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 m $\leq D <$ 4.5 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 dB(W/(m$^2 \cdot$ 10 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 heights[1]

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:

$$\text{RHorizon}_{nominal} = \sqrt{2 \cdot a_e} \cdot \left(\sqrt{h_0} + \sqrt{h_{es}}\right) / 1\,000 \qquad \text{km}$$

where:

$h_0 =$ 36 m for a low-water mark path or 3 m for a land border path

h_{es}: earth station height (m) above mean sea level.

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.

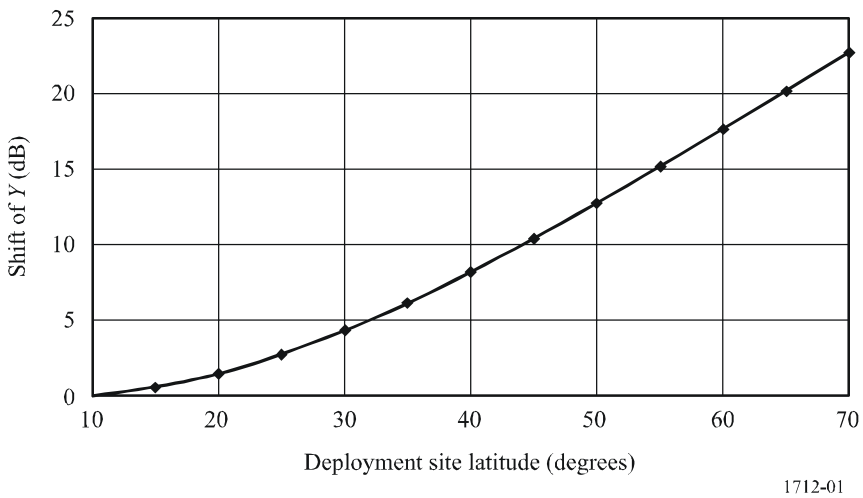
Step C: This step also assumes a spherical Earth. Furthermore, it requires a more detailed analysis of the paths toward the low-water mark (or border). Appendix 2 to Annex 1 of Recommendation ITU-R P.452-11 is used to determine if a path is LoS or trans-horizon. The specific procedure is detailed in § 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



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:

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

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:

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

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

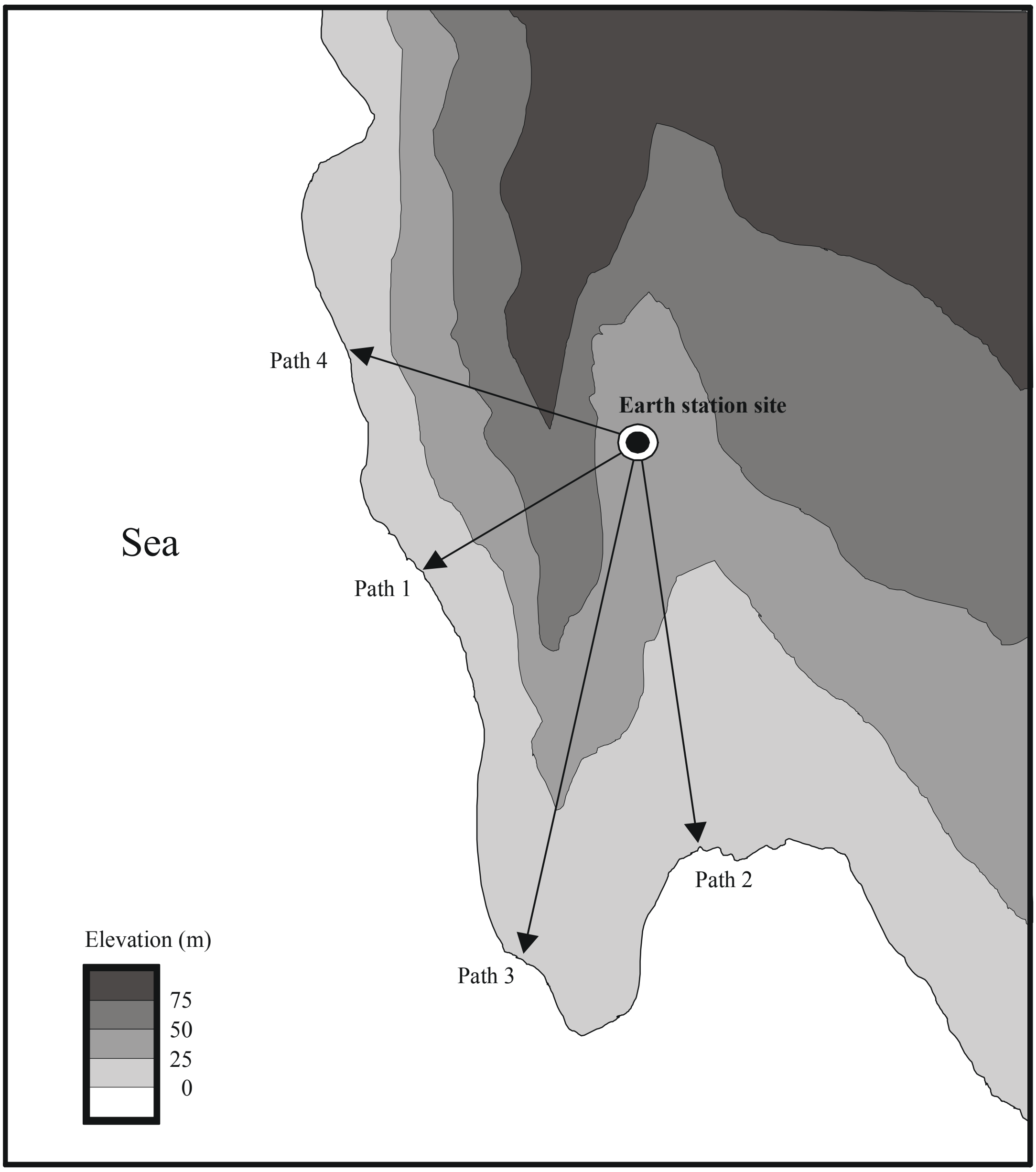
Earth station height AMSL = 40 m

Local annual mean $\Delta N = 45$

Latitude is 35°.

FIGURE 2

Example contour map showing potential ES site



Path lengths:

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

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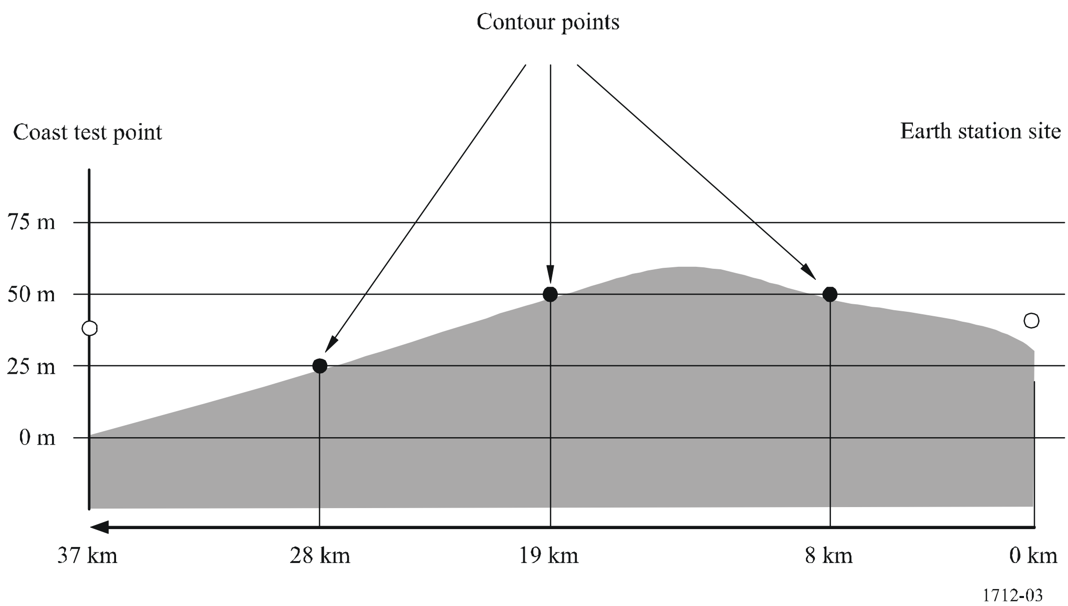
A quick check of Fig. 4 shows that the LoS required separation distance for this earth station (ES) is 63.5 km. The shortest path to the low-water mark (Path 1) is clearly much less than the required LoS distance. Step A does not show compliance. Using ΔN and the earth station height AMSL shows that 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 θ_{ES} = 0.8 mrad and θ_{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.

