ON THE ASSESSMENT OF THE MICROWAVE BACKSCATTERING COEFFICIENT AMPLIFICATION WITHIN A GUIDING STRUCTURE OVER THE SEA

M. Mikhalev, I. Sirkova

Department of Microwave Remote Sensing, Institute of electronics, Bulgarian Academy of Sciences,
blvd. "Tzarigradsko shausse" 72, 1784 Sofia, Bulgaria,
e-mail: iraids@yahoo.com

1. INTRODUCTION

The lower troposphere inhomogeneities, especially ducting, play dominant role in the design of radar and communication systems working in microwave frequency range over the sea. The available experimental data [1] point to the high probability of temperature inversions and quick humidity decrease for the Black sea region giving rise to over sea duct appearance. Well known is the effect of the ducting as a long-range phenomenon, but its effects in the case of line-of-site propagation are less studied. Recently attention is drawn to the influence of ground-based (evaporation or not) ducts at short ranges, [2]-[4].

In this report results are presented from a theoretical investigation of the effect of the microwave backscattering coefficient amplification in the case of an object submerged within an "evaporation" duct with rough boundaries.

2. THEORETICAL BACKGROUND

Assessment of the maximal possible microwave backscattering coefficient amplification based on seven rays modification of the three rays propagation model [5]-[7] under the idealized assumption of identical upper and lower rough boundaries of the duct is made using only the coherent components of the scattered electromagnetic field. The radiating aerial (with horizontal polarization) is supposed submerged within the guiding structure and situated at equal distances from the boundaries. According to [7], in the case of identical upper and lower boundaries we can write for the reflected field $\vec{E}$ (see Figure 1):

$$\vec{E} = \vec{E}_0 + 4\vec{E}_1 + 2\vec{E}_2. \tag{1}$$

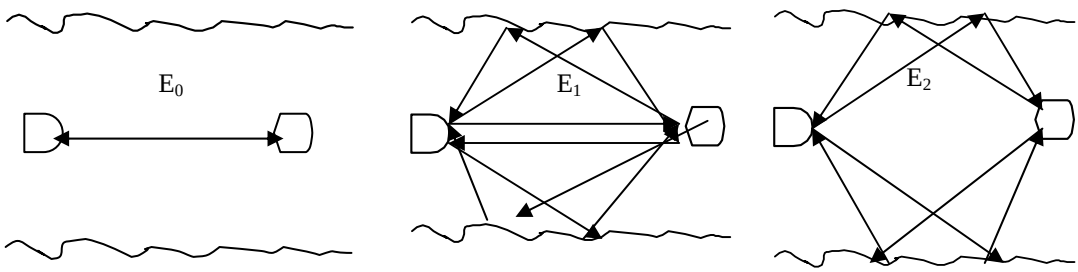

Figure 1

Then the intensity in the far zone is

$$EE^* / R^2 = E_0^2 / R_0^2 + 8\,\mathrm{Re}\left(E_1 E_0^*\right)/\left(R_1 R_0\right) + 4\,\mathrm{Re}\left(E_2 E_0^*\right)/\left(R_2 R_0\right) + \\ +16\left|E_1\right|^2 / R_1^2 + 4\left|E_2\right|^2 / R_2^2 + 16\left(E_1 E_2^*\right)/\left(R_1 R_2\right), \tag{2}$$

where R_i stays for the corresponding ray path, $i=1,2,3$, and the field strength is given by

$$E_i = E_0 \exp\left[i\left(\omega t - kR_i + \Delta_i + \varphi_i\right)\right], \tag{3}$$

with Δ_i, φ_i being the phases due to reflection from smooth flat surface and from rough surface, respectively; $k=2\pi/\lambda$ is the wave number in vacuum, λ - the wave length. To obtain the averaged field intensity from (2), (3), the computation of the following expressions is needed

$$\overline{E_i E_j^*} \approx E_0^2 \exp\left[ik\left(R_i - R_j\right) + i\left(\Delta_i - \Delta_j\right)\right]\overline{\exp(i(\varphi_i - \varphi_j))}. \tag{4}$$

To calculate (4) the following assumption is made: $h<<R_0$, $h_0<<R_0$, where h is the antenna height, h_0 - the height of the reflecting object (target), R_0 – the distance between them. Then we can write, [7]

$$R_1 R_2 \approx R_0^2; \quad k(R_1 - R_0) \approx k(R_2 - R_1) \approx 4\pi h h_0 / \lambda R_0;$$
$$k(R_2 - R_0) \approx 8\pi h h_0 / \lambda R_0. \tag{5}$$

In the case of absolutely reflecting boundaries with smooth irregularities which characteristic size is greater than λ, according to [8] we can assume $\Delta_2=-3\pi$, $\Delta_1=-2\pi$, $\Delta_0=-\pi$, $\varphi_2=2\varphi_1$, $\varphi_1=2k\xi\sin(\Psi)$, where ξ is the irregularities height $(\bar{\xi}=0)$, Ψ is the grazing angle of reflection from smooth flat surface in the specular direction.

