

# Influence of Tropospheric Duct Parameters Changes on Microwave Path Loss

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**Abstract** – This work studies the influence of essential evaporation and surface-based ducts parameters on microwave path loss in the context of a communications link. Discussed is the need to use range dependent refractivity profiles in order to increase the accuracy in path loss prediction especially in coastal regions.

**Keywords** – Tropospheric ducts, microwave propagation modeling, wireless network planning.

## I. INTRODUCTION

This work follows the investigation made on tropospheric ducting and its possible effects on wireless communications systems design reported in [1]. Coastal areas worldwide are known to be especially “rich” in super refractive layers and ducts that affect microwave propagation [2]. In this report the attention is focused on a) evaporation duct, due to evaporation from sea surface, and b) surface-based duct, caused, for instance, by advection. Ducts due to evaporation are practically almost present at lower latitudes [3], their depths increasing during the summer months and during the daytime. Even in moderate latitudes evaporation duct is not an occasional event. In [4] are reported refractometer measurements data accomplished in years 1973-1976 at the north part of Black sea indicating super refraction and ducting conditions in the layer 0-40 m above sea level during 20-25% of the time with maximum in July. Advection ducts arise when warm air from a dry landmass moves over the cooler sea water. Surface ducts of such nature appear about 15% of the time worldwide [5]. Advection may reinforce a preexisting evaporation duct and increase its depth. Even though stable formations, ducts suffer seasonal and diurnal variations [6] especially in the coastal zone where the sharp contrast between land and sea contributes to temporal and spatial variability. This leads to highly variable propagation conditions and thus affects significantly radio communications links performance.

This report studies the influence of the changes of the duct parameters on path loss assessment. For range independent refractivity models path loss calculations is made using the parabolic equation (PE) electromagnetic field propagation model based on finite element numerical scheme as described in [1]. When range dependent refractivity profiles are applied the Advanced Propagation Model (APM) routines of the

SPAWAR Systems Center, San Diego, CA, USA, are used. This code is based on the radio physical optics model and the Terrain Parabolic Equation Model and makes essentially use of the split-step Fourier PE method [7]. Horizontally polarized Gaussian beam antenna with frequency 2 GHz, 2.5 GHz and 5.8 GHz is used and smooth perfectly conducting underlying surface is assumed. The limit values of the duct parameters have been chosen following the values reported in [6] and [8].

## II. RESULTS AND DISCUSSION

The evaporation duct is modeled using the log-linear model [9]:

$$M(z) = M_0 + 0.13 \left[ z - z_d \ln \left( \frac{z + z_0}{z_0} \right) \right], \quad (1)$$

where  $M$  is modified refractivity,  $z$  is altitude in m,  $M_0$  is the value of modified refractivity at the sea surface,  $z_d$  is evaporation duct height in m, and  $z_0$  is the aerodynamic roughness parameter assumed here to be  $1.5 \times 10^{-4}$  m. When the electromagnetic field is calculated in a single frequency the parameter  $M_0$  can be set to an arbitrary constant without affecting the interference pattern in height, thus the evaporation duct model is entirely governed by  $z_d$ . The refractivity in the case of surface-based ducts is modeled by bilinear model with important parameters duct height  $z_d$  and M-deficit  $dM = M(z_d) - M_0$  (once again, the offset of the profile is not important). The slope above the inversion is set to 0.118 M-units/m (standard troposphere). This simple model is rough but allows pointing out the influence of basic parameters.

To illustrate the influence of  $z_d$  in the case of evaporation duct a series of duct height measurements taken over a 100-minutes period by means of a series of atmospheric sensors [10] is used, Table I. During this 100-minutes time interval  $z_d$  has suffered significant changes. For the evaporation duct from Table I two frequencies,  $f=2.5$  GHz and  $f=5.8$  GHz, and two links are investigated over distances of  $r=3$  km, 5 km and 10 km: 1) the first link has transmitter height  $z_t=30$  m ( $z_t$  is always above the duct), receiver height  $z_r=10$  m; 2) the second link has  $z_t=15$  m (for this link  $z_t$  is submerged in the duct during 1/3 of the time),  $z_r=10$  m. For both links  $z_r$  is within the duct during 2/3 of the time. For all cases antenna beamwidth= $2^\circ$  and tilt= $0^\circ$  are used. Dashed line indicates standard troposphere path loss.

