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Comparison of Image and Transmission Line Models of Energized Horizontal Wire Above Two-Layer Soil

The paper presents comparison between two approximate models of energized horizontal thin-wire conductors above two-layer soil. The formulation is posed in frequency domain by using two approaches. The first one is based on quasi-static image theory within Mixed Potential Integral Equation. The second one is based on transmission line theory with approximation of per unit length parameters. The authors compare currents computed by the both approximate models of a center fed wire to establish the computation errors over a wide frequency range. The main objective is to validate the proposed image and transmission line models for various lengths of wire conductors, and various cases of low and high conductivities of two-layer soil. The verification of the results is done by comparison with exact model based on full-wave theory. Detailed parametric analysis clearly illustrate validity domain and problems when using both approximate models with respect to their use in practical EMC studies.

Key words: Full-wave theory, transmission line theory, quasi-static image approximation, two-layer soil

Usporedba zrcalnog modela i modela prijenosnih linija u analizi horizontalne žičane strukture iznad dvoslojnog tla. U radu je prikazana usporedba dviju približnih modela analize pobuđenog horizontalnog tankog žičanog vodiča iznad dvoslojnog tla. Formulacija problema je izvedena u frekvencijskoj domeni pomoću dva pristupa. Prvi pristup se temelji na kvazi-statičkom zrcalnom modelu unutar integralne jednadžbe s mješovitim potencijalima. Drugi se temelji na teoriji prijenosnih linija s aproksimacijom jediničnih parametara. Autori su usporedili distribucije struje izračunate s pomoću obje približne metode kako bi odredili pogrešku metoda u širokom rasponu frekvencija. Glavni cilj bio je potvrditi predloženi zrcalni i linijski model za različite duljine žičanog vodiča i razne slučajeve niske i visoke vodljivosti slojeva tla. Provjera rezultata obavljena je usporedbom s modelom bez aproksimacija temeljenog na punovalnoj teoriji. Detaljna parametarska analiza jasno pokazuju valjanosti domene i vrste problema uz korištenje obje približne metode s obzirom na njihovu primjenu u praktičnim EMC razmatranjima.

Ključne riječi: punovalna teorija, teorija prijenosnih linija, kvazi-statička zrcalna aproksimacija, dvoslojno tlo

1 INTRODUCTION

The electromagnetic analysis of thin wire structures above finitely conductive soil (homogeneous or stratified) is often part of in both antenna and complex electromagnetic compatibility (EMC) studies, such as transient analysis of transmission lines due to lightning or faults, powerline communications, etc. Different strategies for modeling have been developed, ranging from transmission line theory to exact approaches based on electromagnetic theory [1]. The most accurate solution is formulated by using antenna theory with at least approximations [2]. It is based on rigorous formulation for the electric field due to elementary Hertz dipole sources in presence of lossy half-space. This solution involves Green's functions that take into account effects of interfaces between mediums via exact Sommerfeld formulation. Although practical studies

are often based on a homogeneous earth model, there are situations when two-layer model is needed to better estimate effects of inherently non-homogeneous earth [3]-[6]. However, because of computational difficulties due direct numerical integration, approximate approaches are of interest in view that such exact solution becomes time consuming and very complex. The survey of the published work in this area implies that such approximations usually involve quasi-static theory concepts of images [7].

In this paper the authors present two approximate approaches. The first one is based on quasi-static image theory in order to obtain approximate Green's functions for the given problem. The second approach is based on transmission line theory and uses the propagation effects via distributed parameters that are determined by using equivalent homogeneous soil approach. To determine the validity domains of both approximate models, the authors com-
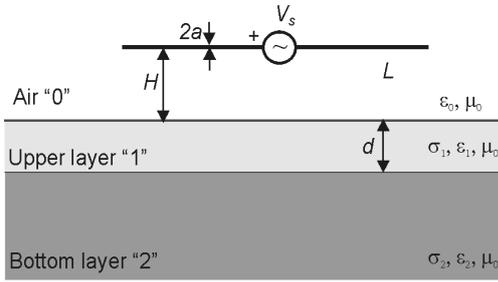
Fig. 1. *A center fed horizontal wire conductor above two-layer soil*

Fig. 2. *Approximation of the current with roof-top basis functions over two neighbor segments*

pare the results of the current in the feed point with respect to exact solution. The calculations are done in wide frequency range from 0.1 to 10 MHz. Detailed parametric analysis clearly illustrate validity domain and problems in using both approximate models with respect to their use in practical EMC studies.

2 HORIZONTAL CENTER FED CONDUCTOR ABOVE TWO-LAYER SOIL

Consider x–directed horizontal conductor of radius a and length L placed at height H above two-layer soil, as shown in Fig. 1. The central fed energization is assumed by a harmonic voltage generator V_S in frequency range from 0.1 to 10 MHz, the time variation $e^{j\omega t}$ is assumed and suppressed. The air, denoted as medium "0", occupies the upper half-space ($z > 0$), whereas the soil occupies the lower half-space ($z < 0$). The soil non-homogeneity is represented by two parallel homogeneous finitely conductive layers denoted by "1" for the upper layer of finite depth d, and "2" for the lower semi-infinite layer. All mediums are characterized by corresponding values for permeability μ_0, permittivity $\varepsilon_i = \varepsilon_0 \varepsilon_{ri}$ and conductivity σ_i, ($i = 0, 1, 2$), and $\sigma_0 = 0$ for the air.

