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Interference effect of transmissions from earth stations on board vessels operating in fixed-satellite service networks on terrestrial co-frequency stations

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REPORT ITU-R S.2363-0

Interference effect of transmissions from earth stations on board vessels operating in fixed-satellite service networks on terrestrial co-frequency stations

(2015)

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1 Introduction and background

This Report provides the results of studies conducted in response to WRC-15 agenda item 1.8, which calls for a review of the provisions relating to earth stations on board vessels (ESVs) in accordance with Resolution **909 (WRC-12)**. In particular, this agenda item considers the need to review and possibly revise limitations and restrictions contained in Resolution **902 (WRC-03)** in light of the current ESV technologies being deployed (e.g. use of spread spectrum modulation), while ensuring the continued protection of other services to which the frequency bands 5 925-6 425 MHz and 14-14.5 GHz are allocated.

Consideration of ESVs in the ITU started in 1997 when WRC-97 placed ESVs on the WRC-2000 agenda (agenda item 1.8) in its Resolution **721 (WRC-97)**.

At WRC-03 diverging views were expressed on the appropriateness of allowing an earth station on board a vessel, which is a maritime mobile earth station, to operate in the fixed-satellite service, with different classes of stations. The Conference decided to authorize earth stations on board vessels to operate in the fixed-satellite service, adopted Resolution **902 (WRC-03)**, and introduced footnotes RR Nos. **5.457A**, **5.457B**, **5.506A** and **5.506B**.

In particular, Resolution **902 (WRC-03)** limits the use of ESVs to distances of at least 125 km “from the low-water mark as officially recognized by the coastal State” for Ku band (14-14.5 GHz) and 300 km for C band (5 925-6 425 MHz) for operation “without the prior agreement of any administration”.

Since that time, the use of these earth stations on ships has increased but no studies updating the ESV deployment scenario considered in 2003 are available.

However, it should be noted that, for the 14 GHz band, Recommendation ITU-R SF.1650-1 uses the number of ferry arrivals of the Dover port in 1999. The number is approximately 24 000 and the Recommendation derives the number of vessel passes per day multiplying it by the probability of the frequency overlap. This means the Recommendation assumes that all the ferries are equipped with ESV terminals operating in the 14 GHz band.

During the 2007-2012 ITU-R study cycle, an input document called attention to the assumptions used in Recommendations ITU-R S.1587-1 and ITU-R SF.1650-1 to develop Resolution **902 (WRC-03)** considering that they are no longer representative of all current ESV technologies. For example, some of the typical ESVs in the frequency band 5 925-6 425 MHz may operate today with e.i.r.p. density levels that are more than 20 dB lower than those used in Resolution **902 (WRC-03)**. As a consequence, ESV operations at lower power could coordinate more easily with the terrestrial administration if they operate inside the 300 km and 125 km in C and Ku bands, respectively, or even be allowed to operate at smaller distances without the need to coordinate.

It should be noted that the 5 925-6 425 MHz and 14-14.5 GHz frequency bands are extensively used by the fixed service (FS) in many countries, including terrestrial stations that are near to coastlines and that point toward the sea providing basic infrastructure telecommunications of these countries including broadband communications to remote rural communities and communications to offshore oil platforms. These terrestrial services in many cases provide the backbone of infrastructure in developing countries.

The operation of ESVs as authorized by WRC-03 in Resolution **902 (WRC-03)**, was the result of extensive discussions and compromises made at WRC-03. Some administrations were of the view that it might not be possible to retain those compromises if the criteria and parameters currently in force were to be changed. Therefore, careful studies were required in particular using the course of action and methodologies used in studies before WRC-03.

This Report contains the results of calculations of distances beyond which the agreement of the terrestrial administration is not required, for different values of maximum e.i.r.p. density of the ESV stations, as a possible way to implement the necessary protection of terrestrial co-frequency operations while introducing flexibility in the regulatory framework. The above mentioned values of e.i.r.p. density would be part of the ESV license issued by the licensing administrations.

It is noted that Recommendation ITU-R S.1587-2 shows 6 GHz ESV transmitting power densities at the input of the ESV antenna as low as –11.3 dB(W/MHz), 24.3 dB lower than the value of 13 dB(W/MHz) used in the derivation of the Resolution **902 (WRC-03)** protection distances. Likewise, for the 14 GHz band, Recommendation ITU-R S.1587-2 shows ESV transmitting power densities as low as –13.5 dB(W/MHz), 22 dB lower than the value of 8.5 dB(W/MHz) used in the derivation of the Resolution **902 (WRC-03)** protection distances. These ESV systems are the main incentive for carrying out the studies reflected in this Report.

Although it is not expected that all ESV systems will operate with the same low power levels in the future due to the diversity of service requirements, one of the approaches to adapt the regulatory environment to the reality of ESV systems operating with different levels of uplink power density is to allow smaller protection distances for systems with low power density levels, which will effectively make the ESVs appear indistinguishable to the fixed service receivers. Consequently, the spread and distribution of the e.i.r.p. densities will not be a factor to be considered.

In addition, if smaller ESV antennas are to be allowed, the number of vessels equipped with such terminals is likely to increase, which will in turn lead to a greater number of likely ESV passes per day as considered in Recommendation ITU-R SF.1650-1. This would require the base assumptions/simulations of Recommendation ITU-R SF.1650-1 to also be revisited. However, there are no 14 GHz ESV systems described in Recommendation ITU-R S.1587-2 with antenna diameters smaller than 60 cm, the minimum diameter taken into account in Resolution **902 (WRC-03)**. As to 6 GHz ESV systems, the minimum antenna diameter found in Recommendation ITU-R S.1587-2, 1.2 m, is smaller than the minimum diameter considered in Resolution **902 (WRC-03)**. This fact needs to be taken into consideration and is addressed in detail later in this Report.

Since not all vessels will have the new ESVs with e.i.r.p. density levels that are more than 20 dB lower than those used in Recommendation ITU-R SF.1650-1, the maximum e.i.r.p. density levels towards the horizon, as currently contained in Annex 2 to Resolution **902 (WRC-03)**, must still be considered as the worst-case for the calculation of protection distances.

2 Study 1: Study based on increasing the number of passes of ships in the C and Ku bands

One study presented the results of calculations of the off-shore distances from the baseline for protection of the fixed services in the bands 5 925-6 425 MHz and 14-14.5 GHz, for a new range of co-frequency vessel passes (see Table 1 below), with 36° discrimination angle and technical ESV and fixed service receiver (FSR) parameters, as mentioned in Recommendation ITU-R SF.1650-1, using the propagation model described in Recommendation ITU-R P.620-6, as the following:

TABLE 1

Number of vessel passes across the beam of the fixed service receiver (FSR)

Frequency band	Number of vessels
6 GHz band	1 vessel every third day; 1, 3, **4** and **6** vessels every day
14 GHz band	3, 6 and **8** vessels every day

The values of the parameters used for the fixed stations have been tabulated in the following Table 2 and the other parameters are those which were used in the Recommendation ITU-R SF.1650-1.

TABLE 2

FSR parameters

Frequency band	B_{FSR} Bandwidth (MHz)	T_{FSR} (K)	L_{FRX} (dB)
6 GHz band	11.2	750	3
14 GHz band	14	820	3

Using the parameter values described above and based on the methodology specified in Recommendation ITU-R SF.1650-1, the off-shore distance can be calculated as shown in the following Tables 3, 4, 5 and 6 for both 6 GHz and 14 GHz bands.

These Tables show the effect of number of vessels equipped with ESV on the protection distance for C and Ku bands. Calculations have been performed for three different antenna discrimination angles: 10°, 20° and 36°, maximum ESV transmit power at input to antenna is set to 16.7 dBW for 6 GHz and 12.2 dBW for 14 GHz and latitudes are set to 20° and 45°.

To investigate the effect of the distance of the station from shore on the protection distance, results are presented for two cases: the FSR located on the coast (0 km inland) and the FSR located some distance inland (25 km inland for the 6 GHz band and 15 km for the 14 GHz band). As it is seen, by increasing the number of vessels the protection distance also increases.

2.1 Resulting distances

As mentioned above, the ESV parameters agreed upon in Recommendation ITU-R SF.1650-1 have been considered for calculation of the minimum distance. However, it is reasonable to assume that the number of ESVs has increased, and the importance of this parameter was indicated in the above mentioned Recommendation.

Furthermore, it is believed that the definition of the adequate distance to protect the FS should be based upon calculations relative to 36° discrimination.

Therefore, taking into account the new assumptions of the maximum numbers of vessels 4 and 6 for C band and also the maximum numbers of vessels 8 for Ku band with 36° discrimination angle, it is proposed to retain the following administrative protection distances as the recommended off-shore distances for both the C and Ku bands which would not cause unacceptable interference to the FS services.

– 345 km in the C band;

– 125 km in the Ku band.

It means that, with increasing the numbers of the passing vessels, taking into account the operations of ESVs, 300 km for C band could not be reduced but should be increased to the proposed off-shore value, as mentioned above, but the off-shore distance of 125 km for the Ku band could be retained as it is in current Resolution **902 (WRC-03)**.

2.2 Protection distance calculations in the 6 GHz and 14 GHz bands using Recommendation ITU-R P.620-6

Calculation results in the 6 GHz band

TABLE 3

Protection distance in the 6 GHz band using Recommendation ITU-R P.620-6, latitude = 20, B_{FSR} = 11.2 MHz, P_t = 16.7 dBW

		FSR at 0 km from the coast			FSR at 25 km from the coast		
Antenna discrimination angle (degrees)		10	20	36	10	20	36
L_b (dB)		170.7	163.7	156.7	170.7	163.7	156.7
1 vessel every third day	Distance (km)	452	379	307	377	333	282
	P (%)	0.0439	0.0523	0.0646	0.0526	0.0596	0.0703
1 vessel every day	Distance (km)	472	397	322	397	352	299
	P (%)	0.0139	0.0166	0.0204	0.0166	0.0187	0.0220
3 vessels every day	Distance (km)	490	413	336	414	369	313
	P (%)	0.0045	0.0053	0.0065	0.0053	0.0059	0.0070
4 vessels every day	Distance (km)	494	417	340	418	373	317
	P (%)	0.0033	0.0039	0.0048	0.0039	0.0044	0.0052
6 vessels every day	Distance (km)	501	423	**345**	424	378	322
	P (%)	0.0022	423	0.0032	0.0026	0.0029	0.0034

TABLE 4

Protection distance in the 6 GHz band using Recommendation ITU-R P.620-6, latitude = 45, B_{FSR} = 11.2 MHz, P_t = 16.7 dBW

		FSR at 0 km from the coast			FSR at 25 km from the coast		
Antenna discrimination angle (degrees)		10	20	36	10	20	36
L_b (dB)		170.7	163.7	156.7	170.7	163.7	156.7
1 vessel every third day	Distance (km)	427	356	286	344	299	247
	P (%)	0.0465	0.0557	0.0694	0.0577	0.0664	0.0803
1 vessel every day	Distance (km)	451	378	305	368	323	270
	P (%)	0.0146	0.0174	0.0216	0.0179	0.0204	0.0244
3 vessels every day	Distance (km)	472	397	322	389	343	289
	P (%)	0.0046	0.0055	0.0068	0.0056	0.0064	0.0076
4 vessels every day	Distance (km)	477	402	326	394	348	293
	P (%)	0.0034	0.0041	0.0050	0.0042	0.0047	0.0056
6 vessels every day	Distance (km)	484	408	332	400	354	300
	P (%)	0.0023	0.0027	0.0033	0.0027	0.0031	0.0037

Calculation results in the 14 GHz band

TABLE 5

Protection distance in the 14 GHz band using Recommendation ITU-R P.620-6, latitude = 20, B_{FSR} = 14 MHz and P_t = 12.2 dBW

		FSR at 0 km from the coast			FSR at 15 km from the coast		
Antenna discrimination angle (degrees)		10	20	36	10	20	36
L_b (dB)		162.8	155.8	148.8	162.8	165	148.8
3 vessels every day	Distance (km)	215	165	116	213	160	115
	P (%)	0.0080	0.0104	0.0147	0.0080	0.0107	0.0149
6 vessels every day	Distance (km)	219	169	119	218	164	118
	P (%)	0.0039	0.0051	0.0072	0.0039	0.0052	0.0072
8 vessels every day	Distance (km)	221	171	**121**	219	165	120
	P (%)	0.0029	0.0038	0.0053	0.0029	0.0039	0.0053

TABLE 6

Protection distance in the 14 GHz band using Recommendation ITU-R P.620-6, latitude = 45, B_{FSR} = 14 MHz and P_t = 12.2 dBW

		FSR at 0 km from the coast			FSR at 15 km from the coast		
Antenna discrimination angle (degrees)		10	20	36	10	20	36
L_b (dB)		162.8	155.8	148.8	162.8	165	148.8
3 vessels every day	Distance (km)	208	159	110	203	155	108
	P (%)	0.0082	0.0108	0.0156	0.0084	0.0111	0.0159
6 vessels every day	Distance (km)	213	163	114	208	160	112
	P (%)	0.0040	0.0053	0.0075	0.0041	0.0054	0.0076
8 vessels every day	Distance (km)	214	165	116	210	162	113
	P (%)	0.0030	0.0039	0.0055	0.0031	0.0040	0.0057

In the meantime, for the calculations in the 6 GHz band, the FSR antenna height is taken as 120 m above mean sea level. Although this is representative of most cases, in some countries fixed links are located on mountains with an altitude of about 1 000 m which should be considered in the ITU-R studies, as appropriate.