FIGURE 3

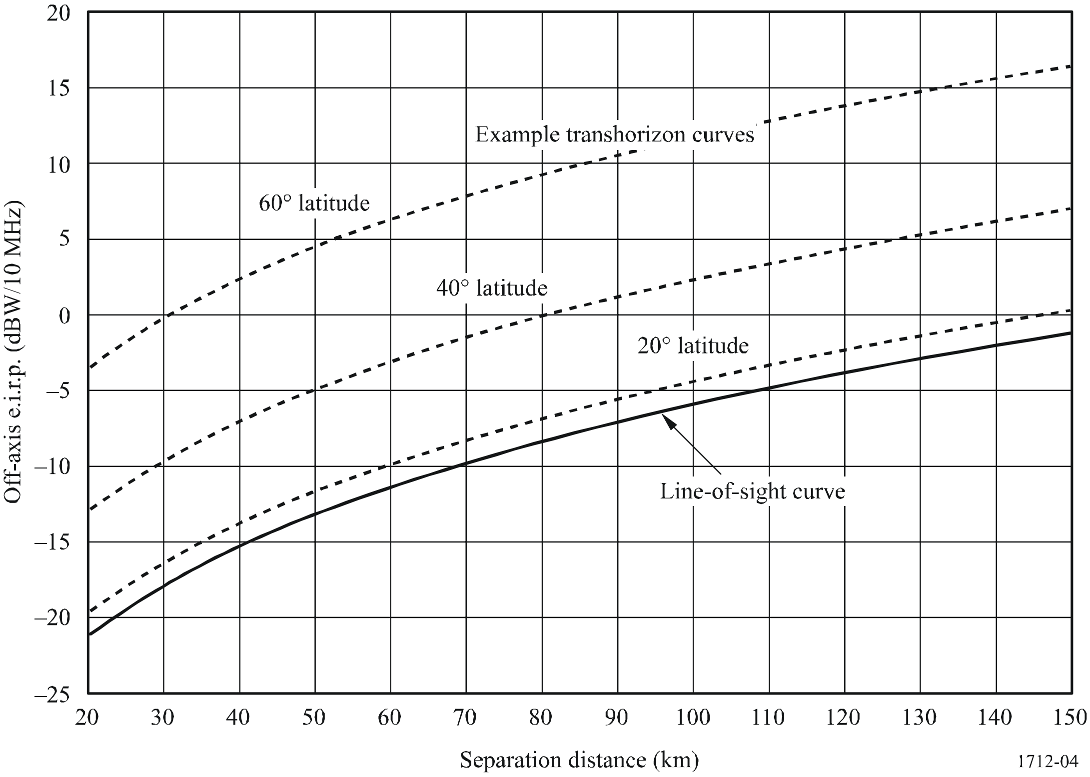
Profile of path 1



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 potential site can be shown to meet the pfd limit criteria through application of Method 3 (Annex 3). To account for different path loss due to different antenna heights, contours are to be defined for a range of earth station heights above local terrain level.

2 Step-by-step description of Method 2

Step 1: Definition of contours: Assuming several typical combinations of antenna diameter and associated on-axis e.i.r.p., a set of contours can be defined as figuring the areas where the considered earth station can be deployed while respecting the limits of RR No. 5.502. Taking into account the earth station discrimination between its direction of pointing and the direction of the border, a value of necessary path loss can be associated with each defined contour.

Step 2: Computation of contours: Knowing the value of the path loss to be associated with each contour, and taking into account an actual terrain database, it is possible to compute the position of each contour on a map. The propagation model to be used is the one described in Recommendation ITU-R P.452-11.

Step 3: Compliance with the pfd limits criteria in RR No. 5.502: This compliance is assessed by the comparison of the position of the earth station intended to be deployed with the contour associated with the corresponding profile:

– if the position of the earth station intended to be deployed is inside the associated contour, the earth station can be deployed with no additional measures while respecting the criteria of RR No. 5.502;

– if the position of the earth station intended to be deployed is outside the associated contour, additional considerations on the actual site environment are required.

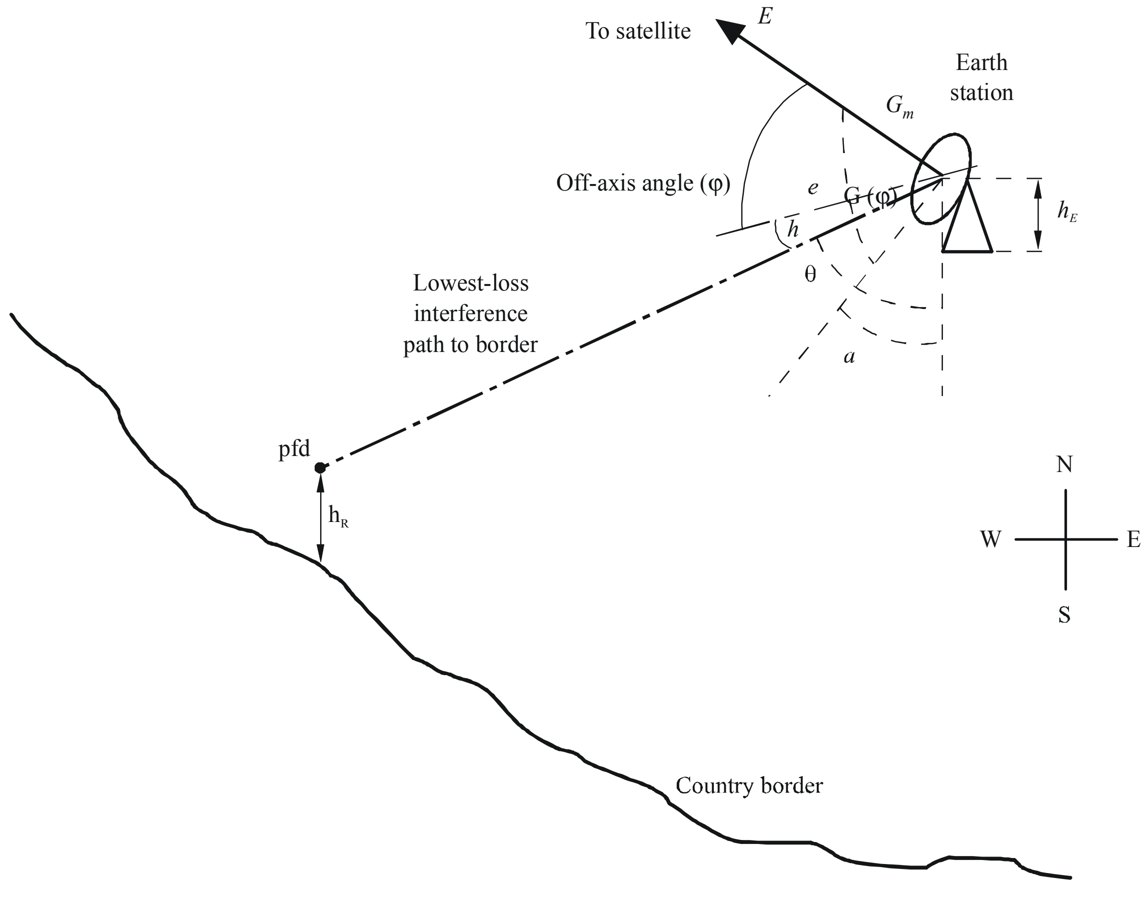
3 Possible application of Method 2

3.1 Interference scenario

The scenario for interference at the border of a country produced by an earth station within the country is illustrated in Figs. 5 and 6.

