FREQUENCY DEPENDENCY OF MULTIPATH FADING OVER THE SEA UNDER DUCTING

Part II: SIMULATION RESULTS FOR SEA SURFACE ROUGHNESS INFLUENCE

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Abstract

The troposphere ducting and sea surface roughness make coastal and over water communication links among the most difficult to predict. Part I of this work studied the influence of evaporation duct log-linear modified refractivity profile parameters' variations on the frequency dependency of multipath fading assuming propagation over smooth sea. In Part II the influence of sea surface roughness is added to evaporation duct conditions. The sea surface roughness is modelled through two roughness reduction factors, one of them accounting for the shadowing. The same ten microwave frequencies and four hypothetical over the sea links as in Part I are used. The results are presented in form of path loss standard deviation versus frequencies for fixed ranges. The path loss is computed by the parabolic equation method.

1. INTRODUCTION

Anomalous propagation conditions due to tropospheric ducting are typical for coastal and maritime areas. They complicate the design and performance prediction of microwave radars and communications systems working in these areas [1]. The multipath fading is among the problems related to ducting propagation mechanism. The most common duct over large bodies of water is the evaporation duct. Part I of this work, [2], studied the influence of evaporation duct log-linear modified refractivity profile parameters' variations on the frequency dependency of multipath fading assuming propagation over smooth sea. Part II of this work combines the influence of sea surface roughness with the evaporation duct conditions as described in [2] in order to check weather a highly frequency dependent propagation mechanism as ducting may result in a rather slight dependence on frequency for multipath fading as suggested by some prediction methods [3, 4].

The correct modelling of electromagnetic propagation over rough sea surface is still an open issue due to the difficulties in implementing all scattering mechanisms in the electromagnetic model. A practical approximate solution is to account for the surface roughness effects by defining an “effective” reflection coefficient R_{eff}, see (1) in Section 2, representing the Fresnel reflection coefficient from flat surface, R_F, multiplied by a roughness reduction factor (RRF) R_{rf} [5]. Two RRFs have been widely used in over-the-ocean microwave propagation: the Miller-Brown one [6] and Ament's RRF [7]. Comparisons of the propagation prediction results based on combination of these two RRFs with different propagation models to measurements' data do not allow concluding which of them is more accurate; a good discussion on this issue may be found in [8]. The propagation at very low grazing angles, typical for tropospheric ducting, is additionally complicated by shadowing effect due to sea surface waves [8, 9]. It is to be noted that both above mentioned RRFs affect only the magnitude of the complex Fresnel reflection coefficient and do not account for the shadowing. In order to go closer to the observed experimental results, theoretical efforts have been made to improve the RRF's accuracy by introducing the shadowing effect [8, 9].

In [2] the important parameters of evaporation duct log-linear modified refractivity profile have been briefly discussed and the parabolic equation (PE) method [5] used for path loss computation has been sketched out. For more information on those topics the reader is referred to [2] and the literature cited there. Part II makes use of the same ten frequencies of microwave range and four hypothetical over the sea line-of-site links as in [2]. On the basis of the “effective” reflection coefficient concept, the sea surface roughness is modelled through two RRFs: the original Ament's roughness reduction factor [7] and modified Ament's RRF with shadowing effect included as proposed in [9] and implemented for ducting propagation in [10].

2. DESCRIPTION OF THE METHOD

To compute the path loss for the studied links, the log-linear *M*-profile (1) from [2] for evaporation duct is combined with the PE method. Equation (2) below presents the original Ament's roughness reduction coefficient R_A [7]. The R_{rf} from (3) is obtained in [9] using the same statistics (Gaussian statistics of sea surface heights and slopes) as the one assumed for the derivation of the original Ament's roughness reduction factor R_A. The R_{rf} from (3) accounts for the shadowing effect of the sea surface roughness by introducing a phase correction to R_A. In (2) and (3) k is the wave number in free space, φ is the plane wave grazing incidence angle to the rough surface, σ_ξ is the standard deviation of the surface height ξ, $\tilde{m}_\xi$ and $\tilde{\sigma}_\xi$ are the mean value and standard deviation of the illuminated surface heights only (see [9] for details), Q=2$k$sin(φ).