2.3 Protection distance calculations in the 6 GHz band using the Recommendation ITU-R P.452-14

The calculations have been made for the fixed stations with the altitudes of 120 m and 1 035 m above the sea level. In the first case, the fixed station with the altitude of 120 m above the sea level and distance of zero from the shore have been considered. In the second case, the fixed station with the altitude of 1 035 m above the sea level and distance of 25 km from the shore have been considered.

Using the parameter values described above and based on the methodology specified in Recommendation ITU-R SF.1650-1 and using the propagation model described in Recommendation ITU-R P.452-14, the results show that almost the same conclusion is reached for C band (~ 345 km) using the propagation model described in Recommendation ITU-R P.620-6. Therefore, it is confirmed that the off-shore distance of 300 km for C band in uplink directions should be increased. To this effect, it is necessary to examine and remedy the assumptions again in Recommendation ITU-R SF.1650-1.

3 Study 2: Establishing different protection distances for different maximum e.i.r.p. density levels, which yields shorter protection distances for e.i.r.p. density levels lower than those currently allowed by Resolution 902 (WRC-03)

This study follows the same methodology described in Recommendation ITU-R SF.1650-1 and the propagation model described in Recommendation ITU-R P.452-14, and also takes into account different values of uplink transmitted power density for ESVs employing state of the art technologies and technical characteristics and, for the 6 GHz band, a doubling in the number of passes of ships when compared with the number assumed by WRC-03. The latter assumption results from the proposed reduction of the 6 GHz ESV minimum antenna diameter from 2.4 to 1.2 m, with the consequent potential increase in aggregate interference into terrestrial services.

This study also considers, for the 14 GHz band, different values of uplink ESV transmitted power density and the deployment scenario of ESVs implicitly assumed by WRC-03 when establishing the protection environment for the FS, including the number of passing vessels used during the studies carried out before WRC-03.

The assumption that the number of passing vessels used during the studies carried out before WRC-03 is still valid today is based on updated maritime traffic statistics in certain regions, shown in Annexes 2 and 3 of this Report.

3.1 Initial data

For the original assessment of the protection distances found in Recommendation ITU-R SF.1650-1, the technical characteristics of ESVs contained in Recommendation ITU-R S.1587-1 were used. However, Recommendation ITU-R S.1587-2 presents technical characteristics of two new types of ESVs which were absent in Recommendation ITU-R S.1587-1, namely System 5 and System 4 in the C and Ku frequency bands, respectively.

Tables 7 and 8 compare, for the C and Ku frequency bands, the ESV parameters used for the derivation of the protection distances found in Recommendation ITU-R SF.1650-1 and the ESV parameters of the new systems added in Recommendation ITU-R S.1587-2.

TABLE 7

ESVs parameters in the frequency band 5 925-6 425 MHz
(frequency of operation – 6 000 MHz, antenna height above sea level – 40 m)

Parameter	Value according to Rec. ITU-R SF.1650-1	Value according to Rec. ITU-R S.1587-2 System 5	Comment
Elevation angle to satellite, degrees	>10		Lower elevation angles may be used provided that the e.i.r.p. towards the horizon is consistent with the 10° elevation angle operational limitation
Emission type (modulation)		QPSK/CDMA	
Horizon gain angle, degrees	0		According to Recommendation ITU-R SM.1448 in the worst case
Data rate, kbit/s	1544	38.4/76.8/128	
Maximum occupied bandwidth, MHz	2.346	9.14/18.29/ 30.48	
Transmit power, dBW		–1.2/3.3/4.8	
Maximum transmit power at input to antenna, dBW	16.7	–1.7/2.8/4.3 (calculated)	Considering feeder loss
Transmit e.i.r.p. the density at input to antenna, dB(W/1 MHz)	13.0 (calculated)	–11.3/–9.8/ –10.5	
Minimum antenna diameter, m	2.4	1.2	
Antenna gain in direction of the fixed service receiver, dBi	+4 to –10		According to Recommendation ITU-R SM.1448
Antenna main beam gain, dBi	41.7	35.7	
Transmit e.i.r.p. density, dB(W/1 MHz)	54.8 (calculated)	24.4/25.9/25.2	

TABLE 8

ESVs parameters in the frequency band 14-14.5 GHz
(frequency of operation – 14.25 GHz, antenna height above sea level – 40 m)

Parameter	Value according to Rec. ITU-R SF.1650-1	Value according to Rec. ITU-R S.1587-2 System 4	Comment
Elevation angle to satellite, degrees	>10		Lower elevation angles may be used provided that the e.i.r.p. towards the horizon is consistent with the 10° elevation angle operational limitation
Emission type (modulation)		O-QPSK/ CRMA	CRMA – Code Reuse Multiple Access
Horizon gain angle, degrees	0		According to Recommendation ITU-R SM.1448 in the worst case
Data rate, kbit/s	1544	16-1024	
Maximum occupied bandwidth, MHz	2.346	6.75–36	For System 4 maximum occupied bandwidth is given according to bandwidth of the transponder
Transmit power at input to antenna, dBW	12.2	12.0/9.0	
Transmit e.i.r.p. density at input to antenna, dB(W/1 MHz)	8.5 (calculated)	–3.6/–6.6	For System 4 transmit e.i.r.p. density is given according to bandwidth of the transponder 36 MHz
Minimum antenna diameter, m	1.2	0.6/1.2	
Antenna gain in direction of the fixed service receiver, dBi	+4 to –10		According to Recommendation ITU-R SM.1448
Antenna main beam gain, dBi	43	37/43	
Transmit e.i.r.p. density, dB(W/1 MHz)	51.6	39.4	For System 4 transmit e.i.r.p. density is given according to bandwidth of the transponder 36 MHz

Recommendation ITU-R SF.1650-1 also contains the parameters of the terrestrial co-frequency FS stations assumed in the analyses of interference from ESVs.

3.2 Protection distances based on short-term protection described in Recommendation ITU-R SF.1650-1 in the band 5 925-6 425 MHz

In Table 1 of Recommendation ITU-R SF.1650-1, the short-term protection requirement in the band 5 925-6 425 MHz is that an interference power level of –110.4 dBW at the input of a FSR facing out to sea and with a feeder-loss of 3 dB should not be exceeded for more than 4.5×10^{-4}% of the time (p_S expressed in %). The FSR antenna gain (G_{av}) is given as an average of 42.5 dBi within its –10 dB beamwidth of 1.72°. Recognizing that there is likely to be an ESV within that beamwidth for only a relatively small proportion of the time, and that this proportion depends on such parameters as the speed of the ESV (v_{ESV}) and its distance (d) from shore when it sails across the beam, Recommendation ITU-R SF.1650-1 describes an iterative process to determine the "*propagation model input parameter, p, which is the time percentage for which the required minimum transmission loss is not exceeded (e.g. in Recommendation ITU-R P.452)*". The value of p depends on the input parameters to the iterative process and thus varies from case to case, but it will be considerably greater than 4.5×10^{-4}%.

Recommendation ITU-R SF.1650-1 also considers, for the 6 GHz frequency band, values of ESV antenna off-axis angle towards the horizon varying form 10° to 36°.

For the purposes of the present analysis, the time percentage was estimated for which an ESV (6 175 MHz) operating near 45° North latitude 300 km from an FSR on the shore, and transmitting the maximum permissible power level of 16.7 dBW with different discrimination angles in the azimuth direction of the FSR, would not exceed –110.4 dBW at the FSR receiver input. The estimate was made by an iterative method, using the implementation of the propagation model of Recommendation ITU-R P.452-14 available at the ITU website[1] and trying various time percentages to find the value corresponding to the required path loss (L) calculated as follows for 10° discrimination angle:

$$L = 16.7 + 29 - 25 \log (10) + 42.5 + 110.4 - 3 = 170.6 \text{ dB}$$

For an off-axis angle towards the FSR of 10°, the e.i.r.p. density in that direction is 17 dBW/MHz. This is an example of a worst-case scenario in which the Resolution **902 (WRC-03)** requirements for minimum off-shore distance and maximum e.i.r.p. density toward the horizon are just met. By using the Recommendation ITU-R P.452-14 methodology to calculate values of L for different time percentages, it was found that the time percentage p for which L = 170.6 dB on the interference path is 0.415%.

According to Recommendation ITU-R SF.1650-1, the yearly number of passes of the ESVs transmitting within the FSR receiver channel bandwidth[2] (f_{ESV}) is inversely proportional to the product of the required separation distance (d) and the time percentage (p) associated with the propagation loss.

This relationship can be derived from Fig. 1 and the definitions of these parameters in Tables 1 and 2 of Recommendation ITU-R SF.1650-1 as follows:

$$p = (p_S/p_{ESV})*100\%$$

$$p_{ESV} = (f_{ESV}*t_{ESV\ in\ beam}/8\,760)*100\%$$

$$t_{ESV\ in\ beam} = d_{ESV\ in\ beam}/v_{ESV}$$

$$v_{ESV} = 18.3 \text{ km/h}$$

$$d_{ESV\ in\ beam} = 2*d*\tan(\theta_{FSR,\ -10dB}/2)$$

In particular, for the 6 GHz frequency band, $p_S = 4.5*10\text{^}(-4)$ and $\theta_{FSR,\ -10dB} = 1.72°$, and therefore the combination of the above definitions yields the following relationship:

$$f_{ESV} = \frac{4.5*10\text{^}(-4)*8760*18.3}{2\tan\left(\frac{1.72}{2}\right)*p*d}$$

[1] http://www.itu.int/oth/R0A0400005F/en.

[2] The total number of passes per year is f_{ESV} multiplied by the ratio of 500 MHz to the FSR receiver channel bandwidth.

In other words, once the product *p*d* is defined, the yearly number of passes of ESVs transmitting within the FSR receiver channel bandwidth is also defined.

Because Resolution **902 (WRC-03)** defined 300 km as the distance required to protect the FSR from ESVs transmitting a maximum e.i.r.p. density of 17 dB (W/MHz) toward the horizon (resulting in a path loss of 170.6 dB, which is met for the latitudes considered in the present analysis for 0.415% of the time), the product *p*d*is 124.5 for these latitudes. Hence the aggregate interference from ESVs transmitting 16.7 dBW carrier power with various transmit antenna off-axis angles toward the FSR assumed at WRC-03 would be equivalent to that of about 19.3 passes per year of ESVs transmitting within the FSR receiver channel bandwidth with the ESV antenna pointing to the FSR with a 10° off-axis angle.