FIGURE 5

Geometry of interference path



E: earth station e.i.r.p. toward satellite (dB(W/10 MHz))

G_m: on-axis gain of earth station antenna (dBi)

$G(\varphi)$: earth station antenna gain in direction of horizon along the lowest-loss path to border (dBi)

a: azimuth angle of earth station antenna axis (degrees West of South)

e: elevation angle of earth station antenna axis (degrees)

h: elevation angle of the horizon in the direction of the lowest-loss path (degrees)

h_E: height above local ground level of earth station antenna focal point (m)

h_R: height above local ground level of radar antenna focal point (m)

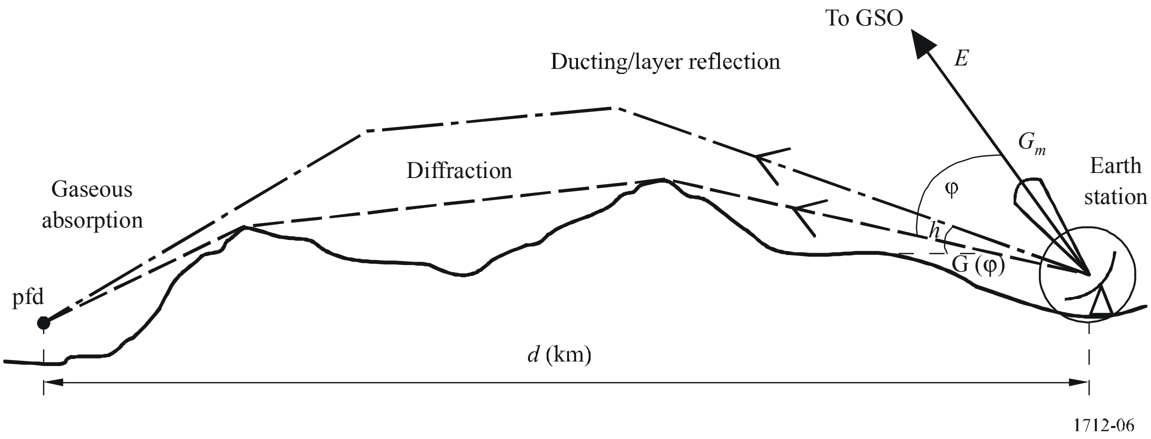
pfd: power flux-density of interference at border (dB(W/(m^2 · 10 MHz)))

θ: azimuth angle of lowest-loss path to the border (degrees West of South)

It should be noted that the off-axis angle, φ, of interest here is the angle between the main beam axis and the axis representing the first part of the lowest-loss interference path, which in general will include a small elevation angle, *h* (usually between about –1° and +3°) (see Fig. 6).

FIGURE 6

Loss on interference path



The pfd at the low-water mark or land border may be calculated by equation (1):

$$\text{pfd} = \text{E} - G_m + G(\varphi) - L - 10 \log (\lambda^2/4\pi) \qquad \text{dB(W/m}^2\text{)} \qquad (1)$$

where:

L: path-loss between isotropic antennas exceeded for all but 1% of the time (dB)

λ: wavelength (m)

At the mid-band frequency of 13.875 MHz, $\lambda = 0.02162$ m, so $10 \log (\lambda^2/4\pi) = -44.29$. Then, to meet the required pfd limit, rearranging equation (1) gives:

$$L = \text{E} - (G_m - G(\varphi)) + 159.29 \qquad \text{dB} \qquad (2)$$

If the factors in the right hand side of equation (2) could be reduced to constants, the areas in which an earth station would meet the pfd limit would be indicated by contours of constant L.

The factor $(G_m - G(\varphi))$ is the discrimination afforded by the earth station transmit antenna pattern in the direction of the interference path, and it depends on the antenna diameter and radiation pattern and on the off-axis angle φ. For the radiation pattern, it is appropriate to employ the algorithms in Recommendation ITU-R S.580 for the side lobes, and to add a main-beam with a square-law roll-off (i.e. $G(\varphi) = G_m - 12(\varphi/\varphi_{3dB})^2$) and a peak gain, G_m, corresponding to an illumination efficiency of 65% (i.e. $G_m = 10 \log [(0.65)\ (\pi D/\lambda)^2]$ where D is the antenna diameter (m), and $\varphi_{3dB} = 70\lambda/D$). Thus, for any given earth station e.i.r.p. and antenna diameter, the value of L required to just meet the pfd limit may be calculated if the relevant value of φ is known.

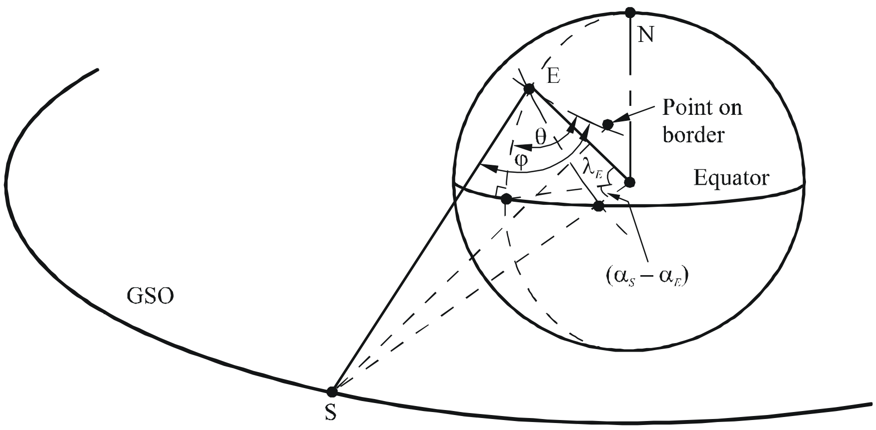
The earth station height above the terrain, $h_{E,}$ should be determined by the concerned administration according to the type of deployment intended. For example, the contours shown later in this Annex were computed for h_E = 11.2 m. This level implies highly-mounted terminals. If the earth station were contemplated for mounting on single-story flat roof structures (such as a gas station), 5 to 6 m would be appropriate. Caution should be used to avoid mounting earth stations above the height used to construct the contours so as to avoid exceeding the permitted pfd at the low-water mark. For mounting on taller buildings in an urban environment, even higher values for h_E would be necessary. In an urban environment, off-axis earth station paths in such locations may be blocked by considerable clutter. In any case, such level of detail goes beyond the intent of Method 2. This method should be based on “typical” deployments rather than extreme cases.

3.2 Earth station off-axis angle for maximum pfd at low-water mark or land border

It can be seen in Fig. 5 that the off-axis angle depends on the direction toward the low-water mark or land border, and on the azimuth, *a*, and elevation, *e*, angles in which the earth station antenna is pointing. From Fig. 6 it can be seen that, to a small extent, φ depends also on the elevation angle, *h*, of the local horizon. From the ITU-R reference patterns it is seen that, for relatively small off-axis angles the antenna discrimination increases fairly rapidly (proportionally to 25 log (φ)), but for larger angles it tends to flatten out. The direction of the lowest-loss path toward the low-water mark or border depends partly on the geography of the terrain between the border and the earth station – i.e. there is a tendency for the lowest-loss path to lie in an azimuth direction near to that in which the distance to the border is shortest, and partly on the nature of the terrain (in hilly terrain the lowest-loss path may not coincide with the shortest path). If the direction of the shortest path is near to the azimuth pointing direction of the earth station antenna and the antenna elevation angle is low then, even if the shortest path is not the lowest-loss path, the highest pfd may be produced because the effect of the antenna discrimination outweighs the effect of the terrain. However, since the azimuth bearing, θ, of the lowest-loss path to the border may be anything from 0 to ±180° with respect to due-South, it is instructive to review how φ varies with θ for different combinations of *a* and *e*. The values of *a* and *e* themselves depend on the latitude of the earth station, λ_E, and on its longitude, α_E, relative to longitude, α_S, of the satellite to which it is transmitting.

FIGURE 7

Relationship of off-axis angle with bearing of point on border



From the geometry of Fig. 7 the off-axis angle φ (when $h = 0°$) was calculated for values of the bearing θ in 5° steps from –180° to + 180°, for earth stations at various different latitudes, and in each case for a range of differences in longitude between earth station E and its satellite S, thus spanning most practicable situations. Considering earth stations in general, all bearings for the lowest-loss path to the low-water mark or the land border are equally likely. Hence it was possible to convert the data thus obtained into cumulative probability distributions of φ. By adjusting these results to allow for $h = +3°$ it was found that in the case of earth stations at ±10º latitude, for example, φ exceeds 48° for 96% of azimuth bearings. Similarly, for earth stations at ±35° latitude φ exceeds 48° for 92% of azimuth bearings, and for earth stations at ±60° latitude φ exceeds 48° for 91% of azimuth bearings. Since 48° is the off-axis angle at which the gain patterns in Recommendation ITU-R S.580 flatten off, the earth station antenna discrimination may thus be regarded as constant in 91% to 96% of cases. The value of that discrimination depends on the antenna diameter, and is as given in Table 1 for antennas with 65% efficiency:

TABLE 1

Maximum antenna discrimination from Recommendation ITU-R S.580

Antenna diameter (m)	1.2	1.5	1.8	2.1	2.6	3.1	4.5
Discrimination ($G_m - G(\varphi)$) for $\varphi \geq 48°$ (dB)	53.0	54.9	56.5	57.8	59.7	61.2	64.4

From the results of the calculations described in the foregoing paragraph it was found that the minimum values of off-axis angle occur for values of θ not far from the difference in longitude between the satellite and the earth station. Therefore, although it is "safe" to employ the present methodology for the great majority of cases, if an earth station site is on or close to the contour relevant to its e.i.r.p. and antenna size and there is reason to believe that the lowest loss path to the low-water mark or land border (e.g. the path to the nearest point is in approximately the azimuth direction of the satellite), and the elevation angle to the satellite is less than ($48°+ h$), it will be necessary to make an individual calculation of the pfd rather than relying on the contour. However, this will only be necessary in a small minority of cases, depending mainly on the latitude of the country in which the FSS earth station is intended to be deployed. In those instances where the FSS earth stations operate above a certain elevation angle (e.g. above $48° + h$ for Recommendation ITU-R S.580 antenna pattern) the e.i.r.p. density towards the horizon will be constant for all azimuths. In such cases, the contours corresponding to the required distance can be computed as a function of input power into the antenna and are independent of the antenna size.

