International Telecommunication Union

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Report ITU-R M.2513-0

(09/2022)

Studies regarding the protection of the primary radionavigation-satellite service (space-to-Earth) by the secondary amateur and amateur-satellite services in the frequency band 1 240-1 300 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

Foreword

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Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R M.2513-0

Studies regarding the protection of the primary radionavigation-satellite service (space-to-Earth) by the secondary amateur and amateur-satellite services in the frequency band 1 240-1 300 MHz

(2022)

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1 Background

Some cases of harmful interference caused by emissions from the stations in the amateur service into radionavigation-satellite service (RNSS) (space-to-Earth) receivers have been observed at least by two Administrations, and those Administrations documented and reported the harmful interference. The sources of interferences have been identified and one of the relevant amateur service transmitters was shut down and the interference was ceased. Report evidence is available in § 9 below.

This Report presents studies intended to be used as the basis for guidelines for administrations that may be applied to stations in the amateur and amateur-satellite services operating in the frequency band 1 240-1 300 MHz to avoid such cases of harmful interference to RNSS receivers in the future. The potential interference issues are studied in detail to identify those stations and modes possibly causing harmful interference, and to propose a basis for future measures that would assure the future protection of the RNSS.

In this regard, WRC-19 invited the ITU-R to review the amateur and amateur-satellite services applications in the frequency band 1 240-1 300 MHz, without considering the removal of these allocations, to determine if additional measures are required to ensure protection of the RNSS (space-to-Earth) operating in the same band in accordance with Resolution **774 (WRC-19)**. The results of this review are to be included in the Director's Report to WRC-23 under agenda item 9.1, topic b).

This Report is therefore devoted to these studies.

2 Introduction

The frequency band 1 240-1 300 MHz is allocated worldwide to the Earth exploration-satellite service (active), radiolocation service (RR No. **5.329** applies), space research service and the radionavigation-satellite service (RNSS) in the space-to-Earth direction on a co-primary basis. The frequency band 1 240-1 300 MHz is also allocated worldwide to the RNSS in the space-to-space direction on a co-primary basis. Additional services are allocated in some countries by footnotes RR No. **5.330** (fixed and mobile) and RR No. **5.331** (radionavigation).

Many RNSS systems and networks are operational in or adjacent to the 1 240-1 300 MHz portion of the 1 215-1 300 RNSS (space-to-Earth) and (space-to-space) primary allocations, as described in Recommendation ITU-R M.1787, and various types of RNSS receivers are used with those systems and networks. Report ITU-R M.2458 summarizes the RNSS applications in this frequency band.

The frequency band 1 240-1 260 MHz is currently used by the Russian Federation GLONASS system, while the frequency band 1 250-1 280 MHz is used by the Chinese COMPASS system and the frequency band 1 260-1 300 MHz is used by the European Galileo system as well as the Japanese QZSS system. The same frequency band is also planned to be used by the Korean Positioning System (KPS). Some transmissions of the United States' Global Positioning System in the 1 215-1 240 MHz frequency band also extend above 1 240 MHz.

The frequency band 1 240-1 300 MHz is also allocated worldwide to the amateur service on a secondary basis and is being used for a range of applications. The amateur-satellite service (Earth-to-space) operates in the frequency band 1 260-1 270 MHz on a secondary basis under RR No. **5.282**.

The RNSS, amateur and amateur-satellite services characteristics and parameters are provided in the relevant ITU-R Recommendations (see § 3 below). Those were completed by additional information from administrations on current and planned systems of the amateur and amateur-satellite services. The full set of characteristics, parameters and protection criteria to be used for interference studies are given in §§ 5 and 6. Technical and operational measures that could be employed to ensure the protection of the RNSS are presented, and conclusions are drawn with regard to the coexistence studies.

3 Relevant publications (ITU Recommendations and Reports and others)

Recommendation ITU-R S.465 – Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Recommendation ITU-R F.1336-5 – Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz

Recommendation ITU-R P.1546-6 – Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz

Recommendation ITU-R M.1732 – Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies

Recommendation ITU-R M.1787 – Description of systems and networks in the radio-navigation-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.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.1904 – Characteristics, performance requirements and protection criteria for receiving stations of the radionavigation-satellite service (space-to-space) operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 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

Report ITU-R M.2220 – Calculation method to determine aggregate interference parameters of pulsed RF systems operating in and near the 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 frequency bands

Report ITU-R M.2284 – Compatibility of radio-navigation satellite service (space-to-Earth) systems and radars operating in the frequency band 1 215-1 300 MHz

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

Report ITU-R RS.2311 – Pulsed radio frequency signal impact measurements and possible mitigation techniques between Earth exploration-satellite service (active) systems and RNSS systems and networks in the band 1 215-1 300 MHz

Report ITU-R M.2458 – Radionavigation-satellite service applications in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

Study Question ITU-R 48-7/5 – Related results of the WP 5A work on the Study Question on techniques and frequency usage in the amateur service and amateur-satellite service

Study Question ITU-R 288/4 – Related results of the WP 4C work on the Study Question on characteristics and operational requirements of radionavigation-satellite systems

Handbook on Amateur and amateur-satellite services

4 Abbreviations and definitions

AFSK	Audio frequency shift keying
AMSAT	International Amateur Satellite Organisation(s)
Bd	Baud (symbol per second)

BNetzA	Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway
C4FM	Proprietary standard for digital voice and data communication (YAESU)
CEPT	Conférence Européenne des Administrations des postes et des télécommunications
CEPT ECC	Electronic Communications Committee (CEPT)
ECC WGFM	Working Group Frequency Management (CEPT ECC)
ECC WGSE	Working Group Spectrum Engineering (CEPT ECC)
CSI	Galileo Expert Group on Compatibility, Signals and Interoperability
CW	Continuous wave (Amateur Service: Morse coded on-off keying of carrier)
DARC e.V.	Deutscher Amateur-Radio-Club e.V., Baunatal
DATV	Digital Amateur TV (applying DVB-S and DVB-S2 Standards)
DLR RfM	Deutsche Agentur für Luft-und Raumfahrt – Raumfahrt Management (German Aerospace Center)
DLR GfR	Certified Air Navigation Service Provider Galileo Control Center Oberpfaffenhofen (www.dlr-gfr.de)
DMR	Digital Mobile Radio (ETSI Standard)
D-Star	Digital Smart Technology for Amateur Radio (Proprietary standard for digital voice and data communication (ICOM))
e.i.r.p.	Effective isotropic radiated power
EME	Earth-Moon-Earth
FM ATV	Analogue (FM) amateur TV
FSK	Frequency shift keying
IARU	International Amateur Radio Union
ICD	Open Service Interface Control Document Issue 1.3 12/2016 (EU Galileo)
ISTA	Institute of Space Technology & Space Applications, Universität der Bundeswehr
ITU-R	International Telecommunication Union – Radiocommunication Sector
JRC	EU Joint Research Centre, Ispra, Italy
MGM	Machine generated modes
PSK31	Phase shift keying mode (31 Hz)
RTTY	Radio teletyping
SATV	Amateur satellite TV
SSTV	Slow scan TV
TDMA	Time division multiple access
WPM	Words per minute (Morse telegraphy)
WSPR	Weak signal propagation reporter
WSJT-X	Weak signal narrow-band data communication (Joe Taylor, K1JT)

5 RNSS characteristics and protection criteria

5.1 System description

RNSS systems and networks provide location, navigation, and timing services to a globally deployed set of user devices that can range from installations in professional systems to portable consumer devices.

As described in Recommendation ITU-R M.1787, the frequency range 1 240-1 260 MHz, is used by the Russian Federation GLONASS system, the frequency range 1 250-1 280 MHz is used by the Chinese COMPASS system and the frequency range 1 260-1 300 MHz, is used by the European Galileo system for the provision of radio navigation-satellite service (RNSS) in the space-to-Earth and space-to-space directions. Some transmissions of the United States' Global Positioning System centred in the 1 215-1 240 MHz frequency also extend above 1 240 MHz.

For a description of RNSS applications, please see Report ITU-R M.2458.

5.2 Characterization of the RNSS receivers

The technical characteristics and protection criteria of the RNSS (space-to-Earth) receivers in the frequency band 1 240-1 300 MHz are listed in Recommendation ITU-R M.1902, which contains the protection criteria from non-pulse radio emissions. Some key parameters are summarized in Table 1 of Recommendation ITU-R M.1902-2, as shown in § 5.2.1 below.

The characteristics, performance requirements, and protection criteria of the RNSS (space-to-space) receivers in the frequency band 1 240-1 300 MHz are listed in Recommendation ITU-R M.1904, which contains the protection criteria from non-pulse radio emissions. Some key parameters and thresholds for continuous and/or pulsed interference are summarized in Tables 1 to 3 of Recommendation ITU-R M.1904-1 (not shown below).

5.2.1 Table of technical characteristics and protection criteria for RNSS (space-to-Earth) receivers

Table 1 of Recommendation ITU-R M.1902-2

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, .., +6	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 1 of Recommendation ITU-R M.1902-2 (*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}	

Notes to Table 1:

* 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.

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 given in Recommendation ITU-R M.2030.

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.

For the protection of RNSS receivers from pulse type emissions, Recommendation ITU-R M.2030 and Report ITU-R M.2220 can be referenced. Thus, if interfering transmitters employ pulsed emissions, Recommendation ITU-R M.2030 and Report ITU-R M.2220 may be taken into account.

5.2.2 Statistical distribution of receivers

RNSS receivers are deployed on a worldwide and ubiquitous basis.

5.3 Calculation of actual interference levels

To complete the analysis, the probability of interference arriving at the input of a RNSS receiver must be evaluated. This will take into account up-to-date propagation models and path factors, which are described in the ITU-R P-Series Recommendations and Reports. It is likely that a single model will suffice for all possible applications. The transmission loss calculation will also include factors such as absorption losses, diffraction losses, scattering loss, polarization coupling loss, and the effect of multipath. Also, both aggregate and single-entry interference levels may need to be considered.

6 Applications and typical operational characteristics of the amateur and amateur-satellite service operating in the frequency band 1 240-1 300 MHz

6.1 Amateur and amateur-satellite applications and station categories

The detailed list of amateur and the amateur-satellite service applications in the band 1 240-1 300 MHz can be divided into three categories:

1) Home station

This refers to equipment located at the station licence holder’s home address.

2) Temporary ‘portable’ station

A temporarily sited station is usually located in an advantageous position (usually high ground) away from a home station location and operational for a short period radiosport contest, an experimental long-distance communication test or a time-limited special activity event.

3) Permanent installation (sometimes referred to as ‘automatic’ or ‘unmanned’ stations)

Permanent installations refer to stations installed away from a home station. They operate as propagation beacons, voice, amateur television (ATV) or data repeaters. As permanently installed stations, these are licensed by the national authority in their own right for their designated location, operating frequency and output power. The licence and responsibility of the station operation are usually associated with an already licensed radio amateur operator known as the ‘keeper’ of the installation.

Propagation beacons are usually intended to operate continuously and are required to transmit a short repeating message using on/off keying or a narrowband FSK signal with call sign ID and location information.

Voice repeaters usually re-transmit narrowband analogue and digital voice traffic when activated with a signal on the input frequency and are mostly associated with extending geographic coverage area. Data and ATV repeater stations transmit wider bandwidth amateur signals and ATV repeater stations may transmit test signals when not being accessed by a user station on the input channel. All repeater stations are required by national regulations to transmit identification information.

Satellite communications (1 260-1 270 MHz, Earth-to-space only; see RR No. **5.282**) and mobile stations are possible, but these are rare in this frequency band. Tables 1 and 2 provide a matrix of the amateur and amateur-satellite applications versus station categories.

TABLE 1

Narrowband amateur and amateur-satellite applications against the station category

<table>
<tr><th rowspan="3">Application</th><th colspan="4">Station type</th><th rowspan="3">Max. bandwidth</th><th rowspan="3">Comments</th></tr>
<tr><th rowspan="2">Home</th><th rowspan="2">Temporary</th><th colspan="2">Installation</th></tr>
<tr><th>Repeater</th><th>Beacon</th></tr>
<tr><td>Voice (Analogue SSB)</td><td>Yes</td><td>Yes</td><td></td><td></td><td>2 700 Hz</td><td>Long distance tropospheric weak signal communications. Radiosport operation (incl. EME).</td></tr>
<tr><td>Voice (Analogue NBFM)</td><td>Yes</td><td>Yes</td><td>Yes</td><td></td><td>12 500 and 25 000 Hz (channel width dependent)</td><td>Local neighbourhood communications.
Satellite communications.</td></tr>
<tr><td>Voice (Digital)</td><td>Yes</td><td></td><td>Yes</td><td></td><td>12 500 Hz</td><td>Local neighbourhood communications</td></tr>
<tr><td>Telegraphy (Morse code On/Off keying)</td><td>Yes</td><td>Yes</td><td></td><td>Yes</td><td>500 Hz</td><td>Long distance tropospheric weak signal communications.
Radiosport[1] operation (incl. EME).</td></tr>
<tr><td>Machine Generated Modes e.g. RTTY, SSTV[2], PSK31[3], WSJT[4]</td><td>Yes</td><td>Yes</td><td></td><td>Yes</td><td>6 to 2 700 Hz
Mode dependent</td><td>Local and long distance tropospheric weak signal communications. (incl. EME). Imaging</td></tr>
<tr><td>Data e.g. AFSK 1k2, FSK 9k6, D-STAR[5], Digital Data 128 kbit/s</td><td>Yes</td><td>Yes (Mobile)</td><td>Yes</td><td></td><td>12.5 to 150 kHz
Mode dependent</td><td>Local neighbourhood communication links.</td></tr>
</table>

[1] See the Handbook on Amateur and amateur-satellite services for further details of radiosport activities.

[2] Slow Scan Television (SSTV) is an imaging protocol which is issued to transmit images at a relatively low speed by using a frequency modulated subcarrier or digital encoding. Such transmissions are designed to fit within the bandwidth of a voice channel.

