International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

A Time-domain Double Diffraction for Non-perfectly Conducting Wedges

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***Abstract*: A time-domain (TD) double diffraction solution is proposed with the source illumination for one or both sides of non-perfectly conducting wedges. The frequency domain redefined reflection angles as well as modified reflection coefficients are used in the different angular region of wedges for developing TD double diffraction. The accuracy of the proposed model is confirmed with IFFT- FD solution. Finally, the table of computational efficiency has been given for both the methods (TD and IFFT-FD) for hard polarization.**

***Keywords* : TD Double diffraction, modified reflection coefficient, IFFT-FD solution, non-perfectly conducting wedges.**

I. INTRODUCTION

In ultra-wide band (UWB) communication the time-domain (TD) propagation models are currently receiving great attention among the researchers. Some heuristic FD solutions have been discussed in [1]-[4] for non-perfectly conducting objects. The solution [5] provides improvement over the solution in [2] in the illumination region.

The focus on multiple diffraction between the wedges has been given in several previous research works. The field due to multiple-diffraction plays an important role. The FD UTD double diffractions have been discussed in [6]-[9]. A new heuristic approach has been presented for multiple-edge diffraction in [10]. Here, the slope diffraction is considered as second-order diffraction for accurate predictions.

Radio propagation models in time-domain (TD) are preferred to the frequency-domain (FD). In TD, the analysis of transient scattering behavior of microwave signals is done. Thus, all the frequencies are treated at a time. In [11], a heuristic TD double diffraction for a double wedge has been proposed based on FD diffraction coefficients of [2]. TD solution for the two-dimensional multiple-diffraction case has been developed in [12].

In the above literatures, double diffraction coefficients in FD and TD with single face source illumination have been considered. They have limitations with the source illumination from both faces of non-perfectly wedges. In this paper, we propose TD solutions for UWB double diffraction based on the FD solutions discussed in [5]. Thus, the proposed model incorporates the all merits of [5] over [2]. Furthermore, the validity of proposed TD model is given by the comparison with the corresponding IFFT solution of FD model. It shows that the proposed model is computationally faster.

II. FORMULATION OF DOUBLE DIFFRACTION

A. Frequency Domain

The FD single diffraction coefficients is given by [5]

$$D^{s,h}=\begin{cases} R_0R_nD^{(1)}+D^{(2)}+R_0D^{(3)}+R_nD^{(4)}, \\ \quad for\ \varphi'\le(n-1)\pi\cup \\ \quad \left(\varphi'>(n-1)\pi\cap\varphi>\left|(2n-1)\pi-\varphi'\right|\right). \\ D^{(1)}+R_0R_nD^{(2)}+R_nD^{(3)}+R_nD^{(4)}, \\ \quad for\ \varphi'>\pi \\ D^{(1)}+D^{(2)}+\Gamma^{s,h}\left(D^{(3)}+D^{(4)}\right), \\ \quad for\ \varphi'>(n-1)\pi\cap\varphi\le\left|(2n-1)\pi-\varphi'\right| \end{cases} \qquad (1)$$

where $D^{(i)}$ with $i=1-4$ given as in [2]. R_0 and R_n are defined as in [5]. φ and φ' are the diffracted angle and incident angle. $\Gamma^{s,h}$ is the modified reflection coefficient given in [5]

$$\Gamma^{s,h}=\frac{(1,\varepsilon)\alpha-\sqrt{\varepsilon-1+\alpha^2}}{(1,\varepsilon)\alpha-\sqrt{\varepsilon-1+\alpha^2}} \qquad (2)$$

where, $\varepsilon=\varepsilon_r-j\sigma/\omega\varepsilon_0$ and

$$\alpha=\begin{cases} 2\sin\left(\frac{\varphi}{2}\right)\sin\left(\frac{\varphi'}{2}\right), & for\ \phi<n\pi-\varphi' \\ 2\sin\left(\frac{n\pi-\varphi}{2}\right)\sin\left(\frac{n\pi-\varphi'}{2}\right), & otherwise \end{cases} \qquad (3)$$

with ϕ is the wedge angle. The field at the receiver after double diffraction is given by [2]

Manuscript published on 30 September 2019
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$$E_{RD} = \frac{E_0 e^{-jk(s_0+s_1+s_2)}}{\sqrt{s_0 s_1 s_2 (s_0+s_1+s_2)}} \times \left[D_1 D_2 - \frac{1}{jks_1}\frac{\partial D_1(\varphi_1,\varphi_1')}{\partial\varphi_1}\frac{\partial D_2(\varphi_2,\varphi_2')}{\partial\varphi_2'}\right] \qquad (4)$$

In (4), only first and second-order field has been considered for simplicity. $D_1(\varphi_1,\varphi_1')$ and $D_2(\varphi_2,\varphi_2')$ are the diffraction coefficients for the first and second wedge. $\frac{\partial D_1(\varphi_1,\varphi_1')}{\partial\varphi_1}$ and $\frac{\partial D_2(\varphi_2,\varphi_2')}{\partial\varphi_2'}$ are the slope diffraction coefficients.