3 EXACT MODEL

The exact model for a given problem is based on the Electric Field Mixed Potential Integral Equation (EF-MPIE) that is solved by the Method of Moments (MoM) using Galerkin formulation [8]. In due course, thin-wire conductor is divided into N fictitious sub-segments. Next, the unknown current I is approximated by a sequence of expansion functions over two-neighbor subsections thus forming a segment of total length l_n. Here, we use roof-top expansion functions which results in a piecewise linear approximation of the current, as shown in Fig. 2.

The boundary conditions regarding the tangential component of the electric field at the wire surface are satisfied
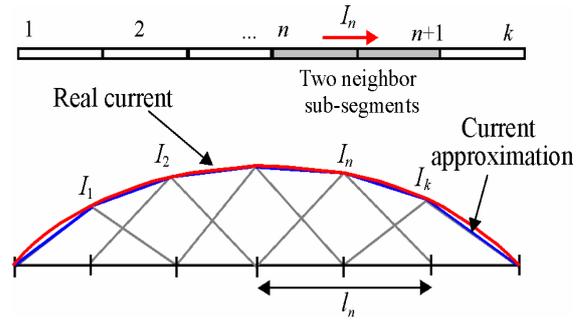
approximately in an average (weighted) way. We choose the weighting functions to be the same roof-top functions.

The current distribution is obtained by solving the well known matrix equation [9]

$$[Z] \cdot [I] = [V], \quad (1)$$

where the column matrix $[I]$ represents the unknown current samples, $[Z]$ is the generalized impedance matrix related to mutual impedances between segments, $[V]$ is the excitation matrix.

The elements of the impedance matrix denoted by z_{mn} represent self or mutual impedances between a pair of observation (m) and source (n) segment

$$z_{mn} = \frac{V_{mn}}{I_n} = \frac{-1}{I_n} \int\limits_{l_m} E_{nx} dl_m. \quad (2)$$

Here, E_{nx} is x–directed component of the electric field vector tangential to the surface of the observation segment m with length l_m due to filaments of current I_n and charge q_n along the axis of the source segment n by using the following Mixed Potential Integral Equation (MPIE) [10]

$$E_{nx} = -j\omega A_{nx} - \nabla V_n, \quad (3)$$

$$\begin{aligned} A_{nx} &= \int\limits_{l_n} G_A^{xx} I_n dl_n \\ V_n &= \int\limits_{l_n} G_V q_n dl_n \end{aligned} \quad (4)$$

This model involves exact formulations for the Green's functions of the vector and scalar potentials. Here, G_A^{xx} is the x-component of the dyadic Green's function for the magnetic vector potential due to x-directed horizontal electric dipole HED in air above two-layer soil. Respectively, G_V is the scalar potential Green's function due to one charge q associated to the HED.

The Green's functions G_A^{xx} and G_V are obtained firstly in the transformed Fourier domain by solving the corresponding wave equations with respect to the boundary conditions at the interfaces. The spectral expressions for the vector and scalar Green's functions relative to this problem may be derived from the generalized expressions [11]

$$\widetilde{G}_A^{xx} = \frac{\mu_0}{2} \left[\frac{e^{-u_0(z-z')}}{u_0} + R_{TEgen} \frac{e^{-u_0(z+z')}}{u_0} \right] , \quad (5)$$
$$= \frac{\mu_0}{2} \left[\widetilde{G}_{dir} + \widetilde{G}_{Aref}^{xx} \right]$$

$$\widetilde{G}_V = \frac{1}{2\varepsilon_0} \left[\frac{e^{-u_0(z-z')}}{u_0} \right.$$
$$\left. + \frac{k_0^2 R_{TEgen} - u_0^2 R_{TMgen}}{\lambda^2} \frac{e^{-u_0(z+z')}}{u_0} \right]. \quad (6)$$
$$= \frac{1}{2\varepsilon_0} \left[\widetilde{G}_{dir} + \widetilde{G}_{Vref} \right]$$

The spatial domain Green's functions are later obtained by solving a Sommerfeld-type integral

$$G_{A,V}^{xx} = S_0 \left\{ \tilde{G}_{A,V}^{xx} \right\} = \frac{1}{2\pi} \int_0^\infty \tilde{G}_{A,V}^{xx}(\lambda) J_0(\lambda\rho) \lambda d\lambda. \quad (7)$$

where $J_0(\lambda\rho)$ is zero-order Bessel function of the first kind, and r is radial distance between the HED and the observation point.

The spatial domain solution of the first term in (5) and (6) stands for so called direct term G_{dir} representing a spherical wave due to source HED in unbounded free space

$$S_0 \left\{ \frac{e^{-u_0(z-z')}}{u_0} \right\} = \frac{1}{2\pi} \frac{e^{-jk_0 R_d}}{R_d} = G_{dir} \quad (8)$$
$$R_d = \sqrt{\rho^2 + (z-z')^2}$$

where R_d stands for the direct distance between the HED and the observation point.