Figs. 3, 8, 12, 6, 9, 10, 11 show strong and moderate influence of the changes in  $z_d$  on path loss. In all these figures path loss values differ markedly from its value for standard troposphere. In Figs. 1, 2, 4, 5 and 7 the influence of  $z_d$  changes is quasi-negligible, but even here path loss values differ (except in Figs. 4 and 5) from the case of standard

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troposphere. Path loss decrease in longer distances due to ducting as well as its fluctuations may cause interference and, in an worse case, reception from an unwanted link and lack of signal from the wanted link. Comparison of Figs. 9 and 10 shows the duct decreased the path loss for both links below the value for standard troposphere but for link 2) this decrease is more important. From Figs. 3 and 4 it is clear that for all  $z_d$  (except at 85<sup>th</sup> minute) the path loss for link 1) is significantly increased above the value for standard troposphere whereas the influence of the duct on link 2) is negligible. Suppose, link 1) is the desired link and link 2) is the unwanted one: the above mentioned examples will aggravate the suppression of link 2) signal. To avoid such cases additional interference reduction techniques could be used or anomalous propagation conditions should be accounted for when link budget is calculated.

Figs. 13 and 14 illustrate the influence of the changes of the surface-based duct parameters  $z_d$  and  $dM$ . Fig. 13 shows path loss for surface-based duct with  $z_d=50$  m and changing  $dM$ : a)  $dM=10$  M-units; b)  $dM=20$  M-units; c)  $dM=30$  M-units; d)  $dM=40$  M-units; e)  $dM=70$  M-units. The other parameters are: frequency  $f=2$  GHz, transmitter height  $z_t=20$  m, receiver height  $z_r=10$ , beamwidth  $1^\circ$  (no tilt).

The path loss vs range for  $f=5.8$  GHz,  $z_t=20$  m,  $z_r=10$  m and changing  $z_d$  ( $dM=10$  M-units) is shown in Fig. 14: a)  $z_d=50$  m; b)  $z_d=60$  m; c)  $z_d=100$  m; d)  $z_d=130$  m; e)  $z_d=150$  m. This Figure (as well as Fig. 15) is computed for antenna beamwidth= $1^\circ$ , tilt= $0^\circ$ . Clearly seen are the differences in path loss provoked by the changes in  $z_d$  even in the case of weak ducts.

Fig. 15 refers to the case of range dependent ducts. It is well known [6] that refractivity profiles over sea and over land differ. Thus, a more realistic description of the propagation conditions along a mixed land-sea path will be the use of two (or more) M-profiles: one at the transmitter site and another close to the receiver. Fig. 15 shows path loss for  $f=2$  GHz,  $z_t=25$  m,  $z_r=10$  m and: a) range independent surface-based duct with  $z_d=100$  m,  $dM=60$  M-units over the entire distance of 10 km; b) surface-based duct with  $z_d=100$  m,  $dM=60$  M-units at the transmitter and standard troposphere at distance of 2 km; c) surface-based duct with  $z_d=100$  m,  $dM=60$  M-units at the transmitter and standard troposphere at distance of 5 km. As it is seen from Fig. 15, in coastal regions the influence of the horizontal changes of refractivity could not be neglected.

### III. CONCLUSION

This report presents simulation results on the influence of the essential evaporation and surface-based ducts parameters on the path loss for a microwave link. Shown is the need to use range dependent refractivity profiles in order to increase the accuracy in path loss prediction especially in coastal areas. In these regions communications systems designed without accounting for the refraction and ducting could potentially

suffer interference from each other. The correct preliminary assessment of the expected path loss using in situ refractivity data and more precise propagation prediction models will decrease the cost of the planning links and improve their performance.

