RECOMMENDATION ITU-R SF.1649

Guidance for determination of interference from earth stations on board vessels to stations in the fixed service when the earth station on board vessels is within the minimum distance*,**

(Questions ITU-R 226/9 and ITU-R 254/4)

(2003)

The ITU Radiocommunication Assembly,

considering

a) that Resolution 82 (WRC-2000) calling for ITU-R to urgently complete its studies related to earth stations on board vessels (ESVs), in particular not to have the potential to cause unacceptable interference to stations of other services of any administration;

b) that vessels may be equipped to operate FSS ESVs which transmit in the FSS networks in the 5 925-6 425 MHz band (Earth-to-space) under No. 4.4 of the Radio Regulations (RR);

c) that vessels may be equipped to operate as ESVs in the 14-14.5 GHz band under RR No. 4.4 or as secondary service in the MSS;

d) that some of the bands in *considering* b) and c) are shared on a co-primary basis with the fixed service (FS);

e) that if ESVs were to be permitted to operate in sea-lanes and channels near to shore it would be necessary to define composite areas for these operations;

f) that Recommendation ITU-R SF.1585 provides a way to define such an area;

g) that stations in the FS within such an area must be examined to determine whether they will experience more than a permissible amount of interference;

h) that many FS digital systems operate under automatic transmit power control (ATPC);

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* For the definition of "minimum distance", see Recommendation ITU-R SF.1650.

** The Administrations of Saudi Arabia, Djibouti, Egypt, United Arab Emirates, Jordan, Kuwait, Morocco, Mauritania, Syrian Arab Republic, Tunisia and Yemen objected to the approval of the Recommendation for the reasons which can be found in the RA-03 Report to WRC-03.

The Administrations of Germany, Australia, Canada, United States and Israel reserve their opinion on this Recommendation for the reasons which can be found in the RA-03 Report to WRC-03.

The Administrations of Gabon and Senegal reserve their opinion on this Recommendation.

j) that interference events of more than a few seconds can result in significant long-term outages in digital FS systems;

k) that Recommendations ITU-R SF.1006 and/or ITU-R SM.1448 provide methods that could be used for the determination of interference potential between stations in the FSS and stations in the FS when the ESVs are stationary (see Note 1);

l) that the methodology for determining the level of interference from ESVs to FS stations is a matter for agreement between the administrations concerned;

m) that guidance to administrations on the detailed determination of these levels for performing a preliminary analysis may nonetheless be of value to some in the detailed assessment of interference;

n) that Recommendations ITU-R F.696 and ITU-R F.1565 define permissible interference criteria for stations in the FS;

o) that different methods and interference criteria are needed to determine the interference potential from ESVs when these are not fixed,

recommends

1 that the guidance described in Annex 1 may be used as a framework for the overall assessment of interference from ESVs operating within the "minimum distance" to stations in the FS;

2 that the guidance in Annex 2 may be used as the basis for the calculation of interference from ESVs (see Note 2 and Note 3);

3 that results of the application of the method in Annex 2 can be used to determine whether portions of the frequency bands in *considering* b) may be considered for use by ESVs when operating within the "minimum distance" (see Note 3).

NOTE 1 – The methods given in this Recommendation make use of FS interference protection criteria. As an example, Recommendation ITU-R SF.1006 provides such criteria but the short-term criteria may only be compliant with ITU-T Recommendation G.821. On the other hand, Recommendation ITU-R SF.1650 provides FS short-term protection criteria for up-to-date links designed to meet the requirements of ITU-T Recommendations G.826 and G.828.

NOTE 2 – When identifying frequencies for ESVs, mitigation techniques may need to be considered. For example, in the case where the FS frequency arrangements are based on Recommendation ITU-R F.383, the use of the 6 GHz FS central band (close to 6.175 GHz) by the ESV transmitters can significantly reduce the potential interference to the FS receivers since, when considering interference to any FS channel, there would be benefit from receiver filtering.

NOTE 3 – The method in Annex 2 may be supplemented by the use of the method in Annex 3.

Annex 1

Guidance for identifying and using points on the operating contour* for the determination of interference from emissions from an ESV in motion to a station in the fixed service (critical contour point method)

The following method may be used as a framework for the overall assessment of interference from ESVs operating within the minimum distance to stations in the FS.

1 Introduction

The method for assessing interference potential between a station in the FSS and a station in the FS is provided in Recommendation ITU-R SF.1006, which assumes that the FSS and the FS stations have a fixed spatial relationship. ESVs moving into a port or harbour to a dock or anchorage have a variable relationship with FS stations while in motion.

Recommendation ITU-R SF.1585 describes a method for using the operating contour of ESV-equipped vessels to determine an area which can be used in identifying the FS stations that could experience unacceptable interference from an ESV as it is travelling along this contour. Under existing procedures, the potential for such interference would need to be evaluated as if it were stationary at each possible point along a vessel's route whenever it is within this area.

This Annex provides a methodology called the critical contour point method which simplifies the determination of interference potential to FS stations to consideration of a small set of points on the operating contour. Each of these points is designated as a critical contour point (CCP). Some of these points are specific to the operating contour, whereas others are specific to the particular FS station.

2 Considerations in determining the CCP

2.1 Stationary operation

For stationary operation of an ESV, the potential for interference can be assessed using Recommendation ITU-R SF.1006 or ITU-R SM.1448 or by any procedures agreed between the administrations involved as they would be applied to any new FSS station.

2.2 In-motion operation

Each FS station within an area (for example, as described in Recommendation ITU-R SF.1585) must be examined to determine whether it will experience more than a permissible amount of interference. This would normally require assessment of the interference potential with respect to each FS station at each point along the route of an ESV-equipped vessel in motion within the

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* The operating contour is defined in Recommendation ITU-R SF.1585.

operating contour. However, the CCP methodology offers an approach to reducing such computational requirements by identifying a small number of points for each FS receiver within a certain area.

2.2.1 Identification of the CCP for each potentially-affected FS receiver

For any interference exposure of a particular FS receiver from an ESV terminal on a moving ship, there are three position-related variables in the calculation:

– propagation loss exceeded for all but a percentage of time. This loss depends on the length of the interference path, the Radio-Climatic Zones and may include the effects of any blockage that may exist on the interference path;