To perform the calculations the rough surface is supposed to be normally distributed. Under the above assumptions we obtain

$$\overline{EE^*} = E_0^2 + 16\overline{E_1^2} + 4\overline{E_2^2} - 24E_0^2 \exp\left(-2k^2\overline{\xi^2}\sin^2\Psi\right)\cos\left(\frac{4\pi h h_0}{\lambda R_0}\right) +$$
$$+ 4E_0^2 \exp\left(-8k^2\overline{\xi^2}\sin^2\Psi\right)\cos\left(\frac{8\pi h h_0}{\lambda R_0}\right). \tag{6}$$

From (6) it is clear that the amplification of the backscattering coefficient in the presence of roughness of the boundaries is due to the combined influence of the specular (coherent) and diffuse (incoherent) components. The coherent components in (6) are the terms with *cos*(**.**), the field E_0 and the average components of $\overline{E_1^2} = \overline{(E_1)^2} + \overline{\Delta E_1^2}$ and $\overline{E_2^2} = \overline{(E_2)^2} + \overline{\Delta E_2^2}$. With the above made suppositions and using [8] for the coherent part of $\overline{E_1^2}$, $\overline{E_2^2}$ we can write

$$\overline{(E_1)^2} \approx E_0^2 \exp(-2k^2\overline{\xi^2}\sin^2\Psi),$$
$$\overline{(E_2)^2} \approx E_0^2 \exp(-4k^2\overline{\xi^2}\sin^2\Psi). \tag{7}$$

3. RESULTS AND DISCUSSION

Figure 2 shows the dependence of $\overline{EE^*}/E_0^2$ on R computed following (6), (7), where only the coherent components are included. The value of $\sqrt{\overline{\xi^2}}$ is 1, $\lambda=0.3$ m, $\Psi=0.2^0$, $h=h_0=10$ m. The examination of (6) (with only the coherent components taken into

account) gives the absolute maximum the backscattering coefficient could reach when microwaves reflect from an object inside a guiding structure with rough surfaces. This value is attained for distances for which $\overline{EE^*}/E_0^2 = 49$ and when $\Psi \to 0$, see Fig. 2. The very high amplification is due to the interference of the coherent components of the backscattered field and decreases strongly with the increase of the incident angle above the grazing sector (see also [7]). The contribution of the diffuse components is negligible because of their strong decrease with the increase of Ψ and spreading in azimuthal directions, [8]. Other practical application of the proposed simple formula (6), although it does not account for the refraction, is the obtainment of the tentative places of the first few interference maxima and minina. The comparison between Figure 2 and Figure 3, where these minima and maxima are obtained by using the program EREPS, [9], and calculating the propagation loss versus range for the same frequency, radar and target heights as in Figure 2 but in presence of evaporation duct, indicates this possibility.

REFERENCES

[1] N. A. Dorfman, V. A. Kabanov, F. V. Kivva and I. S. Tourgenev, “Refractive index statistical characteristics in above the see layer”, Izv. Acad. Sci. SSSR Fizika Atmosferi i Okeana, vol. 14, pp. 549-553, 1978 (in russian).

[2] K. D. Anderson, “Radar detection of low-altitude targets in a maritime environment”, IEEE Trans, vol. AP-43, pp. 609-613, 1995.

[3] R. H. Ott, “A line-of-site propagation model for calculating atmospheric, sea, terrain multipath and clutter at microwave frequencies”, Radio Sci, vol. 32, pp. 369-386, 1997.

[4] D. Rana and A. R. Webster, “Surface reflection at low-angle propagation”, IEEE Trans, vol. AP-43, pp. 639-652, 1995.

[5] A. U. Andreev, L. I. Bogin, V. U. Kobak and V. V. Leontiev, “On the electromagnetic wave scattering from close to the boundary surface bodies”, Radioteknika i Electronika, vol. 35, pp. 734-739, 1990 (in russian).

[6] V. V. Leontiev, V. A. Vinogradov and V. V. Pautov, “Modeling of electromagnetic waves reflection from object, situated close to the rough sea surface”, Radiotechnika i electronika, vol. 44, pp. 1441-1444, 1999 (in russian).

[7] E. A. Shtager and D. E. Shtager, “Backscattering coefficient amplification close to a rough boundary”, Radiotechnika i elektronika, vol. 35, pp. 433-435, 1990 (in russian).

[8] F. G. Bass and I. M. Fuks, Wave scattering from statistically rough surface, Moscow, Nauka, 1963.

