AN IMPROVED UTD BASED MODEL FOR MULTIPLE BUILDING DIFFRACTION BY USING HIGHER ORDER DIFFRACTION COEFFICIENTS

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Abstract

This paper describes an improved model for multiple building diffraction modeling based on the uniform theory of diffraction (UTD). A well-known problem in conventional uniform theory of diffraction (CUTD) is multiple-edge transition zone diffraction. Here, higher order diffracted fields is used in order to improve the result; hence, we use higher order diffraction coefficients to improve a hybrid physical optics (PO)-CUTD model, the results show that the new model corrects errors of PO-CUTD model.

Keywords: Higher order diffraction coefficient, Multiple-edge Diffraction, UTD.

1. Introduction

Neve and Rowe were among the first groups of researchers who introduced uniform theory of diffraction (UTD)-based model to predict the multiple knife-edge diffraction of plane waves. Rodriguez, Molina, Pardo and Llacer have proposed a new formulation expressed in terms of UTD coefficients for predicting of the multiple diffraction produced by an array of finitely conducting buildings [1]. Tajvidy and Ghorbani proposed a new approach to calculate multiple building diffraction loss in microcell environments based on the spherical wave assumption. They showed that the plane wave approximation was not practical for microcell environments [2]. Torabi, Ghorbani and Tajvidy have introduced a new diffraction coefficient for using in UTD [3]. They proved that there were some errors in conventional diffraction coefficients and then corrected them. Ghorbani, Tajvidy, Torabi and Arablouei proposed a new model to predict diffraction loss in presence of trees [4]. In this paper, an improved model based on higher order diffraction coefficients is introduced for predicting multiple diffracted fields caused by an array of dielectric buildings. The present study explores and improves the approach presented in [1] by using higher order diffraction coefficients. Detailed simulations are quoted in order to illustrate the new formulation and are compared with the PO-CUTD model.

2. MODEL CONFIGURATION

In Fig. 1, a mobile radio wave propagation path in a built-up area consisting of n buildings made of dielectric blocks with rectangular cross-sections is considered. This configuration can be seen as an array of dielectric joint wedges with interior right angles. Each building is assumed to have the same thickness, spacing, and constant average height relative to the base station antenna. The transmitter can have any arbitrary height (i.e., above, below, or at the same height as the building). As the transmitter is far away the buildings, so that a plane wave with incident angle α impinges on them. For the above-mentioned configuration, the diffracted fields were calculated at the observation point (we assumed that the observation point is located at the rooftop of the final building), using the proposed model and considering the effect of the higher order diffracted fields.

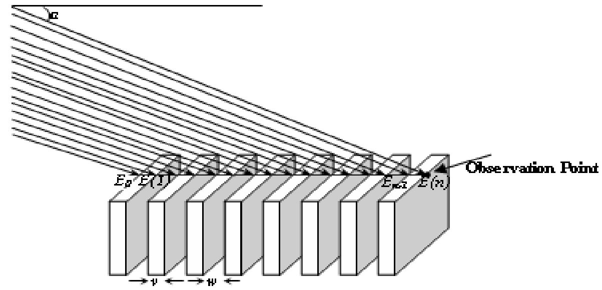

Figure 1. Radio wave propagation in presence of buildings.

3. BASIC THEORY

According to the Heuristic solution [5], the field of the 6 times diffracted ray in Fig. 2 can be written as:

$$E_{UTD} = E_o e^{-jk(s_T - s_1)} \sqrt{\frac{1}{s_2 s_3 s_4 s_5 s_6 s_7}} \times \sum_{i,l,m,n+o=0}^{i+l+m+n+o=N_0} \frac{\partial^i D_1}{\partial \phi_1^i} \frac{1}{i!}\left(\frac{j}{ks_2}\right)^i \frac{\partial^{i+l} D_2}{\partial \phi_2'^i \partial \phi_2^l} \frac{1}{l!} \times \left(\frac{j}{ks_3}\right)^l \frac{\partial^{m+l} D_3}{\partial \phi_3'^l \partial \phi_3^m} \frac{1}{m!}\left(\frac{j}{ks_4}\right)^m \frac{\partial^{m+n} D_4}{\partial \phi_4'^m \partial \phi_4^n} \frac{1}{n!}\left(\frac{j}{ks_5}\right)^n \times \frac{\partial^{n+o} D_5}{\partial \phi_5'^n \partial \phi_5^o} \frac{1}{o!}\left(\frac{j}{ks_6}\right)^o \frac{\partial^o D_6}{\partial \phi_6^o} \quad (1)$$

