Comparison of Propagation over Irregular Terrain

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Abstract

Various cases of electromagnetic wave propagation have been solved such as two obstacles with the sharp edges or the spherical earth especially for low altitude propagation considering several combinations of antenna and observation point heights. Computation results and published solutions for individual special cases agree quite well. That demonstrates the usefulness of the method.

Keywords

propagation of electromagnetic waves, propagation over terrain, low altitudes propagation.

1. Introduction

Irregular terrain reflection computations can be found in [1] where the computer model and computation accuracy for propagation over irregular terrain are presented. Special attention is paid to computation for low altitude propagation and the finite distance between the antenna and the observation point (diffraction field zone) as the higher altitude propagation is considered in [2] where the propagation for flat surfaces, spherical earth and sharp edges is calculated and compared with the published solutions. Programs [2] allow to compute propagation over irregular terrain for both horizontal and vertical polarization considering the Fresnel reflection coefficient for terrain with random deviations and refraction (it is possible to enter the effective earth radius R_e). To compute reflections, the contributions from the irregular terrain are integrated. That cannot be used, if the difference between the incident and reflected rays is too small (less than one third of the wavelength).

This paper studies the electromagnetic wave propagation for low altitudes as well as for the transition zone between the low and higher altitudes. Various cases such as two obstacles with the sharp edges or the spherical earth considering several combinations of antenna and observation point heights are taken into account. Computation results and published solutions for individual special cases agree quite well. That demonstrates the usefulness of a given method.

2. Comparison of computation results and published solutions

If the surface change is stepped (such as the obstacle with the sharp edge on the plane surface), the attenuation of electric field is computed using the relationship for electric field calculation over infinite half-plane. The examples for this case were given in [2]. In this case, the difference is only small.

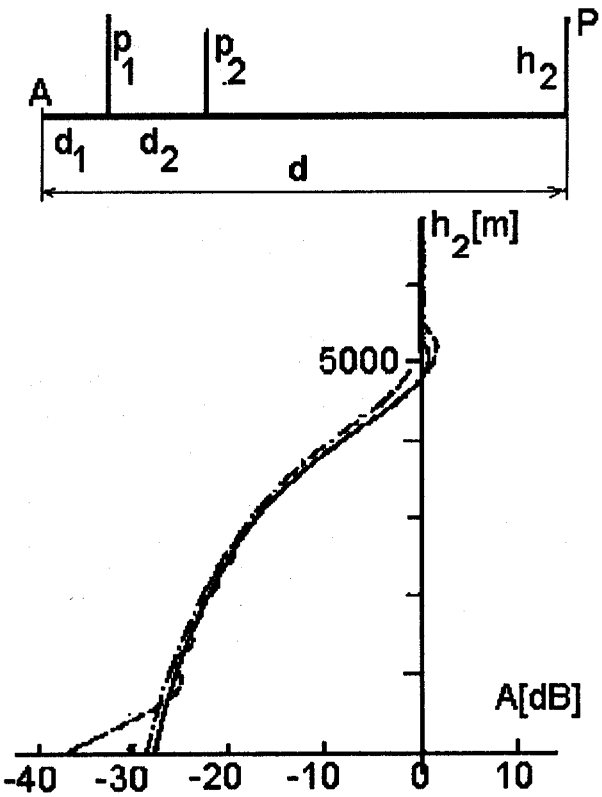

Fig. 1. The attenuation A[dB] for two obstacles with the knife-edges with p_1 = 228m, p_2 = 227.45m, d_1 = 5400m, d_2 = 10600m, d = 100000m and the wavelength is 0.67m. The solid line is the calculation [1], dot and dash line is calculation using the program [2] and dash line is calculation according to [3].

According to [3], two obstacles with the sharp edges, located as shown in Fig. 1 are considered for illustration. Heights h_2, p_1 and p_2 are considered from the antenna height h_1 where p_1 = 228m, p_2 = 227.45m, d_1 = 5400m, d_2 = 10600m, the observing point distance d = 100000m and the wavelength is 0.67m. The solid line is the calculation [1], dash line is calculation according to [3] and dot and dash line is calculation using the program [2].

It can be seen that they are in very good agreement for greater heights but the second obstacle affects the electric field for smaller heights. It can be noted that the agreement between the measurement (38dB) and the calculation (37.18dB) for height $h_2 = h_1$ published in [3] is rather questionable due to the large distance between antennas.