B. Time Domain

Taking inverse Laplace transform of (1), the TD solution is given as in [14]

$$d^{s,h}(t)=\begin{cases} r_0(t)*r_n(t)*d^{(1)}(t)+d^{(2)}(t)+ \\ r_0(t)*d^{(3)}(t)+r_n(t)*d^{(4)}(t), \\ for\ \varphi'\le(n-1)\pi\cup \\ (\varphi'>(n-1)\pi\cap\varphi>|(2n-1)\pi-\varphi'|). \\ \\ d^{(1)}(t)+r_0(t)*r_n(t)*d^{(2)}(t)+ \\ r_n(t)*d^{(3)}(t)+r_0(t)*d^{(4)}(t),\quad for\ \varphi'>\pi. \\ \\ d^{(1)}(t)+d^{(2)}(t)+\gamma(t)*\left(d^{(3)}(t)+d^{(4)}(t)\right), \\ for\ \varphi'>(n-1)\pi\cap\varphi\le|(2n-1)\pi-\varphi'|. \end{cases} \qquad (5)$$

$d^{(i)}(t)$, $(i=1-4)$ in above equation is given as in [12]

$$d^{(i)}(t)=-\frac{Ln}{2\pi\sqrt{2c}}\times\frac{\sin(2\varsigma_i)}{\sqrt{t}\left(t+2Ln^2\sin^2(\varsigma_i)/c\right)}\cdot u(t) \qquad (6)$$

$\gamma(t)$ is given by taking inverse Laplace transform of (2) as

$$\gamma(t)=\mp\left[\frac{1-k}{1+k}\delta(t)+\frac{4k}{1-k^2}\frac{e^{-xt}}{t}\times\sum_{n=1}^{\infty}(-1)^{n+1}nk^nI_n(xt)\right] \qquad (7)$$

with $k=\left(\frac{\sqrt{\alpha^2+\varepsilon_r-1}}{\alpha}\right)^{-1}$ for soft polarization, $k=\left(\frac{\sqrt{\alpha^2+\varepsilon_r-1}}{\alpha\cdot\varepsilon_r}\right)$ for hard polarization and $x=\frac{\sigma}{2\varepsilon_0\varepsilon_r}$.

The leading $-(+)$ sign is for soft (hard) polarization. $I_n(t)$ is the modified Bessel function of order n. Taking inverse Laplace transform on (4), the TD double diffracted field

$$e_{RD}(t)=e_0(t)*\left[\begin{array}{l}\sqrt{\frac{1}{(s_0+s_1+s_2)s_0s_1s_2}}\times \\ \left[d_1(t)*d_2(t)-\frac{1}{s_1}d_1^f(t)*d_2^f(t)\right] \\ *\delta\left(t-\frac{s_0+s_1+s_2}{c}\right)\end{array}\right] \qquad (8)$$

where, $d_1(t)$ and $d_2(t)$ are the single TD diffraction coefficients for wedge 1 and wedge 2 based on (5). In the (8), the derivatives of TD reflection coefficients are complicated. In [11], the early time approximation is used to make it simple. In this case, it is assumed that the derivatives of FD reflection coefficients do not vary with ω. Thus, the Fresnel reflection coefficients of (1) can be modified by complex permittivity $\varepsilon\approx\varepsilon_r$ as

$$R^{s,h}=\frac{\sin\psi-(1,1/\varepsilon_r)\sqrt{\varepsilon_r-\cos^2\psi}}{\sin\psi+(1,1/\varepsilon_r)\sqrt{\varepsilon_r-\cos^2\psi}} \qquad (9)$$

where, ψ is the reflection angles as defined in [5] for 0-face and n-face. The modified reflection coefficient of (2) can also be modified by complex permittivity $\varepsilon\approx\varepsilon_r$ .Using this assumption, the $d_1^f(t)$ and $d_2^f(t)$ of (8) can be given as

$$d_1^f(t)=L^{-1}\left\{\frac{1}{\sqrt{jk}}\frac{\partial D_1}{\partial\varphi_1}\right\}$$