Where E_0 is the incident field at the diffraction point, $s_T = s_1 + \cdots + s_7$, and k is the wave number. Here, D_1 to D_6 are diffraction coefficients. In this formula the upper limit N_0 stands for a chosen order. The field in (1) can be rewritten in a simpler form by defining $d_i\ (m;n)$ as [5]:

$$d_i(m,n) = \frac{1}{m!}\left(\frac{j}{ks_i}\right)^m \frac{\partial^{m+n} D_i}{\partial \phi_i'^m \partial \phi_i^n} \quad (2)$$

It is obtained the following compact expression by using (2):

$$E_{UTD} = E_o e^{-jk(s_T - s_1)} \sqrt{\frac{1}{s_2 s_3 s_4 s_5 s_6 s_7}} \times \sum_{i+l+m+n+o=0}^{i+l+m+n+o=N_0} d_1(0,i) d_2(i,l) d_3(l,m) d_4(m,n) d_5(n,o) d_6(o,0) \quad (3)$$

The expression in (1) can be generalized to more than six wedges. Using above example, it should be obvious how to generalize the result to more than six edges. For calculating the diffracted field in the transition zone, we explored and improved the approach presented in an earlier study [1]. The total field at the observation point (Fig. 1) was calculated using the summation of fields produced by a single and multiple diffraction process. In the proposed model, all beams except E_{n-1} (E_{n-1} are single diffraction from the last edge and, therefore, are not combined with multiple diffractions) were multiple diffraction terms. To present an expression for overall field calculation, the following argument can be used. If there was only one building between the transmitter and receiver, then the received field at observation point can be given by

$$E(1) = E_0 \left[e^{-jkv\cos\alpha} + \sqrt{\frac{1}{v}} D_x e^{-jkv} \right] \quad (4)$$

The above formula is made out of two terms, the first term accounts the contribution of the direct field, for $\alpha < 0$ (4) must be used without this term, and the second term is to calculate the diffracted field. Where D_x the following is denoted:

$$D_x = D\left(\phi = \frac{3\pi}{2}, \phi' = \frac{\pi}{2} + \alpha, L = v\right) \quad (5)$$

$D(\phi, \phi', L)$ is the diffraction coefficient for a imperfect conducting wedge given in [5]. Furthermore, if the number of buildings is more than one (i.e., when there are a row of buildings $n \geq 2$), then the total received field ($E(n)$) can be summarized as follows:

$$E(n) = \frac{1}{2n-1}\left\{ \sum_{m=0}^{n-2} E_m \left[e^{-jk[(n-m)(v+w)-w]\cos\alpha} + \frac{\left(\frac{1}{2}\right)^{n-m}}{\sqrt{v^{n-m} w^{n-(m+1)}}} D_{a,n,m} e^{-jk[(n-m)(v+w)-w]} \right] + E_{n-1}\left[e^{-jkv\cos\alpha} + \sqrt{\frac{1}{v}} D_x e^{-jkv} \right] + \sum_{p=1}^{n-1} E(p) \left[e^{-jk(n-p)(v+w)\cos\alpha} + \frac{\left(\frac{1}{2}\right)^{n-p}}{\sqrt{(vw)^{n-p}}} D_{b,n,p} e^{-jk(n-p)(v+w)} \right] \right\} \quad (6)$$

Where $D_{a,n,m}$ and $D_{b,n,p}$ are the higher order diffraction coefficients (their values depend on the number of buildings). The factor of *1/2* in (6) is used to handle the special case of grazing incidence [5]. With reference to Fig.3, If we assume that only E_0 and *E(1)* are the incident waves at the first and the second wedges, respectively, then the coefficients $D_{a,7,0}$ and $D_{a,7,1}$ for n =7 are given by the following expression:

$$D_{a,7,0} = \sum_{i+l+m+n+o+p+q+r+s+t+u+v=0}^{i+l+m+n+o+p+q+r+s+t+u+v=N_0} d_1(0,i)d_2(i,l)d_3(l,m)d_4(m,n)d_5(n,o)\, d_6(o,p)d_7(p,q)d_8(q,r)\cdot d_9(r,s)d_{10}(s,t)d_{11}(t,u)d_{12}(u,v)d_{13}(v,0) \tag{7}$$

$$D_{b,7,1} = \sum_{i+l+m+n+o+p+q+r+s+t+u=0}^{i+l+m+n+o+p+q+r+s+t+u=N_0} d_1(0,i)d_2(i,l)d_3(l,m)d_4(m,n)d_5(n,o)d_6(o,p)d_7(p,q)d_8(q,0)d_9(r,s)\cdot d_{10}(s,t)d_{11}(t,u)d_{12}(u,0) \tag{8}$$