$$R_{eff} = R_{rf} R_F \quad , \tag{1}$$

$$R_A = \exp\left[-2k^2\sigma_\xi^2 \sin^2(\varphi)\right] \quad , \tag{2}$$

$$R_{rf} = \exp\left(-jQ\tilde{m}_\xi - \frac{Q^2\tilde{\sigma}_\xi^2}{2}\right). \tag{3}$$

The parameters σ_ξ, $\tilde{m}_\xi$, and $\tilde{\sigma}_\xi$ needed to compute (2) and (3) are taken for wind speed of 7 km/s, see [9, 10] for formulas and details.

3. RESULTS AND DISCUSSION

As in [2], for every frequency the path loss (PL*)* is calculated versus height for fixed ranges R = 20 km, R = 40 km for the same four hypothetical links: A) z_t = 40 m, $\theta_0 = 5^0$; B) z_t = 15 m, $\theta_0 = 5^0$; C) z_t = 40 m, $\theta_0 = 1^0$; D) z_t = 15 m, $\theta_0 = 1^0$, where z_t stays for the transmitter height, θ_0 and θ_s are the half power beamwidth and the antenna elevation angle of horizontally polarized Gaussian beam source used as transmitter, see [2], formula (3). Three different values for the critical potential refractivity gradient c_0 (which determines the curvature of the log-linear modified refractivity profile) are used for neutral, stable and unstable troposphere, respectively: c_0 = 0.13, c_0 = 0.11 and c_0 = 0.19. For all cases $\theta_s = 0^0$. The area of interests (determined by the possible receiver heights z_r) extends between 5 m and 150 m and is divided in the same two parts as in [2]: z_1 from 5 m to the top of evaporation layer, defined here as $z_L = 2z_d$, see [2], and z_2 which ranges from the evaporation layer height z_L up to 150 m; z_d is the evaporation duct height.

On Figs. 1-4 are shown results for rough sea surface. Figure 1 shows the influence of the roughness reduction factor R_A from (2) for original Ament roughness reduction coefficient: the introduction of R_A increases the frequency dependency and leads to reduction of the standard deviation values for higher frequencies both in z_1 and z_2 areas. Figures 2-4 present comparison between smooth sea and rough sea modelled with R_A and R_{rf} from (3): Fig. 2 refers to link A) with z_d = 15 m, R = 20 km; Fig. 3 reports comparison between c_0 = 0.11 and c_0 = 0.19 for R_{rf} from (3) for link A) with z_d = 15 m, R = 20 km; Fig. 4 refers to link C) with z_d = 35 m, R = 40 km. The roughness with application of shadowing, (3), increases the frequency dependency in comparison to smooth sea and in z_1 often has opposite trend to that of the roughness introduced through R_A. In z_2, for higher frequencies, the frequency dependency of *PL* standard deviation for R_{rf} from (3) follows that obtained for R_A but with higher values. In [10] it has been demonstrated that the introduction of the rough sea surface and, especially, of the roughness reduction factor given by (3), destroys the (guiding) duct structure and reduces the long-range ducted propagation. The electromagnetic energy is scattered by the roughness and this reduces the fading depths for all links and distances. The higher the frequency, the higher the depths reduction.

In area z_2 increases the difference in *PL* standard deviation frequency dependency between stable (c_0 = 0.11) and unstable (c_0 = 0.19) troposphere stratification, see Fig. 3.

