Minimum Propagation Loss for Ducting Mode Around Cebreros Deep-Space Station

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ABSTRACT. — This article reviews the transmission losses due to different propagation modes given in the Recommendation ITU-R P. 452-14, and derives a general lower bound for the ducting loss. This derived lower bound for the ducting loss is applied to the European Space Agency (ESA) Cebreros deep-space station. In addition, the results of a statistical study of the ducting losses for the Cebreros deep-space station are given. The results indicate that the ducting loss may become smaller than the troposcatter and diffraction losses for separation distances less than 10 km. Since, for most cases, the separation distances between the transmitters and the deep-space station receiver are expected to be greater than 10 km, only the troposcatter and diffraction losses need to be considered in interference analyses, and the ducting losses can be neglected.

I. Introduction

In a past meeting of the Space Frequency Coordination Group (SFCG), we presented a paper that described a methodology for estimating the aggregated interference from high-density fixed service (HDFS) transmitters to deep-space stations operating in the 37-GHz band. In our paper, we stated that, for the deep-space stations, the troposcatter and diffraction modes contributed the most interference, while the ducting mode contributed the least interference. Thus, to calculate the transmission losses between the HDFS transmitters and the deep-space station receiver, we included only the losses due to troposcatter and diffraction modes of the clear-air atmosphere. These modes are described in detail in Recommendation ITU-R P. 452-14, which gives prediction procedures to evaluate interference between stations on the surface of Earth at frequencies above 0.1 GHz.

In a later meeting of SFCG, a study was presented for the European Space Agency (ESA) Cebreros deep-space station that has raised some questions about our methodology for estimating the aggregated interference. This study indicated that interference received from HDFS transmitters through the ducting mode could become dominant for a very small percentage of time.

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Thus, in order to better understand the behavior of the ducting losses, we reviewed all the propagation modes given in Recommendation ITU-R P. 452-14, and derived a general lower bound for the ducting loss. We then applied this lower bound for the ducting losses to the Cebreros deep-space station. We also performed a statistical study of the ducting losses for this case. We found that the minimum ducting loss for $p = 0.001$ percent of time is about 116.9 dB at 1 km. We also found that the ducting loss is less than the troposcatter and diffraction losses for separation distances less than 10 km, confirming the result of the other study for the Cebreros deep-space station. However, for distances greater than 10 km, propagation losses for ducting mode can be neglected. Since, for an HDFS deployment, the transmitters are not expected to be closer than 10 km to any deep-space station, our methodology, as described in our article, can still be used. In the future, we plan to expand our methodology for predicting the transmission loss between the HDFS transmitters and the deep-space station to include the propagation modes of troposcatter, diffraction, and ducting.

In summary, it is important to note that ducting can be the dominant clear-air propagation mode for over-the-sea paths, but for inland paths, which include the three deep-space station sites, ducting will only be the dominant propagation mode for line-of-sight paths and for a small percentage of time.

The following sections give the derivation of the lower bound for the ducting loss.

II. Path Profile Analysis

Recommendation ITU-R P. 452-14 gives the transmission loss equations for the troposcatter, diffraction, and ducting propagation modes using the parameters derived from the terrain profile between the transmitter and the receiver. This path profile analysis requires the specification of terrain heights above mean sea level for enough numbers of terrain points along the path from the transmitter to the receiver.

Figure 1 shows the relevant terrain profile parameters used in this article. Their definitions are included in Table 1.

Assuming that the true Earth radius is 6371 km, the effective Earth radius a_e is given by

$$a_e = 6371k_{50} = 6371 \cdot 157/(157 - \Delta N) \qquad (\text{km}) \qquad (1)$$

