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Analytical Technique to Determine the Electric Field Above a Two-Layered Medium

Marin Galic (1), Dragan Poljak (2), Vicko Doric (3)
(1) Environmental Measurement Center LTD, University of Split, Croatia, e-mail: mgalic@cmo.hr
(2) University of Split, Croatia; e-mail: dpoljak@fesb.hr
(3) University of Split, Croatia; e-mail: vdoric@fesb.hr

Abstract

This paper outlines an analytical model for the assessment of the electric field radiated by a base station antenna system above a two-layered medium. The model used in electric field strength assessment is based on Modified Image Theory method (MIT). The obtained results for the electric field are compared to the results calculated for the single layer configuration. Several variables have been varied to examine the impact of two-layered medium. The calculations have been undertaken for the far field only.

1. Introduction

The assessment of the electric field radiated by a base station antenna system is of continuous interest in electromagnetic compatibility (EMC). This paper aims to extend the previous research by the authors on the subject reported in [1, 2]. Thus, this work is based on the investigation of the impact of two-layered ground on the electric field over a lossy ground radiated by a base station antenna. The approach used to assess reflected field is based on the Modified Image Theory Method [1, 2]. The paper is organized, as follows; the theoretical background is outlined in section 2, while the results are given in section 3. Finally, some concluding remarks are given.

2. Theoretical background

The geometry of the base station antenna radiating over a lossy ground is is shown in Figure 1.

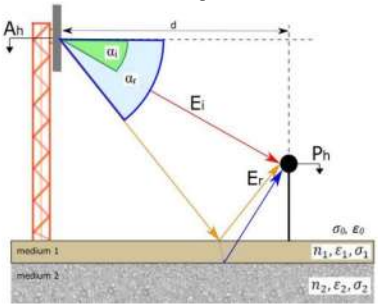

Figure 1. The total electric field above a multilayered medium composed from the incident and reflected fields

As shown in Fig 1, the total electric field is composed from incident and reflected field, respectively.

The incident field is calculated by means of the following analytical formula [4]:

$$E_i = \frac{\sqrt{30 * N * P * 10^{\frac{G}{10}}}}{d} \qquad (1).$$

where N is the total number of channels, P stands for the radiated power (W) and G denotes horizontal and vertical antenna gain (dB), respectively.

The reflected field is computed by using the simplified reflection coefficient arising from the use of the MIT applied to the case of two-layered ground. Therefore, the reflected field from the interface is given by

$$E_{r\_MIT} = \Gamma_{MIT} * \frac{\sqrt{30 * N * P * 10^{\frac{G}{10}}}}{d} \qquad (2).$$

where MIT reflection coefficient for two-layer ground is given by [5]:

$$\Gamma_{MIT} = \frac{R_{01} + R_{12} * e^{-2*\gamma*l}}{1 + R_{01} * R_{12} * e^{-2*\gamma*l}} \qquad (3).$$

where l is the given thickness of the layer 2 and γ is the propagation constant of the medium, while R_{mn} by which the reflection between m-th and n-th layer is taken into account is given by:

$$R_{mn} = \frac{\varepsilon_{eff,m} - \varepsilon_{eff,n}}{\varepsilon_{eff,m} + \varepsilon_{eff,n}} \qquad (4).$$

where the complex permittivity of the ground is

$$\varepsilon_{eff,m(n)} = \varepsilon_{m(n)} - j\,\frac{\sigma_{m(n)}}{\omega} \qquad (5).$$

Finally, total electric field is the sum of incident and reflected field:

$$\overrightarrow{E_{total}}\ (\text{V/m}) = \overrightarrow{E_i} + \overrightarrow{E_{r\_MIT}} \qquad (6).$$

3. Antenna and Environment Configuration

For the purpose of this paper the source of electric field (the base station antenna) has been modelled in Numerical