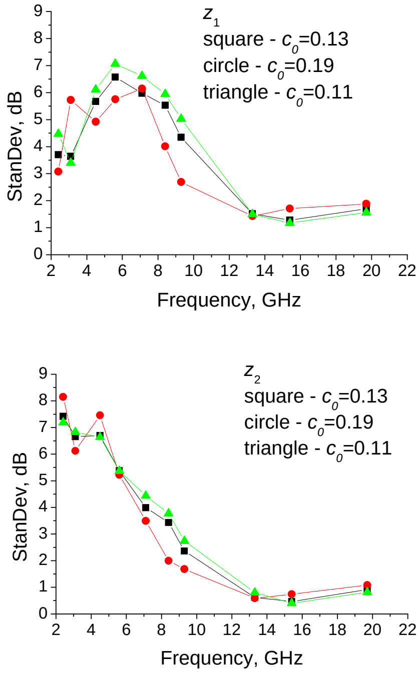


Figure 1. Rough sea surface: R_A from (2), z_d = 35 m, R = 40 km, link C

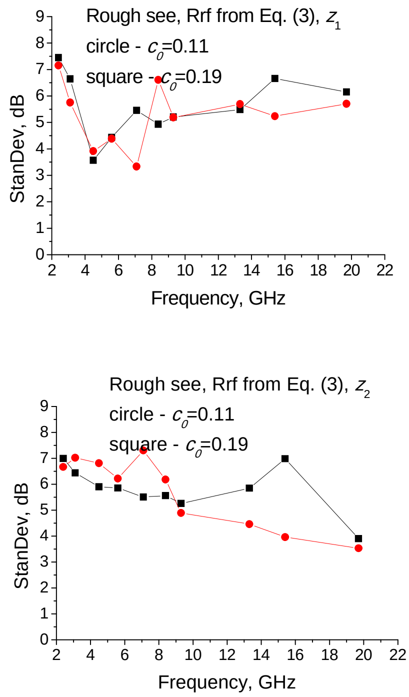
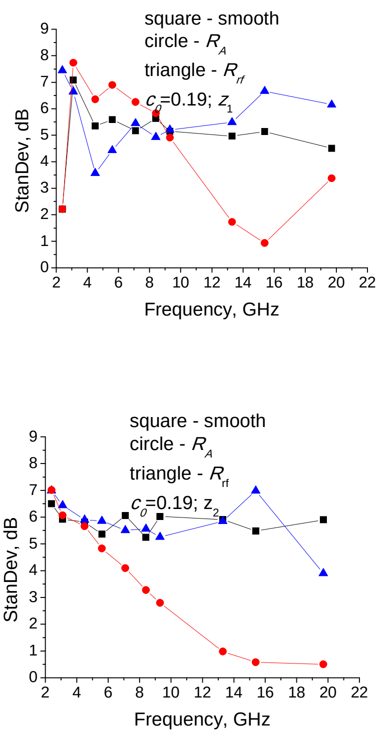


Figure 3. Comparison between c_0 = 0.11 & c_0 = 0.19 for R_{rf} from (3), link A, z_d=15 m, R=20 km



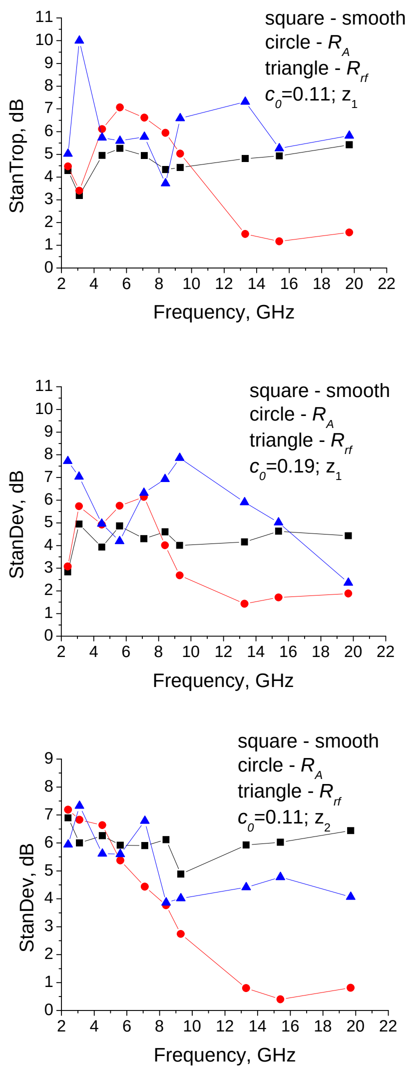


Figure 2. Comparison between smooth sea, original Ament R_A, and R_{rf} from (3), link A, z_d=15 m, R=20 km

