THE RADIATION PROBLEM FROM A VERTICAL SHORT DIPOLE ANTENNA ABOVE FLAT AND LOSSY GROUND: VALIDATION OF NOVEL SPECTRAL DOMAIN ANALYTIC SOLUTION IN THE HIGH FREQUENCY REGIME AND COMPARISON TO EMPIRICAL TERRAIN PROPAGATION MODELS

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Abstract

In this paper the results of a recently introduced novel solution to the well-known 'Sommerfeld radiation problem', are compared to those obtained through the classical Sommerfeld formulation. The method is novel in that it is entirely performed in the frequency domain, yielding simple integral expressions for the received Electromagnetic (EM) field and also in that they can end up into closed-form analytic formulas applicable to high frequencies. In this paper we compare our analytical results with existing numerical calculations found in the literature, based on the Sommerfeld formulation. The above comparison shows good agreement in the corresponding numerical results. Furthermore, a comparison of the method to the well-known Okumura-Hata empirical model is performed in an attempt to roughly estimate the extent to which the proposed model is suitable for real–environment EM field calculations.

1. INTRODUCTION

The 'Sommerfeld radiation problem' is a well-known problem in the area of propagation of electromagnetic (EM) waves above flat and lossy ground [1]. The original Sommerfeld solution to this problem is provided in the physical space by using the 'Hertz potentials' and it does not end up with closed- form analytical solutions.

In [2], the authors considered the problem from a spectral domain perspective, which led to relatively simple 1-D integral representations for the received EM field. Then with the use of the Stationary Phase Method (SPM, [2]) novel, closed-form analytic formulas were derived, applicable in the high frequency regime.

The comparison between the analytical expressions of [2] and their integral counterparts was performed in [3] where the requirements for the applicability of the SPM method were extracted. However, as mentioned there, due to the peculiarities of the integrands, which possess particular singularities, the integral expressions of [2] are not easily evaluated using standard numerical integration techniques, as for example the adaptive Simpson's method used in [3]. As a result, a confirmation of the results by using alternative integral evaluation techniques is justified. In this work, the results for the received EM field, taken via the application of the previously mentioned SPM method are juxtaposed against the ones available in a related research work [4]. The latter are obtained via 'a claimed to be accurate' evaluation of the original Sommerfeld integrals using commercially available simulation software, namely AWAS [4].

The last part of this work is devoted to comparing the above mentioned SPM-based analytical expressions to a well–known empirical model for path loss prediction, particularly Okumura- Hata [5]. This, as well as similar comparisons to be performed in the future, will eventually determine the extent to which the easily implemented model of [2] can be used for radio wave prediction in real life scenarios.

2. PROBLEM GEOMETRY

The problem geometry is shown in Fig. 1. A vertical Hertzian Dipole (HD), of dipole moment *p*, directed to the positive *x* axis, at altitude x_0 above infinite, flat, lossy ground radiates time-harmonic electromagnetic (EM) waves at angular frequency $\omega=2\pi f$ ($e^{-i\omega t}$ time dependence is assumed). The relative complex permittivity of the ground is $\varepsilon_r' = \varepsilon'/\varepsilon_0 = \varepsilon_r + i\sigma/\omega\varepsilon_0$, σ being the ground conductivity, f the carrier frequency and ε_0 = 8,854x10^{-12} F/m the absolute permittivity in vacuum or air. The wavenumbers of propagation are:

$$k_{01} = \omega/c_1 = \omega\sqrt{\varepsilon_1\mu_1} = \omega\sqrt{\varepsilon_0\mu_0} \tag{1}$$

$$k_{02} = \omega/c_2 = \omega\sqrt{\varepsilon_2'\mu_2} = k_{01}\sqrt{\varepsilon_r + i(\sigma/\omega\varepsilon_0)} \tag{2}$$

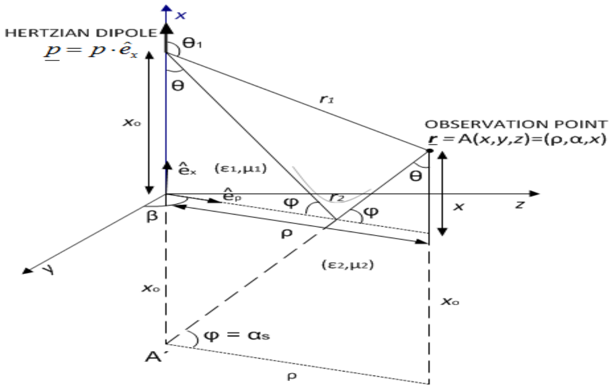

Figure 1. Geometry of the problem

In Fig. 1, point A´ is the image of the HD with respect to the ground, r_1 is the distance between the source and the observation point (OP), r_2=(A´A) the distance between the image and the OP, θ the 'angle of incidence' at the so–called 'specular point' and φ=π/2–θ the so–called 'grazing angle'.