Electromagnetics Code (NEC, [3]). NEC also provided the horizontal and vertical antenna pattern respectively, modelled in free space conditions and used for calculations. The radiated antenna power is set to be 100 W with the operating frequency $f = 936.8$ MHz and one active channel. Antenna is mounted 25 m above the ground. The horizontal antenna gain is supposed to be 0 dB while vertical antenna gain (α) is calculated according to radiation pattern and formula derived from Fig. 1:

$$\alpha\ (°) = arctg\left(\frac{A_h - P_h}{d}\right) - el\_tilt \qquad (7)$$

where A_h denotes an antenna height (m) and P_h calculation point height (m), while *el_tilt* presents the electrical antenna tilt (for this purpose $el\_tilt = 0^0$).

The total electric field is calculated only in the far zone. Considering the antenna height, dimensions of the antenna D and the wavelength λ, the far field area is considered to be at the distance 25 m away from the antenna [4].

$$d \geq 2 * \frac{D^2}{\lambda} \qquad (8).$$

Approximately, the far field area is every distance from 0 m of the antenna pillar pedestal. Therefore, the total electric field is calculated at the distances between 0 m and 399 m from the antenna pillar at the height of 2 m above the ground.

Antenna is set in the air (σ_0, ε_0). The ground under antenna pillar consists of two different layers. Upper layer is presented as medium 1 (n_1, σ_1, ε_1), and the lower one as medium 2 (n_2, σ_2, ε_2), table 1.

Table I. Basic characteristics of ground layers

medium	σ (S/m)	ε_r
0	σ_0	ε_0
1	0.001	10
2	0.05	4

4. Results

This section presents some illustrative computational examples. Following analysis is oriented to the influence of physical and electrical parameters of the medium 1 on the distribution of electric field above a multilayered soil.

First, the impact of the medium 1 thickness is analyzed.

For the purpose of this research the thickness of medium 1 varied as shown in table 2. Other media properties remain constant as shown in table 1.

Table II. Variation in thickness (l) of medium 1

I	1 cm
II	10 cm
III	25 cm
IV	50 cm

Figures 2 and 3 show calculated electric field distribution 2m above the ground for various thickness of the first layer.

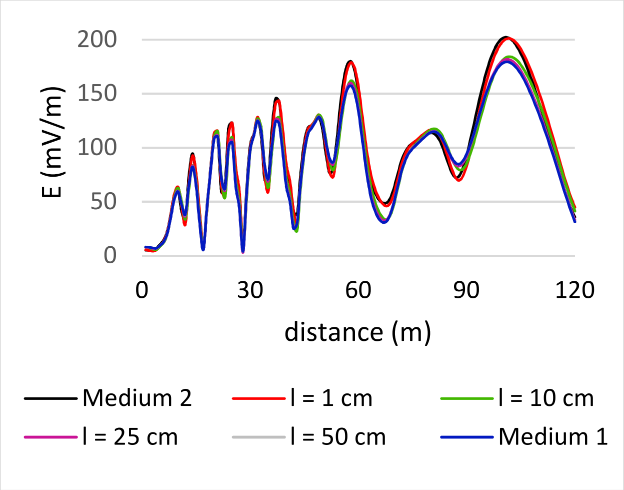

Figure 2. Electric field for different values of the medium 1 thickness at distances up to 119 m away from antenna pillar

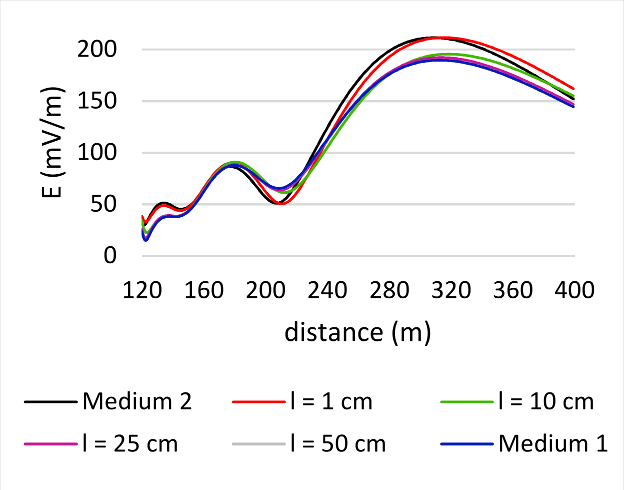

Figure 3. Electric field for different values of the medium 1 thickness at distances between 120 m and 399 m away from antenna pillar