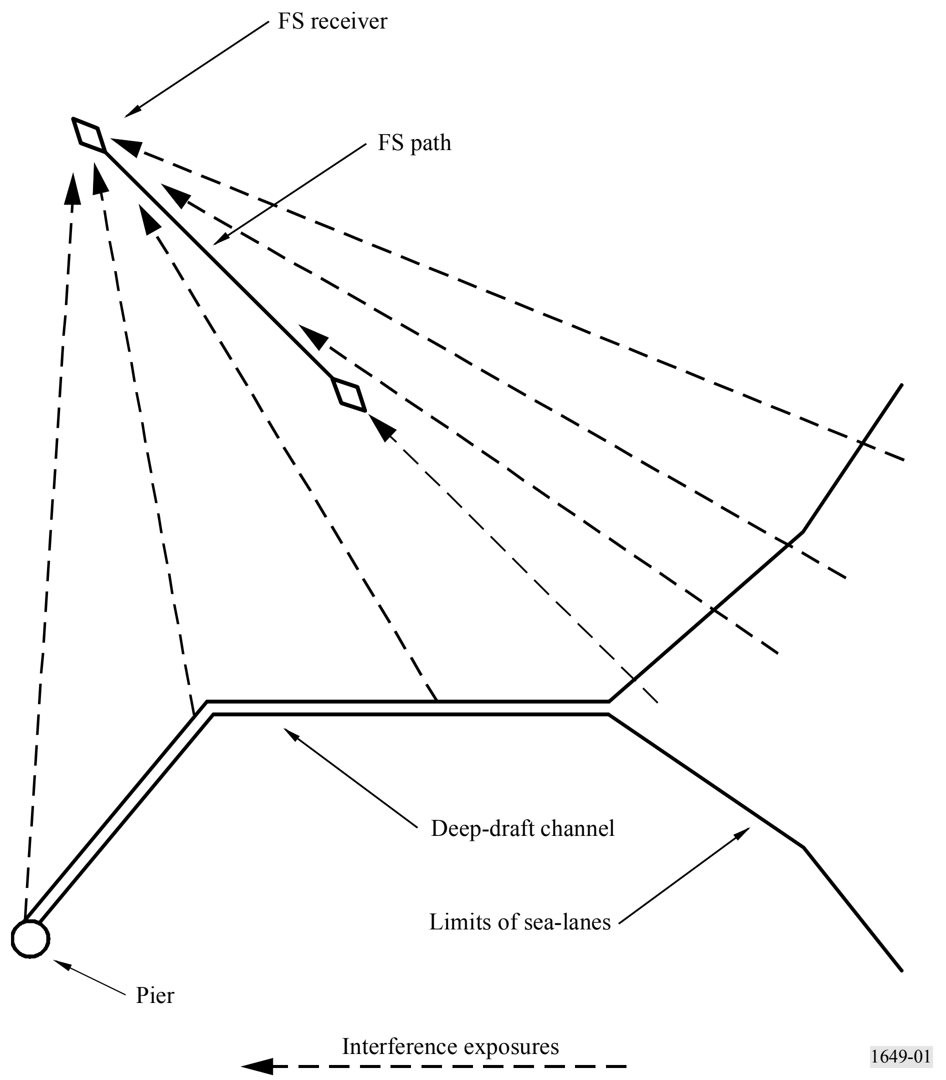
– FS receiver antenna gain; and

– ESV antenna horizon gain.

For every point within the operating contour as defined by the deep-draft channel (see Fig. 1), each of these three factors can be readily determined.

FIGURE 1

Basic interference geometry



For the purpose of evaluating the potential interference the operating contour is approximated by a set of straight-line segments. The identification of the CCPs depends on the position and alignment of the FS path with respect to the operating contour, and several cases need to be distinguished. In those cases where the azimuth of the main beam axis of the FS antenna does not intersect with any portion of the operating area of the ESV, the critical contour points are the points along the operating contour where the contour changes direction or reaches the off-shore limit beyond which coordination is not required. In those cases where the azimuth of the main beam axis of the FS antenna intersects the operating contour it is necessary to augment and/or modify the number of CCPs. In any event, the same CCPs should be used to consider both the long-term and the short-term interference to any FS station under consideration. Interference from in-motion ESV operations to any FS receiver within the area where the potential interference from the ESV needs to be evaluated is assessed by consideration of the operation at each of the CCPs for each receiver using propagation loss models such as those given in Recommendation ITU-R P.452. The goal of this assessment is the identification of frequencies that can be used for in-motion ESV operations without causing unacceptable levels of interference to FS stations.

For the identification of the CCPs with respect to a specific FS receiver, the following three cases need to be distinguished:

Case 1: In this case the main beam axis of the FS receiving antenna does not intersect any portion of the operating contour. The only CCPs required for this case are the points where the operating contour of the ESV changes direction.

Case 2: In this case, the main beam of the FS antenna (within 10 dB of the maximum antenna gain) lies entirely within one segment of the operating contour. The points on the operating contour where the antenna gain is 10 dB below the maximum, determine two additional CCPs. The segment of the operating contour between these two CCPs contains the natural intersection point (NIP), the point where the main beam axis of the FS antenna intersects the operating contour. The NIP is always taken as a CCP.

Case 3: In this case, the NIP is close enough to one of the points where the operating contour changes direction that the main beam of the FS antenna extends over more than one segment of the operating contour. This case is most likely to arise when the NIP is close to one of the points where the operating contour of the ESV changes direction. The intersection of the operating contour with the antenna 10 dB points determine two additional CCPs as in Case 2; however, in this case the original point within the main beam does not need to be considered as a CCP.

A further possibility: If there is a point on the operating contour of an ESV from which the maximum horizon gain of the ESV antenna is directed toward a FS receiver, that point on the contour may be identified as an additional CCP for that FS receiver regardless of which of the three cases applies.

2.2.2 Consideration of long-term interference

The long-term interference is determined by an aggregation of the interference power from each segment of the operating contour from the pier to the end of the operating contour beyond which coordination is not necessary. That is, from in a summation of the contributions resulting from operation between each of the successive CCPs with respect to an FS receiving station. The procedure as elaborated in Annex 2 uses the principle of fractional degradation of performance (FDP) from Recommendation ITU-R F.1108. The only difference is that the propagation loss needed for the calculation is the propagation loss from each CCP that is exceeded for all but 20% of the time. The contribution to the FDP from each segment may be calculated in closed form based on the average interference power received due to ESV operation within the segment, including the effect of the duration of time spent in the segment in multiple passes of ESVs. For a segment that does not contain an NIP this average is computed by assuming that the sum of the gain (dB) of the FS and the ESV antennas varies linearly over the segment. The average over a segment containing an NIP is determined based on a Gaussian-shaped main beam of the FS antenna as in Recommendation ITU-R F.1245.

The criterion that is applied to this interference is the power level taken for long-term interference in Recommendation ITU-R SF.1006 or ITU-R F.758.

2.2.3 Consideration of short-term interference

The acceptability of short-term interference may be determined by considering whether the interference power due to operations near any CCP exceeds the value specified by the short-term criterion for more than an acceptable percentage of time, p_{ST}. The short-term interference criteria used in Recommendation ITU-R SF.1650 for the 6 and 14 GHz bands may be used for this purpose.

The determination of the short-term interference power due to ESV operation near a CCP depends on the propagation loss on the path from that CCP. In particular, it depends on the propagation loss exceeded for all but a small percentage of time, a percentage that is inversely proportional to the percentage of time, p_{ESVi}, associated with the ESV operation near that CCP. This approach, described in detail in Annex 2, is similar to that used in Recommendation ITU-R SF.1485, or in § 2.2.2 of Annex 1 to Recommendation ITU-R SM.1448. The percentage of time associated with ESV operation near a CCP depends on which situation applies of those that can occur under the three cases described above in § 2.2.1.