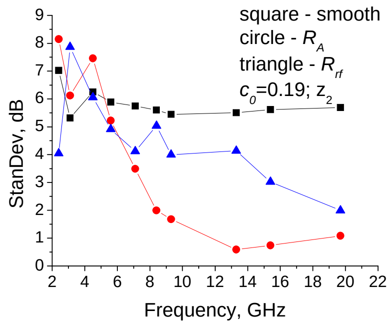


Figure 4. Comparison between smooth sea, original Ament R_A, and R_{rf} from (3), link C, z_d=35 m, R=40 km

4. CONCLUSION

On the basis of Figs. 1-4 (as well as other results not reported here) the following concluding remarks may be drawn:

- the roughness introduced through R_A increases the frequency dependency of the *PL* standard deviation in the same time decreasing its values for higher frequencies;
- the introduction of shadowing effect influences both z_1 and z_2 regions, it modifies the tendency of the original Ament's roughness reduction factor to reduce the values of standard deviation for higher frequencies;
- in further investigations more attention should be paid on the combined effect of different from neutral troposphere stratification and sea surface roughness;
- the reported results for sea surface roughness influence on frequency dependent fading can not be assessed using traditional methods.

More investigations with application of different RRFs and corrections for shadowing (and, possibly, attraction of additional scattering mechanisms as diffraction) as well as further comparisons to measurement data are needed in order to substantiate the reported results.

5. ACKNOWLEDGMENTS

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REFERENCES

[1] *D. E. Kerr, (Ed.)* Propagation of Short Radio Waves, *Peter Peregrinus, London, UK, 1987.*

[2] *I. Sirkova, "Frequency Dependency of Multipath Fading over the Sea under Ducting. Part I: Simulation Results for Refractivity Profiles' Parameters Influence", CEMA, 2019.*

[3] *R. L. Olsen, T. Tjelta, L. Martin, and B. Segal, "World-wide Techniques for Predicting the Multipath Fading Distribution on Terrestrial LOS Links: Comparison With Regional Techniques",* IEEE Trans, *Vol. AP-51, No. 1, 2003, 23-30.*

[4] *ITU-R P.530-9, "Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems", 2001.*

[5] *M. Levy,* Parabolic Equation Methods for Electromagnetic Wave Propagation, *IEE electromagnetic waves series 45, UK, 2000.*

[6] *A. R. Miller, R. M. Brown, and E. Vegh, "New Derivation for the Rough Surface Reflection Coefficient and for the Distribution of Sea-Wave Elevations",* IEE Proc.-H, *Vol. 131, 1984, 114–116.*

[7] *W. S. Ament, "Toward a Theory of Reflection by a Rough Surface",* Proc. IRE, *Vol. 41, No. 1, 1953, 142–146.*

[8] *D. E. Freund, N. E. Woods, H.-CH. Ku, and R. S. Awadallah, "The Effects of Shadowing on Modeling Forward Radar Propagation over a Rough Sea Surface",* Waves in Random and Complex Media, *Vol. 18, No. 3, 2008, 387–408.*

[9] *V. Fabbro, C. Bourlier, and P. F. Combes, "Forward Propagation Modeling above Gaussian Rough Surfaces by the Parabolic Wave Equation: Introduction of the Shadowing Effect",* Progress in Electromagnetics Research, *Vol. 58, 2006, 243–269.*

[10] *I. Sirkova, "Propagation Factor and Path Loss Simulation Results for Two Rough Surface Reflection Coefficients Applied to the Microwave Ducting Propagation over the Sea",* Progress in Electromagnetics Research M, *Vol. 17, 2011, 151–166.*