As could be seen from the obtained results, electric field curves have similar shape with slight amplitude differences particularly at the local minimums and maximus at the distances of approximately up to 120 m away from antenna pillar (Fig. 2).

The field level curve for the $l = 1$ cm thick medium 1 almost perfectly follows the Medium 2 curve. On the other hand, the increase of medium 1 thickness reduces the impact of medium 2 on total field strength to minimum. Thus, for the values of medium 1 thickness $l \geq 10$ cm, the medium 2 soil can be ignored in field calculations (Figs. 2 and 3) since the average difference in comparison to Medium 1[1] calculation is less than 7%.

A field calculation for the $l = 25$ cm shows the highest difference in comparison to the Medium 2[2] (67.8%), while the average difference is less than 11%. For the thickness of medium 1 equal to 1 cm, a maximum difference in

[1] "Medium 1" will be a term for field calculation with medium 1 included only (no medium 2 present).

[2] "Medium 2" will be a term for field calculation with medium 2 included only (no medium 1 present).

electric field strength is 44% while the average difference is only 5%. Increasing the medium 1 thickness up to 50 cm, a maximum difference rises up to 68% with the average difference of approximately 12%.

Once again, for the conditions stated in table 1 it is important to accentuate two very important conclusions:
1. the medium 1 with thickness $l \leq 1$ cm can be ignored in field strength calculations and
2. the medium 2 can be ignored for the medium 1 thicknesses $l \geq 10$ cm.
However, under the conditions with $\sigma_1 \geq 1$ S/m or $\varepsilon_1 \geq 15$ the situation changes. Namely, increasing the relative permittivity at $\varepsilon_1 \geq 15$ or specific conductivity at $\sigma_1 \geq 1$ S/m, the medium 2 can be ignored even for the medium 1 thickness of 1 cm.

Next set of results are related to the impact of the medium 1 conductivity to the electric field distribution.
Supposing the relative permittivity of medium 1 to be 4, the research on the impact of specific conductivity of medium 1 on total electric field is made. Specific conductivity values are varied as shown in table 3.

Table III. Variation in specific conductivity (**σ_1**) of medium 1

I	0.05 S/m
II	0.1 S/m
III	1 S/m
IV	1000 S/m

The specific conductivity value of medium 2 remain the same (0.001 S/m) as well as relative permittivity (10). The results of field calculations are presented in regard to Medium 2 calculation and shown graphically.

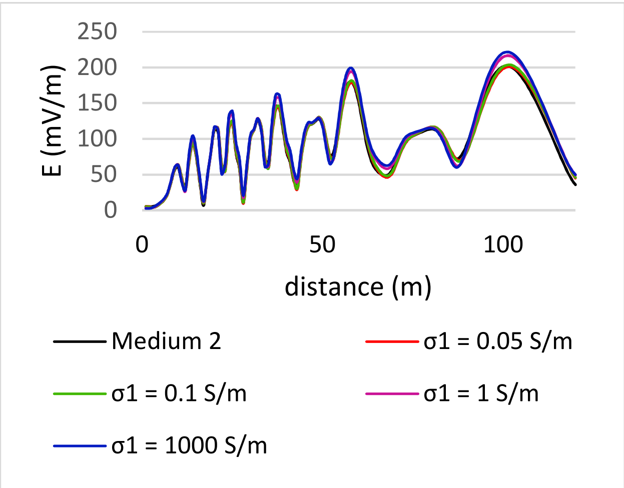

Figure 4. Field level curves with the medium 1 thickness to be 1 cm at distances up to 119 m away from antenna pillar

