

RECOMMENDATION ITU-R S.1712

Methodologies for determining whether an FSS earth station at a given location could transmit in the band 13.75-14 GHz without exceeding the pfd limits in No. 5.502 of the Radio Regulations, and guidelines to mitigate excesses

(2005)

Scope

WRC-03 adopted Resolution 144 to invite the ITU-R to develop Recommendations to establish technical or operational methods to facilitate sharing and greater flexibility in deployment of FSS earth stations smaller than 4.5 m in the band 13.75-14 GHz in conformity with Radio Regulations (RR) No. 5.502, and which may also be used to establish a basis for bilateral agreements between administrations.

This Recommendation proposes three methods for determining whether FSS earth stations at a given location can transmit in the band 13.75-14 GHz without exceeding the pfd limit in RR No. 5.502. It also provides additional measures that administrations of small and narrow countries can consider when deploying FSS earth stations.

The ITU Radiocommunication Assembly,

considering

- a) that WRC-03 revised the sharing constraints on the fixed-satellite service (FSS) (Earth-to-space) in the band 13.75-14 GHz;
- b) that this FSS band is shared with the radiolocation and radionavigation services;
- c) that the revised sharing conditions approved at WRC-03 permit the operation of geostationary FSS earth stations in the band 13.75-14 GHz with antennas of diameter D , with $1.2 \text{ m} \leq D < 4.5 \text{ m}$;
- d) that No. 5.502 of the Radio Regulations (RR) requires an administration planning to operate, within its country, an FSS earth station having an antenna of diameter D less than 4.5 m, and transmitting to a GSO satellite in the band 13.75-14 GHz, to ensure that the pfd that this earth station produces anywhere on the border of a neighbouring country at a height of 3 m above ground, and/or anywhere on its sea border (if it has one) at a height of 36 m above the low-water mark, does not exceed $-115 \text{ dB(W/(m}^2 \cdot 10 \text{ MHz))}$ for more than 1% of the time;
- e) that, since propagation loss increases with distance, and on overland paths is strongly influenced by the nature of the terrain, earth stations located sufficiently far from the neighbouring country's border or from a low-water mark may meet the pfd limit without the application of interference mitigation techniques (e.g. local shielding), and therefore methods to identify the areas in a country where this is so would assist administrations to comply with the requirement in *considering* d);
- f) that natural or man-made site shielding could attenuate the signal transmitted by an earth station in the direction of a neighbouring country's land border and/or low-water mark;
- g) that the use of specific types of earth stations with improved side-lobe performance could reduce the signal produced by an FSS earth station at the neighbouring country's land border and/or low-water mark;

h) that it is appropriate to employ the relevant information in ITU-R Recommendations as a basis for the methods mentioned in *considering e)*, and that it may be appropriate to use a terrain database covering any country in which it is planned to operate FSS earth stations with antenna diameter D less than 4.5 m in the 13.75-14 GHz band;

j) that Resolution 144 (WRC-03) resolves that the administrations of geographically small or narrow countries may exceed the limitations on FSS earth station power flux-density at the low-water mark in RR No. 5.502 if such operation is in conformance with bilateral agreements with administrations deploying maritime radiolocation systems in the band 13.75-14 GHz;

k) that Resolution 144 (WRC-03) further resolves that the technical or operational methods which will further facilitate sharing may allow greater flexibility in the deployment of FSS earth stations in the band 13.75-14 GHz, in conformity with RR No. 5.502, and which may also be used as a basis for the establishment of such bilateral agreements between administrations,

noting

a) that RR No. 5.503 places additional constraints on the operation of FSS earth stations in the 10 MHz band from 13.77 to 13.78 GHz,

recommends

1 that the method in either Annex 1 or Annex 2 or Annex 3, or in a combination of these annexes, as deemed appropriate by the concerned administrations, including those countries referred to in *considering j)*, should be used for determining whether an earth station proposed to operate in the 13.75-14 GHz band would meet the pfd limits of RR No. 5.502;

2 that, in addition, in the case of small or narrow countries, the information in Annex 4 of this Recommendation should be used to help in meeting the pfd limits of RR No. 5.502, and/or as a basis for the establishment of bilateral agreements between administrations when seeking agreement for relief of the pfd limits of RR No. 5.502.