Fig. 2 illustrates calculations for spherical earth according to expressions [4] by the solid line, [5] by the dash line and [6] by crosses for the wavelength of 0.04348m, antenna height h_1 = 94.12m, the distance between the antenna and the observation point d = 80km and effective earth radius R_e=8500km. It is evident that the approximation [5] and the „accurate solution" [6] (of cause, the accuracy of this solution is given by the used numerical method) are in a good agreement. The derivative of approximation [5] is not continuous at the point v = 0 (h_2= 94.12m) and therefore there is the change of a slope. This change is not so important. Approximation [4] is rather worse. Similar conclusions are valid for various examples. Therefore the selection of approximation ([4] or [5]) is not unambiguous. For the program described in [1], the approximation [5] has been chosen.

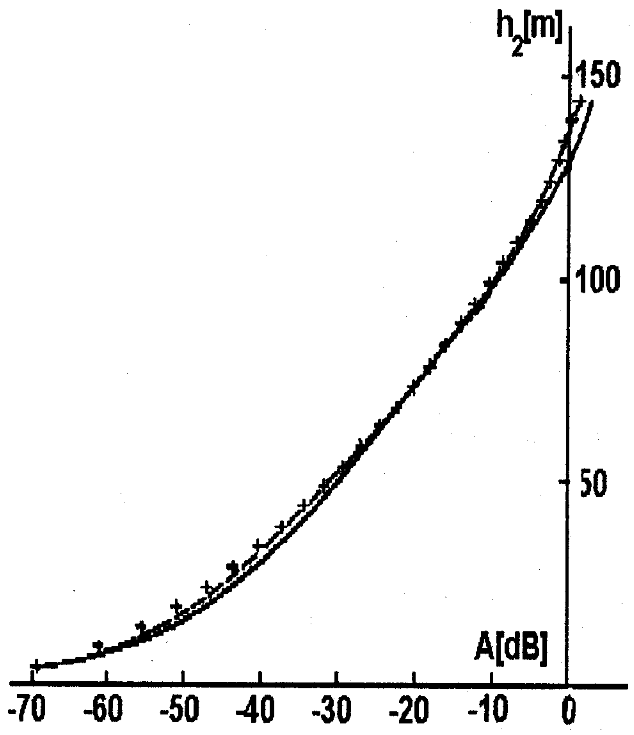

Fig. 2 The attenuation A[dB] for spherical earth. The wavelength is 0.04348m, h_1 = 94.12m, d = 80km a R_e = 8500km. The solid line shows calculations according to [4], the dash line is the calculation [5] and the crosses depict calculations according to program [6]

Calculations of attenuation A for spherical earth with the wavelength of 0.04348m, d = 40km, h_1 = 23.53m and R_e = 8500km are shown in Fig. 3. The resulting attenuation A[dB] calculated according to [1, Eq. (12)] is depicted by the solid line and calculations of A_{VX} according to [5], see [1, Eq. (8)], are shown by circles. For the small antenna height h_1 and the observation point heights h_2, it is not possible to use [1, Eq. (8)]. In this case, the infinite series [6] can be approximated by the calculations of A_{LH} according to [1, Eq. (9)]. The results are shown by the dash line for h_2<20m. For a transient zone between the lower and higher altitudes (50m<h_2<65m), the calculations of A_3 using [1, Eq. (12)] are shown by the dot and dash line. The infinite series calculations using the program [6] are given by crosses. It can be seen that the modification of solution in transient zone using expression (12) is a proper approximation. Similarly, the calculations of A_{VX} according to [1, Eq. (8)] and the calculations of A_{LH} according to [1, Eq. (9)] for small antenna heights agree quite well.