where k_{50} is the median effective Earth radius factor and ΔN represents the average radio-refractive index lapse rate (N-units/km) through the lowest 1 km of the atmosphere, which depends on the latitude of the path center.
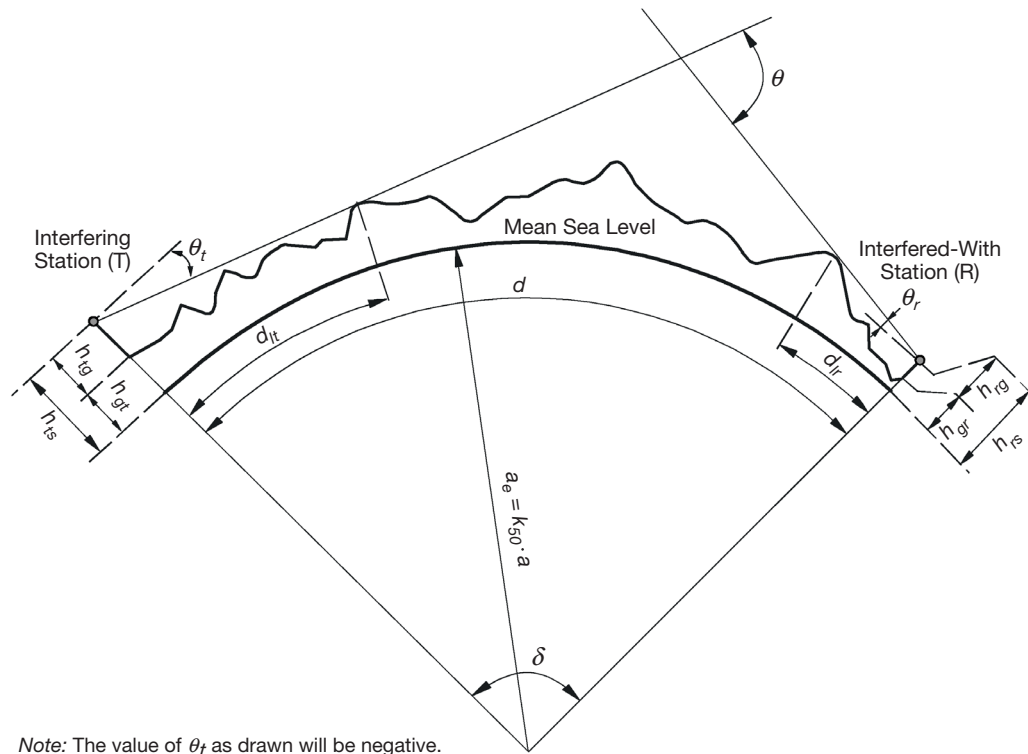
Note: The value of θ_t as drawn will be negative.

Figure 1. A sketch showing a terrain profile with a smooth-Earth surface and other terrain parameters used in path profile analysis.

Table 1. Path profile parameter definitions.

Parameter	Unit	Description
a_e	km	Effective Earth radius
d	km	Separation distance between the transmitter and the receiver along the great circle
d_{lt}	km	Transmitter horizon distance: For a line-of-sight path, it is set to the distance from the transmitter to the principal edge, identified in the diffraction method for 50 percent time.
d_{lr}	km	Receiver horizon distance: For a line-of-sight path, it is set to the distance from the receiver to the principal edge, identified in the diffraction method for 50 percent time.
h_{ts}	m	Transmitter altitude above mean sea level: It is the sum of the transmitter antenna height and the ground altitude.
h_{rs}	m	Receiver altitude above mean sea level: It is the sum of the receiver antenna height and the ground altitude.
θ_t	mrad	Transmitter horizon elevation angle: For a line-of-sight path, it is set to the elevation angle of the receiver seen from the transmitter.
θ_r	mrad	Receiver horizon elevation angle: For a line-of-sight path, it is set to the elevation angle of the transmitter seen from the receiver.
δ	mrad	Separation angle between the transmitter and the receiver at the center of Earth
θ	mrad	Path angle

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Now, using the definitions of the path profile parameters and the geometry depicted in Figure 1, one can easily show the following expressions for the path angle and the separation distance:

$$\theta = \delta + \theta_t + \theta_r = 10^3 d/a_e + \theta_t + \theta_r \tag{2}$$

and

$$d \geq d_{lt} + d_{lr} \tag{3}$$

Recommendation ITU-R P. 452-14 also introduces a modified definition of path angle where, in Equation 2, θ_t and θ_r are not allowed to get larger than 0.1 d_t and 0.1 d_r, respectively. This modified path angle definition is used especially in calculating the site shielding losses and path angle dependent losses. In this article, since we are deriving lower bound for the loss terms, we will not need this detail. Using the path angle as shown in Figure 1 will suffice. In this article, we will use this path angle to classify the paths into three different cases: $\theta = 0$, $\delta > \theta > 0$, and $\theta \geq \delta$.

Case 1, with $\theta = 0$, includes all the line-of-sight paths. It is easy to see that, for this case, we also have the separation distance equal to the sum of the transmitter and receiver horizon distances $(d = d_{lt} + d_{lr})$.

Case 2, with $\delta > \theta > 0$, includes the non-line-of-sight paths whose separation angles are greater than the path angles. This happens when the sum of the horizon angles for the stations is negative, meaning that altitudes of one or both stations are higher than the horizon altitudes.

Case 3, with $\theta \geq \delta$, includes most of the non-line-of-sight paths where the sum of the transmitter and receiver horizon angles is non-negative, i.e., $\theta_t + \theta_r \geq 0$. This condition is true for all the paths where the station altitudes are lower than the surrounding terrain, resulting in positive horizon angles for transmitter and receiver. This condition is also true for some paths with a negative horizon angle for one station, as long as the horizon angle of the other station is large enough so that the sum of horizon angles is positive.