The 6 GHz protection distance established in Resolution **902 (WRC-03)** is associated not only with the path loss required to protect FSRs from ESVs radiating 16.7 dBW of power, but also with a minimum ESV transmit antenna diameter of 2.4 m imposed to limit the number of passes per year.

However, Recommendation ITU-R S.1587-2 – Technical characteristics of earth stations on board vessels communicating with FSS satellites in the frequency bands 5 925-6 425 MHz and 14-14.5 GHz which are allocated to the fixed-satellite service, contains parameters of a system in the 6 GHz frequency band with ESV antennas of 1.2 m diameter (System 5).

Consequently, the impact of a possible increase in frequency of passage (f_{ESV}) due to the use of ESV antennas with diameters smaller than that established in Resolution **902 (WRC-03)** may need to be considered, in addition to that of reduced maximum power density levels found in several current and planned ESV systems.

If it is assumed that the yearly number of ESV passes will double if the minimum allowed 6 GHz ESV antenna diameter is reduced from 2.4 m to 1.2 m, the product *p*d* for the latitudes considered in the present analysis will become 62.25, corresponding to 38.6 passes per year of ESVs transmitting within the FSR receiver channel bandwidth with antennas pointing to the FSR with a 10° off-axis angle.

Distances *d* were derived based on the methodology of Recommendation ITU-R SF.1650-1 for each of the following maximum levels of power radiated by the ESVs, so that the associated required path losses are exceeded for no more than *p*% of the time and subject to the constraint *p*d* = 62.25:

for 16.7 dBW: 170.6 dB of path loss;

for 6.7 dBW: 160.6 dB of path loss;

for –3.3 dBW: 150.6 dB of path loss;

for –13.3 dBW: 140.6 dB of path loss.

Using the implementation of the propagation model of Recommendation ITU-R P.452-14 as implemented on the ITU website, the following minimum protection distances were determined:

– minimum distance of 323 km from shore for ESVs with a maximum transmit power of 16.7 dBW;

– minimum distance of 227 km from shore for ESVs with a maximum transmit power of 6.7 dBW;

– minimum distance of 130 km from shore for ESVs with a maximum transmit power of –3.3 dBW;

– minimum distance of 64 km from shore for ESVs with a maximum transmit power of –13.3 dBW.

If the above analysis is carried out assuming the 300 km is associated with a 20° ESV antenna discrimination angle, the yearly number of passes derived according to the methodology in Recommendation ITU-R SF.1650-1 becomes 560. Assuming a doubling of the number of passes if the minimum allowed ESV antenna diameter is reduced from 2.4 m to 1.2 m, this number increases to 1 120. On the other hand, as the Table 9 below shows, the protection distances derived assuming a 20° ESV antenna discrimination angle are reduced with respect to the numbers derived above for a 10° ESV antenna discrimination angle.

TABLE 9

6 GHz protection distances for 20° discrimination angle

ESV TX Power (dBW)	Path Loss Required (dB)	Protection Distance (km)	*p* for Rec. ITU-R P.452 (%)	Yearly Number of ESV Passes
16.7	163.07	300	0.0143	560 (for 2.4 m)
16.7	163.07	310	0.00692	1 120 (for 1.2 m)
6.7	153.07	203	0.01057	1 120 (for 1.2 m)
–3.3	143.07	95	0.02258	1 120 (for 1.2 m)
–13.3	133.07	40	0.05363	1 120 (for 1.2 m)

If the same analysis is carried out assuming the 300 km is associated with a 25° ESV antenna discrimination angle, the yearly number of passes derived according to the methodology in Recommendation ITU-R SF.1650-1 becomes 4,086.5. Assuming a doubling of the number of passes if the minimum allowed ESV antenna diameter is reduced from 2.4 m to 1.2 m, this number increases to 8,173. On the other hand, as the Table 10 below shows, the protection distances derived assuming a 25° ESV antenna discrimination angle are reduced with respect to the numbers derived above for a 20° ESV antenna discrimination angle.

TABLE 10

6 GHz protection distances for 25° discrimination angle

ESV TX power (dBW)	Path loss required (dB)	Protection distance (km)	*p* for Rec. ITU-R P.452 (%)	Yearly number of ESV passes
16.7	160.65	300	0.00196	4086.5 (for 2.4 m)
16.7	160.65	308	0.00096	8173 (for 1.2 m)
6.7	150.65	196	0.0015	8173 (for 1.2 m)
–3.3	140.65	94	0.00313	8173 (for 1.2 m)
–13.3	130.65	39	0.00754	8173 (for 1.2 m)

From the above analysis, it is concluded that the most conservative set of protection distances is that associated with the 10° ESV antenna discrimination angle.

3.3 Protection distances based on short-term protection described in Recommendation ITU-R SF.1650-1 in the band 14-14.5 GHz

In Table 2 of Recommendation ITU-R SF.1650-1, the short-term protection requirement in the band 14-14.5 GHz is that an interference power level of –109 dBW at the input to the receiver of a FSR facing out to sea and with a 3 dB feeder loss should not be exceeded for more than 2.7 × 10^{-4}% of the time (p_S expressed in %). The FSR antenna gain (G_{av}) is given as an average of 40.5 dBi within its –10 dB beamwidth of 2.2°. Recognizing that there is likely to be an ESV within that beamwidth for only a relatively small proportion of the time, and that this proportion depends on such parameters as the speed of the ESV (v_{ESV}) and its distance (d) from shore when it sails across the beam, Recommendation ITU-R SF.1650-1 describes an iterative process to determine the "*propagation model input parameter, p, which is the time percentage for which the required minimum transmission loss is not exceeded (e.g. in Recommendation ITU-R P.452)*". The value of p depends on the input parameters to the iterative process and thus varies from case to case, but it will be considerably greater than 2.7×10^{-4}%.

Recommendation ITU-R SF.1650-1 also considers, for the 6 GHz frequency band, values of ESV antenna off-axis angle towards the horizon varying from 20° to 36°.

For the purposes of the present analysis, the time percentage was estimated for which an ESV (14.25 GHz) operating at a latitude near 45° North 125 km from shore, and transmitting the maximum permissible power of 12.2 dBW with different discrimination angles toward the horizon in the azimuth direction of the FSR, would not exceed –109 dBW at the FSR receiver input. The estimate was made by an iterative method, using the propagation model of Recommendation ITU-R P.452-14 and trying various time percentages to find the value corresponding to the required path loss (L) calculated as follows for 10° discrimination angle:

$$L = 12.2 + 29 - 25 \log (10) + 40.5 + 109 - 3 = 162.7 \text{ dB}$$

For an off-axis angle towards the FSR of 10°, the e.i.r.p. density in that direction is 12.5 dBW/MHz. This is an example of the worst-case scenario in which the Resolution **902 (WRC-03)** requirements for minimum off-shore distance and maximum e.i.r.p. density toward the horizon are just met. By using the Recommendation ITU-R P.452-14 methodology to calculate values of L for different time percentages it was found that the time percentage for which L = 162.7 dB on the interference path is 0.804%.

The relationship found in Recommendation ITU-R SF.1650-1 between the yearly number of passes of the ESVs transmitting within the FSR receiver channel bandwidth (f_{ESV}) and the product of the required separation distance (d) and the time percentage (p) associated with the propagation loss for the 14 GHz frequency band is the following:

$$f_{ESV} = \frac{2.7*10^{\wedge}(-4)*8760*18.3}{2\tan\left(\frac{2.2}{2}\right)*p*d}$$

The product $p*d$ for the latitudes considered in the present analysis is 100.5. Hence, the aggregate interference from ESVs transmitting 12.2 dBW carrier power with various transmit antenna off-axis angles toward the FSR assumed at WRC-03 would be equivalent to that of about 11.2 passes per year of ESVs transmitting within the FSR receiver channel bandwidth with the ESV antenna pointing to the FSR with a 10° off-axis angle.

Moreover, the minimum antenna diameter of 60 cm for the 14 GHz frequency band contained in Recommendation ITU-R S.1587-2 is already considered in a footnote in Resolution **902 (WRC-03)**, and so there is no reason to consider a different assumed number of ESV passes.

Distances d were derived based on the methodology of Recommendation ITU-R SF.1650-1 for each of the following maximum levels of power radiated by the ESVs, so that the associated required path losses are exceeded for no more than p% of the time and subject to the constraint $p*d$ = 100.5:

For 12.2 dBW: 162.7 dB of path loss;

For 2.2 dBW: 152.7 dB of path loss;

For –7.8 dBW: 142.7 dB of path loss.

Using the implementation of the propagation model of Recommendation ITU-R P.452-14 as implemented on the ITU website, the following minimum protection distances can be determined:

– Minimum distance of 125 km from shore for ESVs with maximum transmit power of 12.2 dBW;
– Minimum distance of 85 km from shore for ESVs with a maximum transmit power of 2.2 dBW;
– Minimum distance of 29 km from shore for ESVs with a maximum transmit power of –7.8 dBW.

If the same analysis is carried out assuming the 125 km is associated with a 20° ESV antenna discrimination angle, the yearly number of passes derived according to the methodology in Recommendation ITU-R SF.1650-1 becomes 6 440. On the other hand, as the Table 11 below shows, the protection distances derived assuming a 20° ESV antenna discrimination angle are reduced with respect to the numbers derived above for a 10° ESV antenna discrimination angle.

TABLE 11

14 GHz protection distances for 20° discrimination angle

ESV TX power (dBW)	Path loss required (dB)	Protection distance (km)	*p* for Rec. ITU-R P.452 (%)	Yearly number of ESV passes
12.2	162.7	125	0.0014	6 440
2.2	152.7	83	0.00211	6 440
-7.8	142.7	25	0.007	6 440

From the above analysis, it is concluded that the most conservative set of protection distances is that associated with the 10° ESV antenna discrimination angle.

3.4 Computation of required ESV long-term separation distances for e.i.r.p. density levels towards horizon lower than that in Annex 2 of Resolution 902 (WRC-03) in the band 5 925-6 425 MHz

For the 6 GHz frequency band, multipath fading is the primary cause of performance degradations and, consequently, the "fractional degradation in performance" (FDP) as developed in Recommendation ITU-R F.1108 – Determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands, for a similar type of intermittent interference provides a simple means of determining acceptable levels of interference.

FDP is the ratio of the time-average value of the interference power (W/MHz) under nominal propagation conditions on the ESV to FSR path to the receiving system noise power N_{FSR} (W/MHz) where both are measured at the receiver input.

From Recommendation ITU-R SF.1650-1, the FS system noise temperature, T_{FSR}, is 750 K and the 6 GHz receiver bandwidth is 11.2 MHz. Hence,

$$N_{FSR} = 10 \log\ (k * 750 * 11.2 * 10^6) = -129.4 \text{ dBW}$$

Long-term interference is considered acceptable if:

a) $FDP = \frac{I_{AV}}{N_{FSR}} \leq 0.1$ or 10 % for at least 80% of the time (see Recommendation ITU-R F.758); and

b) *I/N* is at most 20 dB (see Recommendation ITU-R F.1494 for interference criteria to protect the fixed service from time varying interference from other services sharing the 10.7-12.75 GHz frequency band on a co-primary basis).

The first condition is equivalent in dB to:

$$FDP = \frac{I_{AV}}{N_{FSR}} \leq 0.1 \text{ or 10\% for at least 80\% of the time.}$$

Using equation (2) of Recommendation ITU-R SF.1650-1, the interference power at the FSR due to an ESV under long-term propagation conditions during a pass through the FSR antenna is:

$$I_{FSR} = P_t + G_t + G_{r,AVE} - F - L_{P452}(20\%) \text{ dBW}$$

where:

P_t: transmit power at the ESV antenna flange in dBW

G_t: ESV antenna gain in the direction of the FSR (dBi)

$G_{r,AVE}$: average antenna gain in a 10 dB beamwidth

F : loss in the feed from the FSR antenna to the low-noise amplifier (dBi), and

$L_{P452}(20\%)$: propagation loss on the ESV to FS path that is exceeded for all but 20% of the time as calculated with Recommendation ITU-R P.452.