Annex 1

Method 1: Minimum separation distance curves based on Recommendation ITU-R P.452, utilizing FSS earth station height and e.i.r.p. density toward the horizon, latitude, and possibly terrain heights¹

This method produces two curves, using a smooth Earth model, showing the minimum separation distance from the low-water mark or neighbouring country's land border, an FSS earth station would need to meet in order to respect the pfd limits in RR No. 5.502, as a function of the earth station e.i.r.p. density toward the horizon. The primary curve gives the line-of-sight (LoS) separation distance. The secondary curve gives the trans-horizon separation distance. An FSS earth station deployed at a distance greater than or equal to the minimum separation distance is assumed

¹ Method 2 will maximize the area in which deployments may be made without requiring individual site analysis. If digital terrain data for a country is not available, or a simpler approach is desired, then Method 1 will permit contours to be developed that are somewhat more conservative than the digital terrain approach of Method 2.

to meet the pfd limit criteria. Besides determination of whether the path to the low-water mark or border is LoS or trans-horizon, no further analyses are required. Note that deployment in areas excluded by this method is still possible provided a potential site can be shown to meet the pfd limit criteria through application of either Method 2 or 3 (Annexes 2 and 3). In order to fully account for the variability of terrain in the real world, this Method is separated into three steps of increasing complexity. Step A is by far the simplest and does not account for terrain. In fact, this step assumes a *flat* Earth where all paths are LoS. Step B assumes a spherical Earth with a nominal radio horizon but does not consider the effect of intervening terrain. Like Step B, Step C assumes a spherical Earth, but unlike Step B it does take into consideration the effect of intervening terrain. Each step in order will increase the size of the potential FSS deployment area (exposing the largest possible area using Step C). It is given that if Step A or B shows that a potential deployment site meets the pfd limit criteria, then the following step(s) need not be performed. At the discretion of the user, Steps B or C may be employed without previously implementing Step A.

In order to calculate the value of the distance, some basic assumptions and propagation models are required. Radiocommunication Study Group 3 has developed many propagation models for this specific purpose, and Recommendation ITU-R P.452-11 has been used in many similar sharing situations and would appear to be the most appropriate for the propagation situation covered by Recommendation ITU-R P.452-11.

An in-depth description of Method 1 follows.

Step A: All paths are assumed to be LoS. The LoS curve in Fig. 4 is used to determine the minimum separation distance as a function of earth station e.i.r.p./10 MHz radiated by the station towards the low-water mark (or border). Note that the curve is derived from the LoS loss from Recommendation ITU-R P.452-11 ($p = 1.0\%$). Since this is a flat Earth model, the curve is independent of factors such as local ΔN and antenna height above terrain. If the potential deployment site is farther from the low-water mark (or border) than the required separation distance from the LoS curve, then the station is assumed to comply with the pfd limit criteria of RR No. 5.502. If the path length is smaller than the required separation distance, then proceed to Step B.

Step B: This step assumes a spherical Earth and thus requires the determination of a nominal radio horizon. First, find the effective Earth radius, a_e , using the local ΔN and equations (5) and (6) of Recommendation ITU-R P.452-11 (convert to metres). The radio horizon can then be calculated from the following equation:

$$R\text{Horizon}_{\text{nominal}} = \sqrt{2 \cdot a_e} \cdot (\sqrt{h_0} + \sqrt{h_{es}}) / 1\,000 \quad \text{km}$$

where:

$$\begin{aligned} h_0 &= 36 \text{ m for a low-water mark path or 3 m for a land border path} \\ h_{es} &= \text{earth station height (m) above mean sea level.} \end{aligned}$$

If the earth station site is within the nominal radio horizon of the low-water mark (or land border), then the required separation distance is found using the LoS curve of Fig. 4. If the earth station site is beyond the nominal radio horizon, then determine the required separation distance using the trans-horizon curve of Fig. 4. If the potential deployment site is farther from the low-water mark (or border) than the required separation distance from the applicable curve, then the station is assumed to comply with the pfd limit criteria of RR No. 5.502. If the path length is smaller than the required separation distance, then proceed to Step C.