[3] See Recommendation ITU-R M.2034-0 which establishes a telegraphic alphabet and transmission protocols for phase shift keying at 31 baud (PSK31) in the amateur and amateur-satellite services.

[4] These WSJT applications consist of a number of highly structured data modes which send a limited amount of data with strong Forward Error Correction which allows the data to be recovered at very low signal-to-noise ratios. WSJT modes –Weak Signal Joe Taylor– are named after their inventor Dr Joe Taylor.

[5] D-STAR (Digital Smart Technologies for Amateur Radio) is a digital voice and data protocol specification for amateur radio. The system was developed in the late 1990s by the Japan Amateur Radio League and uses minimum-shift keying in its packet-based standard.

TABLE 2

Wideband amateur applications against the station category

<table>
<tr><th rowspan="3">Application</th><th colspan="4">Station type</th><th rowspan="3">Max. bandwidth</th><th rowspan="3">Comments</th></tr>
<tr><th rowspan="2">Home</th><th rowspan="2">Temporary</th><th colspan="2">Installation</th></tr>
<tr><th>Repeater</th><th>Beacon</th></tr>
<tr><td>Analogue ATV (FM-TV)</td><td>Yes</td><td>Yes</td><td>Yes</td><td></td><td>20 MHz</td><td>Legacy technology, deployments decreasing.</td></tr>
<tr><td>Digital ATV (DVB Standards)</td><td>Yes</td><td>Yes</td><td>Yes</td><td></td><td>1-8 MHz
Symbol rate dependent</td><td>State of the art technology, deployments increasing</td></tr>
</table>

Modern ATV installations employ spectrally efficient digital TV transmitters based on DVB-S/MPEG-2 signals. Symbol rates of 2 MBd or 4 MBd operate in lower bandwidth channels and further experimentation continues to increase the spectrum efficiency of amateur TV signals. It has been shown possible to transmit HD MPEG-4 signals with symbol rates less than 333 kBd in a bandwidth as low as 500 kHz. Note: Bd = Baud (symbol per second).

6.2 Typical amateur station antenna characteristics in the 1 240-1 300 MHz band

There is no standard amateur station and in most cases the antenna installation at any individual amateur station is constrained or influenced by the physical location and town planning restrictions. The following antenna types are typical and based on deployments detailed in published information relating to activity periods and reports from radiosport contests. In general home and temporary stations use highly directional, narrow beam width antennas in this frequency range.

1) Home station and temporary ‘portable’ station antennas

Home stations generally use a single directional antenna, however in a few cases multiple antennas are combined to increase the array gain. This is more usual for EME[6] operators for whom high antenna gain is essential for overcoming the high path and reflection loss. A higher performance EME station might use instead a medium size dish antenna. Table 3 contains the antenna details.

TABLE 3

Typical home station and temporary ‘portable’ station antennas

Antenna type	Gain (dBi)	3 dB beam width (degrees)
Single Yagi beam (23 to 55 element)	18 to 21	18 to 10
Multiple Yagi beams (for EME) Dish antenna (for EME)	21 32 (4 m diameter)	10 4

[6] Earth-Moon-Earth (EME) communications use the Moon as a passive reflector which allows long distance communications between stations that have a simultaneous view of the moon. The reflected signals are very weak, though modern digital signal processing techniques and structured data modes reduce the need for high power transmitters.

2) Permanent installation antennas

Permanent installations operate for different applications using a variety of antenna types characterized by different gain and directivity figures. However, most permanent installations antennas are less directional and (in the case of repeaters) are generally intended to provide coverage over a local area. It should be noted that the antenna type used depends not only on the application but also on the local topography[7]. Table 4 summarizes antenna characteristics with indications of minimum, median and maximum parameter values of a typical installation.

TABLE 4

Antenna characteristic of a typical permanent installation

Antenna types	Gain [(1)]	Beamwidth in the azimuth plane
Various (e.g. linear slot, co-linear array, horn, flat panel etc.)	Minimum = 2.15 dBi Median = 13 dBi Maximum: refer to footnote 7 for information	Median = 60° (−3 dB) Maximum = Omnidirectional

(1) Feeder loss not included which may be up to 3 dB.

Antennas with linear polarization are mainly used, but occasionally circular polarization can also be found.

6.3 Typical amateur station power level distribution in the 1 240-1 300 MHz band

Typical power level distribution can be derived from published information about the stations that submit information resulting from national activity periods and reports from radiosport contests.

NOTE – In the following Tables, the power is specified differently because of the different sources of information.

1) Home station and temporary ‘portable’ station

TABLE 5

Transmitter power ranges in use

Transmitter power (watt)	% home stations	% temporary stations
Up to 10	47%	61.5%
11-25	9%	7.5%
26-100	26%	7.5%
101-300	12%	15%
Over 300	6%	7.5%

7 According to the extract from the database of one administration on unmanned amateur radio stations parameters, the antenna gain for 25th percentile, median and 75th percentile are 8.1 dBi, 11.2 dBi and 12.7 dBi. Minimum and maximum gain are found to be 2.15 dBi and 21.5 dBi. However, a gain of 21.5 dBi is exceptionally high in this application. It should be noted that those installations mostly operate in hilly and mountainous areas.

2) Permanent installation

Propagation beacon and repeater station directories can be consulted to gather information on the permanent stations deployed within a territory. They are usually licensed to operate at a specific e.r.p. Table 6 summarises information on stations in current use extracted from published information from a number of countries.

TABLE 6

Transmitter radiated power ranges in use

e.r.p. (watt)	% propagation beacons	% repeaters
Up to 10	69%	16%
11-25	8%	76%
26-100	20%	8%
101-300	1%	0%
Over 300	1%	0%

According to the information in Table 6, no repeater is currently in use with an e.r.p. of more than 100 W. However, based on the extract from the license database of one administration on unmanned amateur radio stations parameters, it is indicated that some repeater / relay – stations are licensed to operate with a radiated power up to 380 W[8] e.r.p., but the operational status of these stations is unknown. Note that there is a limit on the radiated power of unmanned stations given by national regulation and licensing conditions.

6.4 Representative antenna heights

The following antenna heights are representative of typical amateur station installations.

– Typical antenna height for a home station = 12 m above ground level.

– Typical antenna height for a temporary station = 3 m to 15 m above ground level.

– Typical height for a permanent installation station = 25 m above ground level.

Permanent installation stations are often installed at an advantageous location so as to take advantage of elevated local terrain or tall structures in order to increase the effective antenna height.

6.5 Amateur station 1 240-1 300 MHz band usage patterns

For all home and temporary “portable” station applications, narrowband or wideband, the highest number of actively transmitting amateur stations can be found during the scheduled operating and radiosport contest periods. Table 7 summarises the total scheduled operating and contest periods scheduled in one region for a typical year. As these activities are usually formalised in the amateur operator calendars, the published national results[9] can be consulted to determine the number of transmitting stations that were active during any one activity or contest period.

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[8] According to the extract from the license database of one administration on unmanned amateur radio stations parameters, 30% of repeaters are licensed to operate with an e.r.p. of more than 100 W.

[9] The analysed results were published by the national radio amateur societies in several European countries.

TABLE 7

Scheduled operating periods and active operating station numbers

Usage type	Annual scheduled operating periods	Total active stations per scheduled operating period	Active temporary stations per scheduled operating period
Narrowband activity period and radiosport (in the 1 296-1 297 MHz portion)	Total, on average 108 hours over a year	From 9 to 140 maximum, depending on the country reviewed.	15 to 20 maximum, depending on the country reviewed.
EME activity (in the 1 296-1 297 MHz portion)	5 × 24-hour contest periods	Up to 10 maximum, depending on the country reviewed. (Maximum < 70 across the European area)	None
Wideband (typically ATV) activity period and radiosport (in any portion identified for ATV applications)	Total, on average 120 hours over a year	From 1 to 24 maximum, depending on the country reviewed. (Maximum < 100 across the European area)	10 maximum, depending on the country reviewed.

The figures presented in Table 7 can be used to estimate the amount of time over a one-year period when certain parts of the band (depending on the activity) are at their busiest with the highest number of actively transmitting amateur stations. For those activities concentrated in the 1 296-1 297 MHz portion of the band and assuming the moon is visible for 24 hours (an over estimation) then the following can be deduced:

Total narrowband ‘busy hour’ activity period = 108 hours (1.2% of a year).

Total EME ‘busy hour’ activity period = 120 hours (1.4% of a year).

For the wideband activities taking place in the identified parts of the band plan, the following can be deduced:

Total wideband ‘busy hour’ activity period = 120 hours (1.4% of a year).

Table 7 also shows that the number of active stations involved in the EME and wideband activities is considerably lower than those active in the narrowband activities.

The number of activity periods in Table 7 reflects activity in several European countries with well-developed amateur communities. The densities and numbers are likely to be lower in many other countries, further reducing the probability of harmful interference.

Permanent installation stations present a different scenario when considering the operational time. Unmanned amateur radio stations are more or less in continuous operation, while manned stations only transmit intermittently. Propagation beacon and repeater station directories from a representative region can be consulted to develop the summary presented in Table 8.

TABLE 8

Permanent installation station operating periods in a typical year

Usage type	Annual operation	Active installations
Narrowband propagation beacons	Transmitting continuously usually.	From 4 to 20 depending on the country reviewed Region 1 = 88 in total
Narrowband repeaters	Low and only when activated on the input frequency by a user station. May transmit more regularly if a beacon mode is present.	From 9 to 19 depending on the country reviewed
ATV repeaters (the users are usually home stations)	Low and only when activated on the input frequency by a user station in a random and sporadic manner. May transmit more regularly if a beacon mode is present.	From 10 to 18 depending on the country reviewed 5 to 10 users within the local coverage area transmitting one at a time

6.6 Activity factors of amateur transmitting stations in the 1 240-1 300 MHz band

Activity factor considers the amount of time that any particular station is transmitting during any operational period of activity. All applications involve two-way communication requiring periods of reception as well as transmission. It is usual practice for any home station or temporary portable station to spend more time receiving than transmitting.

Maximum Activity Factor for home station and temporary ‘portable’ stations = 50% and typically less.

Any permanent installation station operating in a beacon mode will exhibit a 100% activity factor.

6.7 User density of amateur transmitting stations in the 1 240-1 300 MHz band

1) Home station and temporary ‘portable’ station

– For narrowband activity periods the maximum density of transmitting stations = 0.000 2 stations/km^2.

– For wideband activity periods the maximum density of transmitting stations = 0.000 1 stations/km^2.

– For EME operations the maximum density of transmitting stations = 0.000 013 stations/km^2.

Recognising that not all active stations may submit a record of their activities, a 33% uplift has been added to the total active stations per scheduled operating period from Table 7.

2) Permanent installation

– For narrowband data and voice repeaters the average density of transmitting stations = 0.000 3 stations/km^2.

– For wideband ATV repeaters, the average density of transmitting stations = 0.000 1 stations/km^2.

– For propagation radio beacon stations, the average density of transmitting stations = 0.000 1 stations/km^2.

The general characteristics of the amateur and amateur-satellite stations are listed in Recommendation ITU-R M.1732.

6.8 Table of transmitter characteristics and parameters extracted from Recommendation ITU-R M.1732

TABLE 9

Characteristics of amateur systems*

Parameter	Value		
Applications	Morse on-off keying, PSK31, NBDP	Analogue voice systems	Data, digital voice and multimedia systems
Frequency range (1)	0.902-3.5 GHz	0.902-3.5 GHz	0.902-3.5 GHz
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A 60H0J2B 250HF1B	2K70J3E 11K0F3E 16K0F3E 20K0F3E	2K70G1D 6K00F7D 16K0D1D 150KF1W 2M50G7W
Transmitter power (dBW) (2)	3 to 31.7	3 to 31.7	3 to 31.7
Feeder loss (dB)	1 to 6	1 to 6	1 to 6
Transmitting antenna gain (dBi)	10 to 42	10 to 42	10 to 42
Typical e.i.r.p. (dBW) (3)	1 to 45	1 to 45	1 to 45
Antenna polarization	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical

(1) Amateur bands within the frequency ranges shown conform to RR Article **5**.

(2) Maximum powers are determined by each administration.

(3) May be limited by RR Article **5** in some cases.

* Notwithstanding the frequency range in this Table, this Report is only addressing amateur systems in the 1 240-1 300 MHz band and amateur-satellite systems in the 1 260-1 270 MHz band.

TABLE 10

Characteristics of Earth-Moon-Earth (EME) systems*

Parameter	Value
Frequency range (1)	1.24-3.5 GHz
Necessary bandwidth and class of emission (emission designator)	50H0A1A, 50H0J2A, 1K80F1B
Transmitter power (dBW) (2)	17 to 31.7
Feeder loss (dB)	1 to 4
Transmitting antenna gain (dBi)	25 to 40
Typical e.i.r.p. (dBW)	40 to 68
Antenna polarization	Horizontal, vertical, LHCP, RHCP

(1) Amateur bands within the frequency ranges shown conform to RR Article **5**.

(2) Maximum powers are determined by each administration.

* Notwithstanding the frequency range in this Table, this Report is only addressing amateur systems in the 1 240-1 300 MHz band and amateur-satellite systems in the 1 260-1 270 MHz band.

Usage note: Main antenna beam direction can be assumed to be pointing above the horizon.

Emission note: EME increasingly employs digital “Weak Signal Modes” which are structured for very basic communications with low data rates and narrow bandwidth for best weak signal performance.

TABLE 11

Characteristics of amateur-satellite systems in the Earth-to-space direction*

Parameter	Value
Frequency range (1)	1.24-3.5 GHz
Necessary bandwidth and class of emission (emission designator)	150HA1A, 150HJ2A
Necessary bandwidth and class of emission (emission designator) (2)	2K70J3E, 2K70J2E, 16K0F3E, 44K2F1D, 88K3F1D, 350KF1D,2M50G7W
Transmitter power (dBW) (3)	3 to 31.7
Feeder loss (dB)	1 to 2
Transmitting antenna gain (dBi)	10 to 42
Typical e.i.r.p. (dBW)	3 to 45
Antenna polarization	Horizontal, vertical, RHCP, LHCP

(1) Amateur bands within the frequency ranges shown conform to RR Article **5**.