The upper limit N_0 stands for the chosen order (in this paper, $N_0 = 4$) and E_m is the field reaching the first corner of the roofs (left-placed wedge forming the rectangular building cross-section) as indicated in Fig.1. Hence, for $m \geq 1$, Em can be presented using (9). In this formula *E(m)* is diffracted field from the last building's edge and can be considered as a single diffraction field. Thus, *E(m)*can be presented as

$$E_m = \frac{1}{2m}\left\{\sum_{q=0}^{m-1} E_m\left[e^{-jk(m-q)(v+w)\cos\alpha} + \frac{\left(\frac{1}{2}\right)^{m-q}}{\sqrt{(vw)^{m-q}}} D_{c,m,q} e^{-jk(m-q)(v+w)}\right] + \sum_{r=1}^{m-1}\left[E(r)\left[e^{-jk[(m-r)(v+w)+w]\cos\alpha} + \frac{\left(\frac{1}{2}\right)^{m-r}}{\sqrt{v^{m-r}w^{m-(r+1)}}} D_{d,m,r} e^{-jk[(m-r)(v+w)+w]}\right]\right] + E(m)\left[e^{-jkw\cos\alpha} + \sqrt{\frac{1}{w}} D_z e^{-jkw}\right]\right\} \tag{9}$$

D_z the following is defined:

$$D_z = D\left(\phi = \frac{3\pi}{2}, \phi' = \alpha, L = w\right) \tag{10}$$

If the incident fields are E_0 and *E(1)*, then $D_{c,6,0}$ and $D_{d,6,1}$ for seven buildings are given by:

$$D_{c,6,0} = \sum_{i+l+m+n+o+p+q+r+s+t+u=0}^{i+l+m+n+o+p+q+r+s+t+u=N_0} d_1(0,i)d_2(i,l)d_3(l,m)d_4(m,n)d_5(n,o)d_6(o,p)d_7(p,q)d_8(q,r)\cdot d_9(r,s)d_{10}(s,t)d_{11}(t,u)d_{12}(u,0) \tag{11}$$

$$D_{d,6,1} = \sum_{i+l+m+n+o+p+q+r+s+t=0}^{i+l+m+n+o+p+q+r+s+t=N_0} d_1(0,i)d_2(i,l)d_3(l,m)d_4(m,n)d_5(n,o)d_6(o,p)d_7(p,q)d_8(q,r)\cdot d_9(r,s)d_{10}(s,t)d_{11}(t,0) \tag{12}$$

After estimating E_m from (9) and substituting it in (6), *E(n)* is calculated.

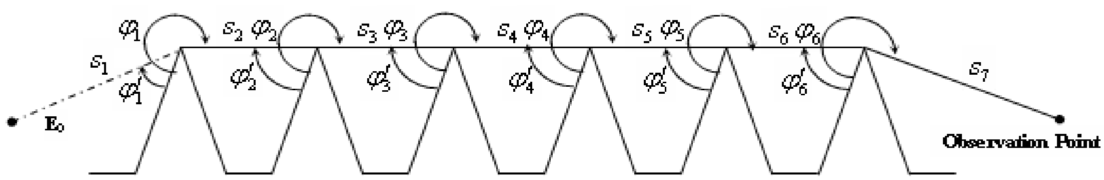

Figure 2. Ray geometry for diffraction by six straight wedges.

