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Backscattering Analysis of Cylinder Shaped Scatterer in Vegetation Medium: Comparison Between Theories

Syabeela Syahali[1,*], Ewe Hong Tat[2], Gobi Vetharatnam[2], Li-Jun Jiang[3] and Hamsalekha A Kumaresan[2]
[1]*FET, Multimedia University, Melaka, Malaysia.*
[2]*LKCFES, Universiti Tunku Abdul Rahman, Sg. Long, Malaysia.*
[3]*DEEE, The University of Hong Kong, Pokfulam, Hong Kong.*
*syabeela@mmu.edu.my
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Abstract - **This paper analyses the backscattering cross section of a cylinder both using traditional method model and a new numerical solution model, namely Relaxed Hierarchical Equivalent Source Algorithm (RHESA). The purpose of this study is to investigate the prospect of incorporating numerical solution model into volume scattering calculation, to be applied into microwave remote sensing in vegetation area. Results show a good match, suggesting that RHESA may be suitable to be used to model the more complex nature of vegetation medium.**

Keywords—Microwave remote sensing, Relaxed Hierarchical Equivalent Source Algorithm (RHESA), Volume scattering

I. INTRODUCTION

Research in theoretical model development in microwave remote sensing can be divided into two; the development of traditional method using approximate models [1-6] and the development using numerical simulation methods [7,8]. Although traditional models can provide some physical insight of the medium and allow the study of the scattering behavior for variation of surface parameters, without using modern full-wave computational electromagnetics in numerical simulation methods, the accuracy of these models are limited because the characterization of the domain of validity for these models are unclear. In this study, backscattering analysis is done for volume scattering, particularly for cylinder shaped scatterer, using both traditional method model and a new numerical method model – Relaxed Hierarchical Equivalent Source Algorithm (RHESA) [8]. This is done to inspect the prospect of applying RHESA in volumes scattering for vegetation medium in future, as cylinder is the basic shape in vegetation area. The main advantage of applying RHESA in vegetation would be the freedom to model any shape of scatterer, as oppose to limited shape of scatterers available in traditional method models, as described in the next section.

A. Traditional Method Models

In [2,3], a study of the microwave scattering of the scatterers of spheres, disks, needles and cylinders in dense medium was done in developing theoretical model for vegetation layer. The mathematical representation of the phase matrix of these scatterers describes the characteristics of the scattered fields due to these discrete scatterers. In the formulation of the phase matrices of different shape of scatterrers, the scattered fields of spherical scatterers are the simplest to calculate. For spherical scatterers' phase matrix with sizes much smaller than the wavelength, Rayleigh scattering [9,10] is used. For scatterers with sizes comparable to the wavelength, Mie scattering is applied instead [10]. In the development of the phase matrices of circular disks and needles [11] as well as of elliptic disks [12], the generalized Rayleigh-Gans approximation has been used. For cylindrical scatterers, the phase matrix is calculated using the infinite cylinder approximation [13].

In taking account the closely spaced scatterers, the Fresnel field terms were included in the formulation of the scattered field [2,3]. Moreover, the effect of spatial arrangement of the scatterers in electrically dense medium where there is more than one scatterer within the distance of a wavelength, are taken into account by applying the Dense Medium Phase and Amplitude Correction Theory (DM-PACT) [14] in the phase matrix. The study in [2,3] was further improved in [4] by including the Fresnel terms in the formulation of the scattered fields of general ellipsoids and elliptic disks.

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B. Relaxed Hierarchical Equivalent Source Algorithm

The limitation of scatterer's shape that can be used in traditionally developed model can be overcome by RHESA, as RHESA can simulate arbitrary 3D object model which can be created using 3D modeling software. This can be very useful in modelling the natural shape of scatterrers available in real vegetation medium. RHESA is a new algorithm for volume integral equations (VIEs) that uses the concept of equivalent source to relate the scattered fields to incident fields. A relationship between the unknown coefficients to the excitation vector through impedance matrix was constructed and the equation was solved using Method of Moments (MOM) [15,16]. In RHESA, the 3D scatterer is divided into smaller groups. Then, the equivalence surfaces, ES is used to enclose them, which become child groups. Child groups are enclosed by parent groups, hence, building a hierarchical form of relationship. The induced current on each ES is the equivalent source to be used to compute the upper level of equivalence source. This hierarchical form reduces the number of unknowns and achieves faster computation time [8].

II. Methodology

Figure 1 shows the orientation and geometry of a scatterer. For cylinder shape, $a = b$, which is the radius of the cylinder. Value c represents the half length of the cylinder. Theta is the incident and scattered angle for the backscattering mechanism, and d is the distance from the scatterer. In this paper, the dimensions of the cylinder are chosen to be $a = b = 0.2$ cm and $c = 5$ cm. Theta and d are fixed to be 20 degrees and 10 cm respectively. The relative permittivity chosen is 9.6 – j4.03, and both vertical and horizontal polarization are used for incident and scattered field.