Hence, the average interference power in W over a year is given by:

$$I_{AV} = 10^{(I_{FSR}/10)} \quad p_{ESVR}$$

In terms of $p_{ESV}(\%)$, which is defined Table 1 of Recommendation ITU-R SF.1650-1:

$$p_{ESVR} = p_{ESV}(\%)/100(\%)$$

I_{AV} Can also be expressed in dBW as follows:

$$I_{AV} = I_{FSR} \quad + 10\log p_{ESVR} \text{ dBW}$$

According to Table 1 of Recommendation ITU-R SF.1650-1, p_{ESVR} in number can be expressed as a function of the distance between the ESV and the FSR and of the frequency of passes as follows:

$$p_{ESVR} = \frac{2d\tan\left(\frac{1.72}{2}\right)fESV}{8760 * 18.3}$$

where:

d: distance between the ESV and the FSR in km, and

f_{ESV}: number of passes per year of the ESV through the receive beam of the FSR receive antenna and transmitting within the FSR receiver channel bandwidth.

Consequently, for each value of f_{ESV}, the following relationship can be established between d and the required value of $L_{P452}(20\%)$:

$$L_{P452}(20\%) = P_t + G_t + G_{r,AVE} - F - N_{FSR} + 10 + 10\log(d) + 10\log\left(\frac{2\tan\left(\frac{1.72}{2}\right)fESV}{8760 * 18.3}\right)$$

Assuming that the yearly number of ESV passes is the same as that used for the derivation of the short term protection distances, for the latitudes assumed in the current analysis the last term of the above expression can be calculated based on the data described in § 3.1 above to be equal to –51.41 dB.

Therefore, by making:

$$L_b = P_t + G_t + G_{r,AVE} - F - N_{FSR} + 10$$

$L_{P452}(20\%)$ can be re-written as:

$$L_{P452}(20\%) = L_b + 10\log(d) - 51.41 \text{ dB}$$

Distances d may be determined for each of the following maximum levels of power radiated by the ESVs, so that the associated required path losses are exceeded for no more than 20% of the time and subject to the constraint $L_{P452}(20\%) = L_b + 10\log(d) - 51.41$ dB:

for 16.7 dBW: L_b = 199.6 dB of path loss

for 6.7 dBW: L_b = 189.6 dB of path loss

for −3.3 dBW: L_b = 179.6 dB of path loss

for −13.3 dBW: L_b = 169.6 dB of path loss.

Using the implementation of the propagation model of Recommendation ITU-R P.452-14 available at the ITU website, the following protection distances were determined:

– Minimum distance of 96 km from shore for ESVs with a maximum transmit power of 16.7 dBW with a resulting L_{P452} (20%) of 168 dB and a resulting *I/N* value of 21.6 dB;

– Minimum distance of 81 km from shore for ESVs with a maximum transmit power of 6.7 dBW with a resulting L_{P452} (20%) of 157.3 dB and a resulting *I/N* value of 22.3 dB;

– Minimum distance of 68 km from shore for ESVs with a maximum transmit power of –3.3 dBW with a resulting L_{P452} (20%) of 146.5 dB and a resulting *I/N* value of 23.1 dB;

– Minimum distance of 13 km from shore for ESVs with a maximum transmit power of –13.3 dBW with a resulting L_{P452} (20%) of 129.3 dB and a resulting *I/N* value of 30.0 dB;

In order to ensure that *I/N* ratio at the FS terminal never exceeds a value of 20 dB, the long-term protection distances need to be adjusted as follows, which shows that the controlling distances are those associated with the short-term protection criterion:

TABLE 12

Protection distances for the 6 GHz frequency band

ESV TX power (dBW)	Initial long-term protection distance (km)	Revised long-term protection distance (km)	Short-term protection distance (km)	Proposed protection distance (km)
16.7	96	97	323	323
6.7	81	84	227	227
–3.3	68	70	130	130
–13.3	13	40	64	64

3.5 Computation of required long-term ESV separation distances for e.i.r.p density levels towards horizon lower that in Annex 2 of Resolution 902 (WRC-03) in the band 14-14.5 GHz

For the 14 GHz frequency band, multipath fading is also the primary cause of performance degradations and, consequently, the methodology described in item 4 above can also be used in this case.

From Recommendation ITU-R SF.1650-1, the FSR receiver noise figure, *NF*, is 4.5 dB, and the 14 GHz receiver bandwidth is 14 MHz Hence,

$$N_{FSR} = 10\log\ (k * 290 * 14 * 10^6) + 4.5 = -128 \text{ dBW}$$

For the 14 GHz frequency band, p_{ESVR} in number can be expressed as follows:

$$p_{ESVR} = \frac{2d\tan\left(\frac{2.2}{2}\right)fESV}{8760*18.3}$$

where:

d : distance between the ESV and the FSR in km, and

f_{ESV} : number of passes per year of the ESV through the receive beam of the FSR receive antenna and transmitting within the FSR receiver channel bandwidth.

Consequently, for each value of f_{ESV}, the following relationship can be established between d and the required value of $L_{P452}(20\%)$:

$$L_{P452}(20\%) = P_t + G_t + G_{r,AVE} - F - N_{FSR} + 10 + 10\log(d) + 10\log(\frac{2\tan\left(\frac{2.2}{2}\right)fESV}{8760 * 18.3})$$

Assuming that the yearly number of ESV passes is the same as that used for the derivation of the short term protection distances, for the latitudes assumed in the current analysis the last term of the above expression can be calculated based on the data described in section 4 above to be equal to –55.71 dB.

By making:

$$L_b = P_t + G_t + G_{r,AVE} - F - N_{FSR} + 10$$

$L_{P452}(20\%)$ can be re-written as:

$$L_{P452}(20\%) = L_b + 10\log(d) - 55.71 \text{ dB}$$

Distances d must be determined for each of the following maximum levels of power radiated by the ESVs, so that the associated required path losses are exceeded for no more than 20% of the time and subject to the constraint $L_{P452}(20\%) = L_b + 10\log(d) - 55.71$ dB:

for 12.2 dBW: L_b = 191.7 dB of path loss

for 2.2 dBW: L_b = 181.7 dB of path loss

for −7.8 dBW: L_b = 171.7 dB of path loss.

Using the implementation of the propagation model of Recommendation ITU-R P.452-14 available at the ITU website, the following protection distances were determined:

– Minimum distance of 61 km from shore for ESVs with a maximum transmit power of 12.2 dBW with a resulting L_{P452} (20%) of 153.8 dB and a resulting *I/N* value of 27.9 dB;

– Minimum distance of 12 km from shore for ESVs with a maximum transmit power of 2.2 dBW with a resulting L_{P452} (20%) of 136.8 dB and a resulting *I/N* value of 34.9 dB;

– Minimum distance of 2 km from shore for ESVs with a maximum transmit power of –7.8 dBW with a resulting L_{P452} (20%) of 119 dB and a resulting *I/N* value of 42.7 dB.

In order to ensure that *I/N* ratio at the FS terminal never exceeds a value of 20 dB, the long-term protection distances need to be adjusted as follows, which shows that the controlling distances are those associated with the short-term protection criterion:

TABLE 13

Protection Distances for the 14 GHz Frequency Band

ESV TX power (dBW)	Initial long-term protection distance (km)	Revised long-term protection distance (km)	Short-term protection distance (km)	Proposed protection distance (km)
12.2	61	65	125	125
2.2	12	60	85	85
–7.8	2	22	29	29

3.6 Conclusions

Based on the results of this study, the following protection distances should be used.

TABLE 14

Minimum distances versus maximum e.i.r.p. transmitted toward the horizon – C Band

Maximum e.i.r.p. transmitted toward the horizon (dBW in 11.2 MHz)	Minimum distance from low-water mark* (km)
20.8	323
10.8	227
0.8	130
–9.2	64

* Low-water mark as officially recognized by the coastal State.

TABLE 15

Minimum distances versus maximum e.i.r.p. transmitted toward the horizon – Ku band

Maximum e.i.r.p. transmitted toward the horizon (dBW in 14 MHz)	Minimum distance from low-water mark*(km)
16.3	125
6.3	85
–3.7	29

* Low-water mark as officially recognized by the coastal State.

Lower e.i.r.p. density levels than limits stipulated in Resolution **902 (WRC-03)** may be achieved through spreading of the ESV transmitted carrier in bandwidths larger than 11.2 MHz for the C band and 14 MHz for the Ku band, in which case the probability of frequency overlap between the ESV transmission and the FSR will increase, with a corresponding effect on the protection distances. Quantification of that effect requires knowledge of the extent to which these cases will occur.

4 Study 3: Establishment of different protection distances for different maximum e.i.r.p. density levels accounting for the statistical information on maritime traffic and the probability of frequency overlapping

4.1 Introduction

The represented Study 3 has the purpose to calculate combinations of minimum distance from ESVs/maximum e.i.r.p. spectral density toward horizon, taking into account the statistical information on maritime traffic in the Channel and Dover port, and the probability of frequency overlapping for two scenarios:

– ESVs operation in any place within the entire 500 MHz frequency band in the C and Ku bands;

– ESVs operation only in one satellite 36 MHz transponder.

4.2 Initial data

4.2.1 ESVs and FSR parameters

To assess new protection distances for FSRs, technical characteristics of ESVs which are presented in Recommendation ITU-R SF.1650-1 and Recommendation ITU-R S.1587-2 (2007) are used. Recommendation ITU-R S.1587-2 presents technical characteristics of two new types of ESVs, which are absent in Recommendation ITU-R S.1587-1 (2003), namely, System 5 and System 4 in the C and Ku frequency bands accordingly.

Some of these data, related to the assessments of the protection distances for FSRs, are summarized in Tables 16 to 18.

TABLE 16

ESVs parameters in the C frequency band.
Systems 1-5 from Recommendation ITU-R S.1587-2

Systems from Rec. ITU-R S.1587-2. Systems 1 to 5	Minimum antenna diameter (m)	Maximum occupied bandwidth, (kHz)	Maximum transmit power at input to antenna, dBW/11.2 MHz $P_{t,\,max}$-F	Maximum e.i.r.p. spectral density towards horizon, dBW/11.2 MHz
System 1 Type 1	2.4	23	0	4.0
System 1 Type 2	2.4	153.6	8.5	12.5
System 2	2.74	2 346	21	25.0*
System 3 Type 1	2.4	33	0.8	4.8
System 3 Type 2	2.4	2 300	18.6	22.6*
System 4 Type 1	2.4	107.5	5.6	9.6

TABLE 16 (*end*)

Systems from Rec. ITU-R S.1587-2. Systems 1 to 5	**Minimum antenna diameter (m)**	**Maximum occupied bandwidth, (kHz)**	**Maximum transmit power at input to antenna, dBW/11.2 MHz $P_{t,\ max}$-F**	**Maximum e.i.r.p. spectral density towards horizon, dBW/11.2 MHz**
System 4 Type 2	2.4	1 720.3	17.2	21.2*
System 5 Type 1	1.2	9 140	–1.7	2.3
System 5 Type 2	1.2	18 290	2.8	4.7
System 5 Type 3	1.2	30 480	4.3	4.0
System from Rec. ITU-R SF.1650-1.	2.4	2 346	16.7	20.8

* According to Resolution **902 (WRC-03)** maximum ESV e.i.r.p. towards the horizon is 20.8 dBW.

TABLE 17

ESVs parameters in the Ku frequency band.
Systems 1-4 from Recommendation ITU-R S.1587-2

Systems from Rec. ITU-R S.1587-2. Systems 1 to 4	**Minimum antenna diameter (m)**	**Maximum occupied bandwidth, (kHz)**	**Maximum transmit power at input to antenna, dBW/14 MHz $P_{t,\ max}$-F**	**Maximum e.i.r.p. spectral density towards horizon, dBW/14 MHz**
System 1 Type 1	1.2	16.4	–13.5	–9.5
System 1 Type 2	1.2	163.8	–1.6	2.4
System 2 Type 1	1.2	107.5	0.5	4.5
System 2 Type 2	1.2	860.2	11.5	15.5
System 3 Type 1	0.75	7 372.8	17.8	21.8*
System 3 Type 2	0.75	6 660	24.2	28.2*
System 3 Type 3	0.75	44.1	4.3	8.3

TABLE 17 (*end*)

Systems from Rec. ITU-R S.1587-2. Systems 1 to 4	**Minimum antenna diameter (m)**	**Maximum occupied bandwidth, (kHz)**	**Maximum transmit power at input to antenna, dBW/14 MHz $P_{t,\,max}$-F**	**Maximum e.i.r.p. spectral density towards horizon, dBW/14 MHz**
System 4 Type 1	1.2	36 000	11.5	11.4
System 4 Type 2	0.6	6 750	8.5	12.5
System from Rec. ITU-R SF.1650-1.	1.2	2 346	12.2	16.3

* According to Resolution **902 (WRC-03)** maximum ESV e.i.r.p. towards the horizon is 16.3 dBW.