[9] W. L. Patterson, C. L. Hattan, G. E. Linden, R. A. Paulus, H. V. Hitney, K. D. Anderson and A. E. Barrios, “Engineer’s refractive effects prediction system (EREPS)”, TD 2648 of Nav. Command, Control and Ocean Surveillance Cent., (1994).

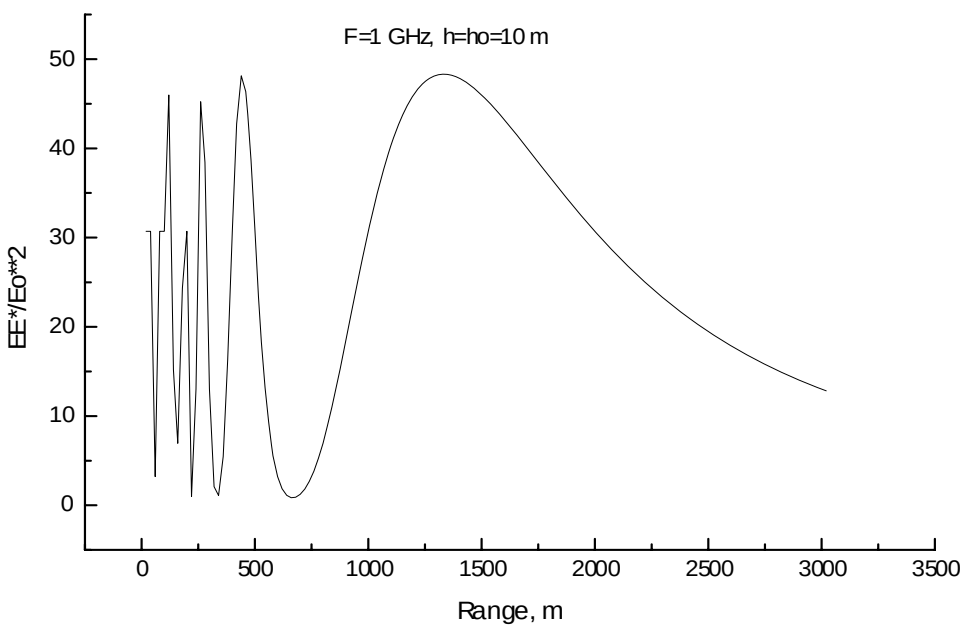

Figure 2 The dependence of $\overline{EE^*} / E_0^2$ on *R* computed following (6), $\Psi=0,2^0$.

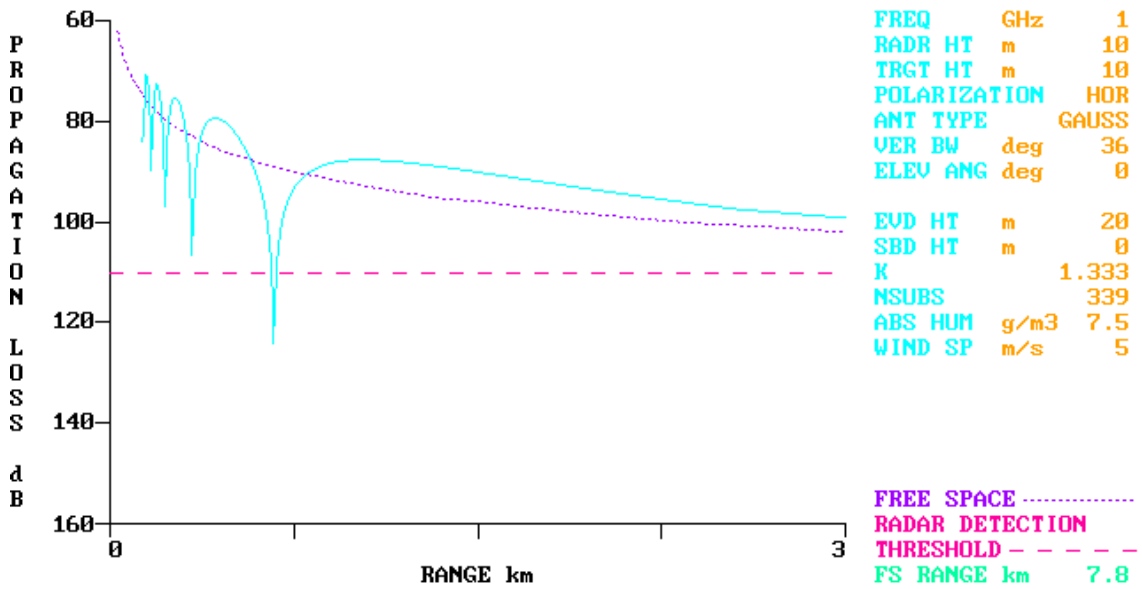

Figure 3 The first 5 interference lobes for propagation in 20 m evaporation duct, horizontally polarized antenna, frequency 1 GHz, radar and target height 10 m.