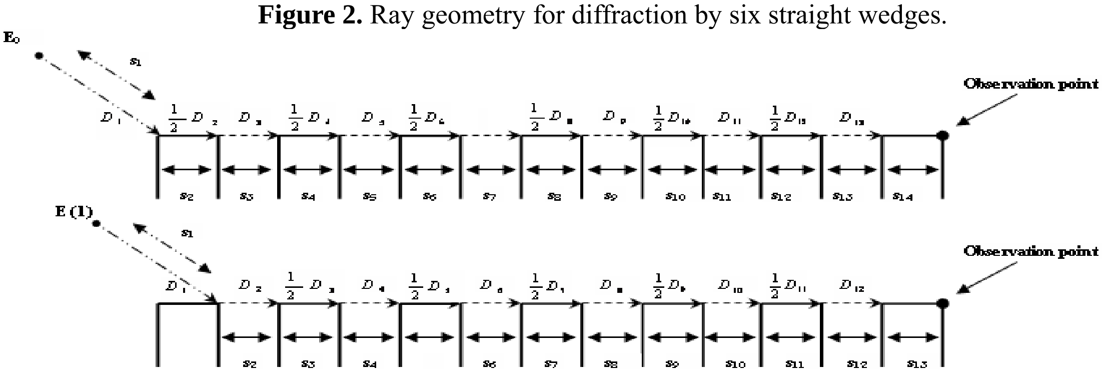

Figure 3. Diffraction mechanism by seven buildings when E_0 and *E(1)* are considered.

4. RESULTS

In Fig. 4 settled normalized diffracted field (for 10 buildings) is plotted against the angle of incidence of the fields (α) by using both the new model and the PO-CUTD model in [1]. Here *v*

$=28\lambda$, $w = 22\lambda$, $\varepsilon_r = 5.5$, $\sigma=0.023$ *S/m*, *f=922 MHz*, it is expected that $|E(n)/E0|$ is settled in a fixed value of less than 1, but it can happen that $|E(n)/E0| > 1$ at $\alpha > 5^o$ for the PO-CUTD model, however it can be understood there is a critical angle between 5^o and $6°$ in this model. So we can observe in Fig. 4, more rational and explainable prediction is available by using the new proposed model. Also in order to review a special case, the normalized total electric field intensity at the observation point against number of existing buildings by using both the new model and the PO-CUTD model is shown in Fig. 5, for $v = 28\lambda$, $w = 50\lambda$, $f = 922$ *MHz*, $\varepsilon_r = 5.5$, $\sigma=0.023$ *S/m*, $\alpha = 4°$ and hard polarization. Comparison of two models shows that the PO-CUTD model predicts the amplification but the new model shows the attention. Comparing the two different sorts of the results shows that the new improved UTD-based model provides a prediction that is more acceptable and its trend is more honest.

5. CONCLUSION

In this paper, an improved model expressed in terms of higher order diffraction coefficients for prediction of the multiple diffraction produced by an array of flat roofed buildings considering plane-wave incidence has been presented. The results show that the proposed model can be corrected errors of the PO-CUTD model in [1]. Figs.4 and 5 are the perfect examples for approving this subject. However it is necessary that higher order diffraction coefficients are applied to improve results especially for $\alpha > 4$ °.

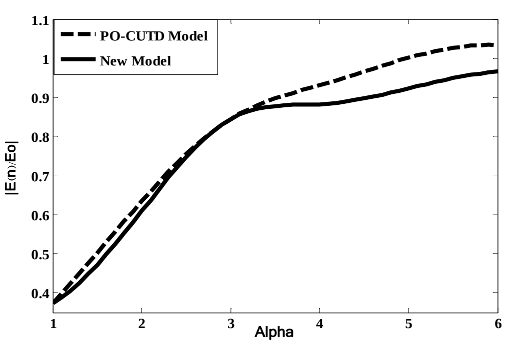

Figure 4.The normalized total electric field intensity at the observation point against the angle of incidence of the fields, for the new model and the PO-CUTD model.

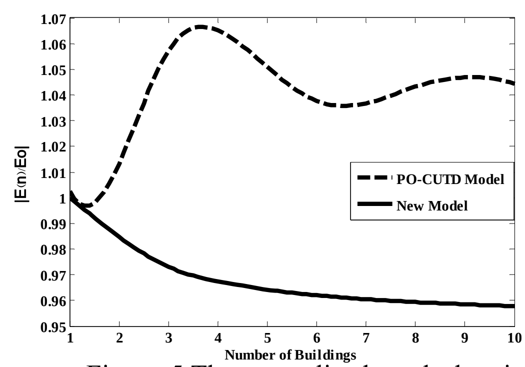

Figure 5.The normalized total electric field intensity at the observation point against number of existing buildings, for the new model and the PO-CUTD model.

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