In cases where the main beam axis of the FS has a natural intersection point on the operating contour of the ESV, the percentage of time, p_{ESVi}, associated with the ESV operation near that NIP is directly related to the time it takes for an ESV to move along the operating contour between the two 10 dB points of the FS antenna.

Except for the CCPs that are adjacent to an NIP, which are treated as end points of the operating contour, the percentage of time p_{ESVi} depends on the time it takes the ESV to move from the mid-point of the preceding segment of the operating contour to the mid-point of the following segment of the contour. Where the CCP is an end-point of the operating contour, one of these segments does not exist and its contribution is set to zero.

There is also a possibility that more complex situations can occur, but these can be addressed using an approach similar to the one suggested here.

3 Application of CCP methodology in identifying available spectrum

The spectrum available for ESV terminals on ships under way in or near ports can be determined using the CCP methodology to evaluate whether use of a particular frequency will result in more than a permissible amount of interference between the ESV and stations in the FS.

After the CCPs have been determined for an FS receiving station, Annex 2 may be used to determine whether both the long-term and short-term interference levels are acceptable. Those frequency ranges where ESV operation can be shown not to cause unacceptable interference to any FS receiver can then be assigned for use by ESVs that visit that particular port.

Annex 2

The calculation of interference from ESVs

1 Introduction

Resolution 82 (WRC-2000) is concerned with provisions for ESVs operating in the frequency bands 3 700-4 200 MHz and 5 925-6 425 MHz. Three new Recommendations were developed in WP 4-9S, two of these only require consideration of short-term interference criteria. These are Recommendation ITU-R SF.1650 which addresses the off-shore distance beyond which interference into the fixed service need not be considered and Recommendation ITU-R SF.1585, which addresses the determination of the area within which the interference potential of ESVs needs to be considered in instances where the possibility of operations within the off-shore distance are contemplated. The third, this Recommendation, addresses the determination of the potential of ESVs to interfere when operating within the offshore distance.

Annex 1 addresses the determination of points for the determination of potential interference from ESVs. Once this determination has been made, it is necessary to consider interference into stations beyond the radio horizon as well as interference into stations that have line-of-sight coupling to the operating positions of an ESV in motion. In the case of fixed transmitting earth stations, the interference into FS receivers beyond the horizon is limited by applying short-term interference criteria, and interference into receivers with line-of-sight coupling is limited by applying long-term interference criteria. Recommendation ITU-R SF.1006 provides the methodology and interference criteria for both long- and short-term interference assessment and recommends that both criteria be met in the determination of interference potential. While ESVs add complexity to the determination of interference potential, the principles remain the same: distant stations are protected from short-duration high-power interference by short-term criteria; nearby stations are protected by long-term criteria, which protect the fade margin of the receiver. This Annex provides the basis for determining the interference potential in all cases of interest.

Section 2 below describes the statistics of the propagation loss between two stations on the surface of the Earth, and shows, for different length paths, the relation between the loss exceeded for all but a percentage of the time and the long- and short-term interference criteria that are applied when the transmitting earth station is at a fixed location. Section 3 considers how to determine the interference potential in the presence of the additional complexity caused by introducing motion to the position of the interfering station and develops an approach derived from the use of the FDP approach of Recommendation ITU-R F.1108 in conjunction with the CCP methodology of Annex 1 to this Recommendation. It is shown in § 4 that this approach leads to a method for determining the acceptability of the potential interference based on existing long-term interference criteria. An approach to the consideration of short-term interference based on the same set of CCPs is developed in § 5.

2 Minimum required propagation loss for a fixed percentage of time with stationary stations

The minimum required propagation loss required to meet a permissible level of interference power at the antenna terminals of a receiving fixed station for a percentage of time, p, may be obtained with Recommendation ITU-R SM.1448, where the minimum required loss is the loss that needs to be equalled or exceeded by the predicted path loss for all but p% of the time[1]. Thus:

$$L_b(p) = P_t + G_t + G_r - P_r(p) \qquad \text{dB} \qquad (1)$$

where:

- p: maximum percentage of time for which the permissible interference power may be exceeded
- $L_b(p)$: propagation mode (1) minimum required loss (dB) for p% of the time; this value must be exceeded by the propagation mode (1) predicted path loss for all but p% of the time
- P_t: maximum available transmitting power level (dBW) in the reference bandwidth at the terminals of the antenna of a transmitting terrestrial station or earth station
- $P_r(p)$: permissible interference power of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than p% of the time at the terminals of the antenna of a receiving terrestrial station that may be subject to interference, where the interfering emission originates from a single source
- G_t: gain (dB relative to isotropic) of the antenna of the transmitting terrestrial station or earth station. For a transmitting earth station, this is the antenna gain towards the physical horizon on a given azimuth
- G_r: gain (dB relative to isotropic) of the receiving antenna of the terrestrial station or earth station that may be subject to interference. For a receiving terrestrial station, the maximum main beam axis antenna gain is to be used.

For long-term interference the percentage of time is usually taken as 20% and the permissible interference power is given, in accordance with Recommendation ITU-R SF.1006, as:

$$P_r(20) = 10 \log (k\, T_e\, B) + J \qquad \text{dBW} \qquad (2)$$

where:

- k: Boltzmann's constant, 1.38×10^{-23} J/K

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[1] When p is a small percentage of the time, in the range 0.001% to 1.0%, the interference is referred to as short term; if $p \geq 20$%, it is referred to as long term.

T_e: thermal noise temperature of the receiving system (K), at the terminal of the receiving antenna

B: the reference bandwidth (Hz), i.e. the bandwidth in the receiving station that is subject to the interference and over which the power of the interfering emission can be averaged

J: ratio (dB) of the permissible long-term interfering power from any one interfering source to the thermal noise of the receiving system.

For short-term interference the percentage of time is an appropriate portion of the total percentage of time allowed for interference. For the purpose of the present discussion, we take the percentage as 0.001%, and write:

$$P_r(0.001) = 10 \log(k\, T_e\, B) + 10 \log(10^{M_s/10} - 1) \qquad \text{dBW} \qquad (3)$$

where M_s is the link performance margin (dB).