The spatial domain solution of the second term in (5) and (6) represents the wave reflected form finitely conductive two-layer. Here, R_{TEgen} and R_{TMgen} are generalized Fresnel *TE* and *TM* reflection coefficients [12]

$$R_{(TE,TM)gen} = [R_{(TE,TM)01}$$
$$+ R_{(TE,TM)12} e^{-u_1 2d}] \cdot M_{TE,TM}$$
$$M_{TE,TM} = (1 + R_{(TE,TM)01} R_{(TE,TM)12} e^{-u_1 2d})^{-1}$$
$$(9)$$

$$R_{TE\,i,i+1} = \frac{u_i - u_{i+1}}{u_i + u_{i+1}}$$
$$R_{TM\,i,i+1} = \frac{k_{i+1}^2 u_i - k_i^2 u_{i+1}}{k_{i+1}^2 u_i + k_i^2 u_{i+1}} \quad (10)$$

$$u_i = \sqrt{\lambda^2 - k_i^2}; \quad i = 0, 1, 2$$
$$k_0^2 = \omega^2 \mu_0 \varepsilon_0; \quad k_{1,2}^2 = \varepsilon_{r1,2} k_0^2 \quad (11)$$
$$\underline{\varepsilon}_{r1,2} = \varepsilon_{r1,2} - j\sigma_{1,2}(\omega\varepsilon_0)^{-1}$$

The spatial solution of the reflected terms is obtained by direct numerical integration similarly to the approach in [2].

4 QUASI-STATIC IMAGE MODEL

As it is well known, if a Hertz dipole is placed above perfectly reflecting boundary (ideally conductive), the field can be evaluated exactly by the method of images [13]. However, if the boundary is non-perfect the method of images is an approximate solution.

The proposed quasi-static image model is based on the exponential approximation of the spectral Green's functions when frequency tends to zero. The spatial domain Green's functions are later obtained in closed form in terms of infinite sum of Green's functions of the source images. In comparison to the classical quasi- static approach, this image representation involves the propagation effect [14].

As $\omega \to 0$, $k_0^2 \to 0$ it may be assumed $u_0 \approx u_1 \approx u_2$ since $\lambda^2 \gg k_n^2$ ($n = 0, 1, 2$). This makes possible that the *TM* reflection coefficients are approximated by complex reflection constants that represent their near field approximations

$$R_{TM12} \to -K_{12} \quad R_{TM01} \to K_{10}$$
$$K_{12} = \frac{\underline{\varepsilon}_1 - \underline{\varepsilon}_2}{\underline{\varepsilon}_1 + \underline{\varepsilon}_2} \quad K_{10} = \frac{\underline{\varepsilon}_1 - \varepsilon_0}{\underline{\varepsilon}_1 + \varepsilon_0} \quad . \quad (12)$$

By applying (12) into (9) we obtain

$$R_{TMgen} \approx \frac{K_{10} - K_{12} e^{-u_1 2d}}{1 - K_{10} K_{12} e^{-u_1 2d}}. \quad (13)$$

Next, the denominator in (13) is expanded into series

$$1 - K_{10} K_{12} e^{-u_1 2d} \to \sum_{p=0}^{\infty} (K_{10} K_{12})^p e^{-u_1 2dp} \quad (14)$$

That leads the following approximation

$$R_{TMgen-} \approx \left(K_{10} - K_{12} e^{-u_1 2d} \right)$$
$$\cdot \sum_{p=0}^{\infty} (K_{10} K_{12})^p e^{-u_1 2dp} \quad . \quad (15)$$

Respectively, the quasi-static approximation of the terms associated to the *TE* leads to

$$R_{TE12} \to 0 \quad R_{TE01} \to 0 \quad M_{TE} \to 1. \quad (16)$$

Applying above approximations into (5) and (6) it follows

$$\widetilde{G}_A^{xx} \approx \frac{\mu_0}{2} \frac{e^{-u_0(z-z')}}{u_0} \quad (17)$$

$$\widetilde{G}_V \approx \frac{1}{2\varepsilon_0} \left[\frac{e^{-u_0(z-z')}}{u_0} - (K_{10} - K_{12} e^{-u_1 2d}) \right.$$
$$\left. \cdot \sum_{p=0}^{\infty} (K_{10} K_{12})^p e^{-u_1 2dp} \cdot \frac{e^{-u_0(z+z')}}{u_0} \right] \quad . \quad (18)$$

If we introduce $e^{-u_1 h} \approx e^{-u_0 h}$ in (18) it is possible to rewrite in spectral domain

$$\widetilde{G}_V \approx \frac{1}{2\varepsilon_0} \left[\frac{e^{-u_0(z-z')}}{u_0} - (K_{10} - K_{12}\,e^{-u_0 2d}) \right.$$
$$\left. \cdot \sum_{p=0}^{\infty} (K_{10}K_{12})^p e^{-u_0 2dp} \cdot \frac{e^{-u_0(z+z')}}{u_0} \right] \quad . \quad (19)$$

The corresponding spatial domain solutions of (17) and (19) are obtained in closed-form by the direct term G_{dir} and in terms of infinite image representation

$$G_A^{xx} \approx \frac{\mu_0}{2} G_{dir} \qquad (20)$$

$$G_V = \frac{1}{2\varepsilon_0} \left\{ G_{dir} - K_{10}G_{img} \right.$$
$$\left. - (K_{10} - K_{10}^{-1}) \sum_{p=1}^{\infty} (K_{10}K_{12})^p G_p \right\} \qquad (21)$$

where

$$G_{img} = \frac{1}{2\pi} \frac{e^{-jk_0 R_i}}{R_i}; \quad R_i = \sqrt{\rho^2 + (z+z')^2} \quad (22)$$

$$G_p = \frac{1}{2\pi} \frac{e^{-jk_0 R_p}}{R_p}; \quad R_p = \sqrt{\rho^2 + (2dp + z + z')^2}. \quad (23)$$

Finally, if we assume $\omega = 0$, it follows $e^{-u_0 h} = 1$, so that (20) and (21) reduce to dc expressions of static images.