TABLE I EVAPORATION DUCT HEIGHT VARIATION WITH TIME

$z_d$ , m	13.3	9	6.8	10.8	9.6	9.6	10
Time	5	10	15	20	25	30	35
$z_d$ , m	7.5	10	11	11.5	14.2	10	16
Time	40	45	50	55	60	65	70
$Z_d$ , m	21	18	24	21	15.2	17.5	
Time	75	80	85	90	95	100	

### ACKNOWLEDGEMENTS

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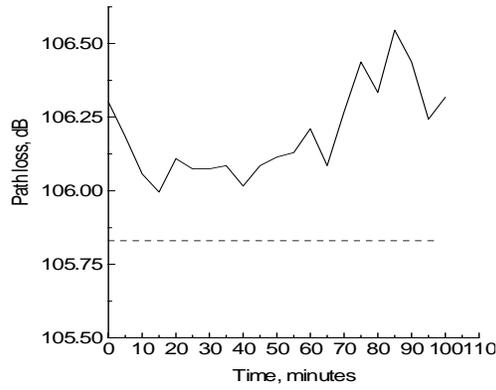


Fig. 1 Path loss vs time for  $f=2.5$  GHz,  $r=3$  km, link 1)

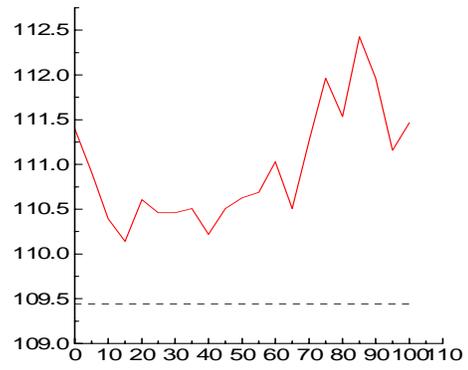


Fig. 2 Path loss vs time for  $f=2.5$  GHz,  $r=3$  km, link 2)

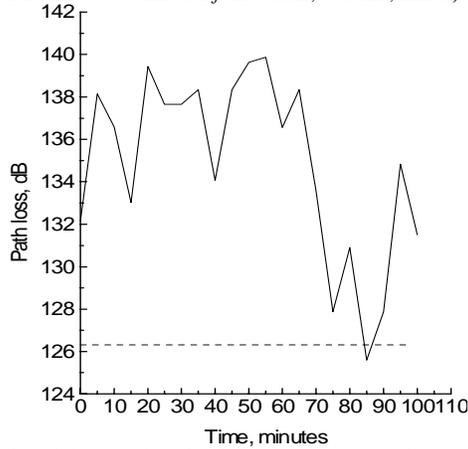


Fig. 3 Path loss vs time for  $f=2.5$  GHz,  $r=5$  km, link 1)

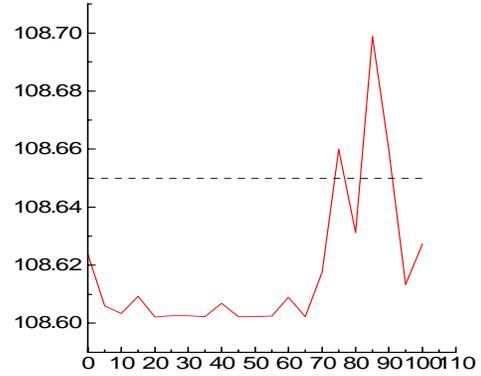


Fig. 4 Path loss vs time for  $f=2.5$  GHz,  $r=5$  km, link 2)

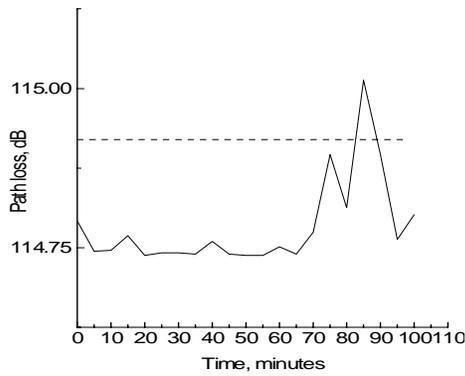


Fig. 5 Path loss vs time for  $f=2.5$  GHz,  $r=10$  km, link 1)