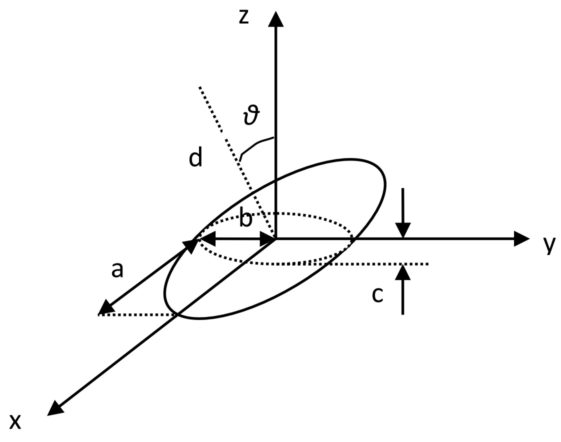

Fig. 1. Orientation and geometry of a scatterer.

In [2,3], the backscattering cross section was calculated using the formula

$$\sigma = \frac{4\pi \left\langle |\psi^2| \right\rangle_n \left| f_{pq}(-\hat{i}, \hat{i}) \right|^2}{n_o} \tag{1}$$

where $|\Psi|^2$ is the array phase correction factor, n_o is the number density, p and q are the scattered and incident polarization respectively and f_{pq} is the scattering amplitude for cylinder shape, given by [2,3]:

$$\begin{aligned} f_{vv} = C\{ & e_{ov}\cos\theta_{il} B_o \cos\theta_{sl} - e_{ov} Z_o \sin\theta_{sl} \\ & + 2\sum_{n=1}^{\infty} [(e_{nv}\cos\theta_{il} B_n - j\eta h_{nv} A_n)\cos\theta_{sl} - e_{nv} Z_n \sin\theta_{sl}] \\ & \cos[n(\phi_{sl} - \phi_{il})]\} \end{aligned} \tag{2}$$

$$f_{hh} = C\{\eta h_{oh} B_o + 2\sum_{n=1}^{\infty} (\eta h_{nh} B_n + j e_{nh}\cos\theta_{il} A_n)\cos[n(\phi_{sl} - \phi_{il})]\} \tag{3}$$

$$f_{vhl} = 2jC\sum_{n=1}^{\infty} \begin{matrix} \{(e_{nh}\cos\theta_{il} B_n - j\eta h_{nh} A_n) \\ \cos\theta_{sl} - e_{nh} Z_n \sin\theta_{sl}\} \end{matrix} \cos[n(\phi_{sl} - \phi_{il})] \tag{4}$$

$$f_{hvl} = 2jC\sum_{n=1}^{\infty} (\eta h_{nv} B_n + j e_{nv}\cos\theta_{il} A_n)\sin[n(\phi_{sl} - \phi_{il})] \tag{5}$$

where

$A_n = \dfrac{k}{2\lambda_i}(Z_{n-1} - Z_{n+1})$, $\quad B_n = \dfrac{k}{2\lambda_i}(Z_{n-1} + Z_{n+1})$ and

$C = \dfrac{k^2}{2} I_z(\varepsilon_r - 1)$

; I_z and Z_n are given by:

$$\begin{aligned} I_z = {} & \exp\left(\frac{jq''^2_z}{2m_n}\right)\sqrt{\frac{\pi}{m_n}}\{f_c(b_2) + f_c(b_1) - j[f_s(b_2) + f_s(b_1)]\} \\ & + \frac{s''_z q''_z}{rm_n} I_{z1} + \frac{js''_z}{rm_n}\left[\exp\left(\frac{m_n L^2}{8j} - \frac{Lq''_z}{2j}\right) - \exp\left(\frac{m_n L^2}{8j} + \frac{Lq''_z}{2j}\right)\right] \end{aligned} \tag{6}$$

$$\begin{aligned} Z_n(n) & = \int_0^a J_n(\lambda_i \rho'') J_n(\lambda_s \rho'') \rho''\, d\rho'' \\ & = \frac{a}{\lambda_i^2 - \lambda_s^2}[\lambda_i J_n(\lambda_s a) J_{n+1}(\lambda_i a) - \lambda_s J_n(\lambda_i a) J_{n+1}(\lambda_s a)] \end{aligned} \tag{7}$$

where

$q''_z = k(s''_z - \cos\theta_{il})$,

$m_n = \dfrac{k}{r}(1 - s''^2_z)$, $\lambda_s = k\sqrt{(s''^2_x + s''^2_y)} = k\sin\theta_{sl}$,

$b_1 = \sqrt{\dfrac{m_n}{2}}\left(\dfrac{L}{2} - \dfrac{q''_z}{m_n}\right)$, $b_2 = \sqrt{\dfrac{m_n}{2}}\left(\dfrac{L}{2} + \dfrac{q''_z}{m_n}\right)$,

$f_c(x) = \sqrt{\dfrac{2}{\pi}}\displaystyle\int_0^x \cos(t^2)\,dt, \quad f_s(x) = \sqrt{\dfrac{2}{\pi}}\int_0^x \sin(t^2)\,dt$

a is the radius of the cylinder and L is the length of the cylinder. Details of the formulation can be obtained from [2,3].