5 TRANSMISSION LINE MODEL

The transmission line (TL) equations for a horizontal wire conductor above two-layer soil excited by the voltage generator can be derived from the Maxwell's equations and expressed in terms of voltage and current induced along the conductor [1]

$$\begin{array}{c} \frac{\partial V(x)}{\partial x} + ZI(x) = 0 \\ \frac{\partial I(x)}{\partial x} + YV(x) = 0 \end{array} \quad . \quad (24)$$

The mathematical details regarding the solution of the frequency domain transmission line equations are based on the chain matrix. Here, we use quasi-static approximations for per unit length parameters Z and Y

$$Z = \frac{j\omega\mu_0}{2\pi} \ln \frac{2H}{a} + Z_g \qquad (25)$$

$$Y = \frac{j\omega 2\pi\varepsilon_0}{\ln \frac{2H}{a}} \parallel Y_g, \qquad (26)$$

where Z_g and Y_g are earth return impedance and admittance respectively [16]

$$Z_g = \frac{j\omega\mu_0}{2\pi} \ln \frac{1 + \gamma_{eq}H}{\gamma_{eq}H} \qquad (27)$$

$$Y_g = \frac{\gamma_{eq}^2}{Z_g} \qquad (28)$$

$$\gamma_{eq} = jk_{eq} \qquad (29)$$

$$k_{eq} = k_1 \frac{(k_1 + k_2) - (k_1 - k_2)e^{-j2k_1 d}}{(k_1 + k_2) + (k_1 - k_2)e^{-j2k_1 d}}, \qquad (30)$$

where k_{eq} is the equivalent soil propagation constant [15].

The solution of (24) thanks to boundary conditions $I(0) = I(L) = 0$ leads to following expression for the current distribution

$$\begin{array}{ll} I(x) = \frac{V_g \sinh \gamma L/2}{Z_0 \sinh \gamma L} \sinh \gamma(L - x) & for\ x \geq L/2 \\ I(x) = \frac{V_g \sinh \gamma L/2}{Z_0 \sinh \gamma L} \sinh \gamma x & for\ x \leq L/2 \end{array} \quad . \quad (31)$$

where $Z_0 = \sqrt{\frac{Z}{Y}}$ and $\gamma = \sqrt{Z \cdot Y}$ are respectively the characteristic impedance and the propagation constant along the transmission line.

6 NUMERICAL EXAMPLES

To determine the domain of applicability of proposed approximate image model and TL model we have compared the current in the center feed point of a horizontal conductor above two-layer soil. The studies cases are: $L = 20$-m (short conductor) and $L = 200$-m (long conductor), with radius $a = 0.01$ m positioned at height H: 0.5 m, 2.5 m and 5 m. Two values for the upper layer depth are assumed: $d = 0.2$ m (thin layer) and $d = 1.2$ m (thick layer). The two-layer soil is assumed by fixed conductivity $\sigma_1 = 0.01$ S/m for the upper layer, whereas two distinct conductivities are assumed for the bottom layer: $\sigma_2 = 0.001$ S/m and $\sigma_2 = 0.1$ S/m. In both cases the relative permittivity of two-layer soil is $\epsilon_r = 10$.

The excitation is central feed by a harmonic voltage source of 1 V, in frequency range from 0.1 to 10 MHz.

In the following section the results obtained by using exact moment method approach are denoted by "Exact" (solid line), the image approximation is denoted by "Image" (dash line) and TL approximation is denoted by "TL" (dotted line).

6.1 Short 20-m conductor

Fig. 3 to Fig. 5 show respectively the current at the feed point of a 20-m (short) conductor at height H: 0.5 m, 2.5 m and 5 m above two-layer soil with thin upper layer ($d = 0.2$ m). Respectively, in Fig. 6 and Fig. 7 it may be observed the current at the feed point in case of a thick upper layer ($d = 1.2$ m).

The results show that Image and TL models represent good approximation in the lower frequencies, but also in the range up to few MHz. Differences are observed at frequencies around the resonance (~7 MHz). The results show that the parameters of the two-layer soil and the position of
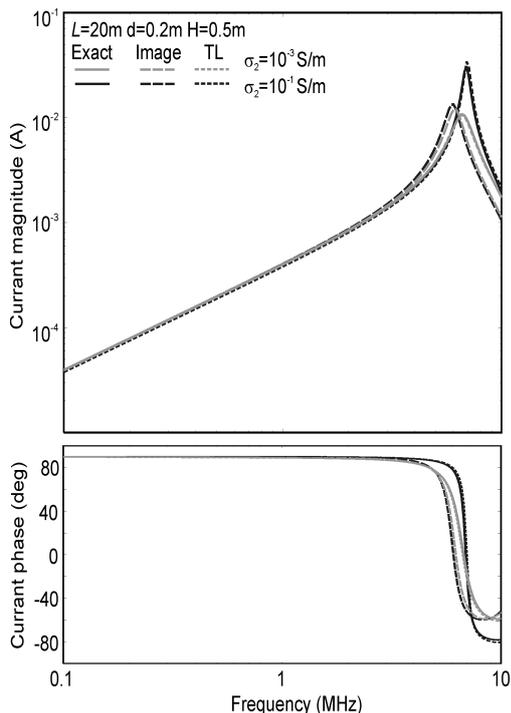
Fig. 3. Current at the feed point of a 20-m conductor at H = 0.5 m (thin layer d = 0.2 m)