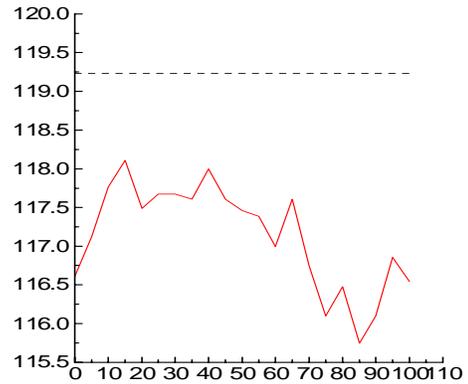


Fig. 6 Path loss vs time for  $f=2.5$  GHz,  $r=10$  km, link 2)

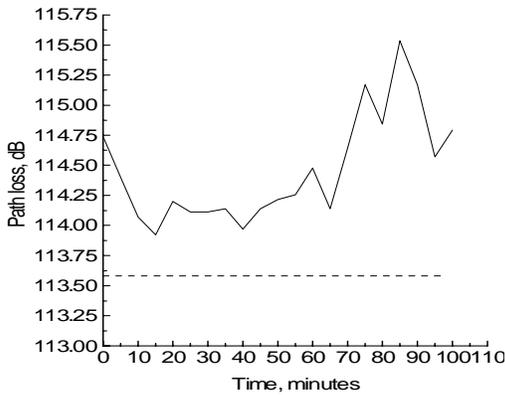


Fig. 7 Path loss vs time for  $f=5.8$  GHz,  $r=3$  km, link 1)

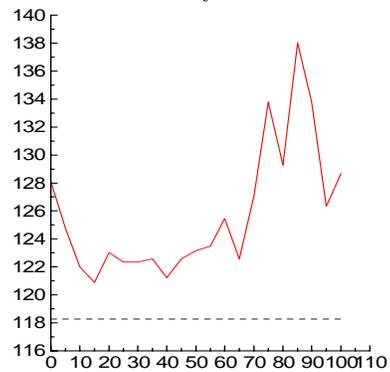


Fig. 8 Path loss vs time for  $f=5.8$  GHz,  $r=3$  km, link 2)

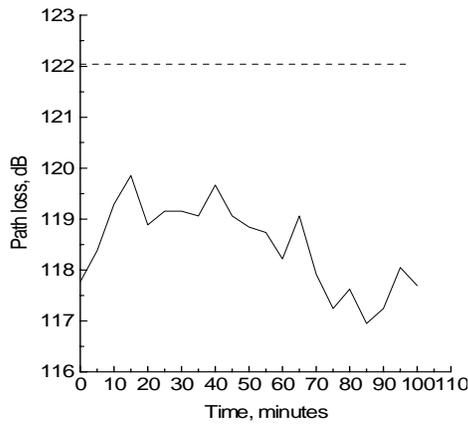


Fig.9 Path loss vs time for  $f=5.8$  GHz,  $r=5$  km, link 1)

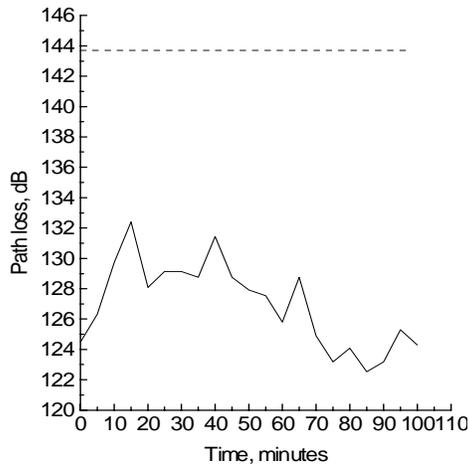


Fig.11 Path loss vs time for  $f=5.8$  GHz,  $r=10$  km, link 1)