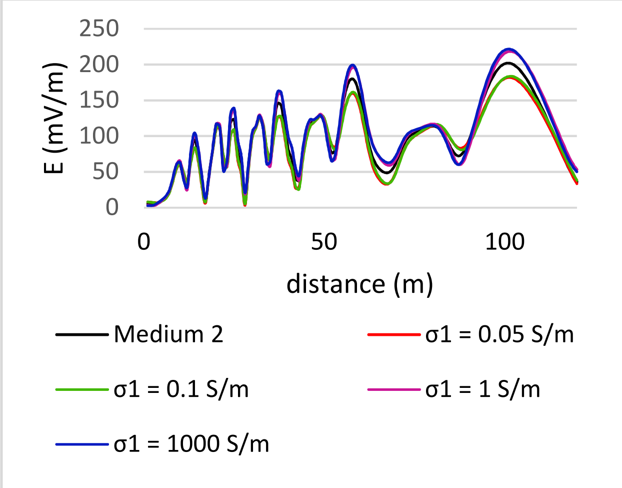

Figure 5. Field level curves with the medium 1 thickness to be 25 cm at distances between 120 m and 399 m away from antenna pillar

At Figs 4 and 5 the differences in field level can be seen, especially at the points of local minimum and maximum where the highest differences appear. It is also interesting to notice the mostly lower values in field with specific conductivity $\sigma 1 \leq 0.1$ S/m in comparison to the cases with $\sigma 1 \geq 1$ S/m in which the reflected field has much more influence on total filed level.
The higher specific conductivity of medium 1, the bigger difference in field level in comparison to Medium 2. For the values of $\sigma_1 \leq 0.1$ S/m a maximum field difference varies between 44% and 68%. Increasing the σ_1 at 1 S/m and 1000 S/m respectively, the highest field difference grows up to 96% and 114% respectively
Although the differences in field level at $\sigma_1 \leq 0.1$ S/m reach up to 68% of Medium 2 calculation, the average differences are not crossing over 12%. The same conclusion is valid for calculations with $\sigma_1 \geq 1$ S/m. However, the most significant growth in average field difference appears in the case with 1 cm thickness of medium 1 (between 5.2% and 10.9%) while the changes at other values of medium 1 thickness are much lower (between 9.7% and 11.6%).

The last set of Figs deals with the impact of the Medium 1 permittivity to the field above a multilayered soil.

Assuming the specific conductivity of medium 1 to be 0.05 S/m, the impact of relative permittivity of the medium 1 on the total electric field is examined. Relative permittivity of medium 1 varied as shown in the table 4 while characteristics of medium 2 remain the same (table 1).

Table IV. Variations in relative permittivity (**ε_1**) of medium 1

I	4
II	5
III	15
IV	80

The results of field calculations are presented in regard to Medium 2 and shown graphically.

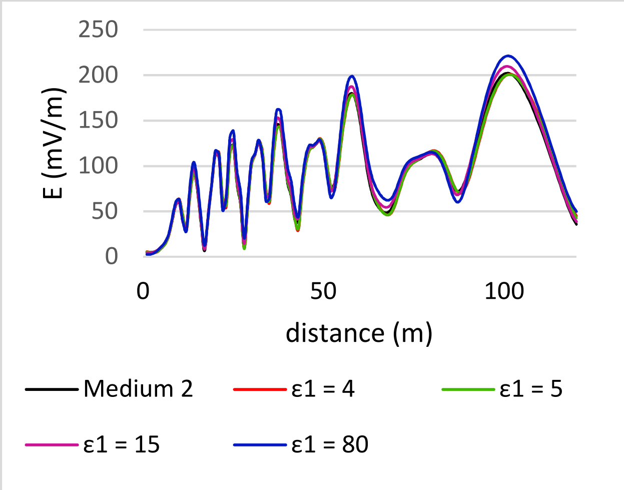

Figure 6. Field level curves with the medium 1 thickness to be 1 cm at distances up to 119 m away from antenna pillar

A higher relative permittivity ε_1 results with higher total field level (Figs 6 and 7).