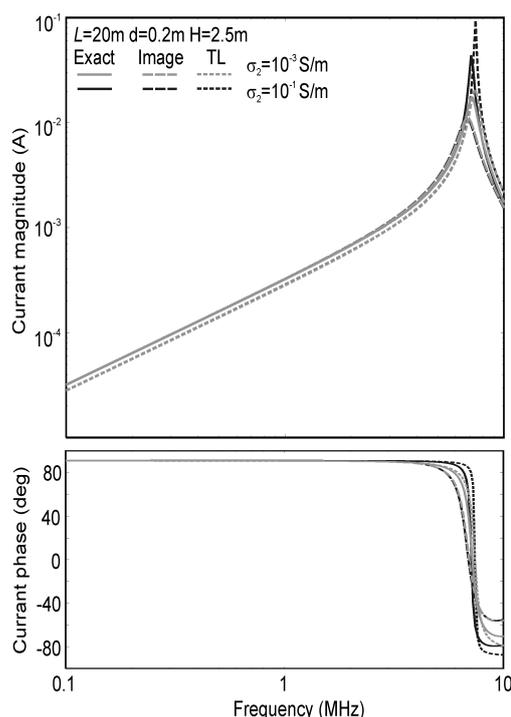Fig. 4. Current at the feed point of a 20-m conductor at H = 2.5 m (thin layer d = 0.2 m)

the conductor play important role that affects significantly the accuracy of the approximate models.

The Image model shows mismatch of the resonant frequency in case when the conductor is close to the air-soil interface, as shown in Fig. 3 and Fig. 6 (H = 0.5m). However, these differences decrease when increasing the conductor height, as shown in Fig. 5 and Fig. 7.

The accuracy of the Image model is higher when increasing the upper layer depth, since the influence of the bottom layer decreases.

On the other hand, the TL model shows very good agreement with the Exact model when the conductor is close to the air-soil interface (Fig. 3 and Fig. 6). However, the accuracy of the TL model decreases when increasing the height H, as shown in Fig. 5 and Fig. 7. As may be observed, the current peaks are much higher than the exact values which lead to more significant calculation errors around the resonance.

Generally, both approximate models show better agreement in the case when the bottom layer is less conductive (here $\sigma_2 = 0.001$ S/m).

In order to measure the accuracy of both approximate models we determine the calculation error in frequency domain by comparing the currents at the feed point computed by
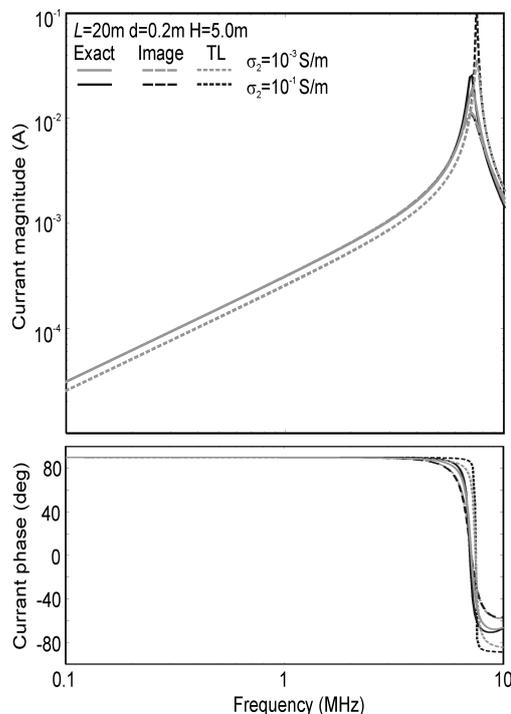

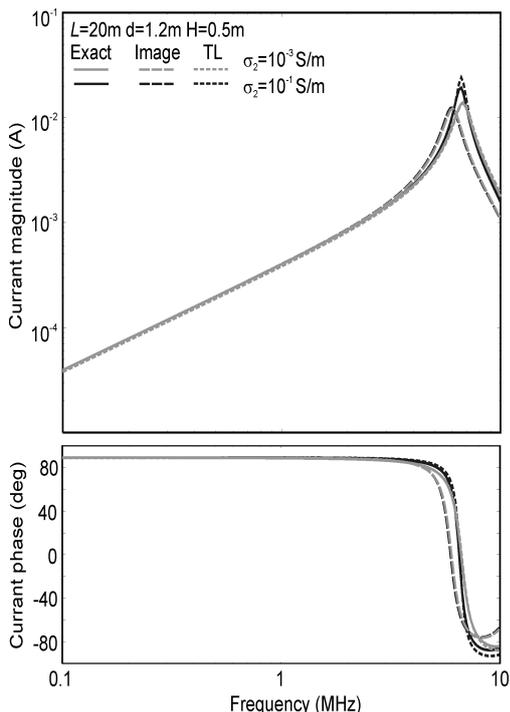Fig. 5. Current at the feed point of a 20-m conductor at H = 5.0 m (thin layer d = 0.2 m)

Fig. 6. Current at the feed point of a 20-m conductor at H = 0.5 m (thick layer d = 1.2 m)