Step C: This step also assumes a spherical Earth. Furthermore, it requires a more detailed analysis of the paths toward the low-water mark (or border). Appendix 2 to Annex 1 of Recommendation ITU-R P.452-11 is used to determine if a path is LoS or trans-horizon. The specific procedure is detailed in § 4.1 of that appendix: “Test for a trans-horizon path”. The terrain data can be taken from Digital Elevation Maps or even derived from the elevation contours of printed maps. Since in

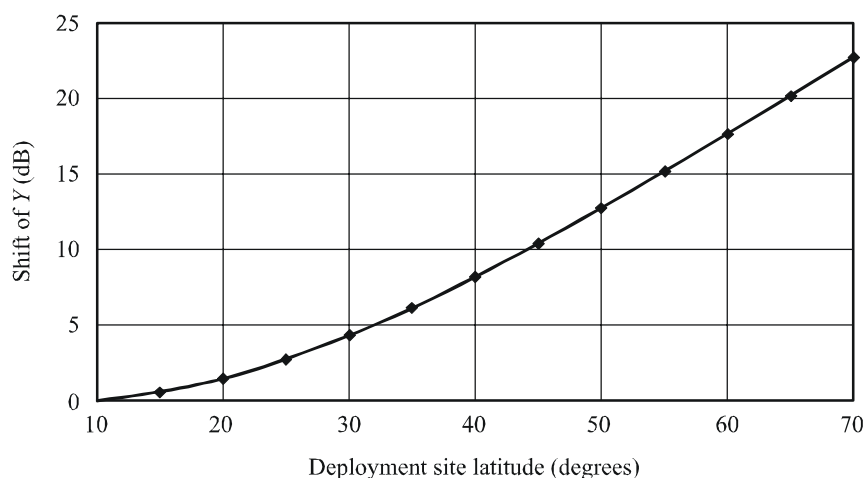
actual terrain, the path with the lowest loss is not necessarily the shortest path, several paths in radial around the potential earth station site should be tested. If any path is shown to be LoS, then the required separation distance is found using the LoS curve of Fig. 4 (using the shortest LoS path). If the test shows that all paths are trans-horizon, then the required separation distance is found using the trans-horizon curve of Fig. 4. If the potential deployment site is farther from low-water mark or the neighbouring country's land border than the required separation distance from the applicable curve, then the station is assumed to comply with the pfd limit criteria of RR No. 5.502. If the path length is smaller than the required separation distance, it is likely non-compliant with the pfd limit.

It is important to note that the required separation distance found with any of the three steps above is not an absolute minimum. If the earth station distance to the low-water mark or the neighbouring country's land border is smaller than the required value, further analysis using either Method 2, which includes digital terrain data and propagation modelling, or Method 3, which also includes terrain data and allows for factors such as site shielding, may be used to verify whether the pfd limit criteria in RR No. 5.502 can be met.

As described above, the use of Method 1 requires two curves (for different path types) that give the minimum distance X to the low-water mark (or land border), as a function of the e.i.r.p. density toward the horizon, to meet the pfd limit criteria. Deployment sites that are less than X from the low-water mark (or land border) are possible but require application of the other methods. In order to calculate the (LoS) value of X some basic assumptions and propagation models are required. The LoS curve is calculated directly from the LoS equation of Recommendation ITU-R P.452-11. This is equation (9) of § 4.2 of the Recommendation. Use an appropriate frequency and set the percentage of time p to 1.0%. The resulting loss is used with equation (2) to find the e.i.r.p./distance combination that satisfies the pfd limit. The trans-horizon curve is simply the LoS curve shifted up the e.i.r.p. scale by Y dB. The value of Y is found from the curve in Fig. 1. As noted above, the pfd level given in RR No. 5.502 specifies the height at the low-water mark or at the border of a neighbouring country.