In the following sections, lower bounds for the ducting loss will be derived for these three cases. The results show that the lower bounds for line-of-sight and non-line-of-sight paths can vary considerably depending on which terms are replaced by their lower bounds.

III. Ducting Loss Analysis

The Recommendation ITU-R P. 452-14 gives the following equation to predict the basic transmission loss, L_{ba}, occurring during periods of anomalous propagation due to ducting and layer reflection:

$$L_{ba} = A_f + A_d(p) + A_g \quad (\text{dB}) \tag{4}$$

where A_f is the total fixed coupling loss (dB) between the antennas and the anomalous propagation structure within the atmosphere, $A_d(p)$ is the path-angle and time-percentage dependent loss (dB) within the anomalous propagation mode, and A_g is the total gaseous absorption loss (dB) for the whole path length. The following sections give the equations for how to estimate these loss terms and derive some lower bounds for them.

A. Total Fixed Coupling Loss

The first term of the ducting loss equation is the total fixed coupling loss. It is estimated by

$$A_f = 102.45 + 20\log f + 20\log(d_{lt} + d_{lr}) + A_{lf} + A_{st} + A_{sr} + A_{ct} + A_{cr} \quad (\text{dB}) \quad (5)$$

where f is the frequency (GHz), d_{lt} and d_{lr} are the horizon distances (km) for transmitter and receiver (see Figure 1), A_{lf} is the empirical correction (dB) to account for the increasing attenuation with wavelength in ducted propagation, A_{st} and A_{sr} are the site-shielding diffraction losses (dB) for transmitter and receiver, and A_{ct} and A_{cr} are the over-sea surface duct coupling corrections for transmitter and receiver. Now, we can write a lower bound for A_f as

$$A_f \geq 102.45 + 20\log f + 20\log(d_{lt} + d_{lr}) \quad (\text{dB}) \quad (6)$$

by replacing the last five A-terms with zeros since these terms represent additional losses. Note that this bound is also the greatest lower bound for the total fixed coupling loss since the last A-terms can all actually be zero. In fact, $A_{lf} = 0$ dB for $f \geq 0.5$ GHz, $A_{st} = A_{sr} = 0$ dB for line-of-sight paths where there can be no transmitter or receiver site shielding, and $A_{ct} = A_{cr} = 0$ dB for paths that do not have any over-sea surface sections.

B. Path-Angle and Time-Percentage Dependent Loss

The second term of the ducting loss equation is the loss term that depends on the path angle and time percentage. It is estimated by

$$A_d(p) = \gamma_d\theta + A(p) \quad (\text{dB}) \quad (7)$$

where $\gamma_d = 5 \times 10^{-5} a_e (\sqrt[3]{f})$ is the specific attenuation (dB/mrad) that depends on the frequency and the effective Earth radius, θ is the corrected path angle (mrad), and $A(p)$ is the time percentage variability (dB) for the path. The time percentage variability is given by

$$A(p) = -12 + (1.2 + 0.0037d)\log\left(\frac{p}{\beta}\right) + 12\left(\frac{p}{\beta}\right)^{\Gamma} \quad (\text{dB}) \quad (8)$$

where p is the required time percentage for which the calculated transmission loss is not exceeded, d is the separation distance (km) between the transmitter and the receiver, β is the time percentage for which the refractive index lapse-rates exceeding 100 N-units/km can be expected in the first 100 m of the lower atmosphere and depends on the latitude of the path center, and Γ is a number that depends on d and β. Interested readers can find

the complete expressions for all these parameters in Recommendation ITU-R P. 452-14. We do not need these rather complex expressions in deriving the following lower bound for the path-angle and time-percentage dependent loss:

$$A_d(p) \geq \gamma_d \theta = -12 + (1.2 + 0.0037d) \log\left(\frac{p}{\beta}\right) \quad (\text{dB}) \quad (9)$$

This inequality is obtained simply by dropping out the last non-negative term of the expression for the time percentage variability that depends on Γ.