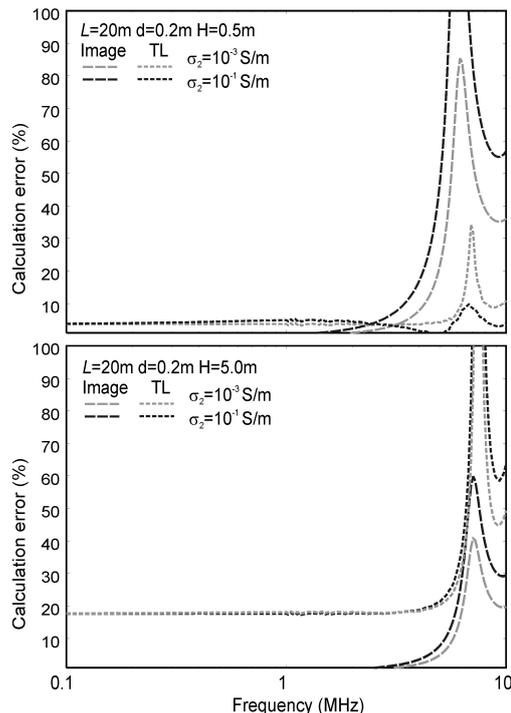*Fig. 7. Current at the feed point of a 20-m conductor at H = 5.0 m (thick layer d = 1.2 m)*

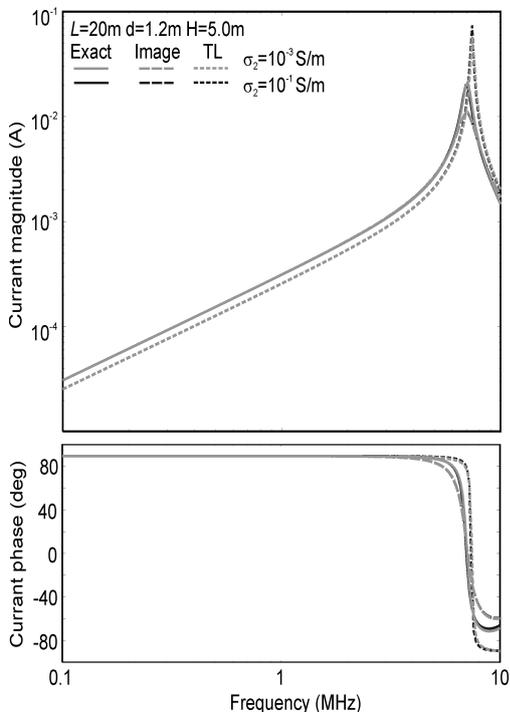*Fig. 8. Calculation error for 20-m conductor obtained by using Image and TL models for d = 0.2m*

$$Abs \left[\frac{I_{Exact} - I_{Image,TL}}{I_{Exact}} \right] \cdot 100, \qquad (32)$$

where I_{Exact} is complex value of the current obtained by using Exact model, and $I_{Image,TL}$ are corresponding approximate values obtained by using Image model and TL model respectively.

In Fig. 8 and Fig. 9 it may be observed respectively the values of the calculation error (up to 100%) (32) in case of 20-m wire conductor above two-layer soil with thin layer ($d = 0.2$ m) and thick layer ($d = 1.2$ m) for two values of the conductor height $H = 0.5$ m and $H = 5.0$ m.

As may be observed, the Image model shows good agreement in the lower frequency range up to few MHz. High calculation error is obtained in the higher frequency range above 4 MHz. The TL model shows better agreement in case when the conductor is close to the air-soil interface practically in all frequency range. However, in case when the conductor is set to greater heights the calculation error even in the lower frequency range is about 20%. Both models introduce very high calculation error around the resonant frequency.

6.2   Long 200-m conductor

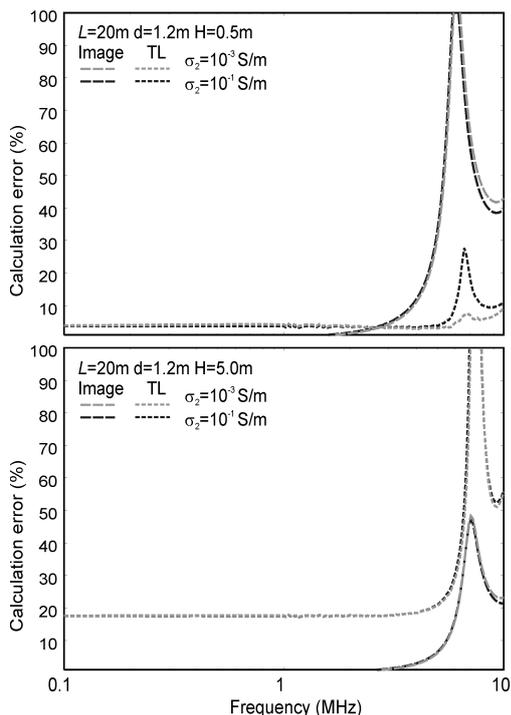In this section we represent the results obtained in case of long 200-m (long) conductor. Fig. 10 to Fig. 12 repre-

Fig. 9. Calculation error for 20-m conductor obtained by using Image and TL models for d = 1.2m

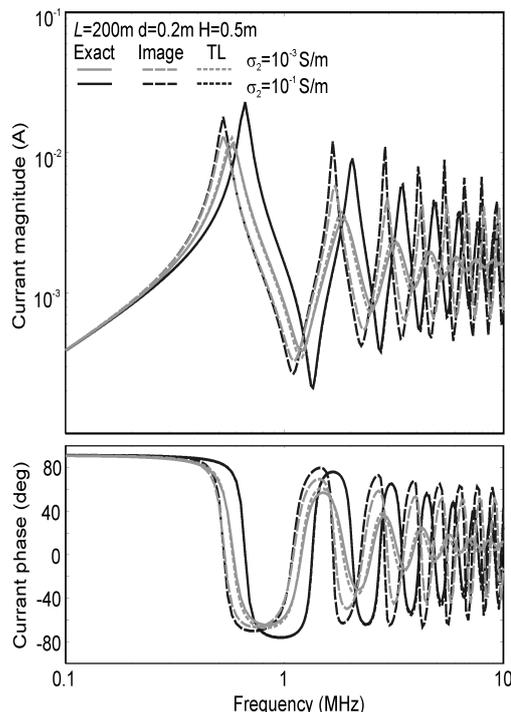Fig. 10. Current at the feed point of a 200-m conductor at H = 0.5 m for d = 0.2 m

sent respectively the current at the center feed point calculated for three conductor heights H: 0.5 m, 2.5 m and 5.0 m in case of a thin upper layer ($d = 0.2$ m). Respectively, in Fig. 13 and Fig. 14 it may be observed the current at the feed point in case of a thick upper layer ($d = 1.2$ m) for two conductor heights H: 0.5 m and 5.0 m.