Note that the permissible power for short-term interference is significantly larger than the permissible power for long-term interference. That is:

$$P_r(0.001) - P_r(20) = 10 \log(10^{M_s/10} - 1) - J \qquad \text{dB} \qquad (4)$$

Recommendation ITU-R SF.1650 used a value of 19 dB for M_s in developing a short-term permissible interference power. Assuming –10 dB as a representative value for J, the difference in equation (4) would be:

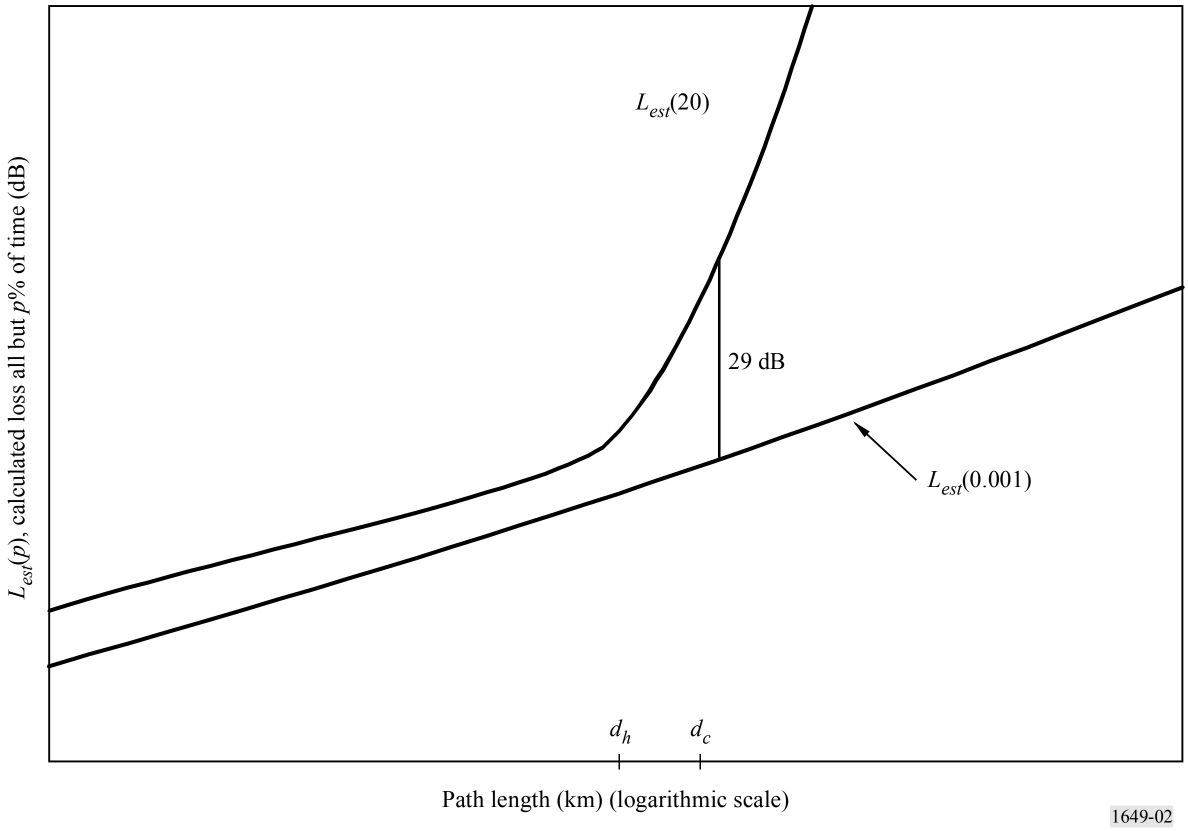
$$P_r(0.001) - P_r(20) \approx 29\,\text{P} \qquad \text{dB} \qquad (5)$$

These permissible interference powers can be used in equation (1) to determine minimum required propagation loss, which must be exceeded by the predicted path loss for all but the same percentage of time. The predicted path loss that is exceeded for all but a percentage of time p may be calculated by the procedure in Recommendation ITU-R P.452, and denoted as L_{452} (p). The dependence with distance of the predicted path loss exceeded for all but 20% of the time and for all but 0.001% of the time typically appears as shown in Fig. 2.

For the chosen antenna heights, the propagation path from the interfering source to the FS receiver is just grazing at the path distance d_h. At larger distances the receiver is beyond the radio horizon and the predicted loss exceeded for all but 20% of the time, $L_{452}(20)$, increases rapidly with distance. At the critical distance d_c, the difference between the predicted loss exceeded for all but 20% of the time is larger than that exceeded for 0.001% of the time by 29 dB. Hence at this distance, the long-term and the short-term interference criteria for these time percentages are both met or neither is met. At larger distances the long-term interference criterion is always met if the short-term criterion is met. At shorter distances the short-term interference criterion is always met if the long-term criterion is met. It is for this reason that only short-term interference criteria are used in the determination of coordination area.

FIGURE 2

Distance dependence of the predicted path loss for all but 20% and 0.001% of the time (estimated)



3 Implications of time variations in parameters other than propagation loss

In the case of ESVs, the interfering power at the receiving antenna is subject to changes in received power due to movement of the transmitting earth station as well as those due to a propagation loss that changes with time. The considerations for long-term and short-term interference can be addressed by adapting techniques used in other sharing scenarios. The separate treatments that are necessary for the consideration of short-term and long-term interference for ESVs in motion are provided in the following subsections.

3.1 Short-term interference consideration

The considerations of short-term interference from ESVs are not unlike, although more complex than, those used for the determination of coordination area for a receiving fixed station with respect to earth stations operating to non-GSO space stations. For the non-GSO case, only the horizon gain, G_t, shown in equation (1), varies with time. The time-varying gain (TVG) method in § 2.2.1 of Recommendation ITU-R SM.1448 is suggested as a supplementary method for these scenarios (see also Recommendation ITU-R SF.1485). The application of the TVG method requires the determination of the cumulative distribution of the horizon gain in the direction of the fixed station exceeded for percentages of time, p_n. For each percentage p_n the associated horizon gain and the permissible interference power, $P_t(p)$ are used in equation (1), to determine a minimum required loss that should be exceeded for all but p_v% of the time, with the constraint:

$$p_v = \begin{cases} 100\ p/p_n & \text{for } p_n \geq 2\ p \\ 50 & \text{for } p_n < 2\ p \end{cases} \quad \% \tag{6}$$

The predicted path loss for p_v% of the time must exceed this loss for each p_n at the coordination distance, in the determination of coordination area.

The ESV case is more complex in that the interfering path from the ESV to the fixed station also changes as the vessel moves. Thus, there is no unique association with the percentages p_n and the gains, G_n. For the determination of interference potential, it is necessary to consider a number of points along the operating contour of the ESV as CCPs and to associate a transmit antenna horizon gain and a percentage of time with each of these points.

3.2 Long-term interference consideration

The consideration of long-term interference from ESVs is necessary only for the determination of interference potential. This scenario is not unlike the scenarios of space-to-Earth interference from non-GSO satellites into FS receivers, for which the concept of FDP was developed. Recommendation ITU-R F.1108 defines FDP as:

$$FDP = \frac{\sum_i f_i I_i}{N_T} = \frac{Average\ interference\ power}{N_T} \tag{7}$$

where:

N_T: effective noise power at the receiver input (dB(W/B))

B: reference bandwidth

I_i: i-th level of interference power present at the receiver input (dB(W/B))

f_i: fraction of time that the i-th interference level is present.

In the case of interference from non-GSO satellites, it is usually assumed that the satellite emissions propagate under free-space conditions, although atmospheric losses have been included in some cases. Thus, the FDP is determined with equation (7) by using a simulation to obtain the values of interference power and the fraction of time for which they occur. In considering interference between fixed terrestrial stations and fixed earth stations, the usual procedure is to use a propagation model such as that of Recommendation ITU-R P.452 for the determination of propagation loss. A composite approach can be developed by using Recommendation ITU-R P.452 to determine the propagation loss, exceeded for all but 20% of the time, to a CCP. By scaling this loss in accordance with the distance-squared dependence of the free-space loss, the contribution to the FDP from operations along portions of the track of an ESV can be determined in closed form by direct integration. To conform more closely to the methodology used with earth stations for the determination of interference potential, the interference potential will be determined on the basis of the average interference power – the numerator of the expression in equation (7). This average power can be compared directly with the permissible value of long-term interference. The approach is described more fully in § 4.