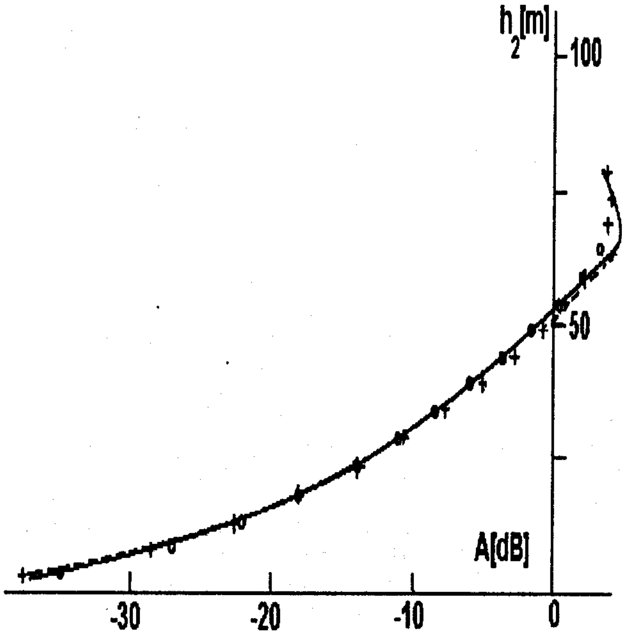

Fig. 3. Calculations of resulting attenuation A[dB] according to [1, Eq.(12)] are shown by the solid line, calculations [6] are given by crosses, the dash line gives the calculations A_{LH} according to [1, Eq. (9)], A_{VX} according to [1, Eq. (8)] are shown by circles and A_3 using [1, Eq. (12)] are shown by the dot and dash line. The wavelength of 0.04348m, d = 40km, h_1 = 23.53m and R_e = 8500km.

Approximation [1, Eq. (9)] assumes that antenna height h_1 is very small. If this condition is not fulfilled and the expressions [5], see [1, Eq. (8)], cannot be used, the approximation according to [1, Eq. (10)] can be used. This case is analyzed in Fig. 4. The wavelength is 0.03162m, h_1 = 70m, d = 42km and R_e = 8500km. Calculations of resulting attenuation A according to [1, Eq. (12)] are shown by the solid line, calculations [6] are given by crosses, the dash line gives the calculations A_{LH1}

according to [1, Eq. (10)]. A_{VX} according to [1, Eq. (8)] are shown by circles and A_3 using [1, Eq. (12)] is shown by the dot and dash line.

It can be seen that the transition between [1, Eq. (8)] and the integration over irregular terrain (for h_2 = 21m) is continuous due to [1, Eq. (12)] but it is not smooth at all. This is caused by various calculation methods. Of cause, it would be possible to smooth the transition but this problem cannot be solved generally. Fig. 3 illustrates the same problem even if that is not so important. The modification of the expression [1, (9)] by the relationship [1, (10)] is not optimum but that is rather exception. This modification is only used for great heights h_1 and small h_2 as for greater h_2 the expression [1, (8)] is used.

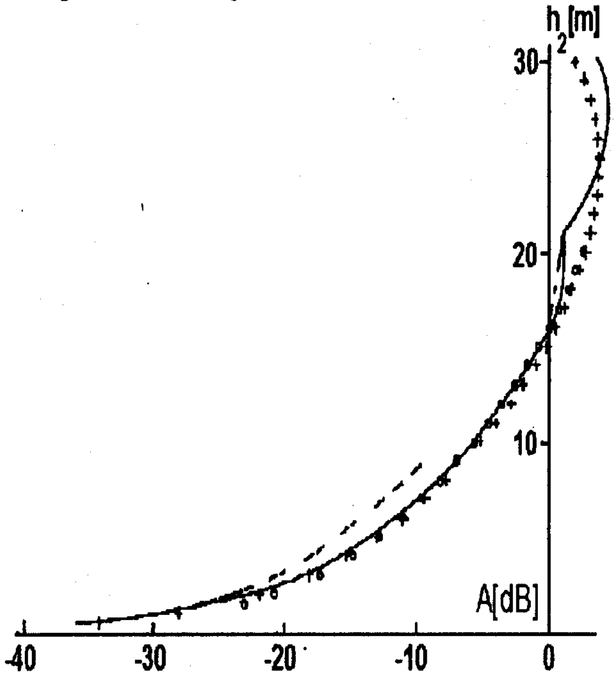

Fig. 4. Calculations of resulting attenuation A according to [1, Eq. (12)] are shown by the solid line, calculations [6] are given by crosses, the dash line gives the calculations A_{LH1} according to [1, Eq. (10)], A_{VX} according to [1, Eq. (8)] are shown by circles and A_3 using [1, Eq. (12)] is shown by the dot and dash line. The wavelength of 0.03162m, h_1 = 70m, d = 42km and R_e = 8500km.