In order to simplify this lower bound further, we can replace the time percentage β with its maximum value, β_m, which is derived from the definition of β as follows:

$$\beta = \mu_1 \mu_2 \mu_3 \mu_4 \times 46.8 \times 10^{-0.015 \min\{|\varphi|, 70\}} \leq \beta_m = 46.8 \times 10^{-0.015 \min\{|\varphi|, 70\}} \quad \% \quad (10)$$

where φ is the latitude of the path center. The above inequality is true since all the μ-factors are upper bounded by 1. Definitions of these rather complex μ-factors can be found in Recommendation ITU-R P. 452-14. Note that β_m is a decreasing function with respect to latitude, starting with a value of 46.8 percent for 0 deg latitudes and decreasing to a value of 4.17 percent for latitudes greater than or equal to 70 deg. Thus, replacing β with its maximum value in Equation 9, we can simplify the lower bound to

$$A_d(p) \geq \gamma_d \theta = -12 + (1.2 + 0.0037d) \log\left(\frac{p}{\beta_m}\right) \quad (\text{dB}) \quad (11)$$

C. Total Gaseous Absorption Loss

The third term of the ducting loss equation is the total gaseous absorption loss. It is estimated by

$$A_g = [\gamma_o + \gamma_w(\rho)]d \quad (\text{dB}) \quad (12)$$

where γ_o and γ_w are specific attenuation (dB/km) due to dry air and water vapor, respectively, ρ is the water vapor density (g/m³), and d is the separation distance (km) between the transmitter and the receiver. Complete expressions for these terms can be found in Recommendation ITU-R P. 676. In this article, we will replace the total gaseous absorption loss by zero, since

$$A_g > 0 \quad (\text{dB}) \quad (13)$$

for all paths.

D. Lower Bound for the Ducting Loss

Now, using the lower bounds derived above for all the terms of the ducting loss expression given in Equation 4, we can write the following general lower bound for the ducting loss:

$$L_{ba} \geq 90.45 + 20\log f + 20\log(d_{lt} + d_{lr}) + \gamma_d\theta + (1.2 + 0.0037d)\log\left(\frac{p}{\beta_m}\right) \quad \text{(dB)} \tag{14}$$

Note that this lower bound depends on the transmit frequency f, transmitter and receiver horizon distances d_{lt} and d_{lr}, path angle θ, path distance d, exceedence percentage p, and maximum time percentage β_m of the refractive index lapse rate for the path. Now we can give the lower bounds for the three different cases of paths introduced before.

Case 1 ($\theta = 0$): For the line-of-sight paths, the general lower bound can be simplified to

$$L_{ba} \geq 90.45 + 20\log f + 20\log d + (1.2 + 0.0037d)\log\left(\frac{p}{\beta_m}\right) \quad \text{(dB)} \tag{15}$$

since $\theta = 0$ and the sum of the transmitter and receiver horizon distances is equal to the separation distance between them.

Case 2 ($\delta > \theta > 0$): For the non-line-of-sight paths included in this case, the lower bound can be simplified only by replacing the term for the path angle attenuation by zero, which results in

$$L_{ba} \geq 90.45 + 20\log f + 20\log(d_{lt} + d_{lr}) + (1.2 + 0.0037d)\log\left(\frac{p}{\beta_m}\right) \quad \text{(dB)} \tag{16}$$

Note that this lower bound for non-line-of-sight paths is smaller than the lower bound for the line-of-sight paths, since $d_{lt} + d_{lr} \leq d$. In fact, if the horizon distances are much smaller than the separation distance, this lower bound can be orders of magnitude smaller than the line-of-sight lower bound. It is also interesting to note that the linear term with respect to d has a slope that is negative for $p < \beta_m$.

Case 3 ($\theta \geq \delta$): For most of the non-line-of-sight paths included in this case, we have the following lower bound for the attenuation due to the path angle:

$$\gamma_d\theta \geq \gamma_d\delta = 5\times10^{-5}a_e(\sqrt[3]{f})\frac{10^3 d}{a_e} = 0.05(\sqrt[3]{f})d \quad \text{(dB)} \tag{17}$$

Now, using this lower bound for the attenuation due to the path angle, we obtain the following lower bound for the ducting losses:

$$L_{ba} \geq 90.45 + 20\log f + 20\log(d_{lt} + d_{lr}) + 0.05(\sqrt[3]{f})d + (1.2 + 0.0037d)\log\left(\frac{p}{\beta_m}\right) \quad \text{(dB)} \tag{18}$$

This lower bound has two linear terms with respect to d with the resultant slope determined by the parameters f, p, and β_m. It is positive for the parameters considered in this study (see Figure 2).

IV. Lower Bound of Ducting Loss for the Cebreros Deep-Space Station

In this article, we assume that the HDFS transmitters are operating at 37 GHz and are distributed around the Cebreros deep-space station for 360 azimuthal directions and with separation distances varying from 1 km to 300 km at 1-km steps. Using the latitude of the Cebreros deep-space station (40 deg N), we first calculate the maximum time percentage β_m of the refractive index lapse rate as

$$\beta_m = 46.8 \times 10^{-0.015 \times 40} = 11.8\% \tag{19}$$

Now, using this maximum time percentage of the refractive index lapse rate and $p = 0.001$ percent, we can obtain the lower bound for the ducting losses around the Cebreros deep-space station for the three cases identified before.

