hz)**	**Tx PW (µs)**	**PDC (%)**
1	1 050	67	7.14
	1 860	37	7.07
30	1 050	67	10.18
	1 860	37	12.46

3.2.2 GLONASS receiver pulsed RFI degradation computation

The pulsed RFI degradation ratio for the GLONASS receiver is computed from the PDC values in Table 15 by using equation (8)[17]. The computation result is to be compared with an allowable degradation ratio limit (in dB) from Table 10. Using equation (8) in logarithmic form for the largest PDC value (0.1246) for the case of 30 µs overload recovery time from Table 15, the degradation ratio in dB is 10 log ($N_{0,EFF+Y}/N_{0,EFF}$) = –20log(1-PDC) = 1.16 dB. Additionally, for the largest PDC value (0.07144) for the case of 1µs overload recovery time, the degradation ratio is 0.64 dB. Both of these results based on usage of the unity overlap bandwidth factor exceed the allowable degradation ratio limit provided from Table 9 indicating that a more detailed analysis is needed. The increase of the estimation of interference from spaceborne active sensors resulting from the use of a unity overlap bandwidth factor should be taken into account when conducting this more detailed analysis.

3.2.3 Results of PDC and receiver pulsed RFI degradation computation for GLONASS receiver from all types of active sensors

The calculation results of PDC and pulsed RFI degradation of the GLONASS receiver affected by the six example SAR EESS active sensors are presented in Tables 16 and 17. These results were obtained by the methodology described in Annex 1, § 4.2. However, when evaluating these results it should be considered that Report ITU-R M.2220 does not indicate the RNSS receiver bandwidth associated with the necessary attenuation level for the pre-correlator filter that should be used to calculate the overlap bandwidth factor ($\Delta f/Chirpwidth$). This level depends on technical implementation of RNSS receivers. Because this information is lacking, a worst-case assumption was used for GLONASS air navigation receivers in Table 9. However, the increase of the estimation of interference from spaceborne active sensors resulting from the use of a unity overlap bandwidth factor should be taken into account when evaluating the results of the more detailed analysis.

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[17] Equation (8) is used since the Air navigation receiver N_{LIM} value = 1 (see Table 9).

TABLE16

PDC parameters of certain EESS active sensors and the result of SNR degradation for GLONASS receivers

Receiver type	**Overload recovery time (μs)**	**Active sensor**	**Standard SAR1**		**Standard SAR2**		**Standard SAR3**	
		Freq. (MHz)	**1 257.5**		**1 257.5**		**1 257.5**	
Air navigation	1	PDC	0.06	−	0.06	−	0.19	−
		SNR (dB)	−0.54	−	−0.52	−	−1.83	−
	30	PDC	0.11	−	0.10	−	0.26	−
		SNR (dB)	−1.02	−	−0.96	−	−2.61	−
Indoor positioning	30	PDC	0.11	−	0.10	−	0.26	−
		SNR (dB)	−1.02	−	−0.96	−	−2.61	−
General purpose	30	PDC	0.11	−	0.10	−	0.26	−
		SNR (dB)	−1.02	−	−0.96	−	−2.61	−

TABLE 17

PDC parameters of certain EESS active sensors and the result of SNR degradation for GLONASS receivers

Receiver type	**Overload recovery time (μs)**	**Active sensor**	**Standard SAR4**		**Standard SAR5_PW_min**			**Standard SAR5_PW_MAX**			**Standard SAR6_PW_min**			**Standard SAR6_PW_MAX**		
		Frequency (MHz)	**Centre freq. (MHz)**		**Centre freq. (MHz)**			**Centre freq. (MHz)**			**Centre freq. (MHz)**			**Centre freq. (MHz)**		
			1 257.5		**1 236.5**	**1 257.5**	**1 278.5**	**1 236.5**	**1 258**	**1 278.5**	**1 236.5**	**1 257.5**	**1 278.5**	**1 236.5**	**1 257.5**	**1 278.5**
Air navigation	1	PDC	0.12	0.12	0.07	0.07	–	0.07	0.07	–	0.07	0.07	–	0.07	0.07	–
		SNR (dB)	−1.08	−1.08	−0.64	−0.64	–	−0.64	−0.64	–	−0.62	−0.62	–	−0.61	−0.61	–
	30	PDC	0.19	0.16	0.12	0.12	–	0.10	0.10	–	0.17	0.17	–	0.11	0.11	–
		SNR (dB)	−1.88	−1.55	−1.16	−1.16	–	−0.93	−0.93	–	−1.67	−1.67	–	−1.04	−1.04	–
Indoor positioning	30	PDC	0.19	0.16	0.12	0.12	–	0.10	0.10	–	0.17	0.17	–	0.11	0.11	–
		SNR (dB)	−1.88	−1.55	−1.16	−1.16	–	−0.93	−0.93	–	−1.67	−1.67	–	−1.04	−1.04	–
General Purpose	30	PDC	0.19	0.16	0.12	0.12	–	0.10	0.10	–	0.17	0.17	–	0.11	0.11	–
		SNR (dB)	−1.88	−1.55	−1.16	−1.16	–	−0.93	−0.93	–	−1.67	−1.67	–	−1.04	−1.04	–

4 Summary

Annex 2 presented example applications of the worst-case received power portion of the interference evaluation analysis methodology (Annex 1, § 4.1) between each of six representative SAR systems in the EESS (active) of Annex 1 and three receivers in the RNSS. It also presented example applications of the pulsed RFI performance degradation evaluation method (Annex 1, § 4.2) to the pulsed RFI effects from one of the several representative spaceborne active sensors provided in Annex 1 on two RNSS receiver types.

In addition, it must be noted that the evaluation of the potential for pulsed interference from an EESS (active) sensor to an RNSS receiver should also consider the cumulative impact of multiple spaceborne active sensors that simultaneously illuminate the RNSS receivers, wherever relevant. One means of mitigating the potential aggregate interference from multiple spaceborne active sensors is through operational collaboration by EESS (active) operators of such sensors.