The results show that in case of a long conductor the Image model introduces more visible differences around resonant frequencies. More precisely, there is a mismatch in the current peaks particularly when the conductor is close to the soil surface, Fig. 10.

Again, the errors are higher when the bottom layer is more conductive.

Figures 15 and 16 show the calculation error (up to 100%), that the application of the Image model is limited to the lower frequency range below the first resonance (here 0.3 MHz).

On the other hand, the TL model shows very good agreement in case when the conductor is close to the air-soil interface in all frequency range. However, in case when the conductor is set high above the soil surface, the application of the TL model is limited to frequencies up to about 1 MHz.
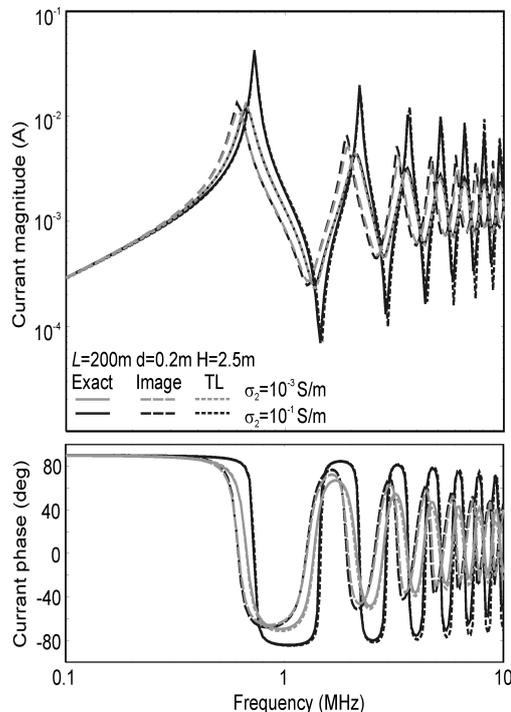

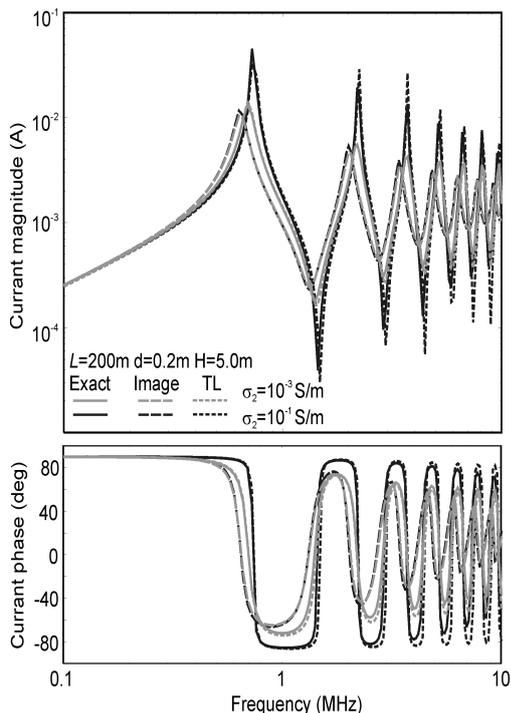Fig. 11. Current at the feed point of a 200-m conductor at H = 2.5 m for d = 0.2 m

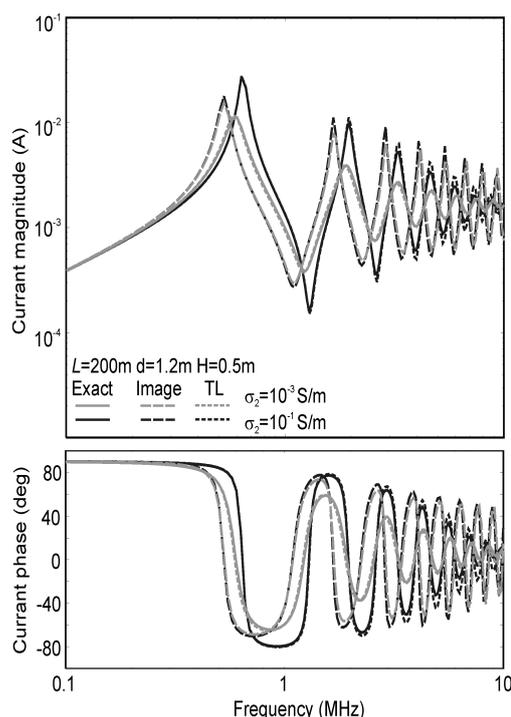Fig. 12. Current at the feed point of a 200-m conductor at H = 5.0 m for d = 0.2 m

Fig. 13. Current at the feed point of a 200-m conductor at H = 0.5 m for d = 1.2 m

7   CONCLUSION

The exact modeling of horizontal wire-conductor above two-layer soil is considered as numerically most precise. In the practice however, often most simplified models are needed due to time consuming numerical calculations.