4 Detailed consideration of long-term interference

To consider the long-term interference from ESVs operating on a proposed contour within the off-shore distance, it is first necessary to break the operating contour into a set of straight-line segments. The ends of these straight-line segments provide the basis for the determination of all of the CCPs defined using the method of Annex 1 needed to determine the average interference power. In the cases where the main beam axis of the FS antenna intersects one of the segments, the intersection point is also a CCP for that FS station. The average interference power is developed as the sum of the contributions from each segment of the operating contour. Following the usage and notation of Recommendation ITU-R SF.1650, it is assumed that f_{ESV} vessels per year traverse the operating contour, each at a constant speed of ν_{ESV} km/h.

When a segment contains an intersection with the main beam axis of the FS antenna, the contribution due to the passage of the ESV through the main beam is likely to dominate the contribution from that segment to the average interference power. The contributions due to a main beam passage and due to passage through a segment that has no main beam axis intersection are considered in the following two subsections, respectively. The overall procedure for including all contributions to the average interference power is contained in a third subsection.

4.1 Contribution from a main beam passage to the average interference power

Recommendation ITU-R F.699 or ITU-R F.1245 may be used to provide the functional form of the FS antenna gain (dBi) at an angle of φ_d (degrees) from boresight as:

$$G_r(\varphi_d) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \right)^2 \varphi_d^2 \qquad \text{for } \varphi_d < \varphi_{dm}$$

where:

$$\frac{D}{\lambda} = 10^{(G_{max} - 7.7)/20} \quad \text{(ratio of antenna diameter to wavelength)}$$

$$\varphi_{dm} = \frac{20\lambda}{D} \sqrt{G_{max} - G_1} \quad \text{(off-boresight angle to the first side lobe (degrees))}$$

G_1 = 2 + 15 log (D/λ) (antenna gain at the first side lobe (dBi)).

Then the gain ratio in the main beam within an angle of φ_d (degrees) from boresight is given by[2]:

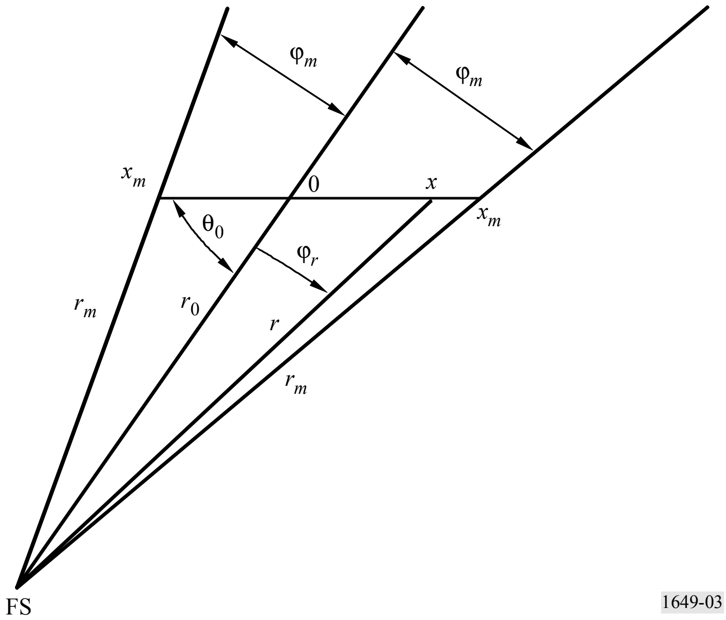
$$g_r(\varphi_r) = g_{max}\ e^{-\alpha^2 \varphi_r^2} \qquad \text{for} \quad \varphi_r < \varphi_{dm} \tag{8}$$

where:

$$\alpha^2 = \frac{\ln(10)}{10}(2.5 \times 10^{-3})\left(\frac{D}{\lambda}\right)^2$$

FIGURE 3

Geometry of a main beam passage of an ESV



The geometry of the main beam passage is shown in Fig. 3. The operating route for the ESV is along the x-axis, which crosses the main beam axis at $x = 0$ with an angle θ_0. The main beam of the antenna has a –10 dB beamwidth (2 φ_m) of less than 2° for an antenna with a maximum gain of 45 dBi which is representative for the 6 GHz band. The main beam intersects the ESV track over the range of x between x_{-m} and x_m. The received power (Watts in the reference bandwidth) received when the ESV is displaced from the point where the main beam axis crosses the ESV track by x km, and from the FS receiver by r km, may be written as:

$$p_{r,x} = \frac{p_t\, g_{t0}\, g_{r\,max}}{\ell_{452}(20)\ \ell_F}\ \frac{r_0^2}{r^2}\ e^{-\alpha^2 \varphi_r^2} \tag{9}$$

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[2] Throughout these developments, quantities in dB, dBi or dBW are identified by capital Roman italic symbols. The same quantities, when expressed in power ratios or power units, are denoted by the lower-case form of the same Roman italic symbols with the same subscript. Thus, $g_{max} = 10^{G_{max}/10} = e^{G_{max}\ln(10)/10}$.

where:

p_t: transmit power (W) in the reference bandwidth

g_{t0}: transmit antenna gain (as a ratio) toward the FS receiver when the ESV is at the beam intersection

$g_{r\,max}$: maximum gain (as a ratio) of the receiving antenna

ℓ_F: feeder loss ratio of the FS receiving system

$\ell_{452}(20)$: propagation loss ratio to the beam intersection, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but 20% of the time

φ_r: off-main beam axis angle (degrees)

φ_m: off-main beam axis angle (degrees) for which the gain of the receiving antenna is 10 dB below its maximum.

Note that the transmit antenna gain is assumed to be constant over the narrow (less than 2°) angular region, and the propagation loss has been scaled for the distance r.

Since the half-width of the main beam is less than 1°, one can write approximately:

$$r = r_0 + x\cos\theta_0$$

$$\varphi_r = (180/\pi) x \sin\theta_0 / (r_0 + x\cos\theta_0)$$

The mean value of the interference power for a transmitter uniformly distributed over the route from x_{-m} to x_m is:

$$\overline{p_{r,0}} = \frac{1}{x_m - x_{-m}} \int_{x_{-m}}^{x_m} p_{r,x} \quad \mathrm{d}x$$

where $p_{r,x}$ is given by equation (9). With a change in the variable of integration to φ_r, this becomes:

$$\overline{p_{r,0}} = \frac{p_t\, g_{t0}\, g_{r\,max}}{\ell_{452}(20)\ \ell_F} \ \frac{2\varphi_m r_0 (\pi/180)}{(x_m - x_{-m})\ \sin\theta_0} \left[\frac{1}{2\varphi_m} \int_{-\varphi_m}^{\varphi_m} \mathrm{e}^{-\alpha^2 \varphi_r^2} \mathrm{d}\varphi_r \right] \qquad (10)$$

The term in square brackets is the average gain relative to $g_{r\,max}$ (as a ratio) of the main beam measured between the angles where the gain is 10 dB below the maximum gain. For the reference antenna pattern of Recommendation ITU-R F.699 or ITU-R F.1245, this quantity has a value of 0.565.