TABLE 18

FSR parameters

	C-band	**Ku-band**
Frequency of operation, f (MHz)	6 000	14 250
Antenna height above mean sea level, $h_{rs} = h_g + h_{rg}$ (m)	120	80
Maximum boresight antenna gain, $G_r = G_{FSR}(0)$ (dBi)	45	43 - for antenna 1.2 m
–10 dB beamwidth, θ_{FSR}, –10 dB (degrees)	1.72	2.2
Average antenna gain in –10 dB beamwidth, Gr, $_{AVE}$ (dBi)	42.5	40.5
Receiver bandwidth, B_{FSR} (MHz)	11.2	14

4.2.2 Statistical information on maritime traffic

Table 19 presents the total number of ship movements (arrival + departure) in French 2 major ports and in Dover port. It is necessary to note that the previous data for Dover port were as the reference in Recommendation ITU-R SF.1650-1 for determining the minimum protection distances.

TABLE 19

Total number of ship movements (arrival + departure) in French 2 major ports, and England Dover port

	2012	**2011**	**2010**	**2009**	**2008**	**2003**
Calais	26 521	27 661	30 370	33 236	34 210	49 260
Marseille	15 669	15 957	16 308	16 909	17 379	19 282
Dover	17 202	17 772	20 198	21 649	22 118	27 471

The above-mentioned statistical information in certain regions is also contained in Annex 3 of this Report. These figures show that the total number of vessel passes in the shown ports decreased by 20-46%.

Figure 1 shows the graphical representation of the evolution of maritime traffic in the Channel.

FIGURE 1

Evolution of maritime traffic in the Channel

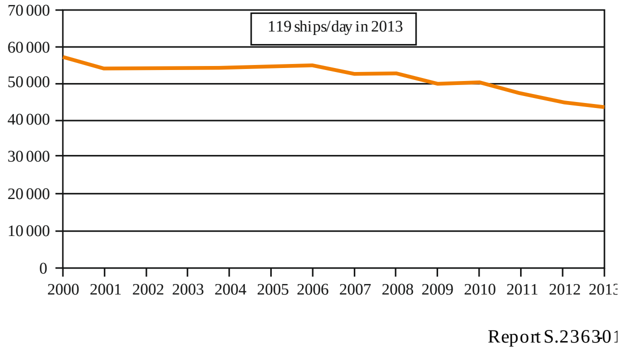

Table 20 presents the number of ship movements per day taking into account the statistics on the shown ports, and the Channel for two scenarios:

– ESVs operation in any place within the entire 500 MHz frequency band;

– ESVs operation only in one satellite 36 MHz transponder.

Total number of vessel passes should be divided on two frequency bands (C and Ku). Because of the absence of such data it is assumed an equal division.

TABLE 20

Number of ship movements per day in the co-frequency conditions for the ESVs and FSR

	Calais (2012)	**Marseille (2012)**	**Dover (2012)**	**Channel (2013)**
ESVs operation in any place within the entire 500 MHz frequency band	1.6	1.0	1.2	2.6
ESVs operation only in one satellite 36 MHz transponder	22.8	13.4	14.8	36.8

For example in the C band (5 925-6 425 MHz), Recommendation ITU-R SF.1650-1 sets 3 vessel passes per day as a maximum in co-frequency sharing conditions (related to the fixed service receiver bandwidth of 11.2 MHz). In this case 3 vessel passes per day correspond to:

– 134 vessel passes per day working in any place within the entire 500 MHz frequency band; or

– 10 vessel passes per day working only in one satellite 36 MHz transponder of the C band.

For the Ku band (14-14.5 GHz) 3 vessel passes per day correspond to:

– 107 vessel passes per day working in any place within the entire 500 MHz frequency band; or

– 8 vessel passes per day working only in one satellite 36 MHz transponder of the Ku band (related to the fixed service receiver bandwidth of 14 MHz).

4.3 Results for C and Ku bands

The calculations are based on the methodology, using the propagation model described in Recommendation ITU-R P.452-14, and the iterative method for determining the minimum distance presented in Recommendation ITU-R SF.1650-1.

Parameters, presented in Annex 1 (Table A1) of this Report, are used for the calculation of the protection distances.

The calculations showed that the second scenario leads to greater protection distances and therefore protection distances presented in §§ 4.3.1 and 4.3.2 are based on the second scenario.

4.3.1 Results for the C-band

The results of calculation of protection distances for the FSR, shown below, are based on the statistics on maritime traffic for the Channel and for the Dover port (which is referred to in Recommendation ITU-R SF.1650-1).

For the discrimination angle 20 deg. of the ESV antenna (according to Recommendation ITU-R SF.1650-1) results for the protection distances D_{min} for FSR from ESVs radiation are presented in Table 21 for the C-band. Here the gradation on e.i.r.p. spectral density towards horizon is accepted as it is used in §3 of this Report.

TABLE 21[3]

Minimum protection distances from low-water mark for the FSRs (km) in co-frequency conditions of the ESVs and FSR. ESVs antenna height above sea level 40 m, for FSR 120 m. C-band

Maximum e.i.r.p. transmitted by ESVs towards the horizon (dBW/11.2 MHz)	Minimum distance Dmin from low-water mark, (km)
20.8	328
10.8	233
0.8	134
−9.2	57

4.3.2 Results for the Ku-band

Using the values of parameters of the ESVs, FSR, and the methodology described above, the minimum protection distances D_{min} for the FSRs are summarized in Table 22.

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[3] Lower e.i.r.p. density levels than limits stipulated in Resolution **902 (WRC-03)** may be achieved through spreading of the ESV transmitted carrier in bandwidths larger than 11.2 MHz for the C band and 14 MHz for the Ku band, in which case the probability of frequency overlap between the ESV transmission and the FSR will increase, with a corresponding effect on the protection distances. Quantification of that effect requires knowledge of the extent to which these cases will occur.

TABLE 22[3]

Minimum protection distances from low-water mark for the FSRs (km) in co-frequency conditions of the ESVs and FSR. ESVs antenna height above sea level 40 m, for FSR 80 m. Ku-band

Maximum e.i.r.p. transmitted by ESVs towards the horizon (dBW/14MHz)	**Minimum distance D_{min} from low-water mark, (km)**
16.3	125
6.3	97
−3.7	43

5 Summary of studies

This section presents the results of three studies conducted in response to WRC-15 agenda item 1.8.

Study 1 presents the results of calculations of the off-shore distances from the baseline for protection of the fixed services in the bands 5 925-6 425 MHz and 14-14.5 GHz for a new range of co-frequency vessel passes with 36° discrimination angle toward the horizon and technical ESV and FSR parameters as mentioned in Recommendation ITU-R SF.1650-1 and using the propagation models described in Recommendations ITU-R P.620-6 and ITU-R P.452-14, unless specified. The results of this study are detailed in § 2. Namely, the offshore distance for 6 GHz of 300 km to be increased to 345 km and the offshore distance for 14 GHz of 125 km should be retained as it is in current Resolution **902 (WRC-03)**.

Study 2 calculates revised off-shore distances from the baseline for protection of the fixed services using 4 different values of maximum ESV e.i.r.p. density transmitted toward the horizon in the frequency band 5 925-6 425 MHz, assuming the number of vessel passes twice as large as that implicitly assumed by WRC-03 and these e.i.r.p. density values cover the range used in ESV. The study also calculates revised off-shore distances from the baseline for protection of the fixed services assuming three different values of maximum ESV e.i.r.p. density transmitted toward the horizon in the frequency band 14-14.5 GHz and the same frequency of vessel passes as that implicitly assumed by WRC-03. In both cases the technical FSR parameters as mentioned in Recommendation ITU-R SF.1650-1 and the propagation model described in Recommendation ITU-R P.452-14 were used. The results of this study are detailed in section 3.

Study 3 calculates combinations of "minimum distance from ESVs/maximum e.i.r.p density toward the horizon" taking into account the statistical information on maritime traffic and the probability of frequency overlapping between ESV and FSR. In this study separation distances for FSRs are defined taking into account the probability of frequency overlapping for two scenarios:

1) ESV operation in any place within the entire 500 MHz frequency band in the C and Ku bands;
2) ESV operation only in one satellite 36 MHz transponder. In that case the probability of frequency overlapping between ESVs and FSRs is much higher.

The study showed that the second scenario led to greater protection distances and therefore resulted protection distances are based on the second scenario. The results of this study are detailed in § 4.

6 Issues that were not addressed in this Report

The band 5 925-6 425 MHz is extensively used by the fixed service in many countries for a variety of applications including the communication, control and operation of off-shore oil platforms at sea.

The results of the studies contained in this Report propose possible reduced protection distances applicable to low e.i.r.p. density ESVs referenced to the low-water mark of a country and hence do not take into account fixed service stations on off-shore platforms. It is noted that such stations can be hundreds of km out at sea from the low-water mark of the responsible country.

Some Administrations highlighted that the current distances established by Resolution **902 (WRC-03)** may allow the protection of the fixed service stations on off-shore platforms operating in the band mentioned above; this is true in particular in the North Sea.

Discussion was held with the aim of finding measures that would preserve the protection currently enjoyed by such stations. The Bureau clarified that the notification of an assignment to a terrestrial station situated in international waters on the oil platform is receivable by the BR. RR No. **8.3** stipulates that:

"*Any frequency assignment recorded in the Master Register with a favourable finding under No. **11.31** shall have the right to international recognition. For such an assignment, this right means that other administrations shall take it into account when making their own assignments, in order to avoid harmful interference. In addition, frequency assignments in frequency bands subject to coordination or to a plan shall have a status derived from the application of the procedures relating to the coordination or associated with the plan.*"

Some administrations highlighted that any regulatory action that a conference may take to amend the provisions contained in Resolution **902 (WRC-03)** should be subject to ensuring adequate measures are in place to protect fixed-service stations installed on off-shore platforms operating in the 5 925-6 425 MHz band.

7 Concerns of some administrations

1) During the preparation of this Report some views were expressed that if the harmful interference in the worst-case between the ESVs and the FS stations could be completely removed in all possible situations, it could be concluded that there would not be any interference on the other FS stations, but in this case all possible situations and the required conditions would have to be carefully analyzed to completely eliminate the harmful interference. Therefore, those holding these views concluded that in reply to WRC-15 agenda item 1.8 and Resolution **909 (WRC-12)**, it is required to define/establish worst-case conditions between the ESVs and FS stations which correspond more closely with the real operation of the stations.

2) Other views were expressed that the same methodology followed by WRC-03 leading to Resolution **902 (WRC-03)**, i.e. a review of possible interference based on acceptable rather than harmful interference, should be pursued in response to WRC-15 agenda item 1.8. Those holding these views developed their technical studies based on that premise.