In this paper, the scattering amplitude for cylinder is calculated by using RHESA output, and compared with the results from [3]. RHESA algorithm evaluates field contributions from source group *Gs* to observation group *Go* through three steps; Inside-out Radiation, Translation and Outside-in Radiation. In the first step, equivalent sources on spherical ES of group *Gs* is determined by the *E* and *H* fields due to the primary sources. In the second step, these equivalent sources calculate the radiated *E* and *H* fields in *F(Go)* from source group *Gs* through the Stratton-Chu integral formulation. Finally, the equivalent sources on the ES of observation group *Go* is determined in the last step. The expression of the radiated electric field E_F at any position *r* inside group *Go* is given by [8]:

$$E^F(r) = \sum_{G^s \in F(G^o)} \sum_{f_n \in G^s} I_n C_E^o \left\{ \begin{matrix} \gamma_t^o C_H^s[S_H(f_n)] - \gamma_t^o C_E^s[S_E(f_n)] \\ \gamma_n^o C_E^s[S_E(f_n)] \end{matrix} \right\} \quad (8)$$

where S_E and S_H represent equivalent sources accounting for electric and magnetic field, C_E and C_H are the integral operators representing electric and magnetic fields from the Stratton-Chu integral formulation, γ_t and γ_n are twisted tangential trace operator and normal trace operator and f_n is the SWG basis function. Details of the formulation can be obtained from [8].

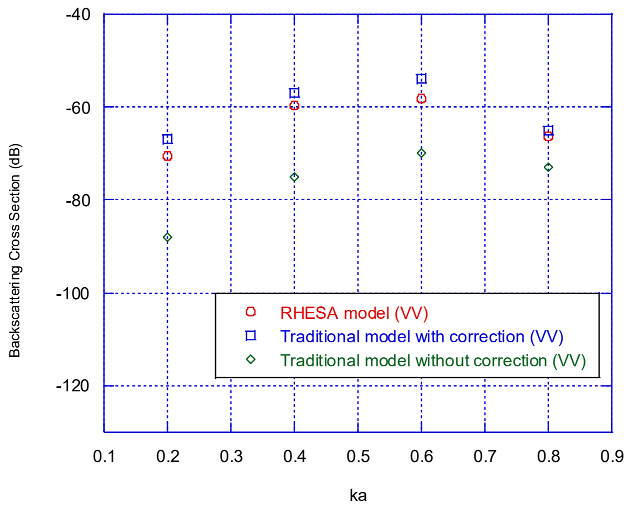

Fig. 2. Comparison between theories for VV backscattering cross section.

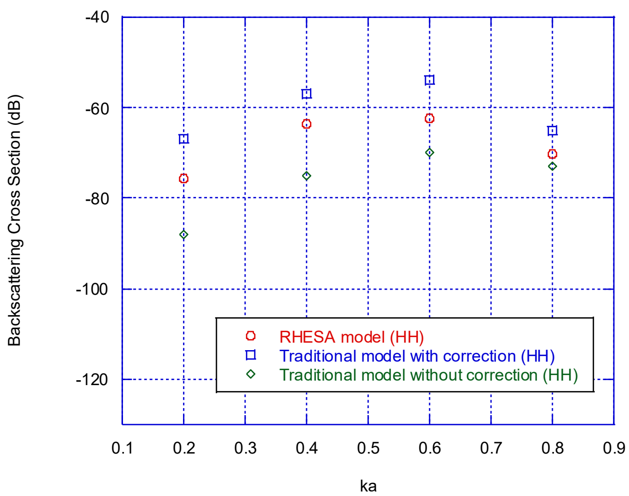

Fig. 3. Comparison between theories for HH backscattering cross section.

The 3D cylinder is first created using ANSYS software. This object, together with the correct angles, coordinates and other input parameters, are used by RHESA to calculate the scattered *E* and *H* field from the incident vertical or horizontal polarized field. The scattered vertical and horizontal fields are derived from the RHESA output, and backscattering cross section is calculated for both VV and HH polarization. The results were plotted for both with and without phase, amplitude and fresnel phase correction.

III. Results and Discussion

Figures 2 and 3 show the backscattering cross section for different values of *ka*. where *k* is the wave number and *a* is the radius of the cylinder and is fixed to 0.2cm. The frequency is changed, from f = 4.8 GHz for *ka* = 0.2 to f = 19.1 GHz for *ka* = 0.8. Backscattering cross section is shown for both VV and HH polarization. Results from [3] with and without phase, amplitude and fresnel phase correction are compared with the results calculated using RHESA output. It can be seen that the results from RHESA is within the acceptable range. This shows that RHESA may be used to replace the traditional model in volume scattering calculation of vegetation medium, with the ability to model a more realistic shape for a more accurate result.

IV. Conclusion

Comparison with theories suggests that there is a good prospect of applying RHESA into microwave remote sensing on vegetation medium in future.

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