Case 1 ($\theta = 0$): For line-of-sight paths, the lower bound for ducting loss is given by

$$L_{ba} \geq 116.9 + 20 \log d - 0.015d \quad \text{(dB)} \tag{20}$$

Note that, in the range 0 to 300 km, this function is monotonically increasing. Therefore, the smallest lower bound for line-of-sight ducting loss is given for $d = 1$ km, i.e.,

$$L_{ba} \geq 116.9 + 20 \log(1) - 0.015 \approx 116.9 \quad \text{(dB)} \tag{21}$$

Case 2 ($\delta > \theta > 0$): For the non-line-of-sight paths included in this case, the lower bound for the ducting loss evaluates to the following:

$$L_{ba} \geq 116.9 + 20 \log(d_{lt} + d_{lr}) - 0.015d \quad \text{(dB)} \tag{22}$$

Note that this lower bound only depends on the separation distance and the horizon distances of transmitter and receiver. For non-line-of-sight paths, since the step size of the terrain profile is 1 km, the transmitter and the receiver local horizon distances are bounded by this step size, i.e.,

$$d_{lt} \geq 1 \text{ km}, \quad d_{lr} \geq 1 \text{ km} \tag{23}$$

Using these bounds, we can further simplify the lower bound for non-line-of-sight ducting loss to

$$L_{ba} \geq 122.9 - 0.015d \quad \text{(dB)} \tag{24}$$

This lower bound of the ducting loss for the Cebreros deep-space station is valid for all azimuthal directions and for all separation distances with $d \geq 2$ km. Note that this lower bound is linear with negative slope. Since the maximum separation distance considered in the study is 300 km, the smallest lower bound for the non-line-of-sight ducting loss for the Cebreros deep-space station is given for $d = 300$ km, i.e.,

$$L_{ba} \geq 122.9 - 0.015 \times 300 = 118.4 \quad \text{(dB)} \tag{25}$$

Case 3 ($\theta \geq \delta$): For the non-line-of-sight paths included in this case, the lower bound for the ducting loss evaluates to the following:

$$L_{ba} \geq 116.9 + 20\log(d_{lt} + d_{lr}) + 0.152d \qquad \text{(dB)} \qquad (26)$$

As before, this lower bound only depends on the separation distance and the horizon distances of transmitter and receiver. Now, using the bounds for the transmitter and the receiver horizon distances as in Case 2, i.e., $d_{lt} \geq 1$ km, $d_{lr} \geq 1$ km, we can further simplify the lower bound for this case to

$$L_{ba} \geq 122.9 - 0.152d \qquad \left(\text{dB}\right) \qquad (27)$$

This lower bound of the ducting loss for the Cebreros deep-space station is valid for all azimuthal directions and for all separation distances with $d \geq 2$ km, where the path angle is greater than or equal to the separation angle. Since this function is monotonically increasing with respect to separation distance, the smallest lower bound for the non-line-of-sight ducting loss for the Cebreros deep-space station is given by

$$L_{ba} \geq 122.9 + 0.152 \times 2 = 123.2 \qquad \text{(dB)} \qquad (28)$$

Considering the lower limits derived above for the three cases, we can conclude that the smallest lower bound for the ducting losses around the Cebreros deep-space station is 116.9 dB, which is derived for the line-of-sight paths, since it is the minimum of the three limits determined for the three different cases considered.

Figure 2 shows the curves for the lower bounds of the ducting losses for the Cebreros deep-space station at $f = 37$ GHz and $p = 0.001$ percent obtained for the three cases considered. It also shows the free space loss for comparison, which is given by

$$L_{fs} = 92.5 + 20\log f + 20\log d = 123.9 + 20\log d \qquad \left(\text{dB}\right) \qquad (29)$$

Note that at $d = 1$ km, free space loss is 123.9 dB. This is 7 dB higher than the expected line-of-sight propagation loss for ducting mode at $d = 1$ km and $p = 0.001$ percent, which is 116.9 dB.

Note that lower bounds for the ducting loss are less than the free space loss, indicating that in transmissions through atmosphere, it is possible to transfer more power from the transmitter to the receiver than predicted receive power using transmissions through free space. This is due to the possible ducts created in the atmosphere that can carry the transmit power further without the usual spreading of the power.