3. INTEGRAL SPECTRAL DOMAIN REPRESENTATIONS FOR THE RECEIVED ELECTRIC FIELD AND ANALYTIC EXPRESSIONS IN THE HIGH FREQUENCY REGIME

In [2] it is shown that the electric field at the receiver's position above the ground level (x>0) can be expressed with the following integral formula ($\underline{E}^{LOS}$ denotes the direct field):

$$\underline{E}(\underline{r}) = \underline{E}^{LOS}(\underline{r}) - \frac{ip}{8\pi\varepsilon_{r1}\varepsilon_0}\times$$

$$\times\left\{\hat{e}_\rho \int_{-\infty}^{\infty} k_\rho^2 \frac{\varepsilon_{r2}'\kappa_1 - \varepsilon_{r1}\kappa_2}{\varepsilon_{r2}'\kappa_1 + \varepsilon_{r1}\kappa_2} e^{i\kappa_1(x+x_0)} \cdot \mathrm{H}_0^{(1)}(k_\rho\rho)dk_\rho - \right.$$

$$\left. -\hat{e}_x \int_{-\infty}^{\infty} k_\rho^3 \frac{\varepsilon_{r2}'\kappa_1 - \varepsilon_{r1}\kappa_2}{\kappa_1(\varepsilon_{r2}'\kappa_1 + \varepsilon_{r1}\kappa_2)} e^{i\kappa_1(x+x_0)} \cdot \mathrm{H}_0^{(1)}(k_\rho\rho)dk_\rho \right\} \tag{3}$$

where:

$$\kappa_1 = \sqrt{k_{01}^2 - k_\rho^2}\ ,\ \kappa_2 = \sqrt{k_{02}^2 - k_\rho^2} \tag{4}$$

and $H_0^{(1)}$ is the Hankel function of first kind and zero order. Application of the 'Stationary Phase Method' (SPM) to (3), leads to the following analytic expressions for the electric field vector scattered from the plane ground, in the far field region and in the high frequency regime (for x>0) [3]:

$$\underline{E}_{x>0}^{SC} = \frac{pk_{01}\cos\varphi}{4\pi\varepsilon_0\varepsilon_{r1}(\mathrm{A'A})} \cdot \frac{\varepsilon_{r2}'\kappa_{1s} - \varepsilon_{r1}\kappa_{2s}}{\varepsilon_{r2}'\kappa_{1s} + \varepsilon_{r1}\kappa_{2s}} \cdot$$

$$\cdot e^{ik_{\rho s}\rho} \cdot e^{i\kappa_{1s}(x+x_0)} \cdot (-\kappa_{1s}\hat{e}_\rho + k_{\rho s}\hat{e}_x) \tag{5}$$

where,

$$k_{\rho s} = \frac{k_{01}\,\rho}{\sqrt{(x+x_0)^2 + \rho^2}} = k_{01}\cos\varphi \tag{6}$$

$$\kappa_{1s} = \sqrt{k_{01}^2 - k_{\rho s}^2} = k_{01}\sin\varphi\ ,\ \kappa_{2s} = \sqrt{k_{02}^2 - k_{\rho s}^2} \tag{7}$$

with $k_{\rho s}$ being the stationary point obtained from the SPM method [2].

4. COMPARISONS WITH EXISTING MODELS – NUMERICAL RESULTS

In this section various illustrations are presented, comparing the model of Section 3 with (i) the accurate Sommerfeld formulation, employed in related research work [4] and (ii) Okumura – Hata empirical model for path loss prediction [5].

4.1. Comparison with Sommerfeld formulation

Fig. 2 depicts the vertical component of the total received electric field, E_x, due to the radiation of a half wavelength, vertical dipole antenna above flat, lossy ground. The various plots refer to different transmitter heights. The set of the simulation parameters used for the production of these plots are shown in Table 1:

Table 1. Simulation parameters

Symbol	Description	Value
f	Operating frequency	1GHz
x_0	Height of transmitting dipole	5m, 10m, 20m 100m, 500 m
x	Height of observation point	2m
j	Distance range	1m – 50km
P	Radiated Power[1]	150W
$2h$	Length of the dipole antenna	λ/2
ε_r	Relative dielectric constant of ground (typical urban ground)	4.0
σ	ground conductivity	0.0002 S/m

[1] Used only in the simulated scenario of Section 3. The respective value used in [4] is not mentioned

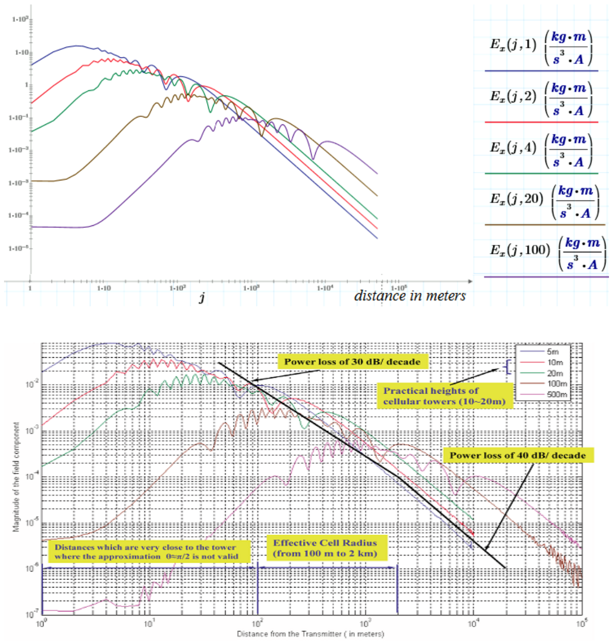

Figure 2. Variation of the magnitude of the E_x component (μV/m), for various transmitting antenna heights

The top plot of Fig. 2 refers to the field values according to the analytical expressions (5) – (7), whereas the bottom one are the respective results obtained after accurately evaluating the 'Sommerfeld integrals' for the total received EM field, [4].