$$=\frac{-L}{\sqrt{2\pi}}\left[\begin{array}{l} R_0R_nF_s^{(1)}(t)-F_s^{(2)}(t)+R_0F_s^{(3)}(t)- \\ R_nF_s^{(4)}(t),\quad for\ \varphi'\le(n-1)\pi\cup \\ (\varphi'>(n-1)\pi\cap\varphi>|(2n-1)\pi-\varphi'|). \\ \\ F_s^{(1)}(t)-R_0R_nF_s^{(2)}(t)+R_nF_s^{(3)}(t)- \\ R_0F_s^{(4)}(t),\quad for\ \varphi'>\pi. \\ \\ F_s^{(1)}(t)-F_s^{(2)}(t)+\Gamma\left(F_s^{(3)}(t)-F_s^{(4)}(t)\right), \\ for\ \varphi'>(n-1)\pi\cap\varphi\le|(2n-1)\pi-\varphi'|. \end{array}\right] \qquad (10)$$

$$+\frac{c}{2n\sqrt{2\pi}}\times\left[\begin{array}{l} R_0\frac{\partial R_n}{\partial\psi}\cot(\varsigma_1)\frac{\sqrt{a_1}}{\sqrt{t+a_1}}+\frac{\partial R_n}{\partial\psi}\cot(\varsigma_4)\frac{\sqrt{a_4}}{\sqrt{t+a_4}} \\ R_0\frac{\partial R_n}{\partial\psi}\cot(\varsigma_2)\frac{\sqrt{a_2}}{\sqrt{t+a_2}}+\frac{\partial R_n}{\partial\psi}\cot(\varsigma_3)\frac{\sqrt{a_3}}{\sqrt{t+a_3}} \\ \frac{\partial\Gamma}{\partial\varphi_1}\left[\cot(\varsigma_3)\frac{\sqrt{a_3}}{\sqrt{t+a_3}}+\cot(\varsigma_4)\frac{\sqrt{a_4}}{\sqrt{t+a_4}}\right]\end{array}\right]$$

and

$$d_2^f(t)=L^{-1}\left\{\frac{1}{\sqrt{jk}}\frac{\partial D_2}{\partial\varphi_2'}\right\}$$

$$=\frac{-L}{\sqrt{2\pi}}\left[\begin{array}{l} -R_0R_nF_s^{(1)}(t)+F_s^{(2)}(t)+R_0F_s^{(3)}(t)-R_nF_s^{(4)}(t), \\ for\ \varphi'\le(n-1)\pi\cup \\ (\varphi'>(n-1)\pi\cap\varphi>|(2n-1)\pi-\varphi'|). \\ \\ -F_s^{(1)}(t)+R_0R_nF_s^{(2)}(t)+R_nF_s^{(3)}(t)-R_0F_s^{(4)}(t), \\ for\ \varphi'>\pi. \\ \\ -F_s^{(1)}(t)+F_s^{(2)}(t)+\Gamma\left(F_s^{(3)}(t)-F_s^{(4)}(t)\right), \\ for\ \varphi'>(n-1)\pi\cap\varphi\le|(2n-1)\pi-\varphi'|. \end{array}\right] \qquad (11)$$

$$+\frac{-c}{2n\sqrt{2\pi}}\left[\begin{array}{l}\frac{\partial R_0}{\partial\psi}R_n\cot(\varsigma_1)\frac{\sqrt{a_1}}{\sqrt{t+a_1}}+\frac{\partial R_0}{\partial\psi}\cot(\varsigma_3)\frac{\sqrt{a_3}}{\sqrt{t+a_3}}\\ \frac{\partial R_0}{\partial\psi}R_n\cot(\varsigma_2)\frac{\sqrt{a_2}}{\sqrt{t+a_2}}+\frac{\partial R_0}{\partial\psi}\cot(\varsigma_4)\frac{\sqrt{a_4}}{\sqrt{t+a_4}}\\ \frac{\partial\Gamma}{\partial\varphi_2'}\left[\cot(\varsigma_3)\frac{\sqrt{a_3}}{\sqrt{t+a_3}}+\cot(\varsigma_4)\frac{\sqrt{a_4}}{\sqrt{t+a_4}}\right]\end{array}\right]$$

where, $F_s^{(i)}(t)=\frac{\sqrt{a_i}}{2(t+a_i)^{3/2}}\cdot u(t)$ and $a_i=2Ln^2\sin^2(\varsigma_i)/c$.

In the next section, the time domain solutions are discussed for different incident angles. The source pulse [12] with duration of 0.1 ns is used for the scenario shown in Fig. 1. Fig. 1 consists of two wedges and its parameters are given in Table I.