(2) Any mode with a necessary bandwidth greater than 44 kHz may require higher e.i.r.p values than shown in the table to achieve a satisfactory link budget.

(3) Maximum powers are determined by each administration.

* Notwithstanding the frequency range in this Table, this Report is only addressing amateur systems in the 1 240-1 300 MHz band and amateur-satellite systems in the 1 260-1 270 MHz band.

6.9 Band plan(s)

Amateur and amateur-satellite services band planning is achieved on a regional basis in order to take into account the regional differences with the frequency allocations. The current IARU recommended band plans for the frequency range 1 240-1 300 MHz across the three regions are summarized in Table 12 below.

The published band plans for each of the three regions may differ and may not be fully harmonised at the detailed level for every amateur service application. However, it is necessary to harmonise parts of the band for specific applications where these could involve inter-regional communications. This applies particularly to parts of the band recommended for narrowband weak signal applications.

The three recommended band plans across each of the IARU regions can be summarized according to Table 12 below.

TABLE 12

Global summary of amateur service and amateur-satellite-service IARU band plans

Frequency range (MHz)	Applications	Comments
1 240-1 260	Low bandwidth telegraphy, voice and data modes up to around 20 kHz. Amateur TV (ATV using Analogue or Digital technologies).	Organised into channelized groups for voice and data applications in some regions. One 16.75 MHz block is identified for ATV in this range in Region 1. Two 6 MHz blocks are identified for ATV in Region 2.
1 260-1 270	Satellite uplink band.	In Region 2 simplex ATV is also identified for experimental use in this range.
1 270-1 296	Low bandwidth telegraphy, voice and data modes up to around 20 kHz. Amateur TV (ATV using Analogue or Digital technologies).	Organised into channelized groups for voice and data applications in some regions. One 18.994 MHz block is identified for ATV in this range in Region 1. Two 6 MHz blocks are identified for ATV in Region 2.
1 296-1 297	Low bandwidth telegraphy, voice and data modes up to 3 kHz.	Focused on narrowband weak signal applications in all three regions including beacons. No channelization.
1 297-1 300	Low bandwidth voice and data modes up to around 20 kHz. Medium bandwidth data up to 150 kHz bandwidth.	Organized into channelized groups for voice and data applications in some regions.

Note: The blocks identified for ATV use can accommodate a number of systems depending on the bandwidth occupied by the technology in use. The actual assignments are planned on a national basis.

6.9.1 IARU-R1 band plan for the frequency band 1 240-1 300 MHz

Table 13 provides the IARU Region 1 recommended usage of the allocations (Band Plan) by operators in the amateur and amateur-satellite services. National versions of this band plan may slightly differ due to national frequency allocations.

TABLE 13

IARU Region 1 UHF Band plan for 1 240-1 300 MHz (Varna, 2014)

Frequency (MHz)	Maximum bandwidth	Mode	Usage
1 240.000 1 240.500	2 700 Hz	All modes	Reserved for future
1 240.500 1 240.750	500 Hz	Telegraphy and MGM	Beacons (reserved for future)
1 240.750 1 241.000	20 kHz	FM Digital Voice	Reserved for the future

TABLE 13 (*continued*)

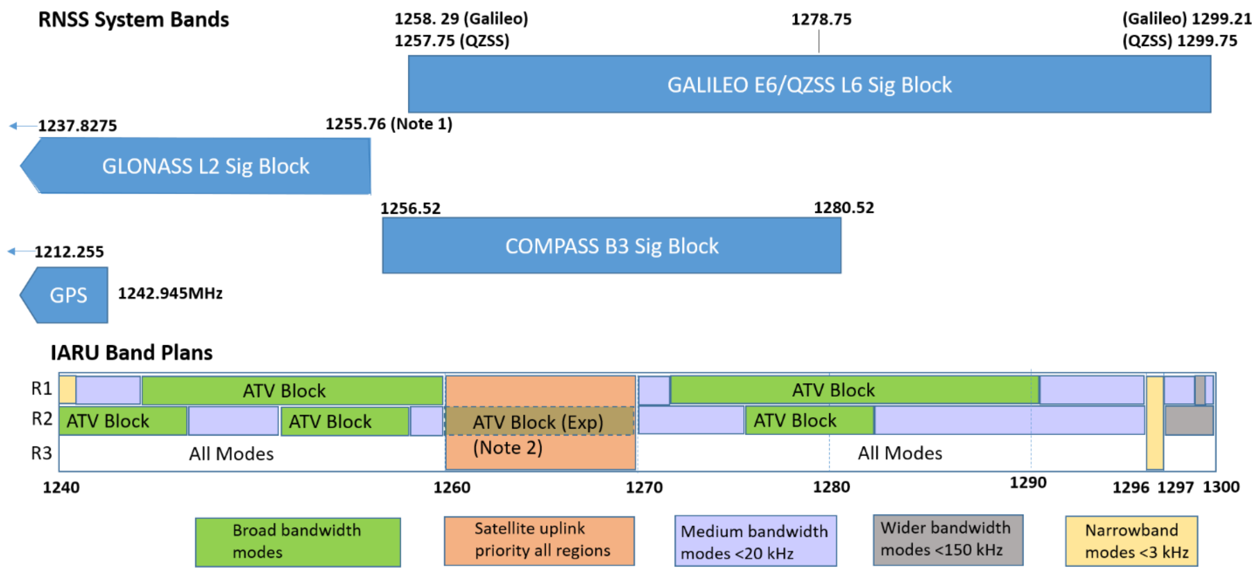
Frequency (MHz)	Maximum bandwidth	Mode	Usage
1 241.000 1 243.250	20 kHz	All Mode	1 242.025-1 242.250 repeater output (RS1-10) 1 242.275-1 242.700 repeater output (RS11-28) 1 242.725-1 243.250 Digital communications (RS29-50)
1 243.250 1 260.000	*	ATV/Digital ATV	1 258.150-1 259.350 repeater output
1 260.000 1 270.000	*	Satellite Service	
1 270.000 1 272.000	20 kHz	All mode	1 270.025-1 270.700 repeater output (RS1-28) 1 270.725-1 271.250 Digital communications (RS29-50)
1 272.000 1 290.994	*	ATV/Digital ATV	
1 290.994 1 291.481	20 kHz	FM digital voice repeater input	RM1 (1 291.000) – RM19 (1 291.475) 25 kHz spacing
1 291.494 1 296.000	*	All modes	1 293.150-1 294.350 repeater input (R20-R68)
1 296.000 1 296.150	500 Hz	Telegraphy MGM	1 296.000-1 296.025 moon bounce 1 296.128 PSK21 centre of activity
1 296.150 1 296.800	2 700 Hz	Telegraphy SSB MGM	1 296.200 narrowband centre of activity 1 296.400.1 296.600 linear transponder input 1 296.500 fax 1 296.600 narrowband centre of activity (MGM, RTTY) 1 296.600-1 296.700 linear transponder input 1 296.750-1 296.600 local beacons
1 296.800 1 296.994	500 Hz	Telegraphy MGM	beacons exclusive
1 296.994 1 297.481	20 kHz	FM digital voice repeater output	RM0 / 1 297.000) – RM19 (1 297.475) 25 kHz spacing
1 297.494 1 297.981	20 kHz	FM digital voice	1 297.500 SM20 1 297.500 centre of FM activity 1 297.725 digital voice calling frequency 1 297.900-1 297.975 Simplex FM internet gateways 1 297.975 SM39
1 298.000 1 299.000	20 kHz	All modes	General mixed analogue or digital use 25 kHz spacing 1 298.025 RS1 1 298.975 RS39
1 299.000 1 299.750	150 MHz	All modes	Arranged as 5x 150 kHz channels for high-speed DD use Centres: 1 299.075, 1 299.225, 1 299.375, 1 299.525, 1 299.675 (±75 kHz)
1 299.750 1 300.000	20 kHz	All modes	8x 25 kHz channels (available for FM/DV use) Centres: 1 299.775-1 299.975

* Bandwidth limits according to national regulations.

6.9.2 Relationship between RNSS system frequencies in 1 240-1 300 MHz and the IARU band plans

Figure 1 highlights the relationship between the various RNSS systems usage across the range 1 240-1 300 MHz and the IARU band plans.

FIGURE 1



Notes to Fig. 1:

Note 1: GLONASS navigation receivers manufactured before 2006 can receive navigation signals in frequency band from 1 237.8275 MHz to 1 260.735 MHz.

Note 2: In Region 2 ATV is also identified for experimental use in this range.

Noting the IARU band plan as introduced in Table 13 and noting the RNSS receiver characteristics of the various systems in the frequency band 1 260-1 300 MHz, a difference between the centre frequencies of certain RNSS systems and the various applications of the radio amateur service can be noted. This difference may lower the impact of amateur emissions on leads to high margins relating to the RNSS receivers in certain cases. Whether this observation has any impact on amateur compatibility with RNSS will obviously also depend on the RNSS receiver bandwidth. Some RNSS receivers use very large bandwidth, up to 40 MHz to provide better performances.

7 Propagation models

The goal is to estimate the dimension of interference areas. For doing so, several propagation models can be used such as ITU-R P.452, ITU-R P.1546 or other models used for mobile radio planning, such as Okumura-Hata.

For each of the models cited above, the following considerations ca be made:

– Okumura-Hata is relatively easy to use and it is well known for its general reliability, but it has the limitation that ideally the transmitting station should be at least 30 m above the ground. The model is intended to calculate the median loss over a pixel of terrain at distance *d* from the transmitter. Because of this, if the model is used to calculate interference area, a margin factor should be inserted in the analysis in order to take into account the spatial variability of the electromagnetic field. If one applies Okumura-Hata, he must be aware of the limitations on its parameters, including a maximum distance of 10 km, a minimum BS antenna height of 30 m. On the other side, since Okumura-Hata is conceived for frequencies up to 1 500 MHz, its frequency range suites the case at hand.

– ITU-R P.1546 does not have the limitation on antenna height of the transmitter (it can be as low as 10 m), but it has a limitation on the minimum distance, that should be at least 1 km. This model has the advantage of having built in location and time probabilities, so that it can be directly used for the analysis of interference areas. For the model ITU-R P.1546 a tested MATLAB implementation is available to ITU members.

In this Report, the propagation loss has been calculated using Recommendation ITU-R P.1546. This Recommendation describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz. It is intended for use on tropospheric radio circuits over land paths, sea paths and/or mixed land-sea paths up to 1 000 km length for effective transmitting antenna heights less than 3 000 m. The method is based on interpolation/extrapolation from empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage of time. The propagation curves represent the field-strength values exceeded for 50%, 10% and 1% of time at 50% of locations. The calculation procedure also includes corrections to the results obtained from this interpolation/extrapolation to account for terrain clearance and terminal clutter obstructions and percentages of location other than 50%. It should be noted that in § 9 of Annex 5 to Recommendation ITU-R P.1546, there is a clutter correction for the receiving terminal. This method cannot be combined with Recommendation ITU-R P.2108.

8 Methodology

In this section, a description of the analytical methodology used for the compatibility studies between the RNSS characterized in § 5 and the amateur stations identified in § 6 are detailed. This primary deals with the computation of the amateur antenna radiation pattern listed in Recommendation ITU-R F.1336 as well as the interference exceedance level (IEL) quantity stipulated from the link budget.

8.1 Calculation of the interference exceedance level

As the protection criteria can vary from service to service, the IEL metric which will be the primary focus of the compatibility studies in this report is the interference exceedance level (IEL) defined below:

$$P_{RX} = 10 \log 10\,(P_{TX}) + G_{amateur}(\theta) + G_{RNSS}(\theta) - L_b - X_{pol} \text{ for narrowband signals} \quad (1a)$$

$$P_{RX} = 10 \log 10\,(P_{TX}) + G_{amateur}(\theta) + G_{RNSS}(\theta) - L_b - X_{pol} - 10 \log 10\,(BW) \text{ for broadband signals} \quad (1b)$$

$$IEL = P_{RX} - RNSS\ protection\ criteria \quad (2)$$

where:

IEL : interference exceedance level (dB)

P_{TX} : power of the amateur station (W)

$G_{amateur}(\theta)$: gain of the amateur antenna station calculated using Rec. ITU-R F.1336 (dBi)

$G_{RNSS}(\theta)$: gain of the RNSS antenna given in Rec. ITU-R M.1902 (dBi)

L_b : transmission losses calculated using Rec. ITU-R P.1546 (dB)

X_{pol} : polarization loss (dB)

BW : bandwidth specified depending on the type of signal BW > 1 MHz

$RNSS\ protection\ criteria$: protection criteria of RNSS given in Rec. ITU-R M. 1902 (dBW).

In this setting, a P_{RX} value should be compared with the respective recommended ITU-R limit of interference specified in Recommendation ITU-R M.1902 and the IEL can be determined using equation (2).

8.1.1 Computation of the gain of the amateur antenna station

Following the procedures set forth in Recommendation ITU-R F.1336-5, in the case of average side-lobe patterns referred to in *considering c)*, the gain of the amateur antenna station $G_{amateur}(\theta)$ from equation (1) can be calculated as follows:

$$G_{amateur}(\theta) = \begin{cases} G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2 & \text{for} \quad 0 \le |\theta| < \theta_3 \\ G_0 - 15 + 10\log(k+1) & \text{for} \quad \theta_3 \le |\theta| < \theta_5 \\ G_0 - 15 + 10\log\left[\left(\frac{|\theta|}{\theta_3}\right)^{-1.5} + k\right] & \text{for} \quad \theta_5 \le |\theta| \le 90° \end{cases} \tag{3}$$

with:

$$\theta_5 = \theta_3\sqrt{1.25 - \frac{1}{1.2}\log(k+1)}$$

where θ, θ_3, G_0 and k are defined and expressed in *recommends* 2.1 of Recommendation ITU-R F.1336-5. For the studies considered in this Report because they are typical antennas that operate in the 400 MHz to 3 GHz range, the parameter k is defined as 0.7.