In the exceptional cases where an earth station site is within but close to the contour relevant to the e.i.r.p. and antenna size concerned, the elevation angle is less than 51° (i.e. 48° + 3°), and the azimuth bearing toward the satellite is near to the bearing of the lowest-loss path to the border, the off-axis angle, φ should be calculated from the expression $\varphi = \cos^{-1}[\cos(\theta - a) \cdot \cos(e) \cdot \cos(h) + \sin(e) \cdot \sin(h)]$ (degrees). If the result is less than 48°, then the earth station might exceed the pfd limit at the border by the difference between the off-axis gain derived according to Recommendation ITU-R S.580 for that particular off-axis angle and –10 dBi, if it was exactly on the contour, or less if inside the contour. This excess could be removed by either relocating the earth station to a site further inside the contour, reducing the e.i.r.p., adding local site-shielding, or a combination of some or all of these factors, depending on circumstances. In the worst (and very unlikely) case where $e = 10°$, $h = 3°$ and $\theta = a$, up to 17.9 dB of such mitigation would be required.

3.3 Considerations concerning earth station e.i.r.p. (E)

The remaining factor to be resolved in equation (2) is E. To ensure that any contours produced will embrace the majority of earth station e.i.r.p. levels likely to be transmitted by small-dish earth stations in the band 13.75-14 GHz, a statistical analysis was made of the replies to the Questionnaire in Administrative Circular CA/90 issued by the Radiocommunication Bureau on behalf of Joint Task Group 4-7-8 in 2002. Those replies were based on current practice in the band 14-14.5 GHz, but it is reasonable to anticipate that a similar pattern of use will now develop in the 13.75-14 GHz band. The replies revealed a preponderance of antennas of particular diameters within the range of interest, and these are indicated in Table 1. It was thus convenient to analyse the data in four ranges of antenna diameter, namely 1.2-1.5 m, 1.5-2.1 m, 2.1-3.1 m and 3.1-4.5 m, and the results were obtained in the form of cumultative distribution functions (CDFs) showing the percentage of earth stations as a function of maximum e.i.r.p./10 MHz.

From these CDFs it was deduced that the range of E to be considered here is from 83 dBW, which would cover 90% of the earth stations with the largest antenna diameters (below 4.5 m), and 35 dBW, which would cover only 30% of the earth stations with the smallest diameter antennas (above 1.2 m).

3.4 Basis for contours

The information summarized in § 2 and 3 enabled equation (2) to be used to identify discrete values of L, the path loss required to be exceeded for 99% of the time in order to meet the pfd limit, for a number of suitable cases. The derivation of contours corresponding to these values of L would then define the area in a country where earth stations not exceeding the relevant e.i.r.p. levels could be deployed, without interference mitigation or individual site analysis, and the pfd limit would automatically be met everywhere on the low-water mark or land border. By trial-and-error it was found that five contours would be appropriate in typical cases, and the basis for them is summarized in Table 2 that was compiled from equation (2) and the information referred to in § 3.2 and 3.3.

TABLE 2

Earth station antenna diameter and e.i.r.p. combinations for suitable contours

Contour reference	Antenna diameter range (D m) and ($G_m - G(48° \leq \varphi \leq 180°)$) for minimum size in the range				Path loss, L, exceeded for 99% of time (dB)
	$1.2 \leq D < 1.5$ $G_m - G(\varphi) =$ 53.0 dB	$1.5 \leq D < 2.1$ $G_m - G(\varphi) =$ 54.9 dB	$2.1 \leq D < 3.1$ $G_m - G(\varphi) =$ 57.8 dB	$3.1 \leq D < 4.5$ $G_m - G(\varphi) =$ 61.2 dB	
	E (dB(W/10 MHz))	E (dB(W/10 MHz))	E (dB(W/10 MHz))	E (dB(W/10 MHz))	
A	≤ 36.5	≤ 38.4	≤ 41.3	≤ 44.7	142.8
B	≤ 45.5	≤ 47.4	≤ 50.3	≤ 53.7	151.8
C	≤ 54.5	≤ 56.4	≤ 59.3	≤ 62.7	160.8
D	≤ 63.5	≤ 65.4	≤ 68.3	≤ 71.7	169.8
F	≤ 72.5	≤ 74.4	≤ 77.3	≤ 80.7	178.8

Thus, for example, earth stations with antennas of diameter between 2.1 m and 3.1 m and transmitting e.i.r.p.s of up to 59.3 dB(W/10 MHz) would meet the pfd limit at the low-water mark or land border, without interference mitigation, if they were located anywhere further from the low-water mark or land border than a contour defined by a path loss of 160.8 dB not exceeded for more than 1% of the time (contour reference C).

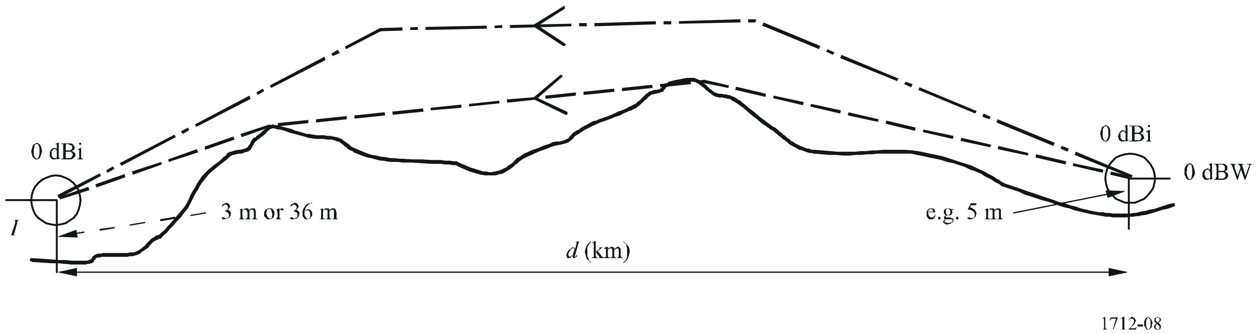
Using the information summarized in § 2 and 3 it is possible to interpolate between contours based on these five path losses. Furthermore, since the values of L in adjacent rows are separated by 9 dB, the benefit of adding 9, 18 or 27 dB of site-shielding local to an earth station may be deduced from the Table; taking the example in the previous paragraph, the addition of 9 dB of site-shielding would enable the earth station either to be deployed up to contour B, or to remain within contour C but increase its e.i.r.p. up to 68.3 dB(W/10 MHz).

3.5 Computation of contours

Losses on an overland path may be calculated by adding (in parallel) the effects of free-space propagation, gaseous absorption, diffraction, tropospheric ducting and layer reflection, using the data and algorithms in Recommendation ITU-R P.452. For a given earth station location, to ensure that the pfd limit is not exceeded it is necessary to find the lowest-loss line to the low-water mark or land border. For flat terrain this will be the line between the earth station and the nearest point on the low-water mark or neighbouring country's land border (as called "border" in this section), but that will not always be the case where the intervening terrain is either moderately or very hilly. Thus a software database containing the heights above sea level over the whole of the area concerned, with a resolution as fine as practicable, is required for the present exercise. The following technique may be used here.

Taking the terrain profile in Fig. 6 as an example, the pfd measurement point may be replaced by a receiver fed by an isotropic receiving antenna, and the FSS transmitting earth station may be replaced by a an isotropic transmitting antenna – as in Fig. 8:

FIGURE 8



Then the level of the received signal I is given by $I = 0 + 0 - L + 0$ dBW. In other words, the level of I (dBW) is numerically equal to minus the value of the path loss L (dB), and this is so regardless of the bearing of the receiver with respect to the transmitter. For the present purpose I should be computed in the manner described in Recommendation ITU-R P.452-11, for 1% of time.