Calculations for the wavelength of 0.03162m, antenna height h_1 = 1m, d = 42km and R_e = 8500km are shown in Fig. 5. Computations of attenuation A_{LH} are shown by the solid line and calculations [6] are given by crosses. The expression [1, (9)] is used for height h_2 < 60m and the relationship [1, (11)] is used for the greater height. It can be seen that the approximation using the expressions [1, (9) and (11)] agrees quite well with calculations [6]. That confirms the selection of this approximation for very small heights. The accuracy of calculation using [6] is also limited as the convergence of calculation [6] is very poor for heights greater than 180m and calculations are not reliable. It can be noted that 10 terms of series have been used for the height of 100m, 44 terms of series have been used for the height of 160m and 66 terms of series have been used for the height of 180m.

Calculations using reflections from infinity plane earth, given by

$$A[\mathrm{dB}] = 20\log(2\sin(2\pi h_1 \frac{\sin\theta}{\lambda})) \qquad (1)$$

where θ is the elevation angle of the observation point P, are shown by the dash line for comparison. That can be used for greater heights because the reflection points approach the antenna for greater heights where the curvature can be neglected.

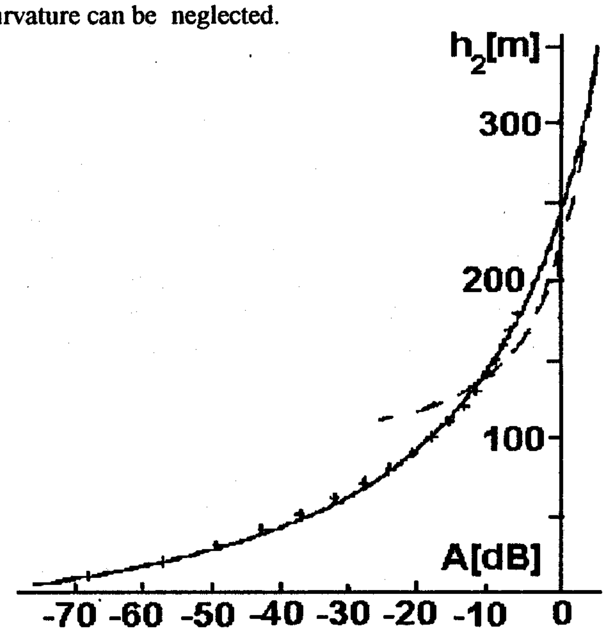

Fig. 5. Computations of attenuation A_{LH} are shown by the solid line, calculations [6] are given by crosses and calculations using reflections from infinity plane earth are shown by the dash line. The expression [1, (9)] is used for height h_2 < 60m and the relationship [1, (11)] is used for the greater height. The wavelength is 0.03162m, antenna height h_1 = 1m, d = 42km and R_e = 8500km

3. Conclusions

The computer model and computation accuracy for propagation over irregular terrain are presented in [1]. Special attention is paid to computation for low altitude propagation and the finite distance between an antenna and an observation point as the higher altitude propagation is considered in [2] where the propagation for flat surfaces, spherical earth and sharp edges is calculated and compared with the published solutions.

Computation results obtained by the described program agree quite well with the calculations of special cases such as two obstacles with the sharp edges or the spherical earth when the computations have been compared with calculations [6] or with calculations using reflections from the infinity plane earth. That demonstrates the usefulness of a given method.

Some problems arise for the transient zone. The transition between the integration over irregular terrain and low altitude propagation is continuous due to expression [1, (12)] but it is not smooth. This is caused by various calculation methods. Of cause, it would be possible to smooth the transition but this problem cannot be solved generally.

The modification of the expression [1, (9)] by the relationship [1, (10)] is not optimum but that is rather exception. This modification is only used for great heights h_1 and small h_2 as for greater h_2 the expression [1, (8)] is used.

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Vladimír SCHEJBAL was born in Hradec Kralové, Czech Republic on January 1, 1941. He graduated in electrical engineering from Czech Technical University, Prague, in 1970. He received the Ph.D. degree in electrical engineering from the Slovak Academy of Science, Bratislava, in 1980. He was with Tesla ÚVR Opočínek since 1969 until 1993. He is currently at University of Pardubice. His research interests include computational methods and measurement in control and electromagnetics, especially microwave antennas and propagation.

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