Evidently, the results are in very good agreement. The SPM–based analytical method of Section 3 predicts the theoretical field behavior and this is true both for the near field as well as the far field region, as they are defined in [4]. In this regard, the so-claimed in [3], 'high frequency regime analytical method' of [2], is validated for such high frequencies as 1GHz.

As another validation of the previous arguments, Fig. 3 depicts the behavior of the electric field, for various scenarios regarding the electrical parameters of the ground, according to Table 2:

Table 2. Simulation parameters

Parameter	Value	
Operating frequency	900MHz	
Height of transmitting dipole	5m	
Height of observation point	2m	
Distance range	1m – 50km	
Radiated Power[1]	150 W	
Length of the dipole antenna	λ/2	
Ground Parameters	ε_r	σ (S/m)
Poor urban ground	4	0.001
Average ground	15	0.005
Good ground	25	0.02
Fresh water	81	0.01
Sea water	81	5.0
[1] Used only in the simulated scenario of Section 3.		

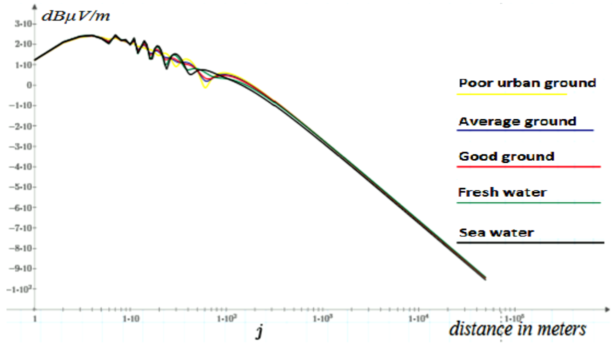

Figure 3. Variation of the magnitude of the E_x component (dBμV/m) for various types of ground

The field behavior shown in Fig. 3 is almost identical to that presented in Fig. 7 of [4], which is the equivalent case to the scenario considered here. In other words, the analytic expressions (5) – (7) validate the important finding of [4] (reached by numerical evaluation of the 'Sommerfeld integrals'), namely the fact that the type of the ground does not influence significantly the received EM field values.

4.2. Comparison with Okumura Hata empirical model

A preliminary check of the model proposed hereby against the well- known Okumura – Hata (OH) empirical model [5], commonly used for predicting signal loss in land mobile radio services, is carried out. Fig. 4 below illustrates the comparison.

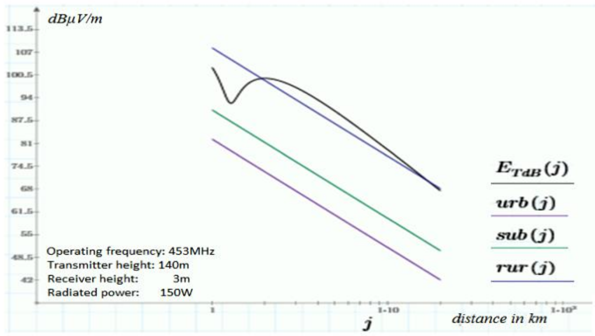

Figure 4. Comparison with OH model for urban (urb), suburban (sub) and rural (rur) environment

From Fig.4 it is evident that the proposed model exhibits similar behavior to the Okumura-Hata model for the case of an open (rural) area. On the contrary, there is an appreciable mismatch between them when applied to urban or suburban environments. A correction factor to accommodate for the specifics of the propagation environment (i.e. the presence of buildings, foliage, obstacles etc – typical to urban/suburban environment) is required and will be the subject of future research.

5. CONCLUSION-FUTURE RESEARCH

In this work, a comparison of a recently introduced solution to the 'Sommerfeld radiation problem in the spectral domain', against theoretical as well empirical approaches for the given problem is demonstrated. The proposed model leads to easily implemented analytical expressions for the received EM field and is proved to be valid in the high frequency regime.

Further validations against theoretically driven, numerical results like those of [4] used here, are required to determine the exact frequency limits of the analytic expressions (5) – (7). For this the perspective described in [3], which is believed to reduce the precision errors appeared there, will be followed, leading to a novel spectral domain representation for the surface wave as well [note that (5) neglects the role of the surface wave].

Finally, an attempt to determine the necessary corrections that will extend the model's applicability to more complex environments is also planned. Such checks will eventually determine the adoptions necessary for turning the novel propagation model of [2] to a robust prediction tool appropriate for radio planning purposes.

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