A software model should be constructed, incorporating a terrain database for the country or area of interest, and containing isotropic receiving terminals at appropriately small intervals along the low-water mark or land border. A grid of equally-spaced 0 dBW isotropic radiators should be added covering the entire country or area concerned. Then the contribution to I at each and every receiver, generated by each and every transmitter should be computed, using Recommendation ITU-R P.452-11 techniques to evaluate the loss exceeded for all but 1% of the time, and all the values for each receiver should be separately stored. The software should be arranged to identify the maximum individual contribution to I for each receiver, and also the individual transmitter in the grid responsible for it[2]. Then, by selecting the transmitters for which the maximum I contribution is closest to minus the value of L required, a contour may be constructed by drawing a line between those transmitters. For improved accuracy it is possible to use linear interpolation between pairs of transmitters corresponding to the maximum I contributions that are the closest above and below the target value, as illustrated in Fig. 9.

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[2] This latter feature enables the lowest-loss path to the border for any individual point on a contour to be identified in those cases where there is doubt that the pfd limit would be met. From the terrain profile of that path, h may be found.

FIGURE 9

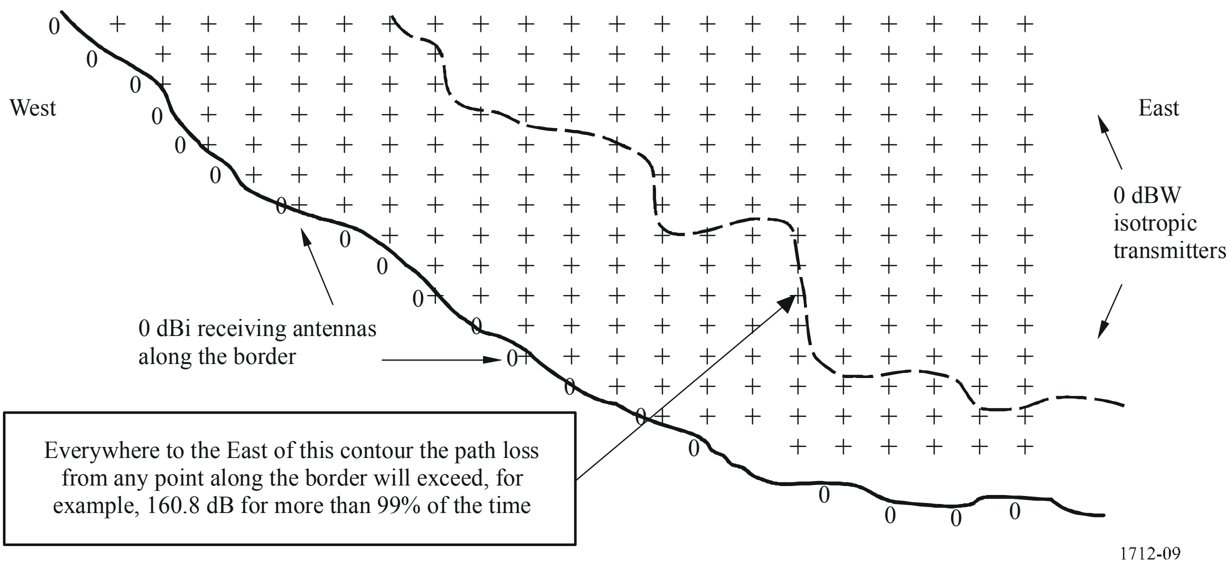
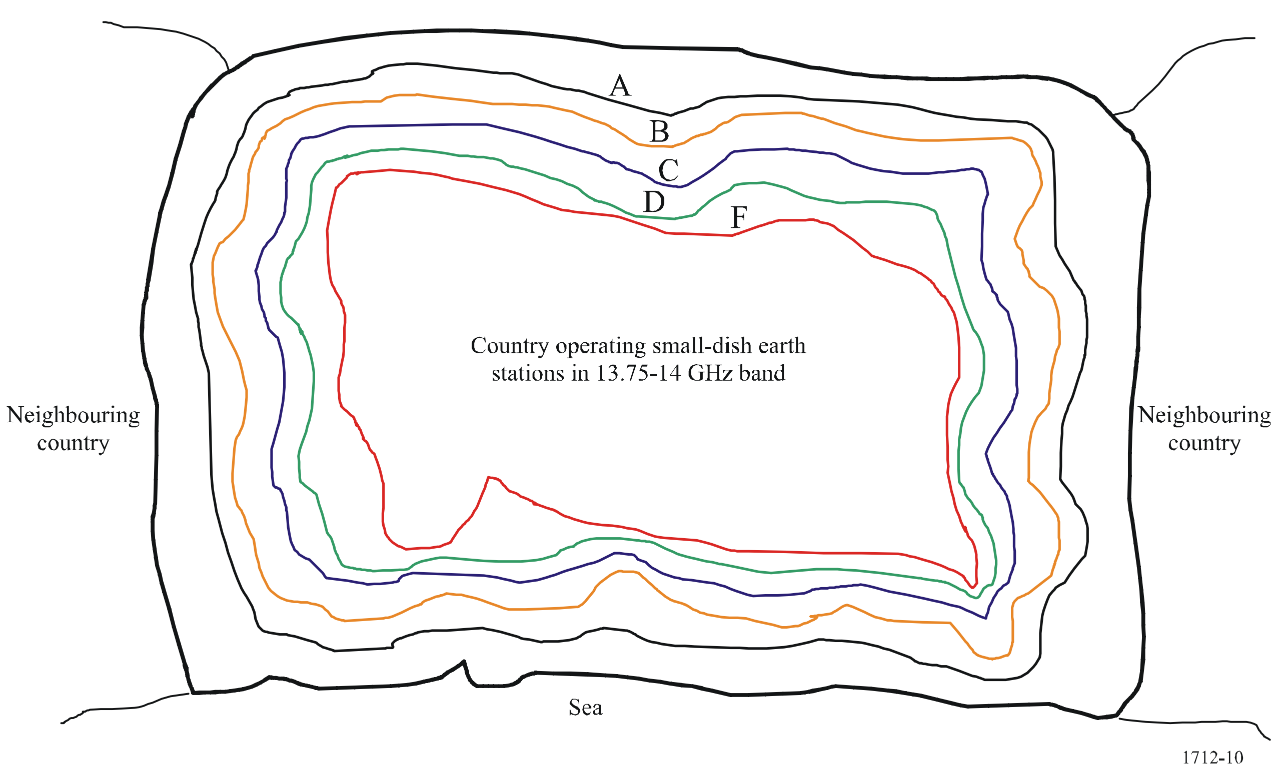


FIGURE 10



In the area between a contour and the low-water mark or land border it may be possible to operate small-dish earth stations if interference mitigation techniques such as restriction to lower-e.i.r.p. carriers and or local site-shielding are applied, but that would have to be determined on a case-by-case basis. In each such case the present methodology could be used to determine the lowest-loss path from the site to the low-water mark or land border, and the loss of that path, and that would determine the degree of mitigation required.

It is worth noting that, for particular cases in which small-dish earth stations are planned always to operate to a single location in the GSO, system-specific contours may be computed by adapting the methodology so that each (+) point in the grid in Fig. 9 includes an antenna pointing toward that location.

3.6 Examples of applying the methodology described in § 3.1 to 3.5

Using a proprietary software package incorporating a global terrain database having a horizontal resolution of 1 km and a vertical resolution of 1 m, the foregoing methodology was employed to construct models of eight different areas, with the aim of covering a variety of country sizes, types of terrain and climate. For each receive point on a coast (in these examples the low-water mark was set at the coast) the antenna height was set at 36 m, and for receive points on land borders the height was set at 3 m. In order to produce contours each covering the whole range of earth station antenna sizes it was necessary to select a single height for all the transmit points. A transmit height of 11.2 m was chosen for the present computations. All the areas selected are in well-populated parts of the world. The details are listed in Table 3.

TABLE 3

Characteristics of software models constructed

Geographical area	Size of country	Climate (ΔN)[(1)]	Type of terrain	Receiver spacing (km)	Transmitter grid interval (km)	No. of paths computed[(2)]
Mississippi Basin	Large	Temperate (51)	Non-hilly	10	10	455 224
Southern England	Medium	Temperate (45)	Medium	10	5	83 582
Southern Turkey	Medium	Temperate (45)	Hilly	10	10	300 000
North-West India	Large	Tropical (60)	Non-hilly	10	10	702 450
Central Mexico	Medium	Tropical (60)	Hilly	10	10	691 114
Cuba	Long, thin island	Tropical (55)	Medium-to-non-hilly	10	10	346 626
Java	Long, thin island	Tropical (60)	Medium-to-hilly	10	10	288 144
Cyprus	Small island	Temperate (50)	Medium	6	4	252 960

(1) ΔN is the average radio-refractive index lapse-rate through the lowest 1 km of the atmosphere, which depends significantly on climate and is needed for the path loss calculation method of Recommendation ITU-R P.452.