The average given by equation (10) may be converted to an average aggregate power over a year by multiplying by the fraction of a year that this average interference power is present. The time in hours for a vessel to pass through the main beam is $(x_m - x_{-m})/\nu_{ESV}$. If the number of vessels per year passing through the main beam is f_{ESV}, the aggregate average interference power averaged over a year is given by[3]:

$$\tilde{I}_{0,av} = \frac{p_t\, g_{t0}\, g_{r\,max}}{\ell_{452}(20)\ \ell_F} \frac{2\pi\varphi_m r_0}{180\ \nu_{ESV} \sin\theta_0} \frac{f_{ESV}}{8\,760}(0.565) \tag{11}$$

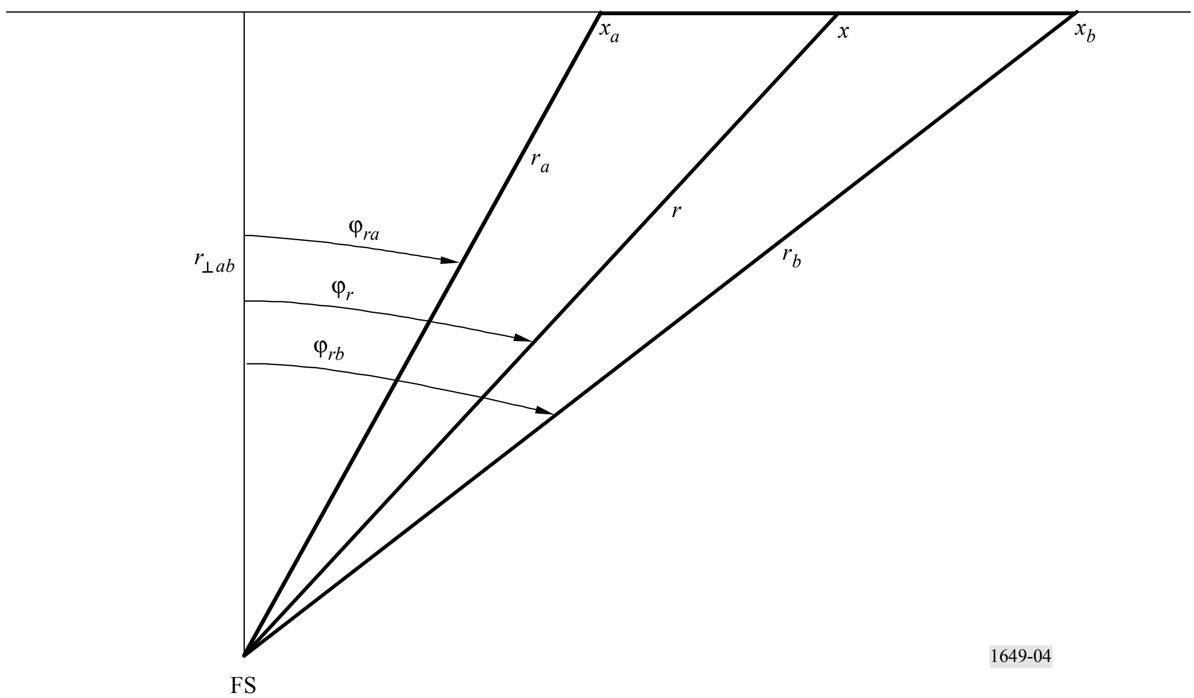
where 8 760 is the number of hours in a year.

Note that the average long-term interference power is significantly lower than that which would be ascribed to an earth station with the same characteristics if it were permanently located at the point where the FS antenna main beam axis crosses the operating track of the ESV. For instance, with a 90° crossing angle, which generates the least interference, and with 1 000 passes of a vessel at a speed of 5 knots (9.261 km/h) at a distance of 20 km, the average interference power given by equation (11) would be 23.8 dB lower. For the same situation, except with a crossing angle of 20°, the average would be only 19.1 dB lower. Of course, contributions from ESV operation on other portions of the operating route would need to be taken into account as they would further reduce this dB difference. Even if these other contributions could be neglected, it is not clear whether the long-term or the short-term criteria would be controlling for this case, given that the short-term criteria would be applied to the interference power at the main beam axis intersection with the operating contour. It is for this reason that both the short-term and the long-term interference criteria must be applied for ESVs in motion.

4.2 Contribution to the average interference power from a segment without a main beam intersection

FIGURE 4

Geometry of the passage of an ESV through a segment of an operating contour outside of the main beam of the FS antenna



[3] The tilde (~) above the symbol for the average interference power is used as a reminder that this quantity is a power with units of Watts in the reference bandwidth.

The geometry and coordinates for this case are shown in Fig. 4. The vessel traverses a segment of the operating contour between x_a and x_b. The formulation is similar to that of equation (9), except that the length of the segment may be much longer than a beamwidth passage. Consequently, in this case the horizon gain of the ESV is replaced by its maximum value on the azimuth to the FS receiver as it passes through the segment. While the actual gain pattern of the FS antenna could be included in an integration, a simpler approach is to assume that the FS gain (dBi) varies linearly with the azimuth angle between φ_a and φ_b. Note that the azimuth angles in this formulation are measured from the perpendicular dropped from the FS station location to the line containing the segment from x_a to x_b. The linear approximation is conservative in that the reference antenna gain patterns outside the main beam are either flat or concave upward; it will not degrade the accuracy of the results because the difference in the gain from one end of the segment to the other is not usually large. Accordingly, the received power (in Watts in the reference bandwidth) when the ESV is on such a segment at a distance x from the intersection of the perpendicular dropped from the FS station to the line containing the segment is given as:

$$p_{r,x} = \frac{p_t \, g_{t,ab}}{\ell_{452.a}(20) \, \ell_F} \frac{r_a^2 \, g_{r\varphi_r}}{r_{\perp ab}^2 + x^2} \tag{12}$$

where:

- p_t: transmit power (W) in the reference bandwidth
- $g_{t,ab}$: maximum transmit antenna gain ratio toward the FS receiver when the ESV is between x_a and x_b
- ℓ_F: feeder loss ratio of the FS receiving system
- $\ell_{452.a}(20)$: propagation loss ratio to the point x_a, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but 20% of the time
- $g_{r\varphi_r}$: gain (as a ratio) of the receiving antenna on the azimuth φ_r to the point x
- $r_{\perp ab}$: distance from the FS station to the line containing the segment from x_a to x_b.