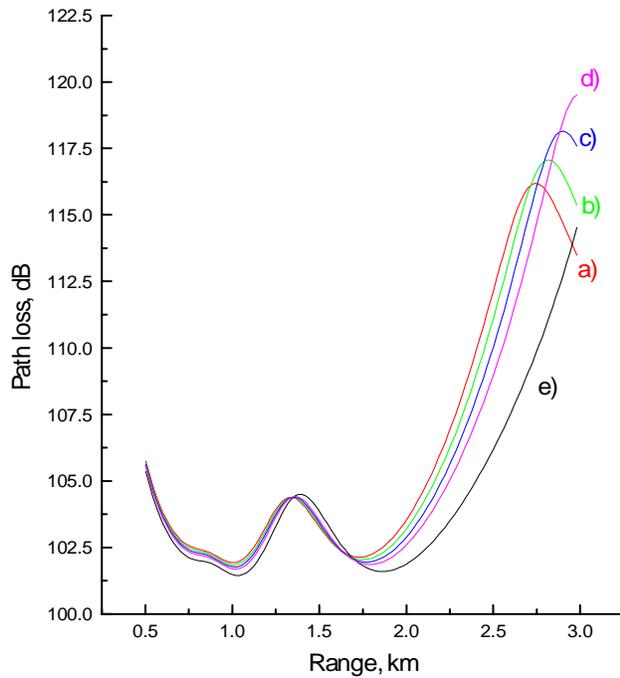


Fig.13 Surface-based duct, influence of  $dM$ .

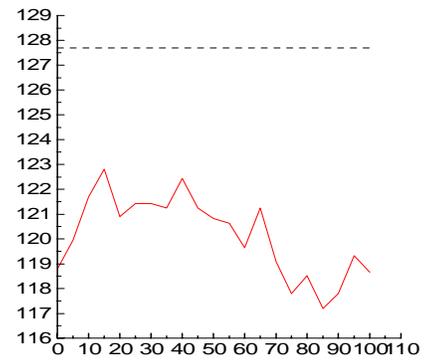


Fig.10 Path loss vs time for  $f=5.8$  GHz,  $r=5$  km, link 2)

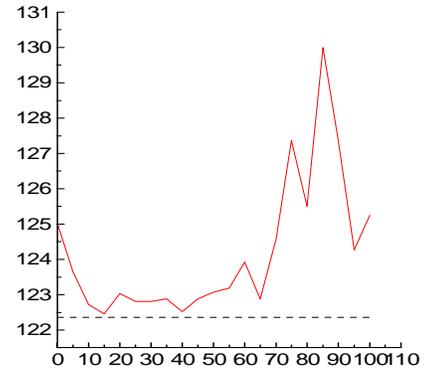


Fig.12 Path loss vs time for  $f=5.8$  GHz,  $r=10$  km, link 2)

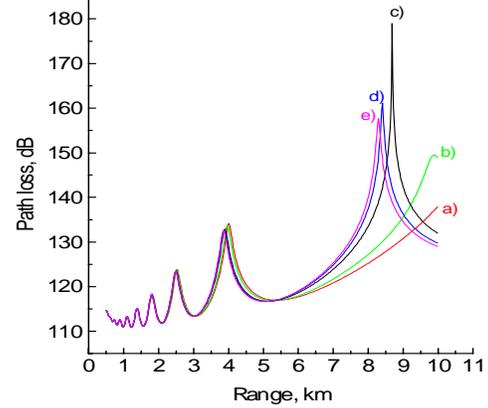


Fig.14 Influence of  $z_d$ : a)  $z_d=50$  m; b)  $z_d=60$  m; c)  $z_d=100$  m; d)  $z_d=130$  m; e)  $z_d=150$  m,  $dM=10$

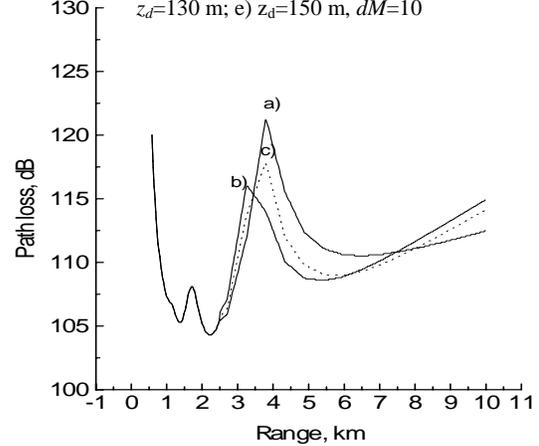


Fig.15 Range dependent duct,  $f=2$  GHz.