(2) i.e. Number of transmit points in grid multiplied by number of receive points on border.

In order to obtain complete contours as illustrated in Fig. 10 it is necessary to model the whole border of a country, which for large countries would require the inclusion of large numbers of transmit and receive points and correspondingly long construction and computing times. Furthermore, the ability to print on a sheet very much larger than A4 size would be needed in order to use such complete contours with accuracy. Ideally a terrain database of higher resolution than the one used here would be employed, and to obtain the benefit of it the spacing between adjacent transmit points and between adjacent receive points should be smaller, which would further increase the modelling and computing times. In view of these factors it is probably convenient for an administration to model parts of its country separately, especially if the most accurate contours practicable are required.

Examples from the results obtained for the areas listed in Table 3 are shown in Figs. 11, 12 and 13, in which it can be seen that contours corresponding to the earth station antenna diameter and e.i.r.p. combinations defined in Table 2 are shown. For convenience the contours are labelled A, B, C, D and F as in Table 2 and Fig. 10, and they are displayed in contrasting colours to aid legibility.

Overall the full set of results were found to adequately demonstrate the effectiveness of the methodology in this Annex in determining where the great majority of FSS earth stations using the band 13.75-14 GHz could be placed without exceeding the pfd limits in RR No. 5.502. However, it would be preferable for FSS operators in the countries concerned to use more detailed maps, a higher resolution terrain database and a greater density of transmit and receive points per model, for the assessment of sites near the contours.

Fig. 11, Mississippi Basin, United States of America

As expected, the contours for the lowest e.i.r.p.s are nearest the low-water mark while those for the highest e.i.r.p.s are furthest from the low-water mark. The mean distances from the low-water mark vary from about 30 km for contour A to about 130 km for contour F, and thus the zones between the contours and the low-water mark represent fairly large areas in which earth stations transmitting the e.i.r.p.s indicated, and without site-shielding or another interference-mitigation technique, could not legally use the 13.75-14 GHz band. This arises because the terrain in the Mississippi Basin is relatively flat and hence diffraction losses are relatively low. Fortunately the United States of America is a large country, so the proportion of its land mass in which FSS use of the band would have constraints is fairly modest.

Fig. 12, Central Mexico

The fact that Mexico is a mountainous country and is mostly well above sea level allows earth stations to be operated in the great majority of its territory without exceeding the pfd limit at its borders. The terrain near the south coast is such that there is little difference between the five contours, and only earth stations within an average of about 20 km of the sea would face restrictions in the 13.75-14 GHz band. Near the north coast constraints would be faced by earth stations over a rather larger area owing to some relatively low land around river valleys, but even there the average distances between contour and sea are less than in North West India or the Mississippi Basin, despite the tropical climate.

Fig. 13, Cuba (Caribbean)

Clearly, although contour A would cover most of Cuba, contours B, C, D and F cover only small or very small proportions of this thin island, and thus one or more of the interference mitigation techniques described in Annex 4 would be needed unless it should deemed satisfactory for only low e.i.r.p. carriers to be operated (see Table 2). Accordingly the computation was adapted to provide an additional contour G, which corresponds to a minimum path loss to the low-water mark for all but 1% of the time of 138 dB, i.e. about 5 dB less than in the case of contour A. It follows that if 5 dB of interference mitigation can be applied at an earth station conforming to the first row in Table 2, the pfd limit will be met by that station if it is located anywhere inside contour G. Similarly, if 14 dB of mitigation can be applied to an earth station conforming to the second row in Table 2, then that earth station may be located anywhere within contour G. And 23 dB of mitigation for the third row, etc.

Furthermore, the application of 9 dB of interference mitigation to any earth station conforming to one of the rows in Table 2 would enable it to be located within the contour defined by the next row above in the Table.

FIGURE 11

Contours beyond which earth stations without shielding would meet pfd = –115 dB(W/(m^2 · 10 MHz)) at coast for 99% of time

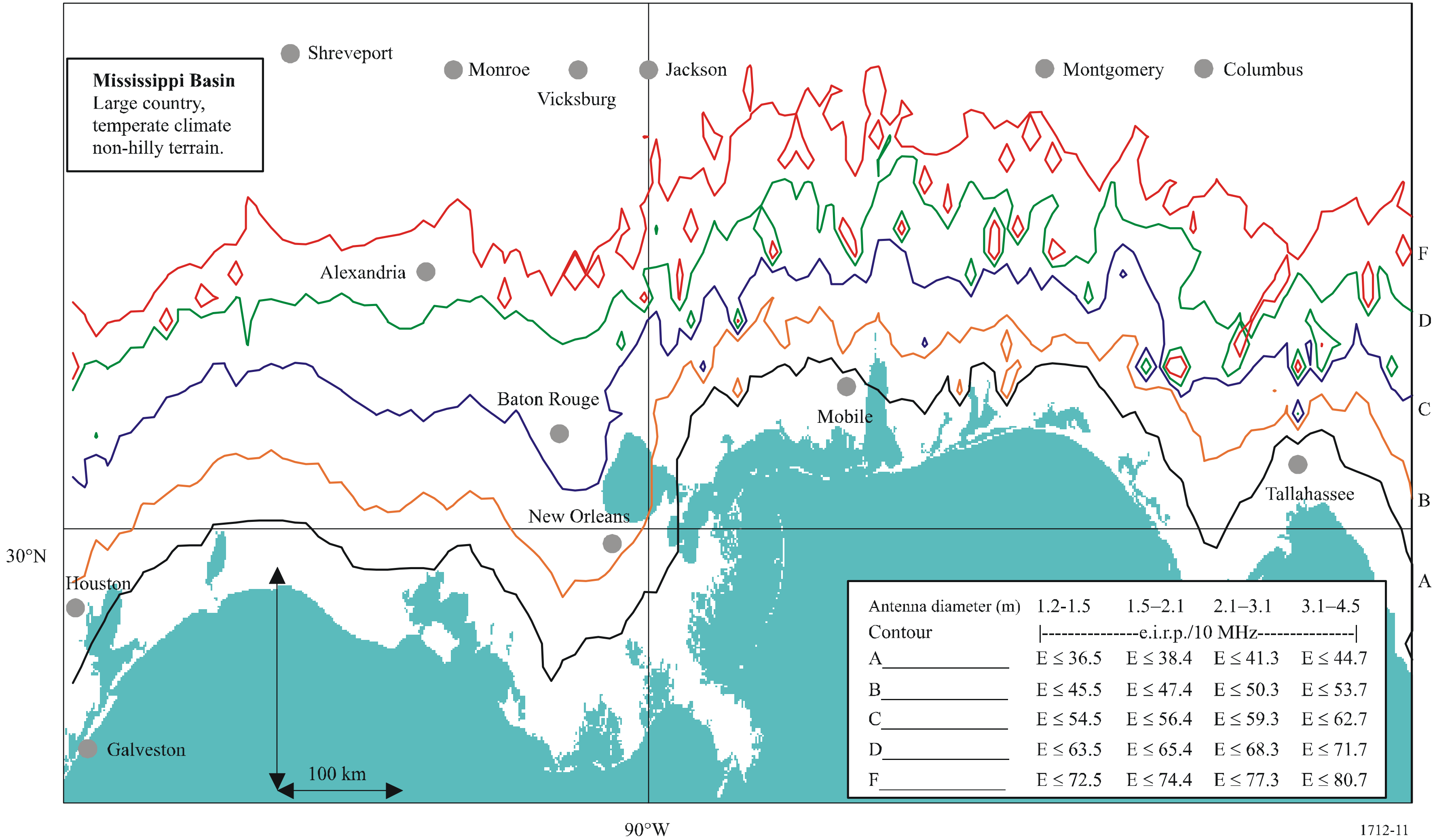
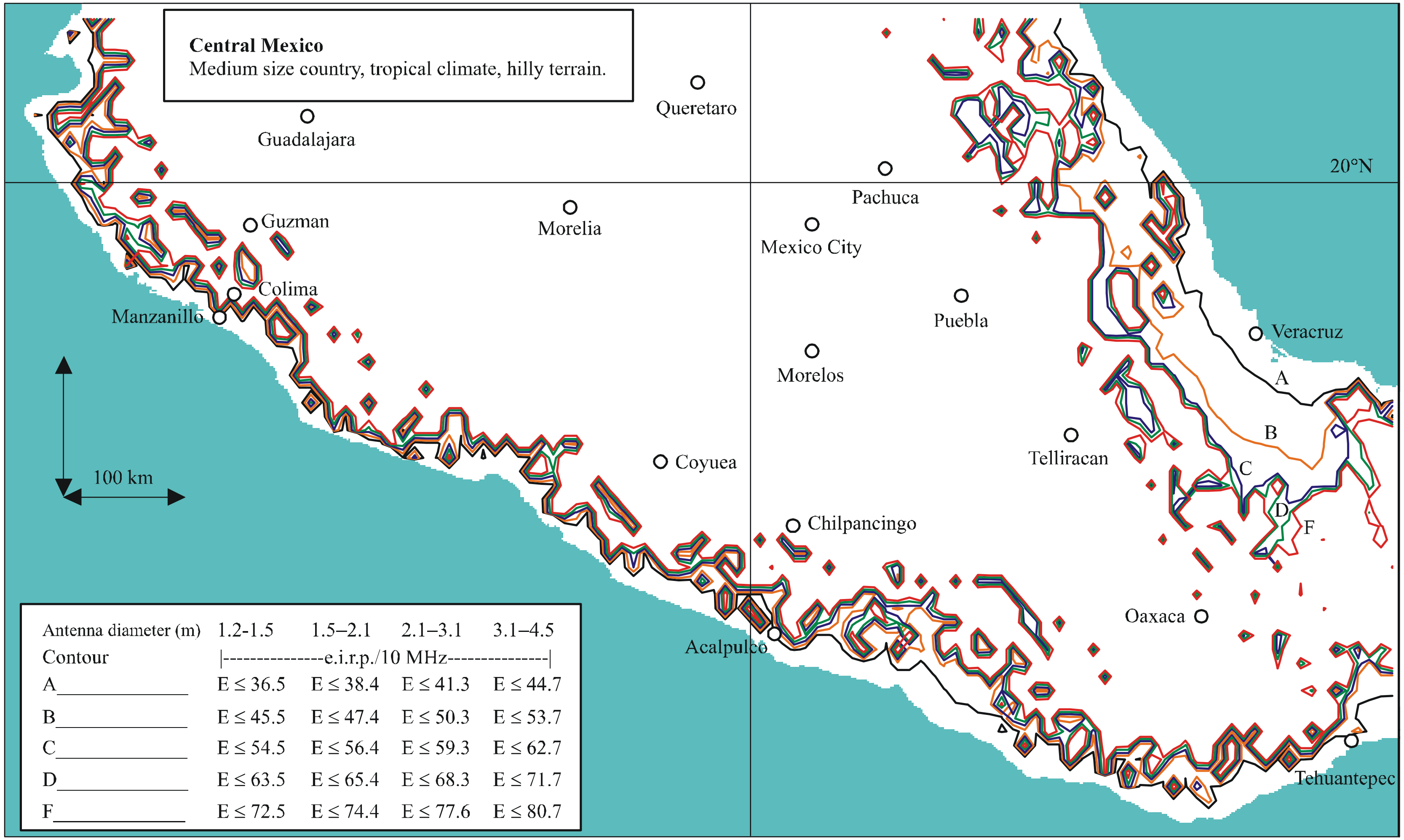