Under the assumption that the gain of the receiving antenna (dB), varies linearly from G_a at φ_{ra} to G_b at φ_{rb}, the gain ratio $g_{r\varphi_r}$ can be written as:

$$g_{r\varphi_r} = g_{ra} \, \mathrm{e}^{\frac{\ln(10)}{10}\left(\frac{G_{rb} - G_{ra}}{\varphi_{rb} - \varphi_{ra}}\right)(\varphi_r - \varphi_{ra})} \tag{13}$$

The mean value of the interference power $\overline{p_{r,ab}}$ over the segment may be developed as in equation (10) by integrating equation (12) over the interval x_a to x_b and dividing by the interval length. Changing the variable of integration to φ_r where $x = r_{\perp ab} \tan(\pi\varphi_r / 180)$ one finds:

$$\overline{p_{r,ab}} = \frac{p_t g_{t,ab}}{\ell_{452.a}(20)\ \ell_F} \ \frac{\pi r_a^2 (\varphi_{rb} - \varphi_{ra}) \sqrt{g_{ra} g_{rb}}}{180 r_{\perp ab} (x_b - x_a)} \ \text{sinch}((G_b - G_a) \ln(10) / 20) \tag{14}$$

where the angles φ_{ra} and φ_{rb} are expressed in degrees:

$$\text{sinch}(x) = \frac{\sinh(x)}{x}$$

The time in hours for a vessel to pass through this segment of the operating route of an ESV is $(x_b - x_a)/\nu_{ESV}$. If the number of vessels per year passing through the main beam is f_{ESV}, the aggregate average interference power from the segment, averaged over a year, is given by:

$$\tilde{I}_{ab,av} = \frac{p_t\ g_{t,ab} \sqrt{g_{ra} g_{rb}}}{\ell_{452.a}(20)\ \ell_F} \ \frac{\pi r_a^2 (\varphi_{rb} - \varphi_{ra}) f_{ESV}}{180 r_{\perp ab} 8\,760 \nu_{ESV}} \ \text{sinch}((G_{rb} - G_{ra}) \ln(10) / 20) \tag{15}$$

The evidence that this development began with an expansion of the propagation loss factor at the point x_a resides in the term $r_a^2 / \ell_{452.a}(20)$ in equation (15). If the average interference power had been determined from the propagation loss factor at the point x_b, the average interference power would be identical except for the replacement of $r_a^2 / \ell_{452.a}(20)$ by $r_b^2 / \ell_{452.b}(20)$. If the propagation loss factor exceeded for all but 20% of the time varied inversely with the square of the distance, these two terms would also be identical. A simple approach that compensates for the deviation from the inverse square-law dependence is to average the two calculations, which gives:

$$\tilde{I}_{ab,av} = \frac{p_t\ g_{t,ab} \sqrt{g_{ra} g_{rb}}}{2\ \ell_F} \ \frac{\pi (\varphi_{rb} - \varphi_{ra}) f_{ESV}}{180 r_{\perp ab} 8\,760 \nu_{ESV}} \left(\frac{r_a^2}{\ell_{452.a}(20)} + \frac{r_b^2}{\ell_{452.b}(20)} \right) \times \text{sinch}((G_{rb} - G_{ra}) \ln(10) / 20) \tag{16}$$

4.3 Aggregate average interference power from an operating contour

The CCPs are identified by breaking the operating contour of the ESV into straight-line segments and locating the geographic locations of the points where the ends of segments join together. After finding the azimuth to each of these critical points from a given FS receiver, it can easily be determined whether the main beam axis of the FS antenna intersects any segment.

If no main beam intersections occur, the average value of the potential interference can be determined by summing the contribution from each segment of the operating contour using equation (16).

If there is a main beam intersection on one of the segments, there will be one, two or three contributions to the total average interference potential from operations on that intersected segment. These contributions are added to the partial sum developed from the contributions of each of the remaining segments as calculated by equation (16).

The three possible contributions from the intersected segment are determined as follows:

– A contribution corresponding to the main beam passage is determined by applying equation (11). If this segment lies entirely within the main beam of the FS antenna, this is the only contribution from this segment.

– The contribution from the portion(s) of this segment outside the main beam of the FS antenna may be determined using equation (16) by identifying additional CCP(s) at the edge of the main beam.

Throughout these discussions, it has been assumed that the horizon gain of the ESV transmit antenna does not have a strong variation with azimuth. The procedure can be easily modified to accommodate for variation in the horizon gain with azimuth. When neither antenna gain has a maximum for an ESV position within a segment, the gain averaging that was applied to the receive gain in § 4.2 can be applied to the product of the transmit and receive gain ratios. In this case equation (16) becomes:

$$\tilde{I}_{ab,av} = \frac{p_t \sqrt{g_{ta} g_{ra} g_{tb} g_{rb}}}{2\,\ell_F} \frac{\pi(\varphi_{rb} - \varphi_{ra}) f_{ESV}}{180\, r_{\perp ab} 8\,760 \nu_{ESV}} \left(\frac{r_a^2}{\ell_{452.a}(20)} + \frac{r_b^2}{\ell_{452.b}(20)} \right) \times \text{sinch}((G_{tb} + G_{rb} - G_{ta} - G_{ra}) \ln(10)/20) \qquad (17)$$

where:

g_{ta}: transmit antenna gain ratio toward the FS receiver when the ESV is at the CCP at x_a

g_{tb}: transmit antenna gain ratio toward the FS receiver when the ESV is at the CCP at x_b.

Alternatively, when the transmit antenna gain has a maximum with respect to an FS receiver when the ESV passes through a segment and the receive gain does not, a more accurate result can be obtained by defining the point on the segment where a particular FS receiver experiences the maximum as an additional CCP to be used to determine the interference potential to that receiver.

5 Detailed consideration of short-term interference

The considerations of the short-term potential interference from ESVs differ in two significant respects from the short-term interference considerations used in the determination of the offshore distance beyond which interference from ESVs need not be considered. In determining the offshore distance, consideration was limited to cases where the ESV crossed through the main beam axis of the FS receiving antenna. Consideration was further limited to the case where the crossing track was perpendicular to the main beam axis. The short-term considerations developed in this section accommodate all of the possibilities and, hence, will parallel the development in the preceding section.

In considering the potential for short-term interference to an FS receiver from an ESV on its operating contour, it is necessary to determine a short-term potential interference power from each of the critical points on that contour in order to determine which point controls the short-term interference. In the following development, it will be assumed that there is a single critical point that determines the potential interference power, which is exceeded for a specified percentage of the time and can be compared to the short-term interference criterion. Because of the inter-relations between the parameters, a direct identification of the controlling point and the associated power cannot usually be made directly. While several approaches are possible, the one in this section appears to be the most direct.