III. RESULTS ANALYSIS

Fig. 2 - Fig. 4 show double diffracted field at the Receiver. In this analysis, hard polarization has been taken into consideration. Here three cases have been considered for wedge structure made as in [13]. In Fig. 2, source illuminates only 0-face of the wedge. In Fig. 3 source illuminates both faces of the wedge. In Fig. 4 only n-face is illuminated by the source. Comparison of the proposed solutions and the corresponding IFFT-FD solutions has good agreement. Therefore, it confirms the accuracy of the proposed solutions.

Finally, Table I shows the proposed model is computationally efficient due to convolution technique used.

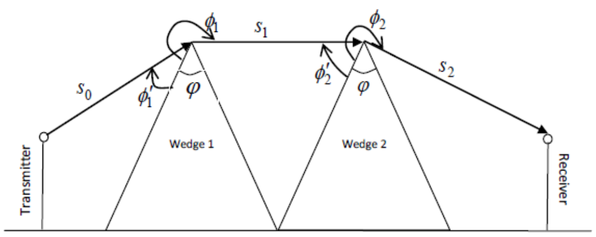

Fig. 1. The propagation path of double-diffracted signal.

Table- I: Computational Efficiency

Illumination face	Wedge angle ϕ	Incident angle φ_1'	Diffracted angle φ_2	$T_{IFFT-FD}/T_{TD}$
0-face	50°	5°	271.5°	15.1230
0-and n-face	50°	145°	271.5°	16.7982
n-face	50°	225°	271.5°	16.2593

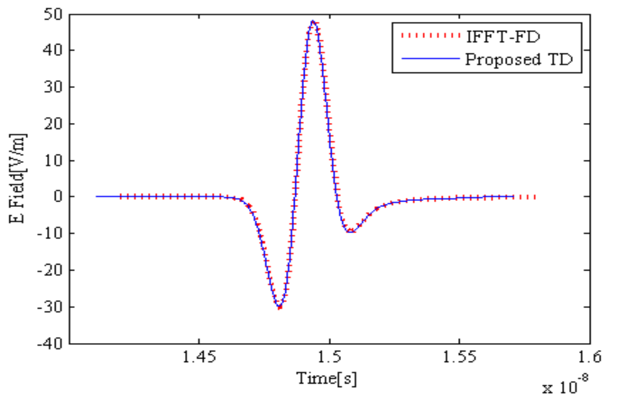

Fig. 2. TD double diffracted fields at the receiver for $\phi=50^\circ$ and $\varphi_1'=5^\circ$.

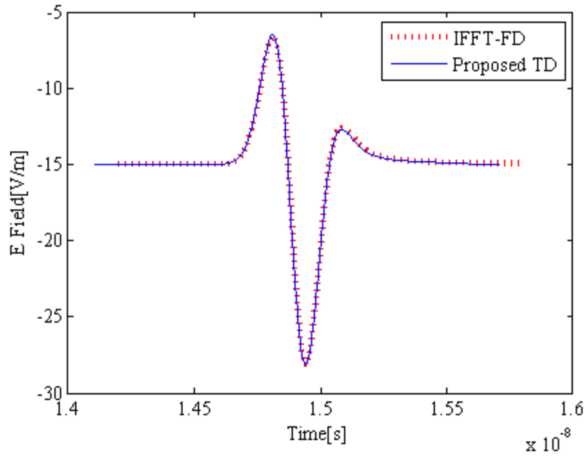

Fig. 3. TD double diffracted fields at the receiver for $\phi=50^\circ$ and $\varphi_1'=145^\circ$.

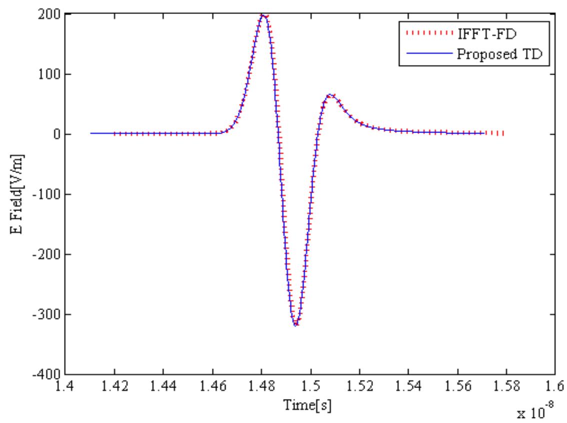

Fig. 4. TD double diffracted fields at the receiver for $\phi=50^\circ$ and $\varphi_1'=225^\circ$.

IV. CONCLUSION

The proposed TD solution is applicable to all possible illumination regions of wedges. Thus it provides improvements to a TD-UTD based single and double diffraction. The redefined reflection angles as well as modified reflection coefficients [5] are used in the different angular regions of wedge. The proposed TD diffraction coefficient is accurate and efficient.

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