All other parameters involved in the calculation of the amateur antenna station $G(\theta)$ as described in equation (3) can be determined from Recommendation ITU-R F.1336-5.

8.1.2 Computation of the transmission losses

From Recommendation ITU-R P.1546, the basic transmission loss can be determined from the field strength for 1 kW e.r.p. as follows:

$$L_b = 139.3 - E + 20\log f \tag{4}$$

where:

L_b : basic transmission loss (dB)

E : field strength (dB(μV/m)) for 1 kW e.r.p.

f : frequency (MHz).

The E field strength from equation (4) can be determined starting from:

Freq (MHz): Desired frequency (for the studies it was considered 1 300 MHz)

t (%): Required percentage of time (for the studies it was considered 1% or 50%)

heff (m): effective height of the transmitting antenna (for the studies it was considered 12 m for Home station 1, 3 m for Home station 2, and 25 m for the Permanent installation)

h_2 (m): receiving antenna height above the ground (for the studies the height above the ground of the RNSS receiver it was considered 1.5 m)

R_2 (m): representative clutter height above ground (for the studies 0 m or 10 m)

Area: Area around receiver (for the studies: Suburban)

Dist (km): Vector of horizontal path lengths over different path zones starting from the transmitter terminal

Path: Path zone for each given path length (in the studies it was considered ‘Land’)

q (%): Location variability (in the studies it was considered 1% or 50%).

The transmission loss (L_b) from equation (1) can be determined using equation (4) and Annex 5 of Recommendation ITU-R P.1546.

8.1.2.1 Required percentage of time

Due to the variation in the atmospheric and propagation conditions, such as ducting, the received interfering signal will generally vary with time. These phenomena are taken into account by Recommendation ITU-R P.1546. However, these time variations are most relevant over long distances, while at short distances they tend to be negligible.

8.1.2.2 Location variability

Another aspect to be considered is the spatial variability of the electromagnetic field. By the way it is conceived, a propagation model usually gives the estimated median value of the received power in a given pixel of terrain. This is the case, for instance, of the curves given by Recommendation ITU-R P.1546.

Inside this pixel of terrain, you can still have slow fading and fast fading. The effect of local statistical variations of the EM field also needs to be taken into account.

To appreciate this fact, consider a pixel of terrain 50 × 50 m wide. Assume that the maximum tolerable interfering power for the RNSS receiver is $\mathrm{P_{int}^{MAX}}$. To declare that the pixel is free from interference it is not sufficient to verify that the interfering received power from the amateur radio station, calculated with the chosen propagation model, is equal to or below $\mathrm{P_{int}^{MAX}}$. For instance, when its value is exactly equal $\mathrm{P_{int}^{MAX}}$ this means that 50% of the locations inside the pixel will still be above this value. For this reason, the analysis of interference shall be conducted in such a way that, for a given pixel to be declared to have an acceptably low level of interference, the interfering EM field shall be below the reference threshold for, say, X=99% of its locations.

It is therefore necessary to have an appropriate statistical model of the spatial variability of the EM field for each pixel. In general, such a variation is modelled as a slow variation (slow fading) plus fast variation (fast fading), that is due to multipath effects.

A characterization of the spatial variability of the field strength in various frequency bands and for different propagation scenarios (the clutter in the vicinity of the RX plays a fundamental role), is described in § 12 of Annex 5 to Recommendation ITU-R P.1546-6.

Recommendation ITU-R P.1546 gives curves of basic propagation loss for different location probability. The curve of propagation loss given for 50% of probability means that, for that given pixel, 50% of the locations will actually have a propagation loss lower than the value given by the model and 50% a propagation loss higher than that. If, on the other hand one considers the curves referring to a location probability equal to 1%, this means that for a given pixel and a corresponding propagation loss, for 99% of the locations inside that pixel the propagation loss will actually be higher (and, therefore, interference lower).

In other words, if one calculates the contour of the interference area with the model set at 50% location probability, the contour will be the focus where, for a pixel of terrain, say 50 × 50 m wide, half of the surface will receive above-threshold interference and half will receive below-threshold interference. Inside the contour, of course, the interference probability will be higher, and outside it will be lower. On the other hand, if one traces the contour with the model set at 1% location probability, the contour will be the focus where, for a pixel 50 × 50 m wide, 99% of the locations inside that pixel will have an acceptably low level of interference. Outside the contour the interference probability will be progressively higher.

9 Reported interference

9.1 Reported harmful interference (Germany)

Evidence of reported harmful interference was/were provided by/an Administration(s). This included an assessment of the interference situation, the related emissions, and their impact to the RNSS receiver.

At an RNSS reference receiver, located near Munich (Germany), some amateur applications caused harmful interference to the RNNS reference receiver operating in the frequency range 1 260-1 300 MHz.

The first assessment identified Amateur TV emissions (analogue and digital), leading to the conclusion that these applications may further interfere with this specific type RNSS receiver and might be constrained by a minimum separation distance to allow for the further use in the bands. However, the amateur and amateur-satellite services comprise several applications, which are expected to be further used in the bands 1 240-1 300 MHz and a separation distance is not considered practicable for the protection of RNSS receivers ubiquitously used in this band.

Consecutive measurement reports covering the above interference case are attached as Annex 2 – Measurements realized in Germany.

9.2 Reported harmful interference (Region of Varese, Italy)

Further evidence of harmful interference has been provided referring to multiple events observed in May/June 2021 in the region of Varese (Italy) and assessed by the Joint Research Centre (JRC) of the European Commission. As widely documented in Annex 6 – Reported Interference, several high-end GNSS receivers were interfered during a data collection dealing with the testing of the new Galileo High Accuracy Service (HAS), currently in a pre-operational testing phase of its Signal in Space (SiS) and transmitted in the 1 260-1 300 MHz band. It was found out that the interference was caused by a strong narrowband emission received at 1 297.3 MHz and characterised by a strong power, being more than 40 dB above the noise floor. The emission was analysed and it was identified to be an FM modulated signal transmitted by an Amateur Radio Repeater. The repeater was identified through the Ministerial identifier transmitted through the signal, which included also a code specifying its position.

The elements provided in Annex 6 – Reported Interference clearly demonstrate how the presence of such an emission in the band induced a major degradation of the performance of the GNSS receivers, causing a degradation of the C/N_0 of up to 20 dB, also for very long period of time, corresponding to a harmful interference.

Within the annex it is shown that the emission has the potential to interfere a wide and densely populated area. It is also explained that the events as described have been reported to the competent authorities in Italy (Ministero dello Sviluppo Economico, MISE) on 21 June 2021.

Following the events reported and using them as a reference, further measurements have been performed within the JRC laboratories in the effort to characterize the effect of different AS emission types (at various carrier frequencies and power levels) on multiple GNSS receivers. Results are provided in § 11.1 and within Annex 4.

10 Simulations

Values and characteristics in these studies were selected from those provided in § 6. Some non-typical operational characteristics of the stations in amateur and amateur-satellite services are also studied to see the impact of the difference from the typical values.

10.1 Analysis for geographical extent of interference

Multiple analyses are conducted for the assessment of the geographical extent of the interference from transmitting amateur stations into some RNSS receivers.

10.1.1 Study 1

In Annex 1 a study that provides the assessment of the geographical extent of the interference caused by transmitting station of the amateur service into Galileo E6 receivers is presented. The Annex considers several types of transmitting amateur radio stations and calculates the area around them where they received interference that would exceed the protection criterion of the Galileo E6 receiver.

From the simulation studies in Annex 1, some initial aspects were extracted, and they are presented below. Firstly, the maximum distance where the RNSS protection criteria was not respected was determined for different amateur stations and for all three Regions. This determination has been performed depending on the amateur application, bandwidth and frequency band.

Secondly, for specific chosen distances, it was determined in the direction of the maximum amateur antenna gain the exact value of the RNSS protection criteria exceedance.

Both studies have been performed for the following amateur stations:

TABLE 14

Amateur antenna characteristics

	Home station 1 (also for Satellite Uplink)	**Permanent installation**	**Home station 2 (only for EME signals)**
Antenna	Single Yagi, 18 dBi gain, 18° 3 dB aperture	13 dBi gain, 60° 3 dB beam width	Dish (4 m), 32 dBi gain, 4° 3 dB aperture
Tx power	1 mW - 300 W	1 mW - 300 W	1 mW - 300 W
Antenna height above ground	12 metres	25 metres	3 metres
Polarization	Linear	Linear	Linear

Furthermore:

– no cluttering has been considered in order to consider the worse-case scenario,
– on the RNSS side, an antenna with a gain of −6 dBi located at 1.5 metres from the ground has been used;
– the polarization loss used was of 3 dB;
– the noise figure also of 3 dB;
– the studies have been done only in a suburban area;
– location probability of 50%.

The analysis below is based on the methodology above (section 8) where the Galileo protection criteria was chosen to be −134.5 dBW for narrowband amateur applications and −140 dBW/MHz for broadband amateur applications.

Using the amateur antennas presented above various amateur applications were studied depending on the frequency band as it can be seen in the figures below.

TABLE 15

Region 1 – Galileo

Freq. (MHz)	**1 260-1 270**	**1 270-1 271**	**1 271-1 290**	**1 290-1 296**	**1 296-1 297**	**1 297-1 298.5**	**1 298.5-1 299**	**1 299-1 300**
Amateur application	Wider bandwidth mode	Medium bandwidth mode	Broad bandwidth mode	Medium bandwidth mode	Narrowband mode (including EME)	Medium and wider bandwidth mode		
Amateur antenna	Home station 1 (Satellite uplink)	Home station 1, Permanent station			Home station 1, Home station 2 (EME), Permanent station	Home station 1 Permanent station		
Bandwidth	128 kHz or less		1.7 MHz	128 kHz or less				
RNSS protection criteria	−134.5 dBW		−140 dBW/MHz	−134.5 dBW				

TABLE 16

Region 2 – Galileo

Freq. (MHz)	**1 260-1 270**	**1 270-1 276**	**1 276-1 282**	**1 282-1 296**	**1 296-1 297**	**1 297-1 300**
Amateur application	Wider bandwidth mode	Medium bandwidth mode	Broad bandwidth mode	Medium bandwidth mode	Narrowband mode (including EME)	Wider bandwidth mode
Amateur antenna	Home station 1 (Satellite uplink)	Home station 1, Permanent station			Home station 1, Home station 2, Permanent station	Home station 1, Permanent station
Bandwidth	128 kHz	15 kHz	1.7 MHz	15 kHz	1 kHz / 128 kHz	128 kHz
RNSS protection criteria	−134.5 dBW		−140 dBW/MHz	−134.5 dBW		

TABLE 17

Region 3 – Galileo

Freq (MHz)	**1 260-1270**	**1 270-1 296**	**1 296-1 297**	**1 297-1 300**
Amateur application	Wider bandwidth modes	Broad bandwidth mode	Narrowband mode (including EME)	Broad bandwidth mode
Amateur antenna	Home station 1 (Satellite uplink)	Home station 1 Permanent station	Home station 1, Home station 2 (EME), Permanent station	Home station 1, Permanent station
Bandwidth	128 kHz	10 MHz	1 kHz / 128 kHz	10 MHz
RNSS protection criteria	−134.5 dBW	−140 dBW/MHz	−134.5 dBW	−140 dBW/MHz

10.1.1.1 Maximum interference distance extracted from the propagation model studies

10.1.1.1.1 Home station 1

From Table 14, an amateur antenna with a gain of 18 dBi, an aperture of 18 degrees and located 12 metres above ground was used. Also, depending on the region the values from Table 15 to Table 17 were used for different amateur transmission powers, bandwidth and Galileo protection criteria.

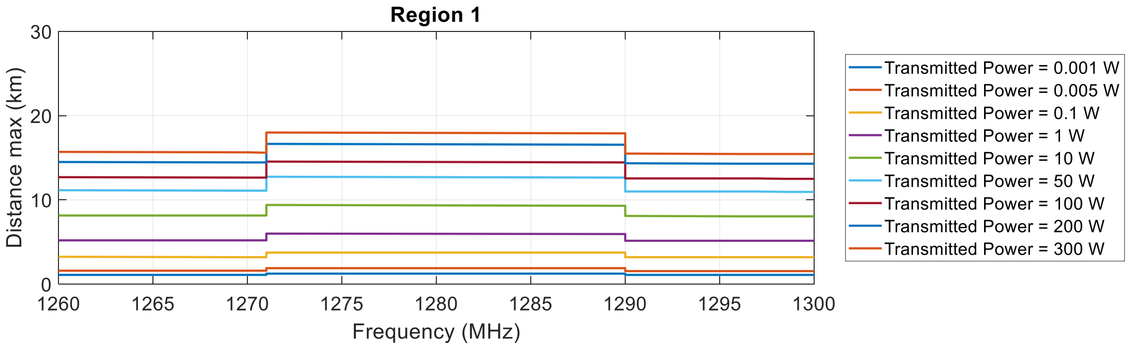
The results in the Figures below were obtained by taking the maximum distance, in the direction of the maximum amateur antenna gain, where the protection criteria of Galileo is exceeded.