3) It is worth mentioning that, in discussions dealing with ESV use of advance technologies such as spread spectrum technology, some administrations raised the following questions which they believe are still required to be clarified as appropriate before proceeding further or making any conclusions: How many ESVs operating with parameters in line with Recommendations ITU-R SF.1650-1 and ITU-R S.1587-2 are deployed today and how many are foreseen to be deployed in the future; how many ESVs with significantly reduced e.i.r.p. density (up to 20 dB) are operating today and how many are foreseen to be deployed in the future; what are the technical characteristics of the corresponding satellite networks with which these low e.i.r.p. density of ESVs are communicating; and what is the overall link performance and what is the service availability of such links; has any of these low e.i.r.p. density of ESVs been notified to the BR reflected in the BR publication; what were the conclusions of the BR; can statistics on the ESVs and their status be formally provided with

sufficient evidence; are these low e.i.r.p. density of ESVs understood to communicate with the corresponding space station within the typical characteristics contained in the coordinated satellite networks as recorded with the ITU-R; what is the status of an ESV operating under characteristics of a typical earth station (E/S) pertaining to a given satellite network if the E/S drastically reduces the e.i.r.p. density up to 20 dB compared to that of the typical E/S associated with the satellite network; could such a drastic e.i.r.p. density reduction make the ESV more sensitive to interference from other satellites than what was agreed during the coordination; and would this imply that such an ESV would accept the increased interference?

4) Some other administrations have the following views concerning the above questions:

As ESVs are not required to be notified and are not entitled to claim protection against interference, BR databases do not provide meaningful information about their numbers.

The level of protection received by ESV terminals is that level afforded indirectly by the coordination of the typical FSS earth stations filed for the respective satellite network. Lower RF *C*/*N* levels associated with reduced levels of e.i.r.p. density are associated with appropriate types of modulation and coding in order to ensure the required quality of service. Additionally, it is not unusual to find in satellite filings differences between maximum and minimum power levels as high as 30 dB for the same frequency assignment.

In several parts in the studies in the above sections, references are made to technical characteristics of ESVs communicating with FSS satellites in the C and Ku bands. In this connection, it is worth mentioning that most of these references are related to ESV Systems 4 and 5 (for Ku and C band, respectively) of Recommendation ITU-R S.1587-2 in which the antenna diameters are 60 cm and 1.2 m, respectively, whereas other ESV systems contained in the above mentioned Recommendation use antenna diameters of 2.4 m and 1.2 m for C and Ku bands, respectively.

In view of the above, ESV Systems 4 and 5 in Recommendation ITU-R S.1587-2 are not representative of all ESV systems used in the current studies. However, some administrations are of the view that, although it is recognized that ESV Systems 4 and 5 in Recommendation ITU-R S.1587-2 are not representative of all ESV systems used in the studies undertaken in response to this agenda item, the regulatory solutions proposed in response to this agenda item are not exclusive to these systems, but cover all types of EVS systems described in that Recommendation.

5) Some administrations, in discussing studies dealing with reduction of protection distances as result of use of advance technologies such as spread spectrum technology and use of dynamic power density control of the ESV, raised the following questions:

1 How the terrestrial administrations should react on the need for coordination without precise knowledge that which ESV operates on what e.i.r.p. density and what antenna elevation angle?

2 Moreover, even if that administration has received information on the exact e.i.r.p. density and exact antenna elevation angle, how that administration should be ensured that such announced e.i.r.p. density and antenna elevation angle would be respected during the actual operation of the ESV?

3 How the terrestrial administrations should react in regard with the coordination requirement of the ESV with respect to its terrestrial services of numerous ESV each with different e.i.r.p. density and eventually different antenna elevation angles?

4 How the terrestrial administrations should react in regard with the required off-shore distance arising from the cumulative effects of a) different earth stations mounted on a

given board vessels and b) the cumulative effects of different earth stations mounted on a given board vessels and different earth stations mounted on other board vessels?

5 How the terrestrial administrations should react on the required off-shore distance arising from the pass of different ESVs consisting of a) a ship having either one or several earth stations on its board with different e.i.r.p. density and different eventual antenna elevation angles and b) various ships each having either one or several earth stations with different e.i.r.p. density and different angles on each day?

6 How the terrestrial administrations should react on circumstances in which some ESVs continue to operate under the current environment as prescribed in Resolution **902 (WRC-03)** and some other ESVs operate under the new operational environment (different e.i.r.p. density and different eventual antenna elevation angle as outlined above)?

7 The burden, compared to the current single distance requirement, on that terrestrial administration, in particular those of developing and least developed countries, to take into account the variety of cases mentioned above to ensure that its terrestrial services are duly protected.

8 The issue of reduction of e.i.r.p. density of the ESV resulting from advances in technology, is an interesting issue which should not be limited and deployed for ESV only. On the contrary, it should be deployed and/or used for all FSS earth stations. In fact, if such advance in technology is available and used in all type of FSS earth stations, this could contribute to the efficient rational economical use of the orbital spectrum resources as highlighted in Article 44 of the Constitution.

In view of the above, ITU-R needs first to examine the applicability and implementation of advance technology, such as use of spread spectrum and use of lower e.i.r.p. density mentioned in some studies under WRC-15 agenda item 1.8, in the orbit spectrum utilization in other space services, if such technique is practical, valid and implementable in these other services. No information is yet officially available on such use. Consequently, any claim that this technique is only available for ESV seems to undermine the fact and reality in saying that such technique in only available to ESV and not to other services.

9 Based on the studies for different off-shore distances using different maximum e.i.r.p. densities, the question is how the terrestrial administration measures or monitors the e.i.r.p. density of each ESV terminal?

10 As mentioned in § 6, the studies in this Report are based on establishing reduced protection distances applicable to ESVs when referenced to the low water mark of a country and hence do not take into account fixed service stations on off-shore platforms. These stations on off-shore platforms can be 100s km out in the sea from the low water mark of the concerned country.

6) However, some other administrations are of the view that:

The answer to question 1 above lies on the fact that Resolution **902 (WRC-03)** already requires the ESV licensing administration and service providers to ensure that the operational provisions and technical limitations of the Resolution are met. If coordination is needed, the information required to conduct the coordination process, such as precise e.i.r.p. density and elevation angle, will be provided by the administration licensing the ESV, in accordance with *encourages concerned administrations* in Resolution **902 (WRC-03)**;

The answer to question 2 above lies on the fact that, in accordance with items 1 and 2 of Annex 1 of Resolution **902 (WRC-03)**, enforcement of the provisions and technical limitations, including conditions agreed during coordination, are to be ensured by the ESV licensing administration and ESV service providers;

The answer to question 3 above lies on the fact that the methodology used in the derivation of the protection distances takes into account multiple passes of ESVs transmitting the maximum allowed e.i.r.p. density toward the horizon, and therefore the derived protection for terrestrial services cater for the aggregate effect of multiple worst-case transmitting ESVs. ESVs operating with power levels and elevation angles such that the e.i.r.p. density toward the coast is smaller than the maximum value assumed in the derivation of protection distances can only improve the interference scenario;

The answer to question 4 above lies on the fact that the derivation of protection distances was made for the 6 and 14 GHz independently, which does not prevent the same vessel from being equipped with terminals operating in both frequency bands. As to multiple ESVs operating on the same vessel in the same frequency band, this situation would only arise if the service provider used several different satellite networks for service to the same vessel, which is highly unlikely for this type of service. The issue of aggregation of interference from multiple ESVs was addressed in the paragraph above;

The answer to question 5 above lies on the fact that the regulatory regime applies to the operation of individual ESVs and not to the vessels. Consequently, each ESV is or is not allowed to operate in accordance with the terms of Resolution **902 (WRC-03)** and with the terms of agreements reached between the ESV licensing administration/service providers and the potentially affected administrations;

Question 6 above can be addressed in a new version of Resolution **902**;

The answer to question 7 above lies on the fact that, once ESVs operating with e.i.r.p. density levels lower than the maximum levels currently prescribed by Resolution **902 (WRC-03)** are allowed to come closer to the coast before they need to coordinate, the total number of requests to coordinate will necessarily be smaller than it would be the case if all ESVs, regardless of their potential to cause interference, were required to coordinate if they were to operate within the current protection distances. Consequently, the proposed new regulatory regime can only decrease the administrative burden of administrations; and

The answer to question 9 above lies on the fact that it should be up to the licensing administration to ensure that the ESVs under its responsibility conform to the international regulations and implement mechanisms to avoid their infringement. Monitoring of ESV transmitted power levels should not be required of administrations in whose territory terrestrial facilities are deployed just as no requirement exists for potentially affected administrations to monitor the transmit power levels filed for earth stations or agreed as a result of intersystem coordination of potentially affecting satellite networks.

7) Some administrations note that Study 1 assumes an increase in the number of vessel passes, but no data supporting this assumption have been submitted to ITU-R. Annexes 2 and 3 of this Report show that for certain regions, this assumption does not objectively reflect the current situation.

Annex 1

Path loss calculations

Parameters for path loss calculations based on Recommendation ITU-R P.452-14

The path loss calculation results based on Recommendation ITU-R P.452-14 for 6 GHz and 14 GHz bands are shown in order to provide the overview of relationship between the distances from shore and the propagation losses for various time percentages.

Table A1 shows the parameters for the calculation. Figures A1 and A2 show the calculation results for 6 GHz and 14 GHz band respectively. The parameter *p* in these Figures indicates the time percentage on which the given propagation loss is not exceeded by the calculation based on Recommendation ITU-R P.452-14.

TABLE A1

Parameters used for the calculations

Parameter	6 GHz band	14 GHz band	Note
Frequency	6.00 GHz	14.25 GHz	
ESV antenna height	40 m	40 m	
FSR antenna height	120 m	80 m	
Propagation model	Rec. ITU-R P.452-14	Rec. ITU-R P.452-14	
Average radio refractive index lapse rate (ΔN)	50 NU/km	50 NU/km	See Figure 11/12 of Rec. ITU-R P.452-14
Latitude of FSR station	45 N	45 N	
Difference between the coast and FSR station	0 km	0 km	
Pressure	1 013 hPa	1 013 hPa	To be used in the calculation based on Rec. ITU-R P.676-9
Temperature	15ºC	15ºC	Ditto
Sea-level surface refractivity (N_0)	300	300	See Figure 13 of Rec. ITU-R P.452-14

FIGURE A1

Path loss calculation for 6 GHz band

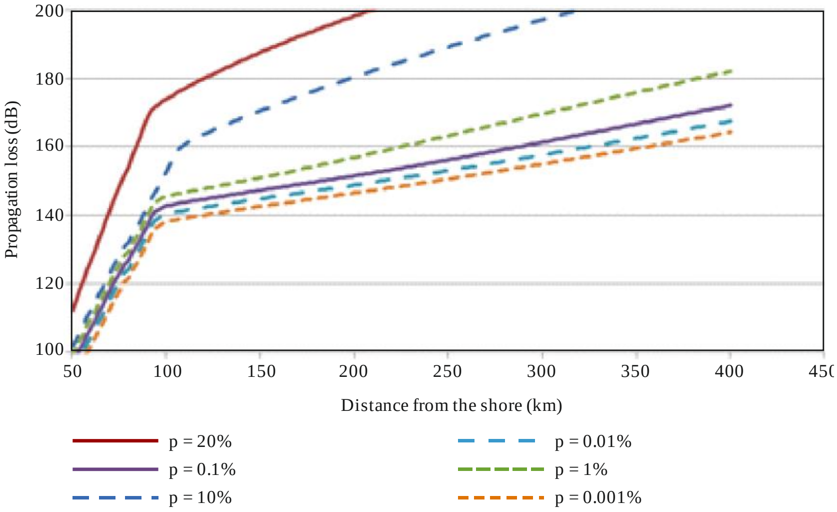

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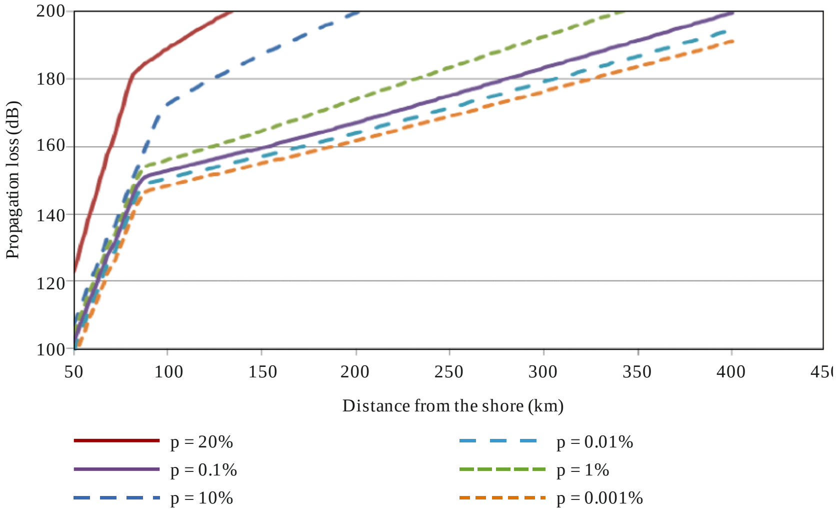
FIGURE A2

Path loss calculation for 14 GHz band



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Annex 2

Port call statistics

This Annex contains the annual number of port calls for some of the largest ports in the world, including those of the port of Dover, based on publicly available data.