It is also interesting to note that, as shown by the lower bound curves for different cases, the non-line-of-sight ducting losses can be lower than the line-of-sight ducting losses, which is contrary to practical observation where the non-line-of-sight paths experience greater ducting losses than the line-of-sight paths. This is mainly due to the way ducting losses are modeled in Recommendation ITU-R P. 452-14, and the assumption that the transmitter and receiver horizon distances are as small as possible, i.e., equal to one step size
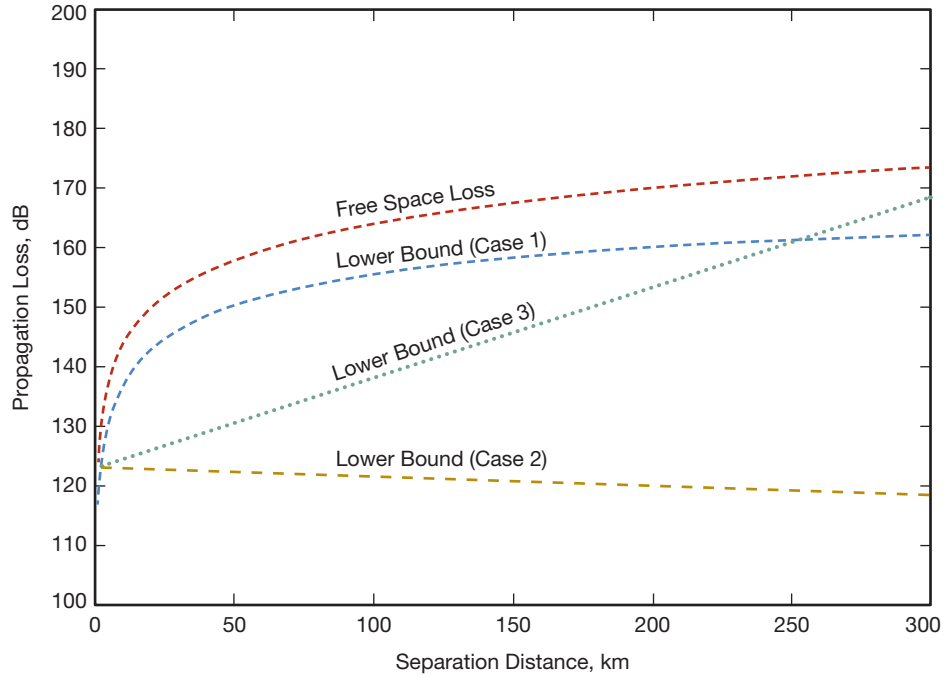
Figure 2. Lower bound curves for the ducting losses for Cebreros deep-space station for f = 37 GHz and p = 0.001 percent for the three cases considered: Case 1 ($\theta = 0$), Case 2 ($\delta > \theta > 0$), and Case 3 ($\theta \geq \delta$). The curve for free space loss is shown for comparison.

of the terrain profile. We will see in the next section that, for most of the paths, the ducting losses, calculated using the full models, are greater than the lower bound given for the line-of-sight ducting losses. The data, however, also show that there are some special non-line-of-sight paths where the ducting loss is smaller than the lower bound given for the line-of-sight paths of Case 1. For these special paths, the lower bounds given for Case 2 and Case 3 establish the limits on how much these losses can dip below the line-of-sight ducting losses.

V. Statistical Study for Propagation Loss for Ducting Mode Around the Cebreros Deep-Space Station

This section shows the results of studies that we performed using the same terrain profiles as the ESA study for the Cebreros deep-space station.

Figure 3 shows the ducting losses as a function of distance from the Cebreros deep-space station for the range of 1 to 300 km and for the time percentage of $p = 0.001$ percent. The line shows the lower bound for the line-of-sight ducting loss (Case 1). We can see that almost all the ducting losses are above this lower bound curve and all of them are above the minimum ducting loss. Actually, the minimum ducting loss in this plot is 117.1 dB. This is consistent with the theoretical lower bound of 116.9 dB derived for the ducting losses around the Cebreros deep-space station.