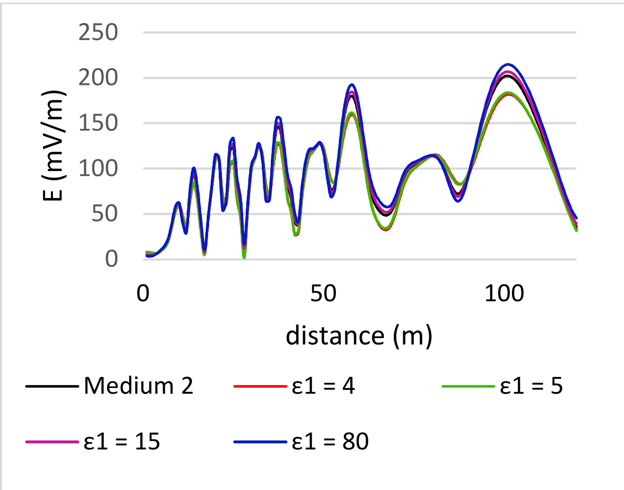

Figure 7. Field level curves with the medium 1 thickness to be 25 cm at distances between 120 m and 399 m away from antenna pillar

It is interesting to notice the appearance of higher field level differences as the medium 1 thickness increase. As in case before, the higher field differences appear at points of local minimum and maximum (Figs 6 and 7).

Increasing the relative permittivity of medium 1, the highest difference in field level mostly increase as well even this assumption doesn't have to always be followed. An interesting irregularity appears at the value of $\varepsilon_1 = 15$ where maximum differences are the lowest in calculations with medium 1 thickness $l > 1$ cm. The highest differences in field level for medium 1 thickness $l \leq 10$ cm appear at the highest value of ε_1. For other medium 1 thicknesses ($l \geq 25$ cm) the highest field differences appear at the value of $\varepsilon_1 = 5$.

A trend of changes in average field strength differences mostly follows the trend of change in maximum field differences. Although, the highest average differences are not necessary present at the same value of ε_1 at specific medium 1 thickness as the maximum difference is. On the other hand, the lowest average differences are present at the relative permittivity value of $\varepsilon_1 = 15$ independently of medium 1 thickness.

5. Conclusion

The thicker the medium 1 is the lower is the impact of medium 2 on the field values. An analysis taken under conditions stated in table 1 has shown that in the case of 1 cm thick medium 1 the impact is negligible. On the other hand, for the case of 10 cm thick medium 1, an impact of medium 2 on total field strength is reduced and can be ignored. This is especially applicable at medium 1 thicknesses of 25 cm and 50 cm respectively, where the impact of medium 2 is brought to minimum.

However, under the conditions with $\sigma_1 \geq 1$ S/m or $\varepsilon_1 \geq 15$ the situation changes and the medium 2 can be ignored even for the medium 1 thickness of 1 cm.

In conditions with lower values of specific conductivity of medium 1 ($\sigma_1 \leq 0.1$ S/m), a maximum difference in comparison to Medium 2 field level is between 44% and 68% with the average difference between 5% and 12%. Increasing the specific conductivity up to 1000 S/m the highest field difference grows up to 114% with the average difference up to 11%.

Considering the impact of relative permittivity of medium 1 on total electric field strength, it is shown that highest field differences reaches up to 112% and maximum difference can appear at any value of relative permittivity. The average field differences don't exceed 11% and also don't have any rule in their appearances.

6. References

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