Inspection of the results shows that there seems to be no grounds to assume that the number of passes of ships has considerably increased since 1999, the year of reference used by WRC-03 in its deliberations resulting in the adoption of Resolution **902 (WRC-03)**. In fact, for several ports this number has actually reduced with respect to the 1999 levels.

The charts and the associated source of information are provided below.

FIGURE A3

Calls at the Port of Portsmouth, according to Portsmouth Commercial Port – Port Statistics

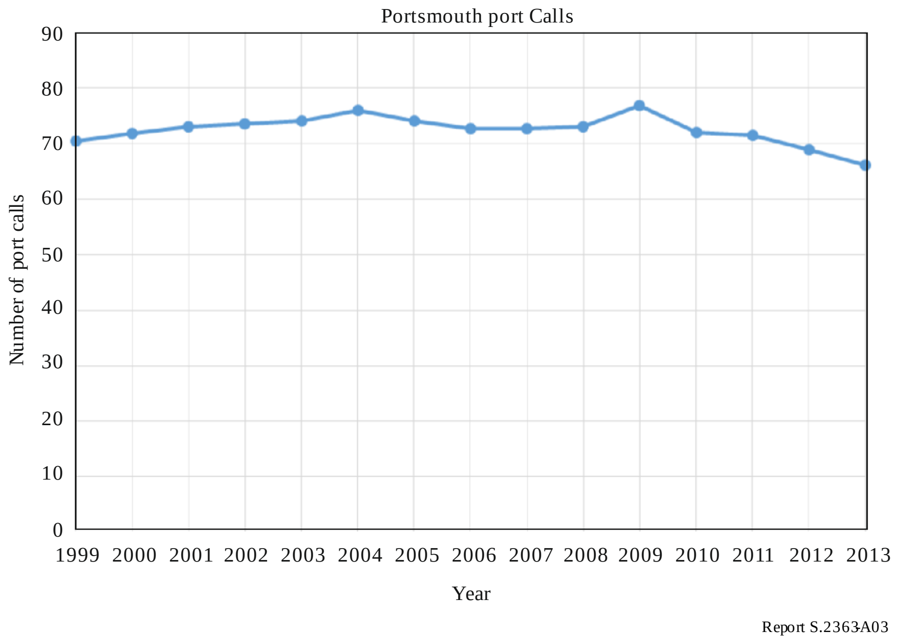


FIGURE A4

Calls at the Port of Dover, according to Port of Dover – Annual Report and Accounts

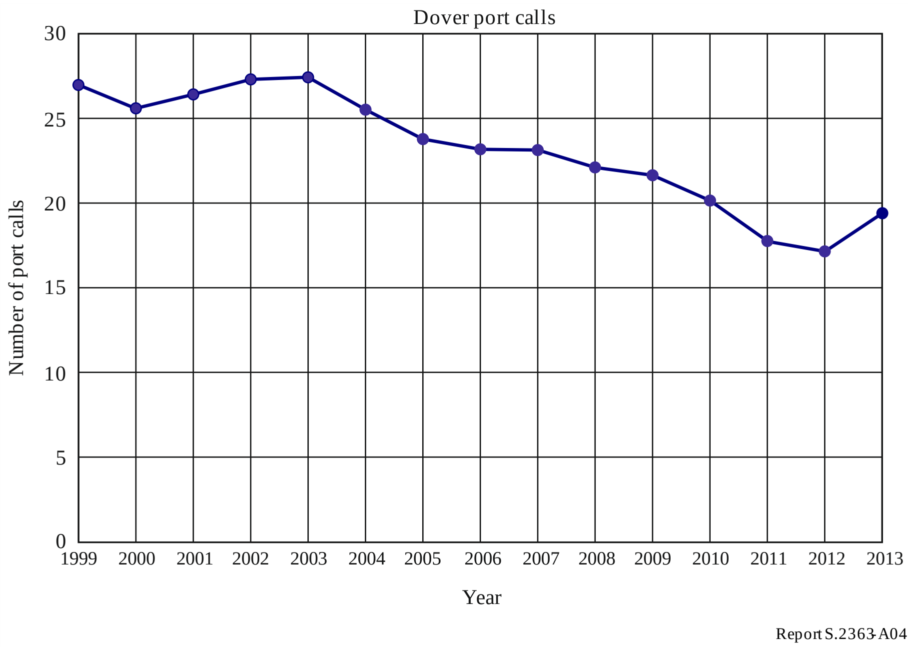


FIGURE A5

Calls at the Port of Singapore, according to Port of Singapore - Ferry Statistics

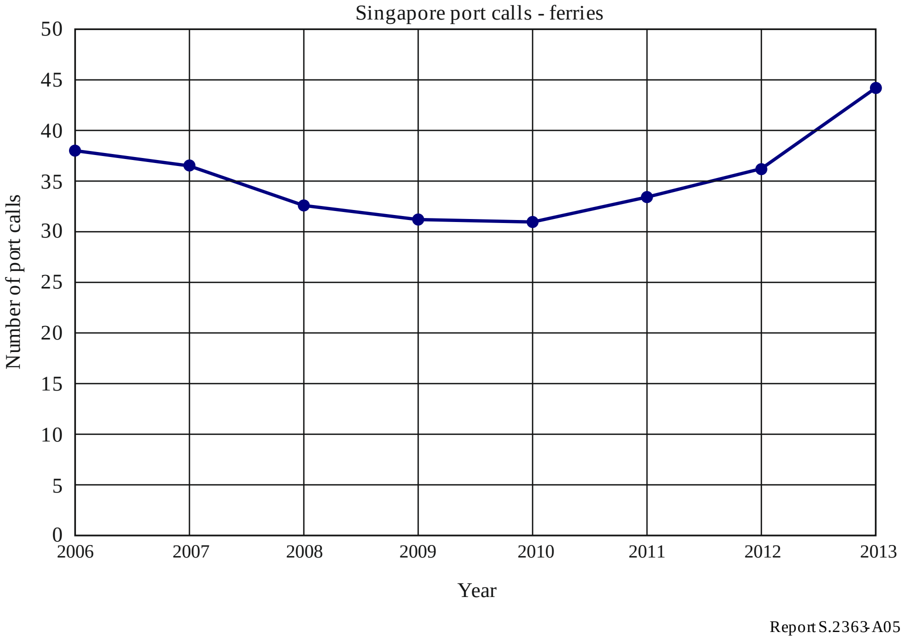


FIGURE A6

Calls at the Port of Hong Kong - Ocean Vessels (Ferries and Cruise) Statistics

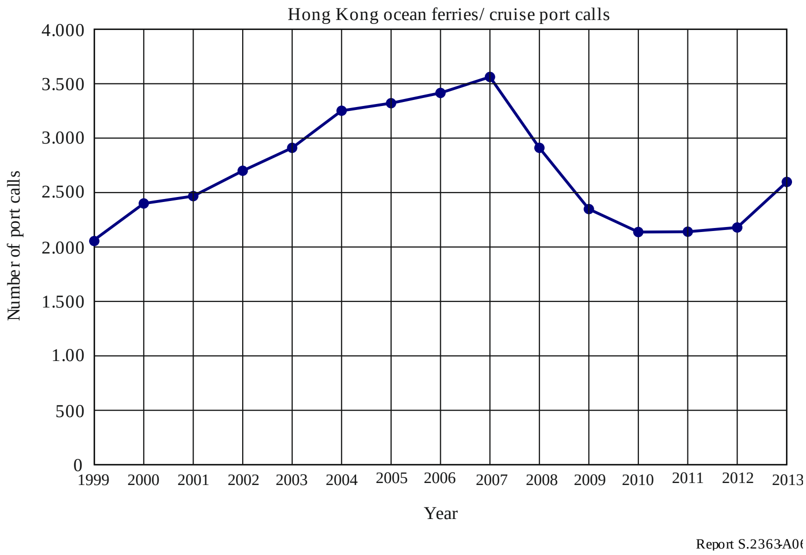


FIGURE A7

Calls at the Port of Tokyo - Tokyo Statistical Yearbook

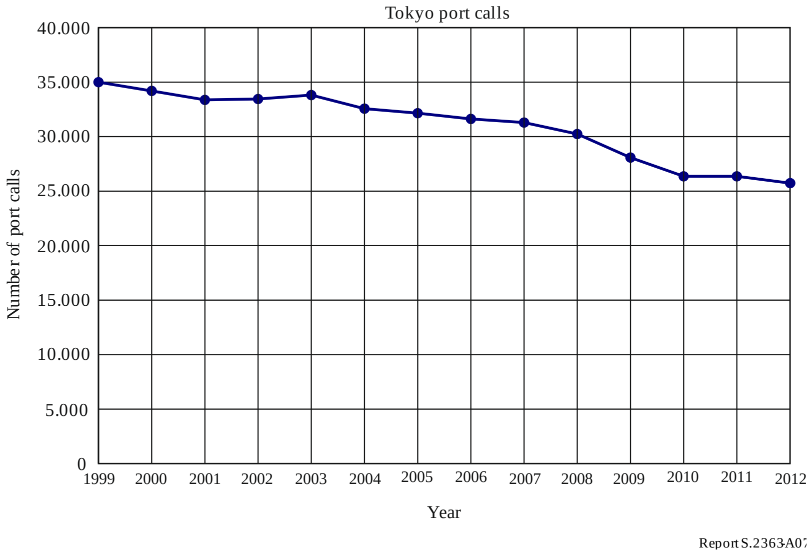


FIGURE A8

Calls at the Port of Los Angeles – Port of Los Angeles Cruise Passenger Statistics