For convenience in the following developments, the critical contour point determined by a main beam crossing, when such a crossing exists, will be designated by the number 0. The remaining CCPs, which identify the points where the operating contour changes direction, will be numbered in sequence along the contour from 1 to N_{ccp}, where N_{ccp} is the number of such CCPs on the operating route of the ESV. In accordance with the discussion in § 3.1 and in conformance with the developments in § 4, the power at the FS receiver (dBW) that is exceeded for p_{ST} % of the time when the ESV is operating near the i-th CCP is given as:

$$I_{ST,i}(p_{ST}) = P_t + G_{t,i} + G_{r,i} - L_F - L_{452.i}(p_{Li}) \qquad (18)$$

where:

- p_{ST}: percentage of time for which the permissible power level for short-term interference (see equation (3)) may be exceeded
- P_t: transmit power (dBW) in the reference bandwidth
- $G_{t,i}$: transmit antenna gain toward the FS receiver when the ESV is at the i-th CCP, for i = 1 to N_{ccp} (dBi)
- $G_{r,i}$: gain of the receiving antenna toward the ESV when the ESV is at the i-th CCP, for i = 1 to N_{ccp} (dBi)
- L_F: feeder loss of the FS receiving system (dB)
- $L_{452.i}(p_{Li})$: propagation loss to the i-th CCP, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but p_{Li}% of the time, for i = 1 to N_{ccp} (dB).

The percentage of time, p_{Li}, is given by:

$$p_{Li} = 100 p_{ST} / p_{ESVi} \qquad (19)$$

where:

- p_{ESVi}: per cent of time associated with the ESV operation near the i-th CCP.

In the case of a main beam crossing, a direct evaluation of the necessary values is possible. The percentage of time associated with the ESV operation near the main beam crossing is the time to cross the main beam of the FS antenna at a specified gain level relative to the maximum gain. In this Recommendation and in § 4 a 10 dB width was used. For consistency the same width should be used for the determination of the short-term interference potential. Using the 10 dB beamwidth as the basis for calculating the percentages p_{ESV0},

$$p_{ESV0} = 4 \times 10^{-4} \frac{f_{ESV}\, \varphi_m\, r_0}{\nu_{ESV} \sin \theta_0} \qquad (20)$$

where the symbols were defined in deriving equation (11).

Using equations (18)-(20), one can determine $I_{ST,0}$, the value of the power at the FS receiver that is exceeded for p_{ST}% of the time due to operation of the ESV in the main beam of the FS antenna.

Although there may be areas close to another critical point on the operating route of the ESV, which could lead to the determination of a short-term power that would be almost as high for the same percentage of time, only a single worst-case maximum power will be considered. The alternative would be to partition the permissible percentage of time, p_{ST}, between these CCPs.

In order to determine the potential interference power from a CCP that is not the result of the intersection of the main beam with a segment of the operating contour, one must first determine the associated percentage of time that the ESV operates close to that CCP. The most direct and conservative approach is to associate with a given CCP half of each of both adjacent operating segments. Thus, denoting by $x_{i,i+1}$ the length of the segment between the CCP numbered i and an adjacent CCP numbered $(i+1)$, the percentage of time associated with this CCP is:

$$p_{ESVi} = \text{Lesser of } \frac{f_{ESV}}{87.6 v_{ESV}} \frac{(x_{i,i-1} + x_{i,i+1})}{2} \text{ and } 100\% \tag{21}$$

The values of each of the critical short-term potential interference powers can be determined ($i \neq 0$) using equations (21) and (19) with (18). The largest of these short-term powers is the controlling power to be used in comparison with the permissible short-term interference power.

6 Summary

This Annex describes a set of procedures that can be used to determine the interference potential of emissions from an ESV operating on a prescribed contour near land.

Although this procedure concentrates on the 6 GHz band, the same approach may also be applicable to the 14 GHz band, which is also addressed in Resolution 82 (WRC-2000). The performance of fixed service links in the 14 GHz band is affected by multipath fading and by precipitation fading, and the relative importance of the two mechanisms depends on the radiometeorological climate. With other considerations constant, sharing conditions are more restrictive when multipath fading controls the performance of a fixed service link. Hence this procedure should also be appropriate for the 14 GHz band.

The table of parameters to be used as guidance in applying the method may be found in Recommendation ITU-R SF.1650. The parameters for ESVs should represent the actual system parameters, which should conform to those in Recommendation ITU-R S.1428. The parameters for fixed links should also represent the actual system parameters. Regarding the interference criteria, Recommendations ITU-R SF.1006 and ITU-R SF.1650 may be referred to.

Annex 3

Alternative method for calculation of interference from ESVs

1 Introduction

This Annex describes a set of procedures by which the method in Annex 2 can be modified so that it can be implemented using simulation techniques. These procedures may require additional computing time, but may lead to more accurate results.

2 Simulation procedure

Initially, the operating contour is subdivided into a large number R of small straight-line segments $\Delta\vec{r}_i$ centred at $\vec{r}_i$ (I = 1, 2, ..., R) in such a way that the length of the segments remains constant.

From the discrete version of the total probability theorem, one has

$$\Pr\{p_{int} > I\} = \sum_{i=0}^{R} \Pr\{p_{int} > I \,|\, (\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2]\} \cdot \Pr\{(\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2]\} \tag{22}$$

In equation (1), $\Pr\{p_{int} > I\}$ is the probability that the level I (dBW) of the interference power be exceeded; $\Pr\{p_{int} > I \,|(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]\}$ is the same probability, conditioned to the positioning of the ESV within the interval $(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]$; and $\Pr\{(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]\}$ is the probability of the interval in the operating contour. Assuming that the ESV velocity v_{ESV} remains constant in the operating contour, that the number of vessels per year passing through the operating contour is f_{ESV}, and since all the intervals have the same probability, it follows that:

$$\Pr\{(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]\} = \frac{f_{ESV} \cdot \Delta t}{365 \cdot 24 \cdot 3600} = \frac{f_{ESV} \cdot \Delta t}{31\,536\,000} \tag{23}$$

where $\Delta t = |\Delta\vec{r}_i| / v_{ESV}$. Combining equations (22) and (23), and remembering that the segments are small, one gets the basic equation of the simulation procedure

$$\Pr\{p_{int} > I\} \approx \frac{f_{ESV} \cdot \Delta t}{31\,536\,000} \sum_{i=0}^{R} \Pr\{p_{int} > I \,|\, \vec{r} = \vec{r}_i\} \tag{24}$$

Equation (24) indicates that $\Pr\{p_{int} > I \,|\, \vec{r} = \vec{r}_i\} = p/100$ should be evaluated at each point $\vec{r}_i$ of the operating contour, the partial values accumulated and the results scaled to produce the probability that the level I (dBW) of the interference power be exceeded. This procedure is then repeated for all the levels I (dBW) of interest. Using straightforward notation, one can write

$$I = P_{tESV} + G_{ESV}(\theta_{ESV}) + G_{FS}(\theta_{FS}) - L_{FS} - L_{P.452,i}(p) \tag{25}$$

In equation (25), which is analogous to equation (18) in Annex 2, $L_{452.i}(p)$ is the propagation loss in the interference path characterized by the ESV located at $\vec{r}_i$ and by the FS receiver, as calculated with Recommendation ITU-R P.452. In the present simulation, equation (25) is inverted (either analytically or numerically, depending on the path type) to yield the value of p (%) related to the given value of I (dBW) and to the particular location $\vec{r}_i$ of the ESV that is used in the right-hand side of equation (25).