FIGURE 12

Contours beyond which earth stations without shielding would meet pfd = –115 dB(W/(m^2 · 10 MHz)) at coast for 99% of time

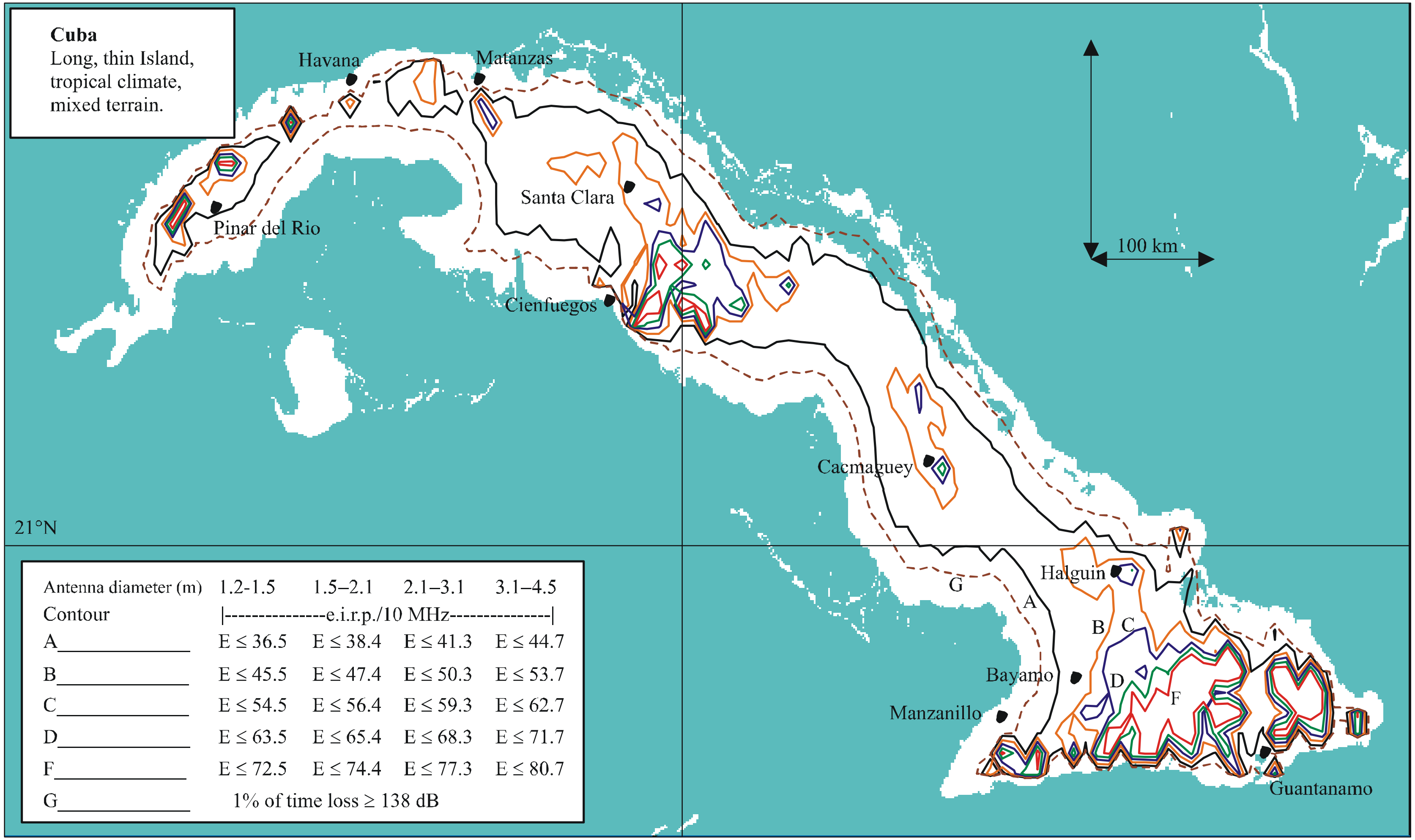


100°W

1712-12

FIGURE 13

Contours beyond which earth stations without shielding would meet pfd = –115 dB(W/(m^2 · 10 MHz)) at coast for 99% of time



80°W

1712-13

Annex 3

Method 3: Method to check compliance of an FSS earth station with the pfd limits of RR No. 5.502 based on site-specific analysis

1 General

The basis of this method is to perform a site-specific analysis for each FSS earth station to be deployed. Deployment may go forward if the analysis shows that the earth station can meet the pfd limits criteria of RR No. 5.502. The analysis is accomplished by using digital terrain data in conjunction with the FSS earth station parameters, appropriate propagation models and any other attenuation due to natural or manmade shielding. It is expected that Method 3 will only be employed when a potential deployment site cannot be shown to be compliant with the pfd limits using either Method 1 or Method 2.

2 A description of Method 3

Step 1: Digital terrain data that includes the earth station site and surrounding area is required. The data should encompass a sufficient area to reasonably perform the pfd analysis. It is recommended that the resolution of the digital terrain data used is at least 30 arc/s horizontally and 1 m vertically (e.g. GTOPO30 or GLOBE). If a higher resolution model is available for the administration concerned, its use is encouraged.

Step 2: The parameters of the FSS earth station to be deployed will be required for the analysis. This includes the earth station's antenna size, height above terrain, carrier spectral density, and GSO satellite assignment(s). The appropriate reference earth station radiation pattern for this method could be the one provided by the earth station operator or the one found in the relevant ITU-R Recommendations. Note that if it is envisaged that the earth station may have widely different pointing directions, whether because it may be reassigned at some future time or if an alternate GSO satellite is needed during the initial deployment, then the site-specific analysis will need to be performed for each of these pointing directions.

Step 3: As with the first two methods, the propagation model best suited to the site-specific analysis is Recommendation ITU-R P.452-11.