Figure 4 shows the curves for the minimum transmission losses around the Cebreros deep-space station for the three clear-air propagation modes of troposcatter, diffraction,
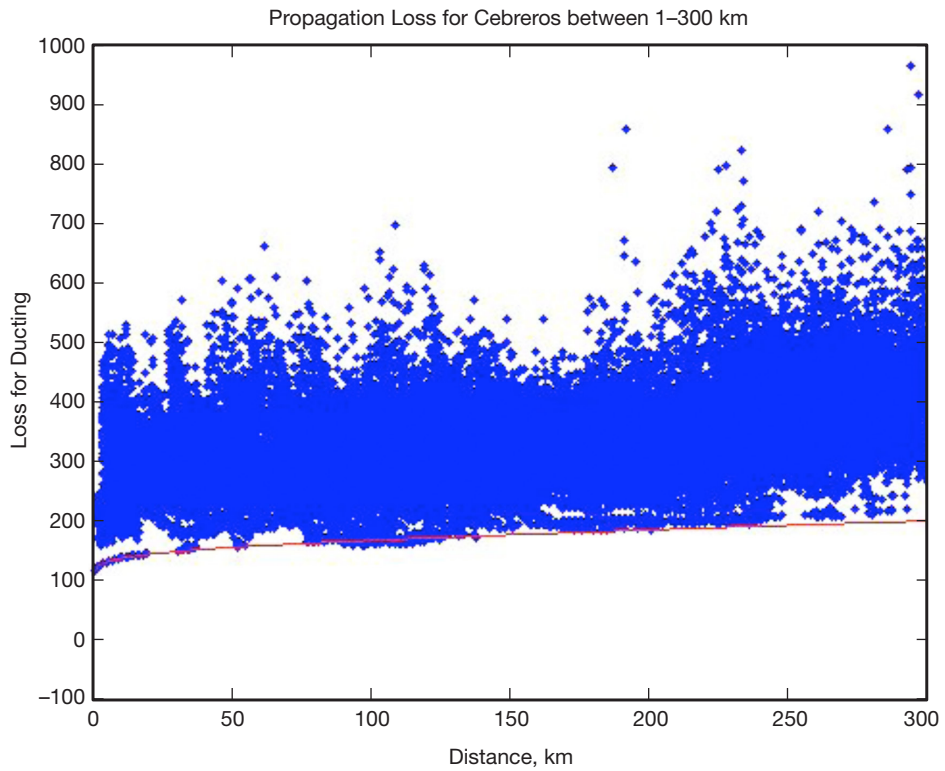
Figure 3. Ducting loss vs. distance around the Cebreros deep-space station for 360 azimuth profiles at p = 0.001 percent of the time. The continuous curve shown is the lower bound for line-of-sight ducting losses. The minimum loss for ducting mode is 117.1 dB over the entire range.
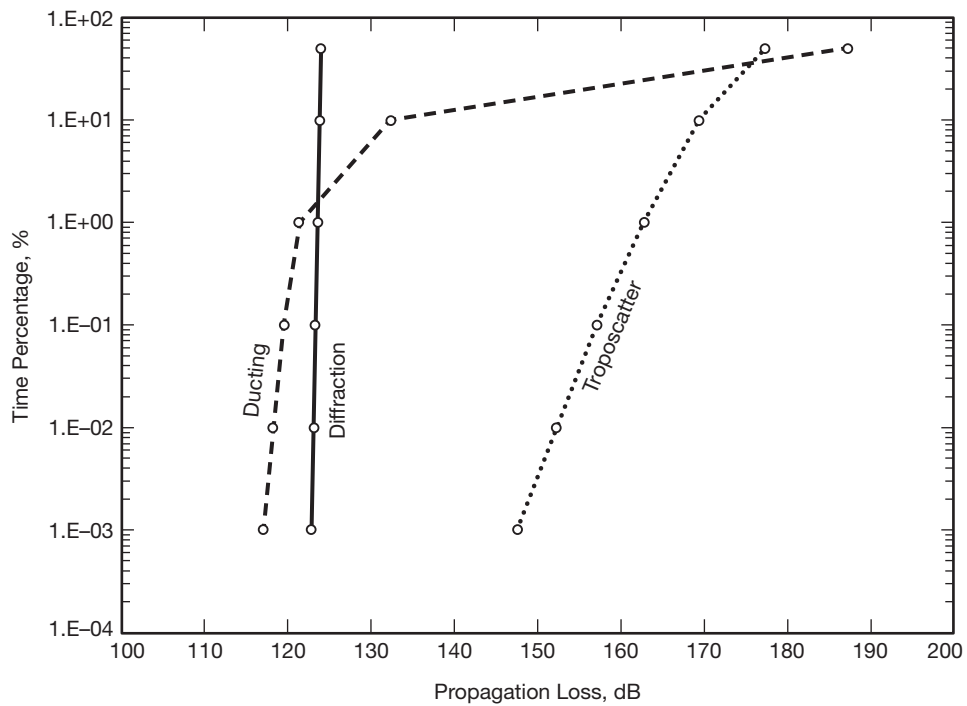

Figure 4. Minimum propagation losses for troposcatter, diffraction, and ducting modes in the range 0 to 300 km around the Cebreros deep-space station at 37 GHz for different time percentages. These minimum losses are observed for all 360 azimuths and for 1-km separation distances.

and ducting. These minimum transmission losses were obtained for $p = 0.001$ percent, 0.01 percent, 0.1 percent, 1 percent, 10 percent, and 50 percent of the time. For each mode and for each value of p, the losses were calculated for 360 azimuth directions and for radial distances increasing from 1 km to 300 km with 1-km steps, and the minimum transmission loss was identified for all the data. We have observed that all the minimums occurred at the shortest separation distance of $d = 1$ km considered in this study and for all azimuth directions. The data show that the ducting mode has the minimum loss value of 117.1 dB for $p \geq 0.001$ percent.