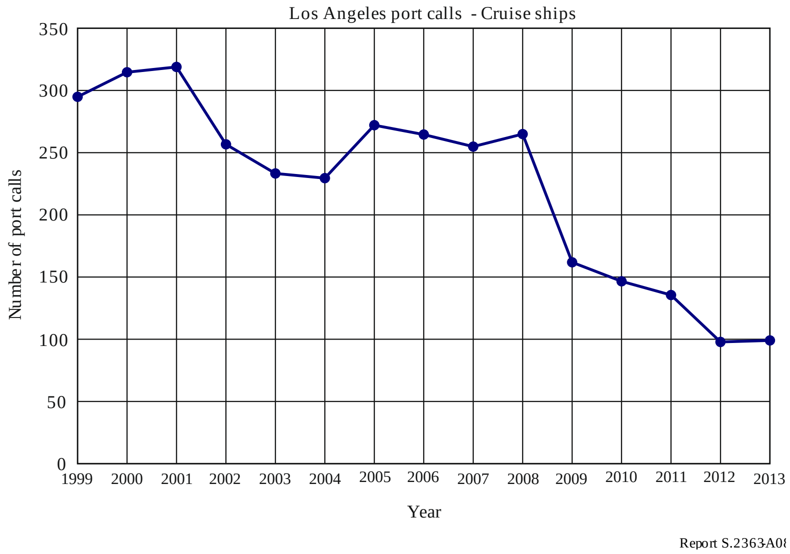


FIGURE A9

Calls at the Port of Los Angeles – US Maritime Administration

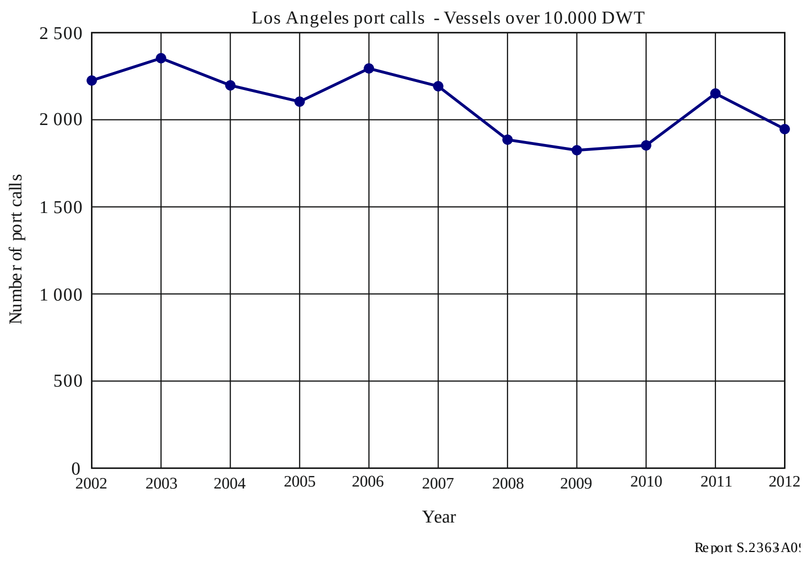


FIGURE A10

Calls at the Port of New York/New Jersey – US Maritime Administration

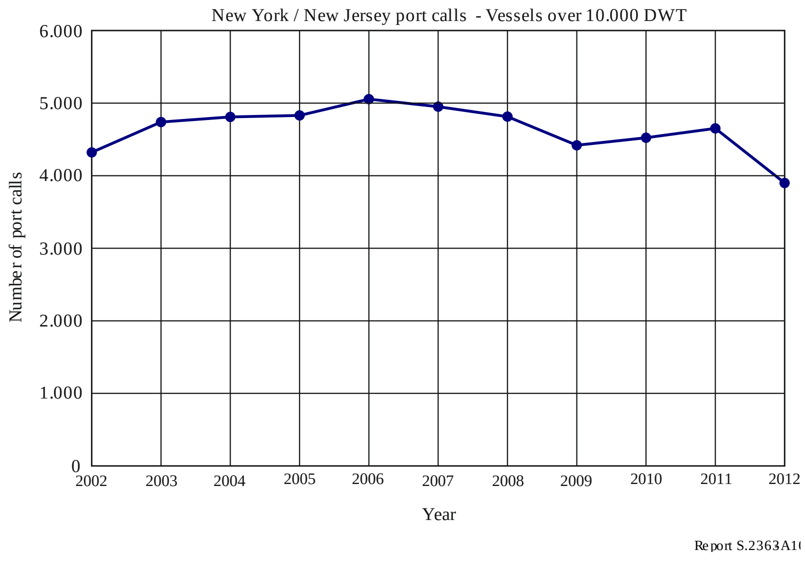


FIGURE A11

Calls at the Port of Miami – US Maritime Administration

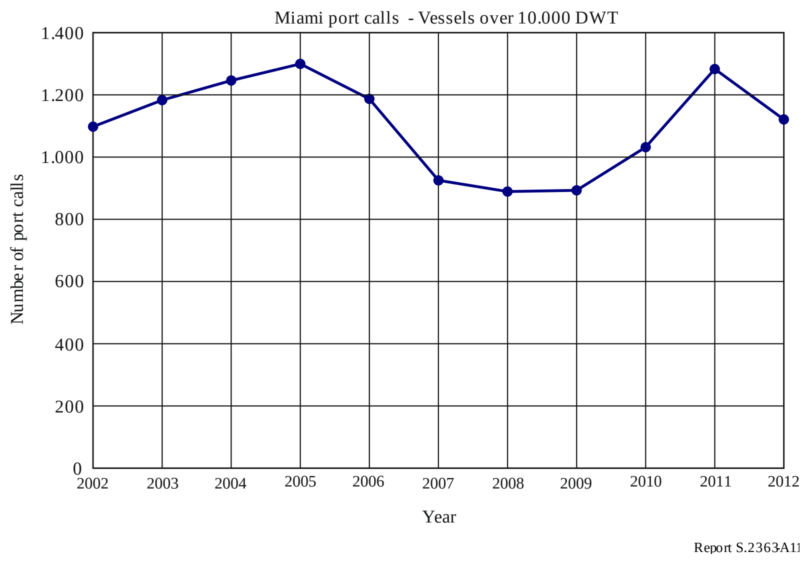
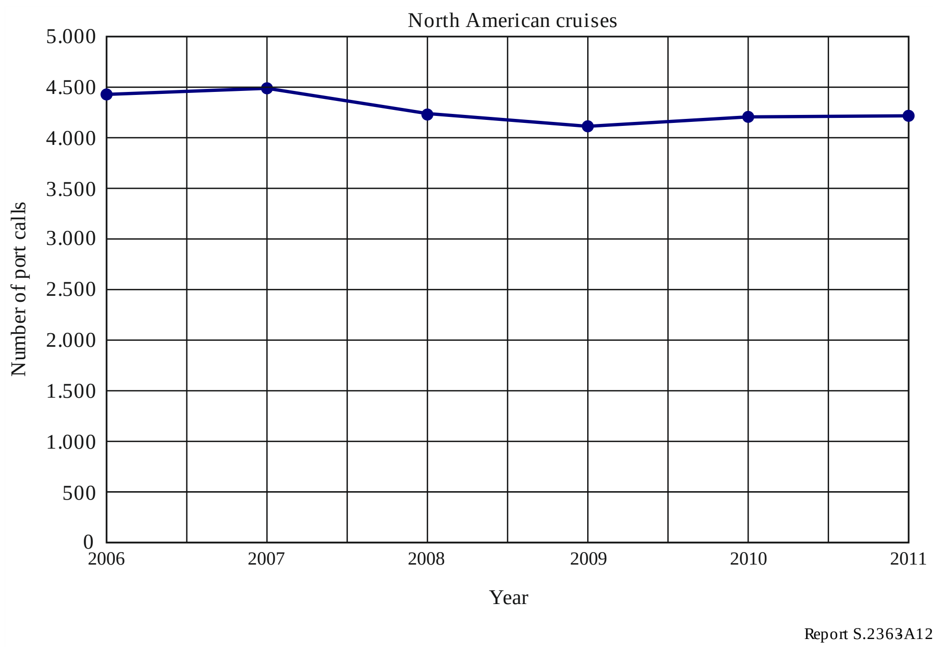


FIGURE A12

North American Cruises – US DoT North American Cruise Statistical Snapshot, 2011



Annex 3

Considerations about scenario to be used in the studies

1 Introduction

For the C band (5 925-6 425 MHz), Recommendation ITU-R SF.1650-1 sets three vessel passes per day as a maximum in co-frequency sharing conditions (to be related to a fixed service receiver bandwidth of 11.2 MHz).

For the Ku band (14-14.5 GHz), this Recommendation sets 6 vessel passes per day as a maximum in co-frequency sharing conditions (to be related to a fixed service receiver bandwidth of 14 MHz).

This section provides updated information on maritime traffic for one of the most crowded maritime area of the world, which is necessary to assess the consistency of the scenario considered in Recommendation ITU-R SF.1650-1 with regard to the current situation.

2 Statistical information in maritime traffic

2.1 Ship movements in French ports

Tables A2 and A3 present the total number of ship movements (arrival + departure) in major French ports.

TABLE A2

Total number of ship movements (arrival + departure) in 24 major French ports (3 of which are located overseas)

2012	2011	2010	2009	2008	2003
111 554	116 668	126 468	128 563	134 975	157 207

These figures show that the total number of vessel passes in French ports is decreasing.

Such a trend may be confirmed for Dover port which has been referred to as the reference in Recommendation ITU-R SF.1650-1 (§ 3.6), by the 2013 annual report of the Dover port: (http://www.doverport.co.uk/downloads/FINAL%20-%20HRO%20Drawing%20Sheet%2001.pdf) (see Appendix).

TABLE A3

Total number of ship movements (arrival + departure) in two major France ports

	2012	2011	2010	2009	2008	2003
Calais	26 521	27 661	30 370	33 236	34 210	49 260
Marseille	15 669	15 957	16 308	16 909	17 379	19 282

It can be seen that, for the port of Calais, 26 521 movements are reported for the year 2012, i.e. an average of 72 passes per day.

Assuming that every ship embarks an ESV and a fixed service receiver of 11.2 MHz in 500 MHz, this leads to 1.6 passes per day in co-frequency conditions for the C band.

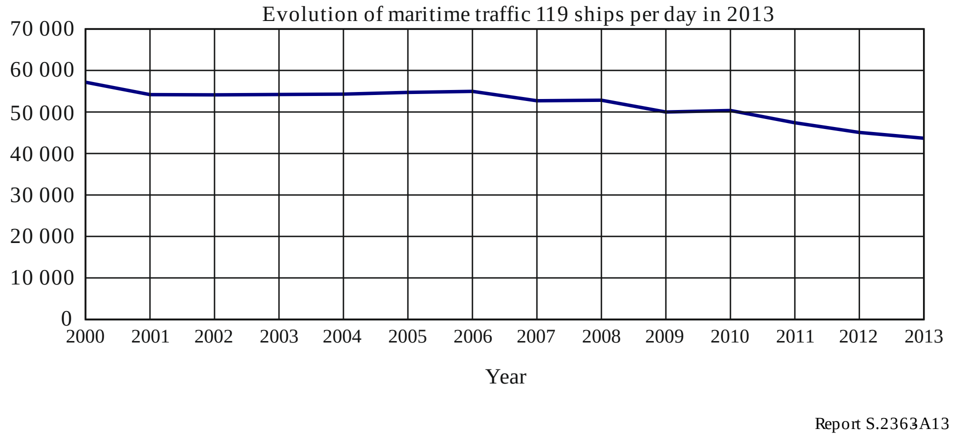
Assuming that every ship embarks an ESV and a fixed service receiver of 14 MHz in 500 MHz, this leads to 2 passes per day in co-frequency conditions for the Ku band.

2.2 Maritime traffic in the Channel

Figure A13 depicts the evolution of maritime traffic in the Channel as reported by the French Maritime Rescue Coordination Centre (Corsen MRCC – Ushant Traffic separation scheme).

FIGURE A13

Evolution of maritime traffic in the Channel



It can be seen that 119 movements per day are reported for the year 2013.

Assuming that every ship embarks an ESV and a fixed service receiver of 11.2 MHz in 500 MHz, this leads to 2.6 passes per day in co-frequency conditions for the C band.

Assuming that every ship embarks an ESV and a fixed service receiver of 14 MHz in 500 MHz, this leads to 3.3 passes per day in co-frequency conditions for the Ku band.

3 Conclusion

Studies contained in Recommendation ITU-R SF.1650-1 had anticipated a potential increase in terms of co-frequency vessels passes.

The above information does not however confirm this trend and enables to consider that the deployment scenarios that were assumed by WRC-03 when establishing the protection environment for the fixed service are still valid today and that only a reduction in antenna size should lead to an increase in number of passes to be considered in the studies.

Traffic statistics of Dover Port
Extract from "Annual report & Accounts 2013"

Summary of Ten Year Traffic Statistics

	Passengers	Coaches	Other tourist vehicles	Commercial road haulage vehicles	Vessels entering the Port
2013	13,004,077	90,478	2,471,193	2,206,728	19,441
2012	12,129,491	84,246	2,400,471	1,952,138	17,202
2011	12,988,524	84,938	2,653,127	2,069,945	17,772
2010	13,461,861	86,035	2,818,380	2,091,516	20,198
2009	13,349,531	81,209	2,775,174	2,300,468	21,649
2008	14,166,935	97,851	2,830,238	2,307,821	22,118
2007	14,497,712	105,338	2,837,559	2,363,583	23,148
2006	14,011,722	105,774	2,647,060	2,324,598	23,207
2005	13,508,055	107,541	2,554,772	2,045,867	23,774
2004	14,512,510	128,464	2,506,667	1,980,662	25,532