FIGURE 1

Trans-horizon curve shift as a function of latitude



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Example of application of Method 1

In considering Step A, in some countries typical very small aperture terminal (VSAT) earth stations operating in the 13.75-14.5 GHz band are limited in the input power density level into the antenna to -14 dB(W/4 kHz). For a typical 64 kbit/s quadrature phase shift keying VSAT digital carrier (rate 1/2 forward error correction with Reed Solomon coding) with an approximate bandwidth of 84 kHz, this level would produce an input power density P_d of:

$$P_d = -14 + 10 \log (84/4) = -0.8 \text{ dB(W/84 kHz)}$$

Assuming that the off-axis angle to the low-water mark in elevation and azimuth exceeds 48° then the gain of the antenna would be -10 dBi and the transmit e.i.r.p. density, assuming one carrier within the 10 MHz bandwidth, would be:

$$(e.i.r.p.)_d = -10.8 \text{ dB(W/10 MHz) bandwidth}$$

Further assume that the path length from the earth station to the low-water mark (in this example the low-water mark was considered to be co-located with the coastline) is 44 km, local $\Delta N = 40$, and that the earth station height is 20 m above mean sea level (AMSL). The latitude is 35° , which yields a 6 dB shift for the trans-horizon curve. Step 1 begins with comparison of the off-axis e.i.r.p. with the LoS curve of Fig. 4. It follows from the curve that the LoS required separation distance would be approximately 66 km. Since the actual path length is less than required minimum separation distance, Step A fails to show compliance with the pfd limit.

Under Step B, the nominal radio horizon is calculated to be 43.3 km. As the actual path length is greater than the nominal radio horizon, the path must be trans-horizon. Therefore, the minimum separation distance can be found using the trans-horizon curve of Fig. 4. Using that curve, a station with an off-axis e.i.r.p. of -10.8 dBW requires a minimum separation distance of approximately 35 km. In this case, the actual path length is greater than the required minimum separation distance. Therefore, Step B shows that this earth station complies with the pfd limit. If Step B had failed to show compliance, analysis using a more accurate estimation of the true radio horizon would follow under Step C.

In the case of a 512 kbit/s carrier with a 669 kHz bandwidth, the e.i.r.p. density would be:

$$(e.i.r.p.)_d = -14 + 10 \log (669/4) - 10 = -1.8 \text{ dB(W/10 MHz)}$$

Step A shows a required minimum separation distance of approximately 140 km would be required. If Steps B or C can show that the path is trans-horizon, then a minimum separation distance of approximately 83 km would be required.

Example of Method 1, Step C

In considering Step C, a potential earth station site is indicated on the example map in Fig. 2. Steps A and B do not show this site to be in compliance with the pfd limit. Therefore, Step C of Method 1 will be utilized. Contours from the map will be used to estimate the radio horizon on paths between the site and different points along the coast (low-water mark). Assume the following parameters:

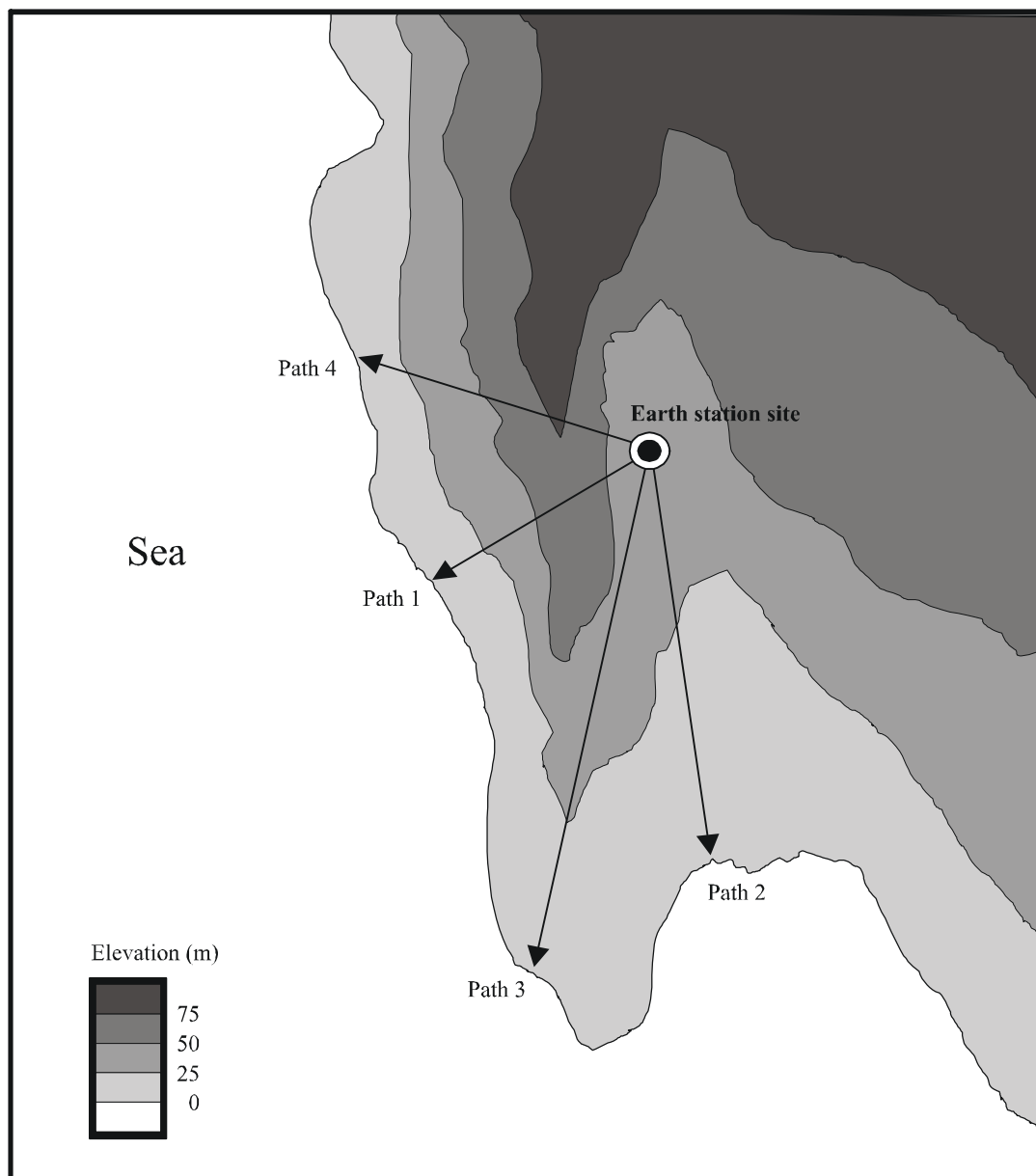
Earth station e.i.r.p. toward horizon in all directions = -10.8 dBW

Earth station height AMSL = 40 m

Local annual mean $\Delta N = 45$

Latitude is 35° .