The highest interference distance is obtained in the frequency bands 1 271-1 290 MHz in Region 1, 1 276-1 282 MHz in Region 2 and 1 270-1 296 MHz plus 1 297-1 300 MHz where there are broadband amateur applications. For a broadband amateur transmission power of 300 W the maximum interference distance can reach 18 km in Regions 1 and 2 and 15 km in Region 3. It is also important to mention that for narrowband amateur applications (example: in Region 1, the frequency band 1 260-1 271 MHz) the maximum distance where the Galileo protection criteria was not respected was of 15.7 km in Regions 1 and 2 and 12.65 km in Region 3. From the results obtained it is clear to see that the frequency bands where there is the highest probability of interference it will be for broadband band amateur applications. With respect to the choice of the frequency band, it was seen that for same amateur applications in different bands the results coincided. By reducing the transmission power to 5 mW, for narrowband amateur applications the maximum interference distance is reduced to 1.55 km in Regions 1 and 2, 1.2 km for Region 3 and for broadband amateur applications to 1.9 km for Regions 1 and 2 and 1.55 km for Region 3.

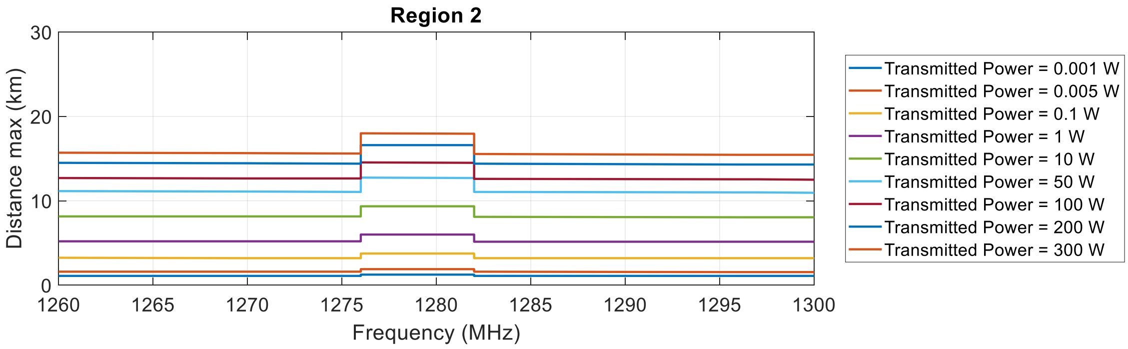
The conclusion of this first study is that the amateur application impact on Galileo can be significant and varies depending on the choice of parameters, and on whether there is narrowband or wideband operation in the band.

FIGURE 2

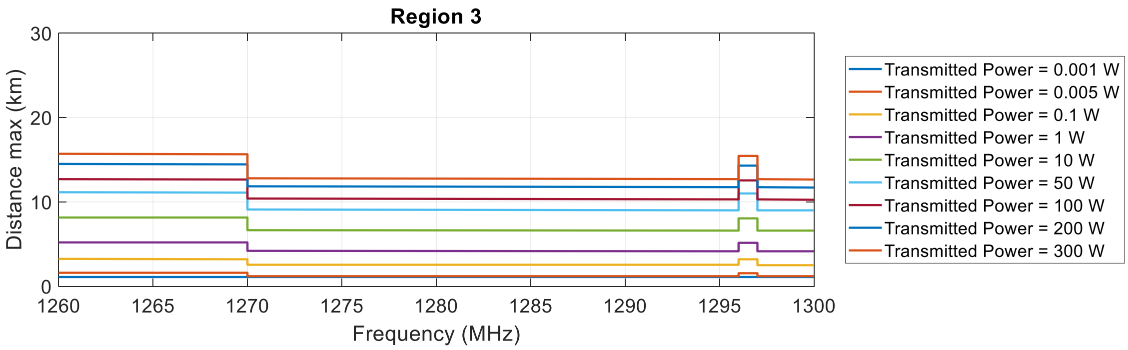
Maximum interference distance where the Galileo protection criteria are not satisfied extracted from the propagation model studies for Home station 1 in: (a) Region 1, (b) Region 2 and (c) Region 3



(a)



(b)



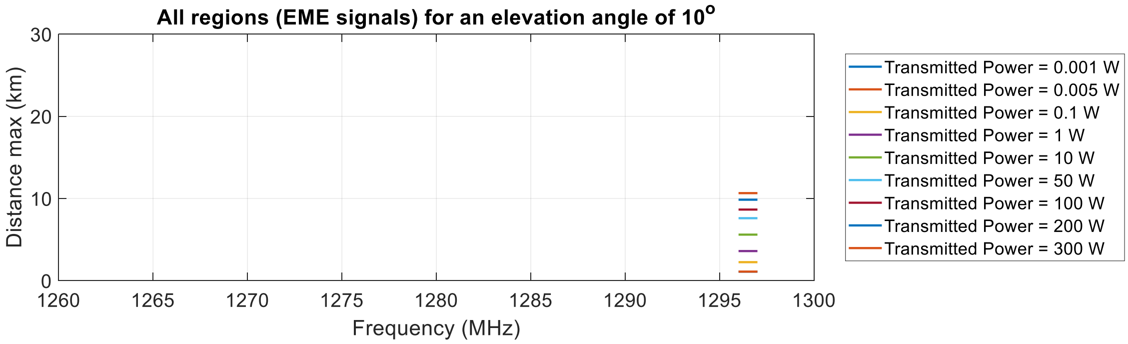
(c)

10.1.1.1.2 Home station 2

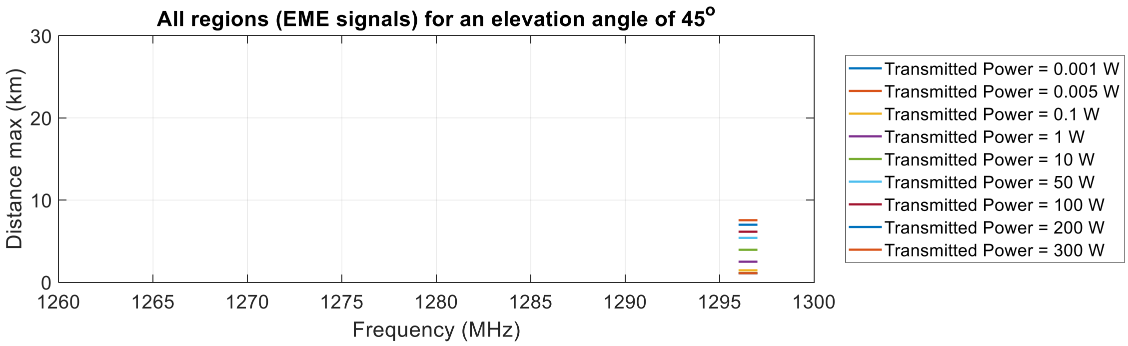
The amateur station called 'Home station 2' is only used for EME transmissions and in only specific frequency bands because the antenna gain for this amateur station is of 32 dBi. In the E6 frequency band EME amateur transmissions only occur in between 1 296-1 297 MHz; therefore the study is done only in this frequency band, and the results can be observed below.

FIGURE 3

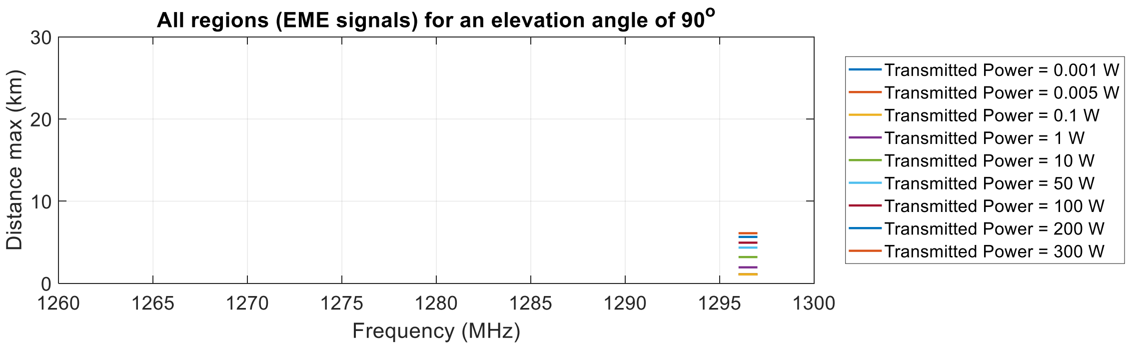
Maximum interference distance where the Galileo protection criteria are not satisfied extracted from the propagation model studies for Home station 2 in all three Regions for an elevation angle of: (a) 10 degrees, (b) 45 degrees and (c) 90 degrees



(a)



(b)



(c)

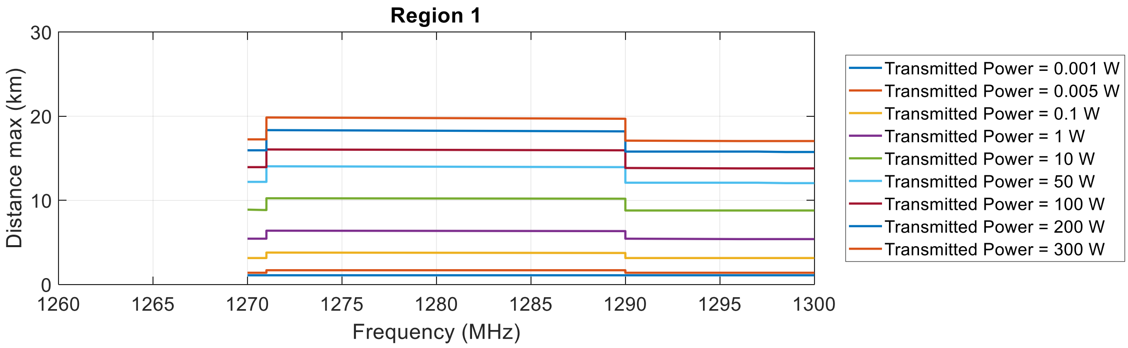
It was considered for the Home station 2 study different transmission powers from 1 mW till 300 W. It can be seen that the maximum distance where the Galileo protection criteria is not respected is of 10.65 km for a transmission power of 300 W and an elevation angle of 10 degrees. It is also important to mention that for EME transmissions, the amateur antenna will not be oriented towards the horizon under normal operating conditions, so two other elevation angles were also studied (45 degrees and 90 degrees). As it was expected, when the elevation angle is different from 10 degrees, the maximum interference distance has decreased from 10.65 km till 7.55 km at 45 degrees and 6.1 km at 90 degrees for a power of 300 W. Even with a low transmission power (ex. 5mW), the protection criteria of Galileo are exceeding till a distance at 10 and 45 degrees of 1.1 km and. At 90 degrees, the protection criterion was completely respected at 1 km for low transmission power (5 mW).

10.1.1.1.3 Permanent station

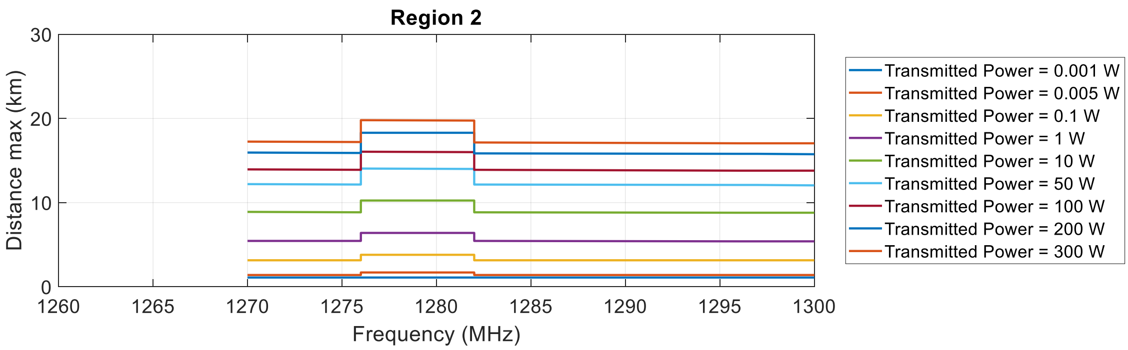
The same type of study has been done for another type of amateur station that has a slightly different antenna gain lower than ‘Home station 1’, of 13 dBi, but also it is less directive.

FIGURE 4

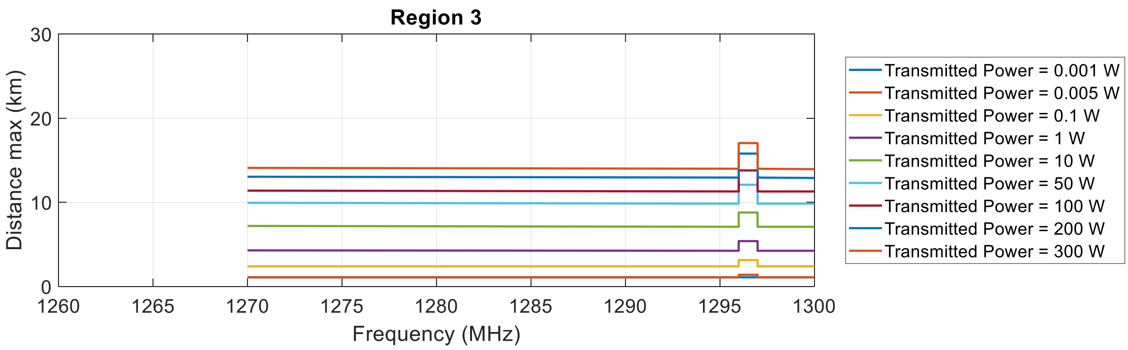
Maximum interference distance where the protection criteria of Galileo are not satisfied extracted from the propagation model studies for permanent station in: (a) Region 1, (b) Region 2 and (c) Region 3



(a)



(b)



(c)

From the study using a Permanent amateur station it was determined that the highest interference distance for broadband amateur applications was of 19.7 km and is obtained in the frequency band 1 271-1 290 MHz in Region 1, of 19.8 km obtained in the band 1 276-1 282 MHz in Region 2 and of 14.1 km in the bands 1 270-1 296 MHz plus 1 298-1 300 MHz in Region 3 for an amateur transmission power of 300 W.

Using a transmission power of 5 mW a maximum interference distance of 1.7 km in Regions 1 and 2 and of 1.1 km in Region 3 is obtained for broadband amateur applications and a minimum of 1.4 km for narrowband amateur applications in all regions.