Step 4: The FSS earth station parameters, digital terrain data, and propagation models enable calculation of the path loss in all direction around the potential site. This in turn yields the pfd at the low-water mark or neighbouring country's land border produced by the station. If the pfd limits criteria of RR No. 5.502 are met, then deployment may proceed. Otherwise, additional interference mitigation techniques may need to be applied. It should be noted that in some locations, particularly those within direct LoS of the low-water mark or land border, deployment may be difficult. Extra attenuation accrued by natural or man-made site-shielding can be applied to this method. The determination of the precise level of attenuation from site-shielding will require further study with a combination of analysis using the above models.

Step 5: A site survey measuring the horizon profile around the earth station from which the actual attenuation from local site-shielding and actual terrain could be derived and applied in the calculations to determine the pfd at the low-water mark or land border produced by the station.

Annex 4

Additional considerations for small and narrow countries to meet the criteria of RR No. 5.502 and/or as a basis for the establishment of bilateral agreements to exceed the limits of RR No. 5.502

1 General

If a country is geographically small or narrow, contours based on the Methods 1 and 2 (Annexes 1 and 2) may exclude the majority of the territory.

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 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.

The following sections introduce measures that all administrations can take to help meet the requirements of RR No. 5.502. These same considerations might be taken into account in bilateral discussions concerning small or narrow countries. Since circumstances differ widely from country to country, no attempt to generalize is made here. It is advisable for each case to be considered on its merits in order to decide which of the possibilities to take into account, and to what extent they are applicable.

2 Restrict operation in the 13.75-14 GHz band to medium or low e.i.r.p. carriers

Table 4 may be used to determine the reduction in maximum e.i.r.p. achievable by restricting the proportion of 14 GHz band carriers in comparison with those currently operated in the 14-14.5 GHz band. To obtain these results the available data were used to compile cumulative distributions giving percentage of earth stations-vs.-e.i.r.p./10 MHz for each of the four ranges of antenna size. Thus, for example, by foregoing the opportunity to deploy the 20% of earth stations with antenna diameters between 1.2 m and 1.5 m that would transmit e.i.r.p. levels at the high end of the range, all other earth stations could be operated up to a contour corresponding to 9 dB lower minimum path-loss to the border, without exceeding the pfd limit anywhere on the border.

TABLE 4

Reductions in maximum e.i.r.p./in 10 MHz-restrictions – restrictions in proportion of carriers

Antenna diameter range	Reduction in proportion of carriers			
	100% to 80%	80% to 60%	60% to 40%	40% to 20%
1.2 m ≤ D < 1.5 m	55 – 46 = 9 dB	46 – 42 = 4 dB	42 – 39 = 3 dB	39 – (-2) = 41 dB
1.5 m ≤ D < 2.1 m	70 – 49 = 21 dB	49 – 47 = 2 dB	47 – 47 = 0 dB	47 – 43 = 4 dB
2.1 m ≤ D < 3.1 m	85 – 61 = 24 dB	61 – 52 = 9 dB	52 – 52 = 0 dB	52 – 52 = 0 dB
3.1 m ≤ D < 4.5 m	95 – 71 = 24 dB	71 – 63 = 8 dB	63 – 56 = 7 dB	56 – 47 = 9 dB

If a given reduction in the proportion of earth stations in a particular antenna size range that would otherwise be operable between 13.75 GHz and 14 GHz could be accepted, the corresponding reduction in maximum e.i.r.p. could be determined in this way, and the relevant contour computed as described in Annex 2. That contour would encompass more of the small country concerned than if the constraint had not been accepted.

3 Apply local site-shielding to earth stations

It is possible to reduce the maximum interference produced at the low-water mark or neighbouring country's land border by any earth station within a country by the addition of shielding attenuation to the site of that earth station. This may be done either by locating the antenna behind a building or other obstacle in the direction of the closest point at which the pfd has to be met, or by the addition of a shield of attenuating material on that side. Since the practicality and/or cost-effectiveness of such measures depends on circumstances, their feasibility can only be assessed on a case-by-case basis. Although shielding in front of an antenna will reduce the interference toward the horizon, the benefit can be offset by signal enhancement due to reflections from buildings or other objects in the vicinity of the antenna. Furthermore, it is difficult to derive worthwhile shielding if the antenna operates at relatively low elevation and the nearest part of the border lies generally in the direction of the Equator. Another factor is that the cost associated with either locating behind a building or adding an artificial shield may increase the cost of a small-dish terminal by a significant percentage.

ITU-R reviewed the shielding and "clutter" attenuations calculated using the empirical algorithms in Recommendations ITU-R P.452 and ITU-R P.526, and compared them with the results of measurements reported in the United Kingdom in 1995. The provisional conclusion of the ITU-R was that, in cases where it is practicable, the attenuation available from site-shielding will usually be between 5 dB and 20 dB depending on circumstances, and is unlikely to exceed 25 dB. More work is needed to confirm this conclusion and expand on the possibilities of site-shielding.

Once the degree of site-shielding attenuation (A dB) available for a specific site has been estimated, and the methodology in Annex 2 has been used to find the magnitude and direction of the minimum loss, L, to the border, equation (2) rearranged and including A can be used to determine the maximum e.i.r.p./10 MHz which an earth station at the site could transmit without exceeding the RR No. 5.502 pfd limit, i.e. $E = L + A + (G_m - G(\varphi)) - 159.29$ dBW.

4 Selection of earth station antenna diameter

If the attenuation in the direction of the lowest-loss path to the low-water mark or neighbouring country's land border is insufficient for the pfd limits to be met by a planned earth station, but only by a modest amount, one possibility might be to use a slightly larger antenna than would otherwise be necessary. This would enable the transmitter power to be reduced by an amount equal to the difference in antenna gain, thus reducing the off-axis e.i.r.p. by the same amount. Since antenna gain is proportional to the square of the diameter, D, Table 5 gives some changes in D to compensate for potential exceedences of the pfd limits within the probable range of interest.

TABLE 5

Increases in antenna diameter to compensate for attenuation shortfall

Excess of pfd to be compensated	1 dB				2 dB				3 dB				4 dB			
Baseline antenna diameter (m)	1.2	1.5	1.8	2.1	1.2	1.5	1.8	2.1	1.2	1.5	1.8	2.1	1.2	1.5	1.8	2.1
Substitute antenna diameter (m)	1.35	1.68	2.02	2.36	1.51	1.89	2.27	2.64	1.70	2.12	2.54	2.97	1.90	2.38	2.85	3.33

5 Seek bilateral agreements to exceed the pfd limit

Given that if a country is small, the length of border near which radar terminals in neighbouring countries, or at sea, may be exposed to interference from FSS earth stations within the country is also small, so the overall impact on the radiolocation service may be correspondingly small. Therefore it may be possible for a small country to conclude for terminals in the 13.75-14 GHz band in that area when the pfd limit is exceeded by up to a specified amount, e.g. 5 dB or 10 dB.

Conceptually it would appear to be possible to reach agreement to relax the time percentage part of the limit, rather than to relax the pfd level – for example to permit –115 dB(W/m^2) to be exceeded for, say, 5% of the time rather than 1% of the time. However, ITU-R studies revealed that, at least in the case of a medium terrain in a temperate climate, contours for a range of specific path-loss levels change very little if the time percentage is increased above about 0.5% (although they tend to worsen significantly from the FSS viewpoint if the time percentage is reduced below that figure). Hence it seems that in practice, whilst modest increases in pfd level may be worth considering, increasing the time percentage is unlikely to be a worthwhile line for bilateral discussions to pursue.

6 Seek bilateral agreements to waive the pfd limit for part of the band

If individual mobile radar signals within the 13.75-14 GHz band occupy bandwidths which are significantly less than 250 MHz, it may be possible for a small country to restrict its FSS use to part of the band, and for another administration to use only the remainder of the band for its mobile radar terminals while they are in the vicinity of the small country. This would be a form of limited band-segmentation.

During the statistical analysis of the available data it was noted that the majority of 14 GHz band earth stations with antennas in the 1.2-4.5 m diameter range transmit single carriers having bandwidths less than 10 MHz, and that very few operate carriers having bandwidths greater than 36 MHz. The criterion used in Radiocommunication Study Group 8 for the protection of 14 GHz band radar terminals is an *I*/*N* ratio of –6 dB in a bandwidth of 10 MHz, and this suggests that the bandwidths of typical radar signals in the band 13.75-14 GHz are of the order of 10 MHz. Hence there appears to be scope for bilateral agreements based on band segmentation, although this might be regarded as a last resort since it would reduce the amount of spectrum available to both services, albeit only in and around small countries. However, RR No. 5.503 must be kept in mind when considering band-segmentation options.