FIGURE 2
Example contour map showing potential ES site



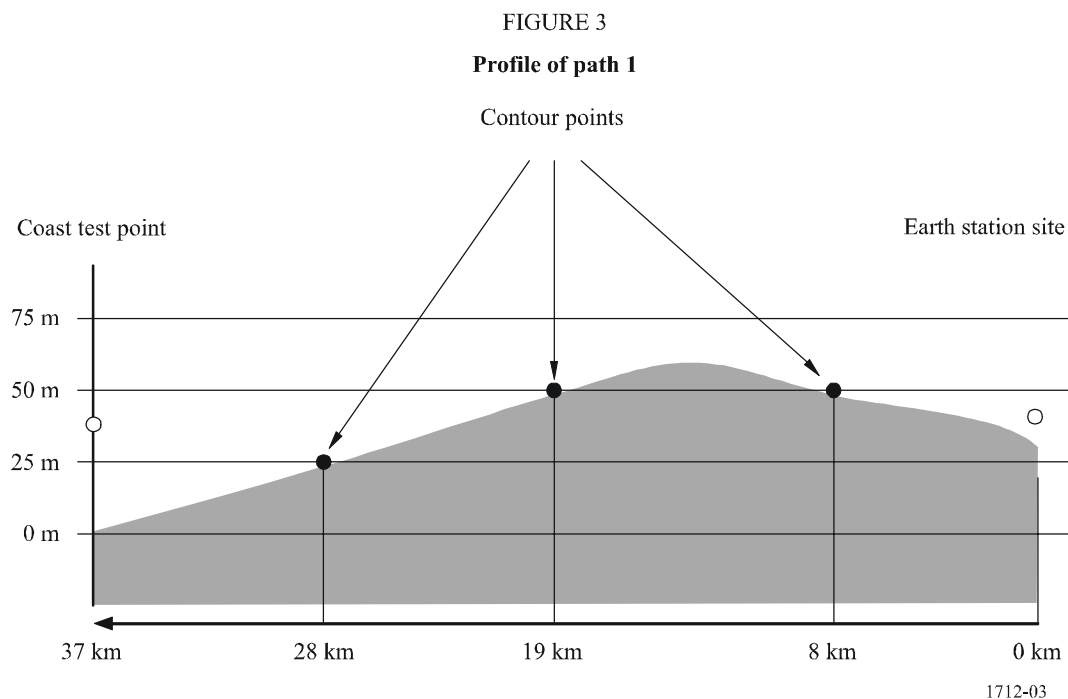
Lengths:

Path 1: 37 km
Path 2: 61 km
Path 3: 80 km
Path 4: 41 km

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A quick check of Fig. 4 shows that the LoS required separation distance for this earth station (ES) is 63.5 km. The shortest path to the low-water mark (Path 1) is clearly much less than the required LoS distance. Step A does not show compliance. Using ΔN and the earth station height AMSL shows that the nominal radio horizon is 52.1 km. Since the length of Path 1 is less than the nominal horizon the required separation distance remains unchanged. Step B fails.