Still, even with this type of antenna, the protection criteria were not respected even with a low transmission power for the two types of amateur applications.

In conclusion, from this study a table has been extracted that gives the maximum distance where the Galileo protection criteria was exceeded depending on transmission power, region and type of amateur antenna. The study has shown that the maximum exceedance distance was of 18 km for broadband amateur applications and of 15.7 km for narrowband amateur applications using a transmission power of 300 W. Furthermore, from the studies in this section which are partially summarized in Tables 18 and 19, it is shown that the protection criteria are exceeded for all transmission powers studied.

TABLE 18

Maximum distance where the protection criteria of Galileo were not satisfied for broadband amateur applications

Power	**Maximum interference distance (km)**								
	Region 1			**Region 2**			**Region 3**		
	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS
1 mW	1.25	-	1.1	1.25	-	1.1	1.1	-	1.1
5 mW	1.9	-	1.7	1.9	-	1.7	1.6	-	1.1
0.1 W	3.75	-	3.75	3.75	-	3.8	3.25	-	2.4
1 W	5.95	-	6.35	6	-	6.4	5.2	-	4.3
10 W	9.3	-	10.2	9.35	-	10.25	8.15	-	7.2
50 W	12.65	-	13.85	12.6	-	14	11.15	-	9.95
100 W	14.35	-	15.8	14.55	-	16	12.7	-	11.4
200 W	15.5	-	18.2	16.6	-	18.3	14.5	-	13.05
300 W	18	-	19.85	17.95	-	19.8	15.7	-	14.1

TABLE 19

Maximum distance where the protection criteria of Galileo were not satisfied for narrowband amateur applications

Power	**Maximum interference distance (km)**								
	Region 1			**Region 2**			**Region 3**		
	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS
1 mW	1.1	-	1.1	1.1	-	1.1	1.1	-	1.1
5 mW	1.55	1.1	1.4	1.55	1.1	1.4	1.2	1.1	1.4
0.1 W	3.25	2.25	3.15	3.25	2.25	3.15	2.55	2.25	3.15

TABLE 19 (*end*)

Power	Maximum interference distance (km)								
	Region 1			Region 2			Region 3		
1 W	5.15	3.6	5.45	5.15	3.6	5.45	4.2	3.6	5.4
10 W	8.15	5.6	8.9	8.15	5.6	8.9	6.6	5.6	8.8
50 W	10.95	7.6	12.2	10.95	7.6	12.2	9.1	7.6	12.1
100 W	12.7	8.65	13.95	12.7	8.65	13.95	10.3	8.65	13.8
200 W	14.3	9.85	15.95	14.3	9.85	15.95	11.85	9.85	15.8
300 W	15.7	10.65	17.25	15.7	10.65	17.25	12.7	10.65	17.05

10.1.1.2 Galileo IEL extracted from the propagation model studies

From the studies presented in Annex 1, it was also extracted the level of IEL for different distances from the amateur station, different amateur antenna stations and different amateur applications depending on the frequency band.

The same amateur antenna stations presented in Table 14 were used here in order to have consistency over the results.

10.1.1.2.1 Home station 1

For the amateur 'Home station 1' antenna, three distances were chosen and the Galileo IEL was determined depending on the type of amateur application. The minimum distance where the IEL was able to be calculated was of 1.05 km because of the limits of the proposed propagation model from Recommendation ITU-R P.1546.

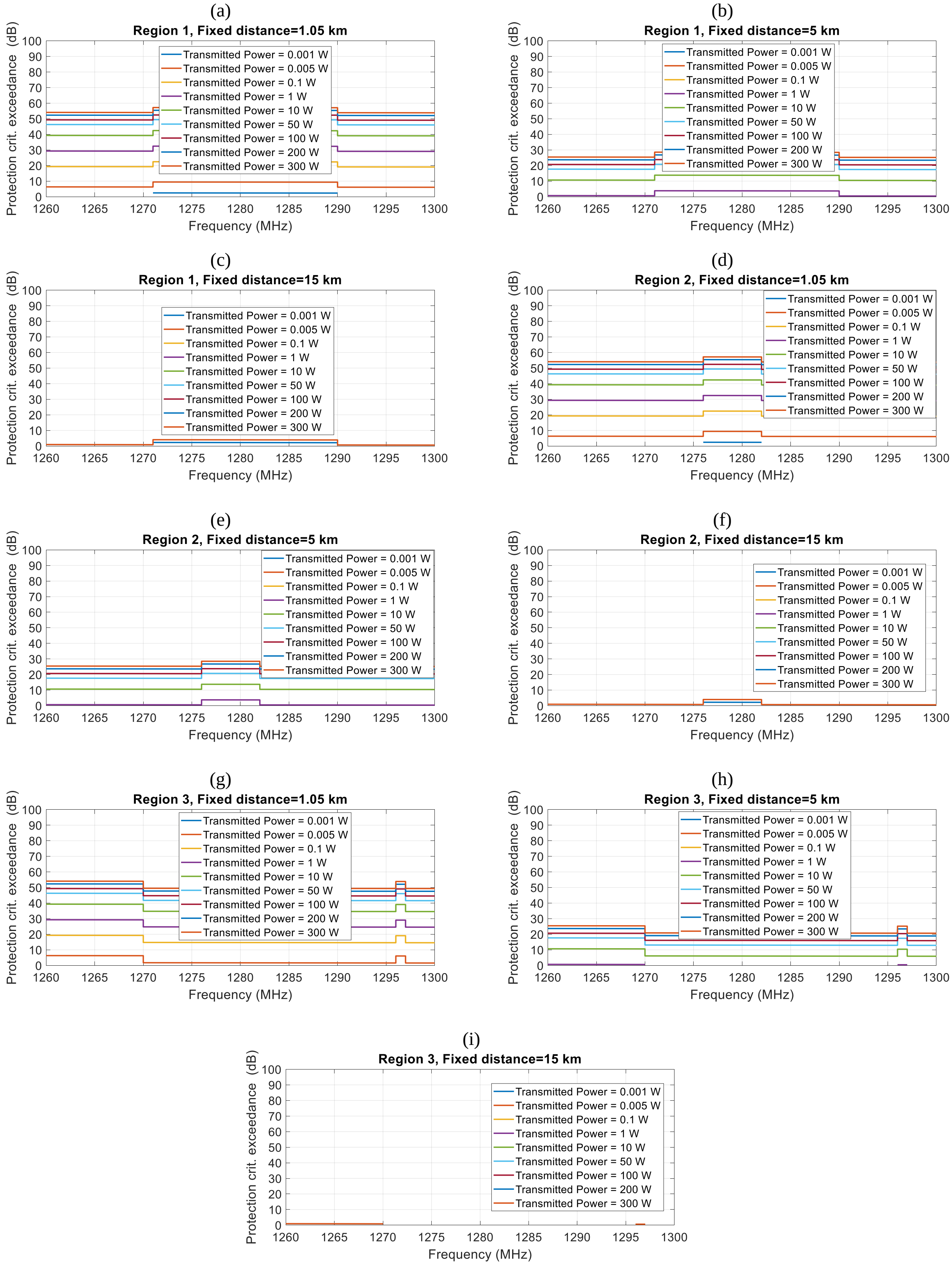
In Fig. 5 below, it was determined the protection criteria exceedance for 'Home station 1' in all three Regions depending on three chosen distances: 1.05 km, 5 km and 15 km.

In order to consider the worst-case scenario, the determination has been done for the maximum amateur gain, and from the results it is clear to see that the highest IEL has been obtained for broadband amateur applications for the three distances and that it has arrived to maximum 57.2 dB IEL at 1.05 km from the amateur station and using a transmission power of 300 W. For narrowband amateur applications, the maximum IEL was of 54.08 dB using 300 W at 1.05 km from the amateur station. The higher the distance, the lower the IEL.

It is also important to mention that for 5 mW transmission power, at 5 km, the protection criterion was not exceeded in the entire frequency band 1 260-1 300 MHz.

FIGURE 5

Galileo IEL extracted from the propagation model studies for Home station 1 in: (a) Region 1 at 1.05 km, (b) Region 1 at 5 km, (c) Region 1 at 15 km, (d) Region 2 at 1.05 km, (e) Region 2 at 5 km, (f) Region 2 at 15 km, (g) Region 3 at 1.05 km, (h) Region 3 at 5 km and (i) Region 3 at 15 km



10.1.1.2.2 Home station 2

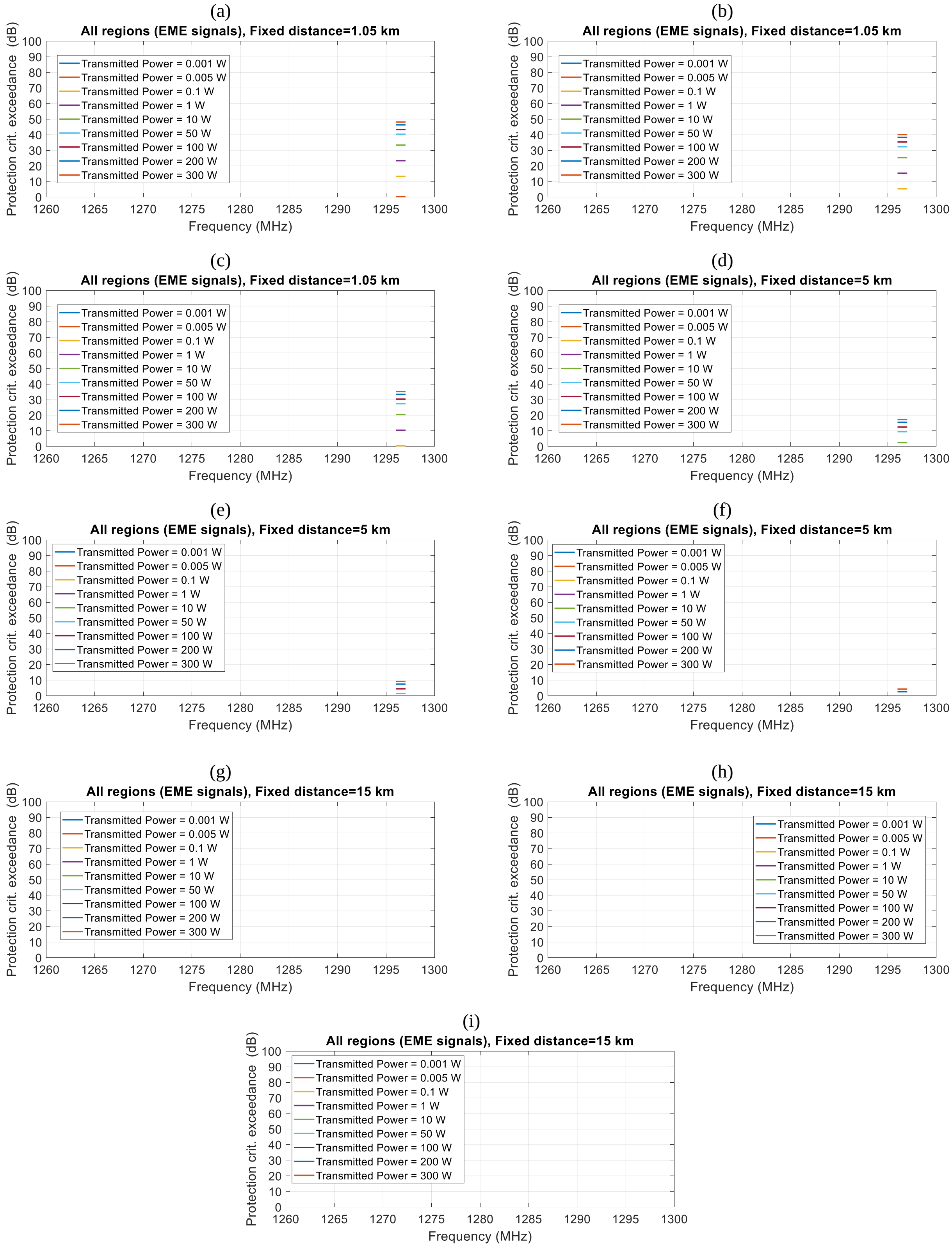
In Fig. 6 below, the Galileo IEL was determined for ‘Home station 2’ in all Regions also depending on three chosen distances: 1.05 km, 5 km and 15 km.

For an amateur station transmission power of 300 W, for narrowband applications the maximum IEL of 48.9 dB has been obtained at 1.05 km from the amateur station.

Using a transmission power of 5mW, at 5 km, the protection criterion was not exceeded in the entire frequency band 1 260-1 300 MHz.

FIGURE 6

Galileo protection criteria exceedance in all 3 Regions extracted from the propagation model studies for Home station 2 at: (a) 1.05 km and 10 degrees, (b) 1.05 km and 45 degrees, (c) 1.05 km and 90 degrees, (d) 5 km and 10 degrees, (e) 5 km and 45 degrees, (f) 5 km and 90 degrees, (g) 15 km and 10 degrees, (h) 15 km and 45 degrees, and (i) 15 km and 90 degrees



10.1.1.2.3 Permanent station

In Fig. 7 below, the Galileo IEL was determined for ‘Permanent station’ in all regions depending on three chosen distances: 1.05 km, 5 km and 15 km.

The maximum IEL has also been obtained in this case for broadband amateur applications with a value of 54.55 dB in Region 1, 54.63 dB in Region 2 and 46.8 dB in Region 3 at 300 W transmission power. For narrowband amateur applications, an IEL of 51.48 dB has been obtained in Regions 1 and 2, and of 51.3 dB in Region 3.

For 5 mW transmission power, at 5 km, the protection criterion was not exceeded in the entire Galileo frequency band 1 260-1 300 MHz.