In this paper, we have presented and compared two approximate approaches: Image model and TL model. The results show that the parameters of the two-layer soil and the position of the conductor play important role that affects significantly the accuracy of proposed approximate models.

The Image model is derived from the exact model by a single substitution of the reflection Fresnel coefficients in the spectral domain with their quasi-static forms. The TL model uses approximate expressions for the per unit length parameters on the basis of homogenous soil approximation of two-layer soil by equivalent resistivity approach. Both approximate models show better agreement in case of less conductive bottom layer.

The Image model is accurate at dc and leads to generally small errors at low frequencies. At higher frequencies (above few MHz for short conductors, and few hundred kHz for long conductors), the error introduced is strongly dependent on resonances. Also, the Image model introduces higher calculation error when the conductor is
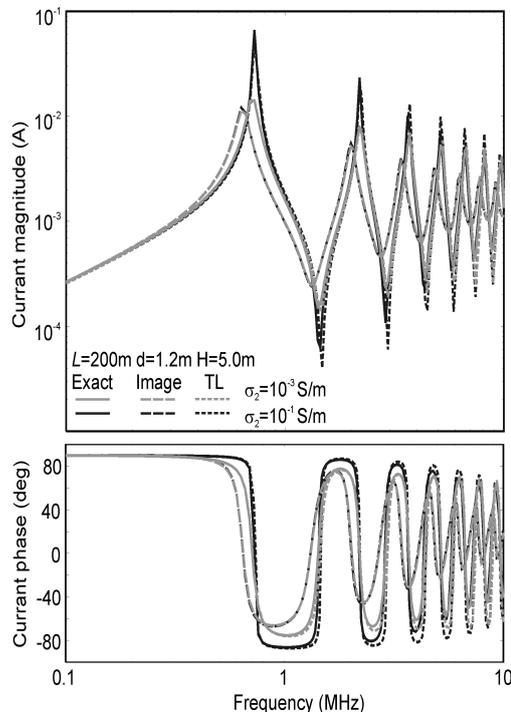

Fig. 14. Current at the feed point of a 200-m conductor at H = 5.0 m for d = 1.2 m
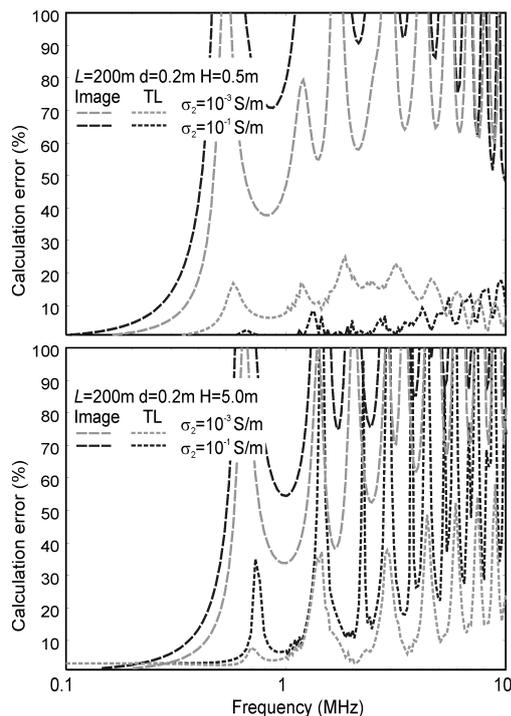
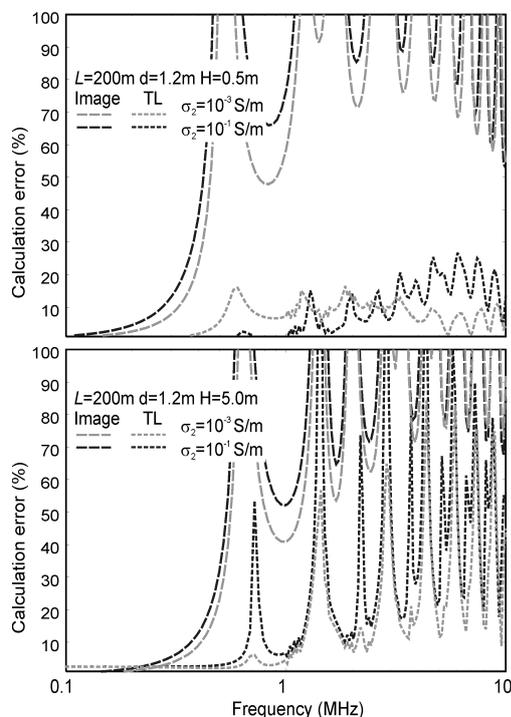*Fig. 15. Calculation error for 200-m conductor obtained by using Image and TL models for d = 0.2 m*

Fig. 16. Calculation error for 200-m conductor obtained by using Image and TL models for d = 1.2 m

close to the air-soil interface, but this error decreases when increasing the conductor height. Better agreement is obtained in cases when the bottom layer is less conductive. When increasing the upper layer depth, the results tend to those obtained for homogeneous soil with parameters of the upper layer.

The TL model shows very good agreement in case when the conductor is close to the soil surface, however larger calculation errors are observed when increasing the conductor height. In case of short conductors at greater heights ($H = 5.0$ m) the TL model introduces errors about 20% even in the lower frequency range. For long conductors, the TL model shows very good agreement with the Exact model but again only when the conductor is close to the soil surface. Otherwise, similarly as the Image model, large calculation errors are observed in the higher frequency range, particularly at resonant frequencies.

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