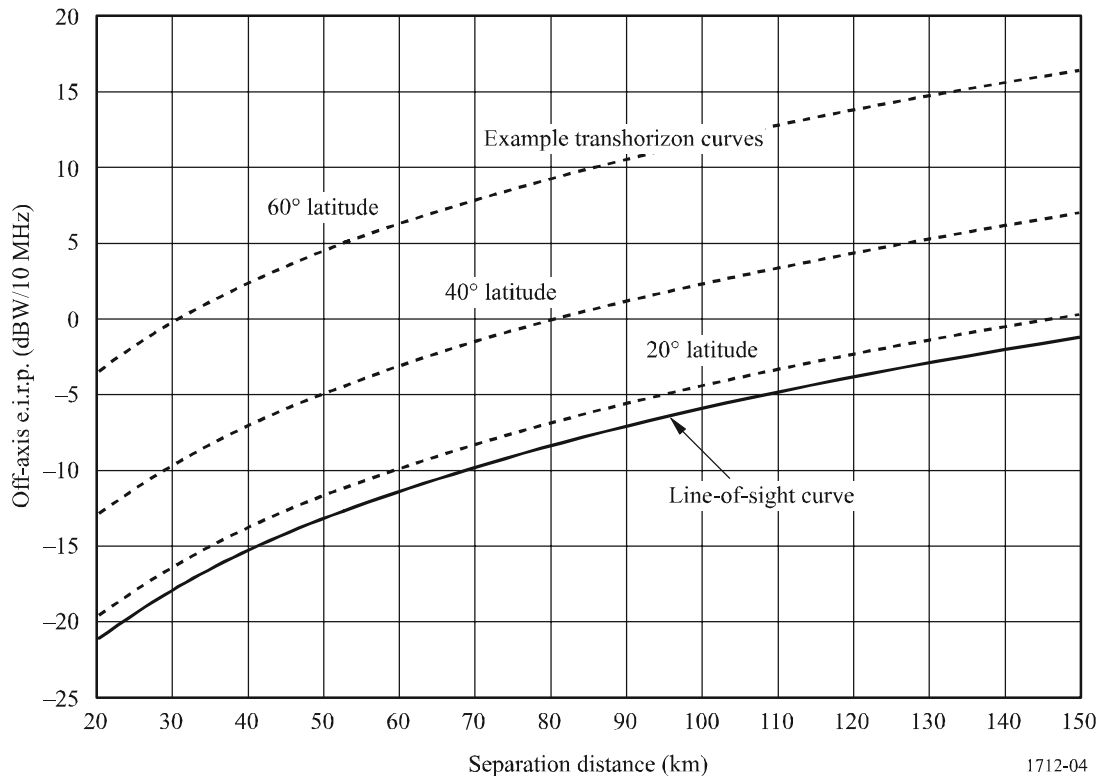
Step C begins with the trans-horizon test found in Appendix 2 to Annex 1 of Recommendation ITU-R P.452-11. The paths are divided into sections to reflect the different elevations along each part of each path. Evenly spaced increments are recommended but this is not necessary. The Recommendation ITU-R P.452 test checks if the physical horizon elevation angle as seen by the earth station, θ_{ES} , is greater than the angle subtended by the angle from the coastal test point, θ_{TP} . See the Recommendation for full details of the procedure. Making the necessary calculations with Path 1 shows that $\theta_{ES} = 0.8$ mrad and $\theta_{TP} = -2.2$ mrad. Since $\theta_{ES} > \theta_{TP}$, this path is trans-horizon. Note that while Path 2 and Path 3 do not cross contours higher than the earth station, their lengths exceed the nominal radio horizon found in Step B. Therefore, these are known to be trans-horizon without application of the Recommendation ITU-R P.452 test. Path 4 is both longer than Path 1 and crosses a higher contour. Calculation of the angles shows this path is indeed trans-horizon. By inspection, there are no other paths that would be expected to produce results different from the paths shown in the map above. Therefore, this earth station site is not within LoS of any point on the coast (low-water mark). The trans-horizon curve of Fig. 4 shows that the required separation distance for this earth station is 34 km. Since the shortest path is greater than this value, the earth station site is found to be compliant with the pfd limit criteria.



Note that the true peak in the profile in Fig. 3 was not actually used in the calculations. The contour map in Fig. 2 only provided with certainty elevation data in 25 m increments. A higher resolution source of terrain data could have been used to take advantage of the true height of the intervening terrain.

FIGURE 4

Method 1: Separation distance curves (minimum distance from the low-water mark as a function of the e.i.r.p. density toward the horizon)



Note that the LoS curve is derived from the loss for LoS paths found in Recommendation ITU-R P.452-11. The trans-horizon curve is simply the LoS curve shifted up the e.i.r.p. axis by Y dB. In reality, diffraction loss is not simply the LoS loss shifted by a constant value. Further analysis of the Recommendation ITU-R P.452-11 model may show that the trans-horizon curve may require some adjustment.

Annex 2

Method 2: pfd contours based on actual terrain data, the propagation model in Recommendation ITU-R P.452-11, the FSS earth station's e.i.r.p. in 10 MHz bandwidth and the diameter and height above ground of its antenna

1 Generalities

This method produces a set of contours, using actual terrain data, showing the minimum separation distance from the low-water mark or neighbouring country's land border, an FSS earth station would need to meet in order to respect the pfd limits in RR No. 5.502, as a function of the earth station e.i.r.p. and the diameter and height of its antenna. An FSS earth station deployed within the contour based on its on-axis e.i.r.p. is assumed to meet the pfd limit criteria. No further analyses are required. This method, using more accurate data than Method 1, permits to obtain larger areas inside which an earth station can be deployed while meeting pfd limits of RR No. 5.502. However, it should be noted that deployment in areas excluded by this method is still possible provided a