FIGURE 7

Galileo protection criteria exceedance extracted from the propagation model studies for Permanent station in: (a) Region 1 at 1.05 km, (b) Region 1 at 5 km, (c) Region 1 at 15 km, (d) Region 2 at 1.05 km, (e) Region 2 at 5 km, (f) Region 2 at 15 km, (g) Region 3 at 1.05 km, (h) Region 3 at 5 km and (i) Region 3 at 15 km

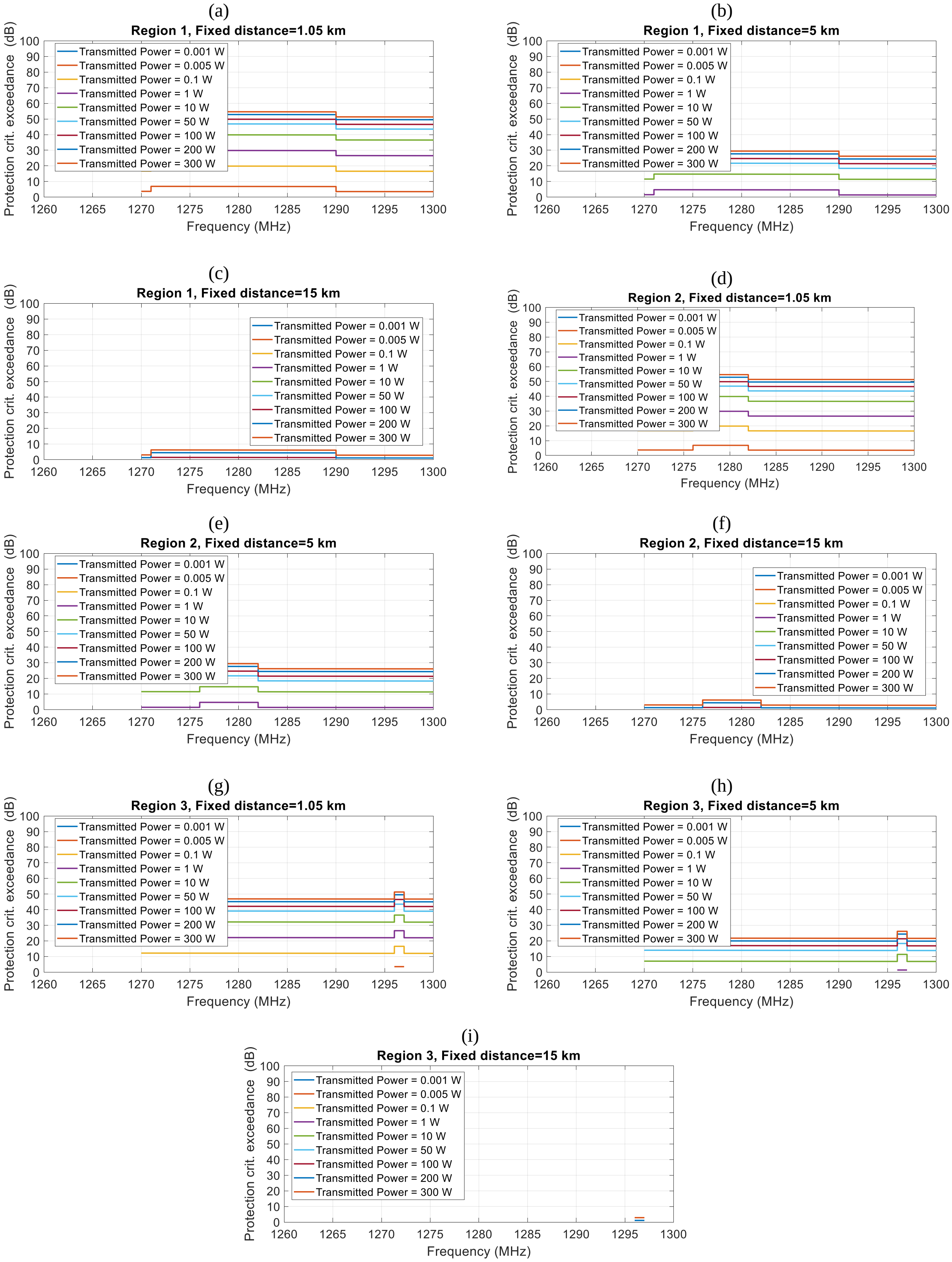


TABLE 20

IEL for Galileo for broadband amateur applications at 1.05 km from the amateur station

Power	IEL (dB)								
	Region 1			Region 2			Region 3		
	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS
1 mW	2.3	-	-	2.4	-	-	-	-	-
5 mW	9.3	-	6.9	9.35	-	6.85	1.7	-	-
0.1 W	22.31	-	19.9	22.4	-	19.82	14.74	-	12.21
1 W	32.31	-	29.9	32.36	-	29.82	24.7	-	22.21
10 W	42.31	-	39.9	42.4	-	39.82	34.7	-	32.21
50 W	49.3	-	46.9	49.35	-	46.85	41.73	-	39.2
100 W	52.31	-	49.77	52.4	-	49.82	44.74	-	42.21
200 W	55.32	-	52.78	55.37	-	52.84	47.75	-	45.03
300 W	57.2	-	54.55	57.17	-	54.63	49.51	-	46.8

TABLE 21

IEL for Galileo for narrowband amateur applications at 1.05 km from the amateur station

Power	IEL (dB)								
	Region 1			Region 2			Region 3		
	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS	HS1	HS2 at 10 degrees	PS
1 mW	-	-	-	-	-	-	-	-	-
5 mW	6.3	0.3	3.7	6.3	0.3	3.7	1.73	0.3	3.53
0.1 W	19.31	13.32	16.7	19.31	13.32	16.71	14.74	13.32	16.54
1 W	29.31	23.31	26.7	29.31	23.31	26.71	24.74	23.31	26.54
10 W	39.31	33.32	36.7	39.31	33.32	36.71	34.74	33.32	36.54
50 W	46.3	40.3	43.5	46.3	40.3	43.7	41.73	40.3	43.53
100 W	49.31	43.31	46.7	49.31	43.31	46.51	44.57	43.31	46.53
200 W	52.32	46.32	49.55	52.32	46.32	49.55	47.59	46.32	49.55
300 W	54.08	48.09	51.48	54.08	48.09	51.48	49.52	48.09	51.3

In conclusion, from this second IEL study two tables have been extracted that give the IEL for Galileo at 1.05 km from the amateur station depending on transmission power, region and type of amateur antenna. The study has shown that the maximum IEL obtained was of 57.2 dB for broadband amateur applications and of 54.08 dB for narrowband amateur applications using a transmission power of 300 W. Furthermore, from the studies in this section which are partially summarized in Tables 20 and 21 show that the protection criteria are exceeded no matter the transmission power at 1.05 km from the amateur station. However, at 5 km from the amateur station the Galileo protection criteria was respected for all cases using a transmission power of 5 mW.

10.1.2 Study 2

A simulation-based study was conducted to assess the geographical extent of interference caused by emissions from ATV, narrowband application, and amateur-satellite transmitting stations into COMPASS B3 general purpose receivers.

Simulation scenarios and parameters are given in Table 22 and Fig. 8.

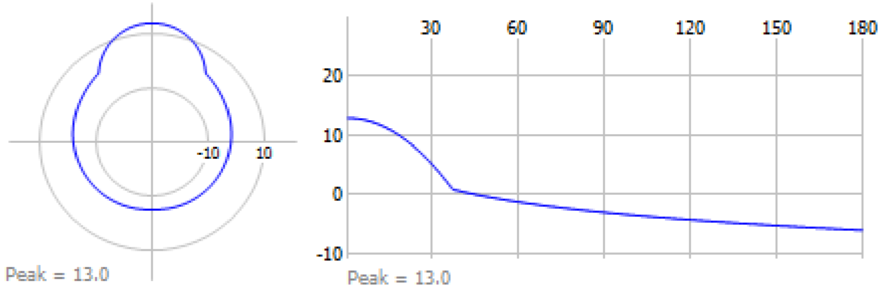
TABLE 22

Amateur and amateur-satellite service station parameters

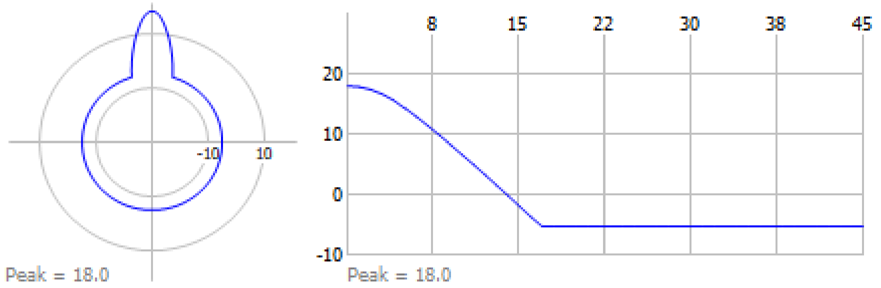
Application	**ATV**	**Narrowband application**	**Amateur-satellite uplink**
Station types	**Permanent installation**		**Home station**
Parameters	**Value**		
Antenna	13 dBi gain, 60° 3 dB beam width		Single Yagi, 18 dBi gain, 18° 3 dB beam width
Tx power	5 mW/1 W/10 W/100 W		5 mW/1 W/10 W/100 W
Frequencies (MHz)	1 272.5-1 291.5 1 243.2-1 260 1 255.5-1 258 1 267.5-1 270	1 270 1 257	1 265 1 260-1 262
Antenna height above ground (m)	25		12
Polarization	Vertical		Vertical

FIGURE 8

Antenna diagram: (a) ATV/Narrowband application station, (b) Amateur-satellite uplink station (c) EME communications



(a)



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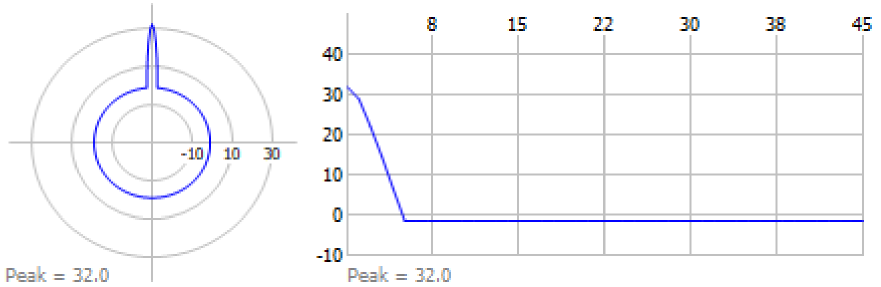


(c)

The parameters of COMPASS B3 general purpose receivers are given in the Table in § 5.2 of this Report.

In Table 23 the maximum geographical extents of various potential interference are collected, under conditions of 50% percentage of location, 0 m Tx representative clutter height for all scenarios and 55-degree elevation angle for amateur-satellite uplink.

Simulation results indicate that, interference areas around an amateur and amateur-satellite station could reach an extent of several kilometres and interference from narrowband applications are stronger compared to wideband applications with same emission power due to the difference in the Compass protection criteria between narrowband and wideband.

The simulation results also show that, amateur emissions within the Compass receiver passband of same power level will have the same impact.

The details of this study are attached as Annex 3.

TABLE 23

Collection of maximum geographic extents of various potential interference

Application	Frequency range	Tx power (km)			
		5 mW	1 W	10 W	100 W
ATV	1 272.5-1 291.5 MHz (only 1 272.5-1 280.5 MHz overlaps with COMPASS B3 passband)	0.49	1.82	3.36	5.90
	1 243.2-1 260 MHz (only 1 256.5-1 260 MHz overlaps with COMPASS B3 passband)	0.51	1.92	3.56	6.12
	1 255.5-1 258 MHz (only 1 256.5-1 258 MHz overlaps with COMPASS B3 passband)	0.78	3.21	5.57	9.13
	1 267.5-1 270 MHz	0.80	3.20	5.50	9.10
Narrowband application	1 270 MHz	1.81	6.78	10.86	17.16
	1 257 MHz	1.81	6.82	10.93	17.07
Amateur-satellite uplink	1 265 MHz	0.81	3.05	5.05	7.98
	1 260-1 262 MHz	0.41	1.45	2.61	4.36

10.1.3 Study 3

The simulation-based study was conducted to assess the geographical extent of interference area caused by emissions from amateur television (ATV) stations and also from narrowband amateur transmitters into GLONASS general purpose receiver and also to GLONASS air- navigation receiver.

The typical parameters of amateur stations are given in Table 24 and in Fig. 9 below.

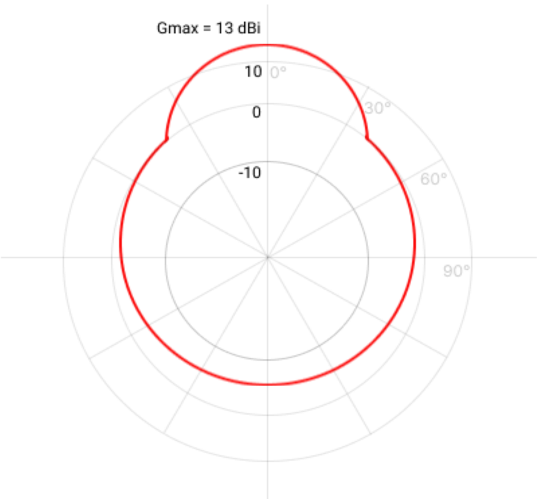
TABLE 24

Amateur station parameters

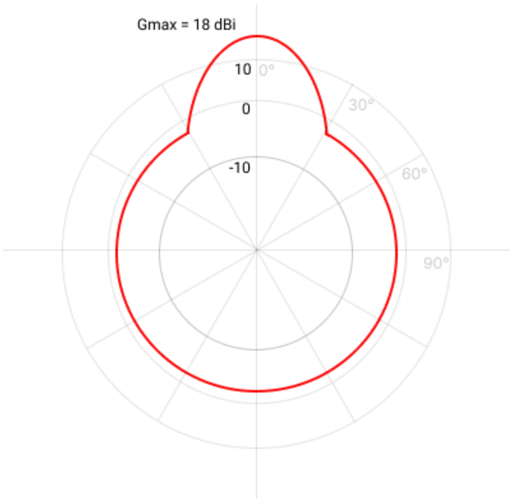
Parameters	Value	
Transmitter type	ATV	Narrowband
Antenna gain (dBi)	13	18
Beamwidth (degrees)	60	18
Tx power (W)	1	1, 100, 300
Bandwidth	16.75 MHz	20 kHz
Antenna height above the ground (m)	25	12
Polarization	Vertical	Vertical

FIGURE 9

Amateur stations antenna pattern



ATV



Narrowband application

The GLONASS receiver parameters are presented in Recommendation ITU-R M.1902 and provided in Table 1 of this Report.