Note that, for the Cebreros deep-space station, the transmission losses due to ducting are smaller than the losses due to diffraction and troposcatter for $p < 1$ percent.

Figure 5 shows the curves for the minimum transmission losses for troposcatter, diffraction, and ducting modes around the Cebreros deep-space station for the range 10 to 300 km. The curves are obtained using the same data set used for generating Figure 4, but the minimum is obtained for only the portion of the data set where the separation distance was greater than or equal to 10 km. We can see from this figure that the ducting losses become comparable with losses generated through the diffraction mode. At separation distances greater than 10 km, the diffraction losses will determine the interference levels received by the Cebreros deep-space station. As shown in the figure, for separation distances greater than 10 km, the minimum transmission loss is due to the diffraction mode, and has a value of 137.3 dB.
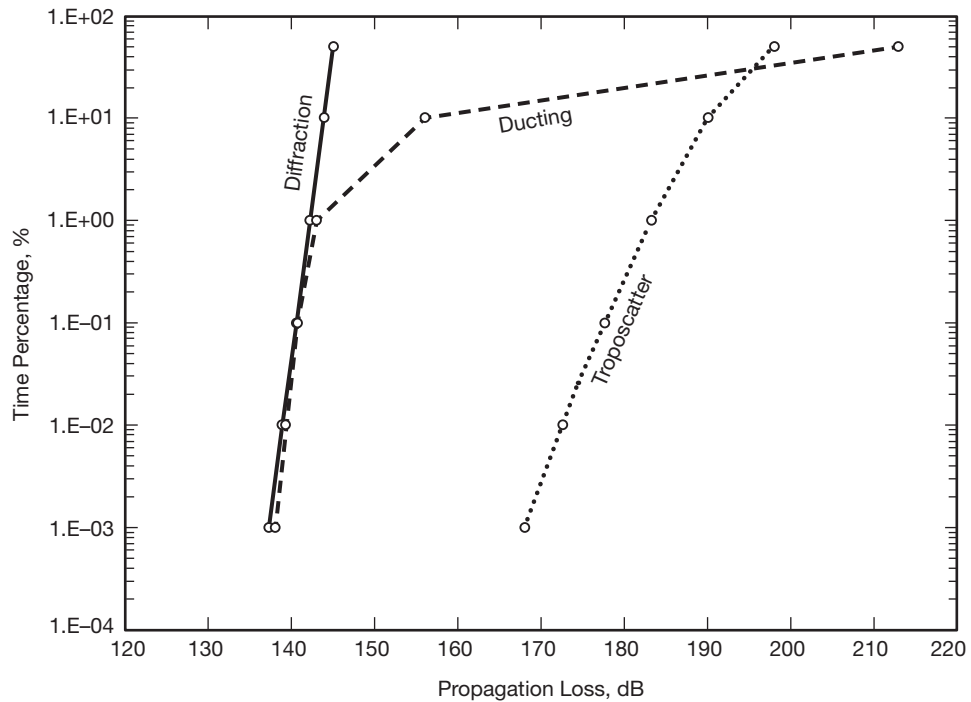

Figure 5. Minimum propagation losses for troposcatter, diffraction, and ducting modes in the range 10 to 300 km around the Cebreros deep-space station at 37 GHz for different time percentages. These minimum losses are observed for most azimuths and for 10-km separation distances.

VI. Conclusion

Based on the models defined in Recommendation ITU-R P. 452-14, we have theoretically derived lower bounds for line-of-sight paths and two cases of non-line-of-sight paths: 1) paths where path angle is less than the separation angle, and 2) paths where the path angle is greater or equal to the separation angle. These lower bounds are used to predict the lowest ducting loss possible for the Cebreros deep-space station at 37 GHz with a time percentage of $p = 0.001$ percent. The results indicate that the lowest ducting losses can be 116.9 dB. This loss occurs at the smallest separation distance of 1 km with a line-of-sight view.

In this article, we also performed a statistical analysis and calculated the transmission losses for troposcatter, diffraction, and ducting modes around the Cebreros deep-space station with a range from 1 to 300 km in all azimuth directions. The results show that the minimum ducting loss is 117.1 dB, which is consistent with the theoretical lower bound of 116.9 dB. The ducting mode has the smallest losses at separation distances less than 10 km for the line-of-sight paths. For separation distances greater than 10 km, it is expected that diffraction or the troposcatter losses would determine the interferences received by the Cebreros deep-space station receivers. For the other deep-space stations, it is expected that similar results would apply.