The simulation results show the geographical extent of interference areas from the ATV repeater and the narrowband amateur station into GLONASS receivers of two types:

1) Interference caused by the broadband ATV repeater:

- for the GLONASS general purpose receiver, the interference area extends to several kilometres;
- for the GLONASS air- navigation receiver the interference area can vary from several tens of km (for the receiver height of 100 m) up to more than 100 km (for the receiver height from 1 to 10 km).

2) Interference caused by the narrowband amateur station:

- for the GLONASS general purpose receiver, the interference area extends to several kilometres (for transmitter power of 1 W) and from several tens of km up to more than 100 km (for transmitter power of 100 W and 300 W);
- for the GLONASS air- navigation receiver the interference area can vary from 150 km up to 350 km depending on the transmitter power of a narrowband amateur station and the altitude of the GLONASS air- navigation receiver. The results obtained are valid in the direction of the maximum of the amateur station antenna pattern. In other directions the area size of the potential interference can be much smaller.

In the study, interference from amateur service stations was assessed by the aggregate interference criterion in accordance with Recommendation ITU-R M.1902. However, in the considered frequency band, in addition to the primary RNSS radio service and the secondary amateur service, the systems of the following primary radio services operate: the radiolocation, EESS, SRS and interference from these services in the current study was not taken into account.

The detailed study results are given in Annex 7 to this Report.

10.2 Analysis for the case of some non-typical operational characteristics of the amateur and amateur-satellite service

The study 1 in § 10.1.1 contains the impact of different transmitting power levels of amateur stations. In similar manner, the impact of different antenna heights of amateur stations (not only the typical values listed in § 6.4) should also be studied.

Annex 8 provides the assessment of the impact of the interference from transmitting stations in the amateur service into High-accuracy and authentication receiver using E6-BC/L6 in Recommendation ITU-R M.1902. As shown in Annex 8, different antenna heights of amateur stations resulted in significant difference in the required geographical separation distance.

10.3 Analysis of potential interference time length

Access analysis is conducted by China using STK (Satellite Tool Kit: software) for the assessment of time length of potential interference from transmitting amateur-satellite uplink stations into Compass B3 receivers.

In this Access analysis, actual TLE orbit data was obtained from AMSAR (www.amsat.org/tle/current/nasabare.txt). Four of them (ORESAT-0, TEIKYOSAT-4, HORYU4, FEES) were selected, since they are active in the relevant frequency ranges. With the assumption of the earth station locations of Beijing, Sanya and Kashi, access time lengths from earth stations to satellites (time duration when elevation angle of an amateur-satellite becomes larger than 5 degrees) per day were computed for all different amateur-satellites. These simulations considered a single 24 h time period from 04:00 of 20th July to 04:00 of 21st July 2022. Results and averaged time lengths among these amateur satellites derived were shown in Table 25 below.

TABLE 25

Simulated access results between amateur-satellites and ground stations

Stations / Satellites	Beijing (40° N, 116° E)	Sanya (18° N, 109° E)	Kashi (39° N, 76° E)
ORESAT-0	1692.55s	1459.64s	1908.56s
FEES	1794.40s	1129.71s	1693.80s
HORYU4	1844.22s	3840.31s	2013.05s
TEIKYOSAT-4	2077.96s	1673.11s	1913.07s
Average duration of access to one satellite	1852.28s	2025.69s	1882.12s
Average duration of access to one satellite (%)	2.14	2.34	2.18

Based on the simulation results, initial conclusion could be achieved as:

1 When one amateur-satellite receives signal in 1 260-1 270 MHz frequency band, averagely, transmitting amateur-satellite uplink station (Tx power at 1 W) could cause harmful interference to Compass B3 receivers in its adjacent area of at least 1.45 km for 2%-3% of time over a one-day period.

2 When N amateur satellites in the 1 260-1 270 MHz frequency band are accessed by the same amateur-satellite station for uplink, average the time length of interference from such amateur-satellite uplink station (Tx power at 1 W) to Compass B3 receivers in its adjacent area of at least 1.45 km could reach (2*N)% of time over a one day period.

Aspects of operational frequency schedule availability could in practice result in shorter durations of access, compared with the values in the Table above, despite the geographical viability of the link for certain locations.

11 Measurements

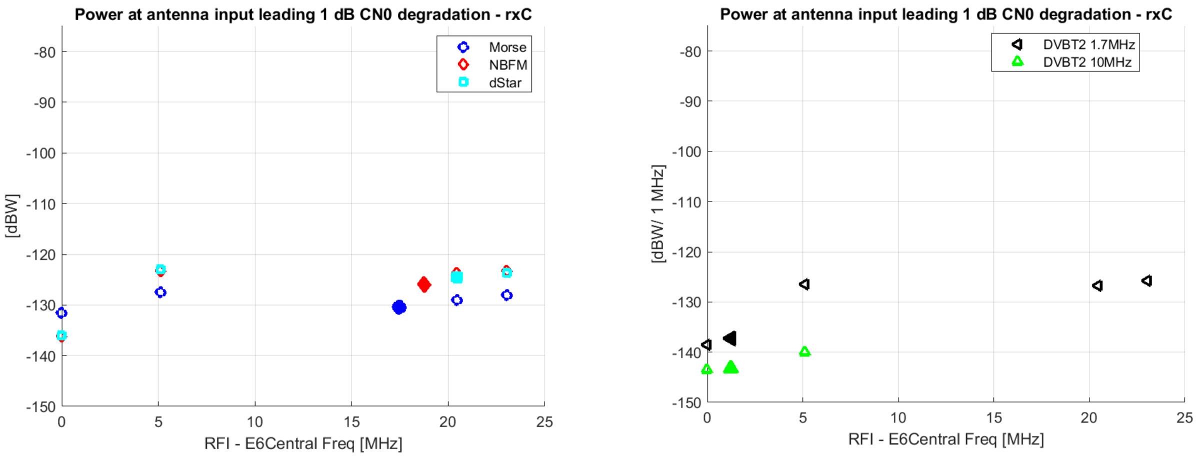
11.1 Compatibility analysis with reference GNSS receivers (EC JRC)

In Q2/Q3-2021 the Joint Research Centre of the European Commission carried out an extensive testing campaign within its premises in order to assess the impact of all different AS modes on a batch of high grade GNSS receivers under different conditions. The main scope of the activity is to study in detail the effect of AS emissions with different power levels at the input of the GNSS antenna and at different central frequencies. At this scope, for the various AS emissions, on top of the typical centre frequencies provided within the IARU band plan, other frequencies across the E6 band have been tested. This was done at the scope of providing the most complete possible picture on the compatibility potential between the two services. In particular, the different receivers under test are characterised by different front-end bandwidth (spanning approximately from 30 MHz to the full 40 MHz).

As documented in Annex 4, the tests provide a characterisation for many different test scenarios, providing for each case and each AS emission type the minimum power (at the input of the GNSS receiving antenna) which is causing a 1 dB degradation of the Galileo E6-B C/N_0, as provided by the different receivers under test. As it is explained in the annex, the three receivers under test are all high-end professional receivers available in the market, and each of those has specific characteristics, including different RF bandwidth. It is also explained how the receiver C is the one which is more representative of E6-BC receiver assumptions within Recommendation ITU-R M.1902 (40.92 MHz receiver bandwidth) and therefore should be taken as a reference in the context of this compatibility assessment.

FIGURE 10

Test results – Narrowband (left) and wideband (right) AS emissions – Receiver C



Results are provided also for the specific AS centre frequencies as detailed in the IARU band plan. The results for those centre frequencies for the receiver C are provided in Table 26.

TABLE 26

	Application	Centre frequency	Bandwidth	Power at antenna input resulting in 1 dB C/N_0 degradation
1	Telegraphy	1 296.2 MHz	< 1 kHz	−130.5 dBW
3	NBFM	1 297.5 MHz	11.1 kHz	−126 dBW
4	Digital Data 128 kbit/s	1 299.2 MHz	128 kHz	−124.5 dBW
5	DVB-T2	1 280.0 MHz	1 MHz	−137.3 dBW/1 MHz
6	DVB-T2	1 280.0 MHz	10 MHz	−143.25 dBW/1 MHz

As detailed in Annex 4, out of the IARU band plan, the two services requiring the highest power to cause the 1 dB degradation (and therefore exhibiting a higher compatibility potential) are NBFM and Digital Data. Still, it is evident that power levels higher than those resulting out of the measurements would cause an unacceptable degradation to the GNSS receivers.

At the same time, the two Amateur TV wideband services are impacting the GNSS receiver even with a relatively low power. This suggests a very small compatibility potential within the E6 band. This remains true almost for any of the considered receivers, also considering that the 1 280 MHz centre frequency is extremely close to the E6 carrier frequency, and as such the result seems almost independent from the specific GNSS receiver bandwidth.

Annex 4 provides a comprehensive overview of the testing setup, assumptions, KPIs and results for the different receivers under and for all the scenarios considered.

11.2 Measurements realized in Germany

Considering the reported interference in Germany, described in § 9.1, a test plan was developed to describe a set of measurements to determine the technical and operational conditions for the future use of the amateur service in this band. The measurements were defined under static operational conditions, a fixed ratio of signal power level of both services at the input of a representative RNSS receiver. The simulated signal comprised the superposition of ten RNSS signals “in view” of the receiver at a typical mix of receive level at the surface of the Earth.

Potential conclusions on the statistical impact, especially under dynamic operational conditions, need to take into account the statistics of potential occurrence of these cases. Further considerations will have to take into account the number and geographical spread of potential operations by radio amateurs and estimate its occurrence over time.

This test plan and consecutive measurement report covering the above interference case are attached as Annex 2 and Annex 5 to this Report.

12 Summary

12.1 Interference areas

Simulations indicate areas around radio amateur stations which show the potential for harmful interference into RNSS receivers, depending on the case (see § 10 and Annexes 1, 3, 5, 7 and 8).

12.2 Amateur applications/transmitter modes causing interference

Evidence of reported and managed inference provided by one Administration highlighted the application ATV relays as the cause of the reported events. Related measurements (Annex 2 and Annex 5) provided further substance to this matter, concluding that ATV emissions with higher bandwidths in part of the band, namely 1 272.00-1 292.994 MHz, were interfering with the RNSS receivers under certain conditions and that certain of the radio amateur emissions will have negative impact on the different RNSS receivers, depending on the centre frequency of the amateur emission, of the RNSS system considered, and of the type of RNSS receiver considered within this system.

Further evidence of interference has also been observed in a second Administration. This related interference is better described in Annex 6, and shows that also narrowband amateur emissions (FM) can cause interference. It was identified that an FM modulated signal transmitted by an Amateur Radio Repeater was used. The emission was observed to last about 15 seconds and repeating regularly every 2/3 minutes causing a degradation of more than 20 dB to the Galileo E6 receivers located at the JRC Ispra site.

12.3 Evaluation of device deployment throughout the Regions

12.3.1 RNSS receivers

– Specific monitoring receivers.
– Ubiquitously deployed RNSS receivers (as part of other devices e.g. cars or phones but also as standalone navigation and other implementations).

12.3.2 Amateur transmitters

Amateur transmitters, analogue and digital, are generally covered under a national licensing scheme for given locations and characteristics. The national frequency allocation tables and relevant national regulations provide the necessary information.

12.4 Technical and operational measures amateur services may possibly employ to ensure the protection of RNSS receivers

As per Resolution **774 (WRC-19)**, the scope of this study is to identify possible technical and operational measures to ensure the protection of RNSS (space-to-Earth) receivers from the amateur and amateur-satellite services within the frequency band 1 240-1 300 MHz, without considering the removal of the Amateur and Amateur-Satellite Service allocations. This section examines the technical and operational measures secondary service users may employ to prevent harmful interference from amateur and amateur-satellite services into RNSS receivers. Results might be used within the ITU-R to recommend a guidance for Administrations on how to deal with the issue on a national level.

One possible solution for the protection of RNSS receivers from amateur emissions would be to define frequency separation from RNSS signals.

Section 10 provides some results which need to be used to define this frequency separation.

However, this frequency separation may not be sufficient, in some cases, to ensure the protection of RNSS receivers.

It may also be necessary to limit the outpower (EIRP) of amateur applications. The power limitation needs to be clearly defined depending on the amateur applications (broadband, narrowband or others).

ITU-R is developing a Recommendation, which intends to provide guidelines for the use of the frequency band 1 240-1 300 MHz by stations of the amateur and amateur-satellite services, in order to encourage the use of specific sub-bands with sufficient frequency offsets from RNSS signals and with amateur applications power limitations to enhance the protection of RNSS receivers in the bands under consideration.

When amateur or amateur-satellite stations antennas are installed at large antenna heights compared to typical values, additional constraints or limitations may need to be considered by Administrations.

Annex 1

Simulation 1

Annex1_Simulation 1.docx

Annex 2

Measurements realized in Germany

Annex2_Measurements in Germany.docx

Annex 3

Simulation 2

Annex3_Simulation 2.docx

Annex 4

Measurement Campaign

Annex4_Measurement campaign.docx

Annex 5

Measurement Test

Annex5_Measurement Test.docx

Annex 6

Reported Interference

Annex6_Reported
Interference.docx

Annex 7

Simulation 3

Annex7_Simulation
3.docx

Annex 8

Simulations concerning the height of amateur stations

Annex8_Simulation
s height_amateur_st

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