Incoherent Scattering Analysis for Radar Clutter

Jae-Ho Lee, Mi-Ryong Park
Automotive IT Platform Research Section
Electronics and Telecommunications Research Institute
Daegu, Korea
jhlee1229@etri.re.kr, mrpark@etri.re.kr

Dong-Wook Seo
Medical IT Convergence Section
Electronics and Telecommunications Research Institute
Daegu, Korea
seodongwook@etri.re.kr

***Abstract*— This paper proposes a method to estimate directly the incoherent scattered intensity and radar cross section (RCS) from the effective permittivity of a random media. The proposed method is derived from the original concept of incoherent scattering. The incoherent scattered field is expressed as a simple formula. Therefore, the proposed method can estimate the incoherent scattered intensity and RCS of random media for reducing computation time. To verify the potentials of the proposed method for the desired applications, we conducted an additional the Monte-Carlo analysis using the method of moments (MoM), and characterized the accuracy of the proposed method using the normalized mean square error (nMSE). In addition, several medium parameters such as the density and analysis volume were studied to understand their effect on the scattering characteristics of random media. The results of the Monte-Carlo analysis show good agreement with those of the proposed method.**

Keywords—coherent; composite; incoherent; random medea; RCS; scattering

I. Introduction

In order to enhance the detection capability of a radar system, it is essential that the clutter signature from the random media surrounding a target be removed. This clutter signal by the random media should be predicted and reflected in the radar system during the design phase [1]-[2]. Even in the case of obtaining synthetic aperture radar (SAR) images, the image quality is highly dependent on the accurate estimation of the radar clutter signal by the random media [3].

In [4], the calculation of the effective permittivity from both an incoherent scattered field and a coherent scattered field is proposed. Based on this method, the present paper proposes a direct method for estimating the incoherent scattered intensity and RCS from the effective permittivity, which is obtained using the GEC method. The potentials of the proposed method is verified through comparison with the results from a Monte-Carlo analysis using the MoM. To investigate the characteristics of coherent and incoherent scattering, we also estimate the RCS of a random medium for various inclusion densities.

II. Formulations

The fluctuations in a scattered field are caused by spatial variations of the dielectric constant between the inclusions/spaces $\varepsilon(x, y, z)$ and the background, ε_{eff}. Such variations operate as the volume current density, J_f. Thus, the wave equation can be summarized as follows [4]:

$$\begin{aligned}\nabla \times \nabla \times \vec{E}_1 - \kappa_{eff}^2 \vec{E}_1 &= \omega^2 \mu \left(\varepsilon - \varepsilon_{eff}\right)\vec{E}_1 \\ &= j\omega\mu \vec{J}_f\end{aligned}, \qquad (1)$$

where E_1 is the electric field in the boundary enclosing the random medium, and ε_0, ε, and ε_{eff} denote the permittivity of free space, the inclusions, and the effective permittivity of the equivalent homogeneous volume, respectively. The volume current density, J_f is the current density induced by the incident field on the equivalent volume, consequently, can be considered an equivalent current source that generates the incoherent scattered field. If the effective permittivity of the random medium is defined using non-dimensional parameter, s as follows

$$\varepsilon_{eff} = \varepsilon_0 (1 - js), \qquad (2)$$

then the volume current density, J_f becomes

$$\vec{J}_f = j\omega\left(\varepsilon_{eff} - \varepsilon_0\right)\vec{E}_1 = \omega\varepsilon_0 s \vec{E}_1. \qquad (3)$$

The magnetic vector potential, $\vec{A}$ based on volume current density, J_f is

$$\vec{A} = \frac{\mu}{4\pi}\iiint_V \vec{J}_f (x', y', z') \frac{e^{-jkR}}{R} dv', \qquad (4)$$

where V is the volume of the equivalent homogeneous media and R is the distance between the source and the observation point. We assume that the observation point is in the far zone from the target, which is located at the origin of the coordinate system. Using this approximation in the integrals for vector potential $\vec{A}$, the incoherent scattered field originating from volume current density, J_f can be written as

$$E_{incoh}^{s} = \frac{-j\omega\mu}{4\pi r} e^{-jk_0 r} \times \iiint_V \left[\vec{J}_f(x',y',z') - \left(\vec{J}_f(x',y',z')\cdot\hat{r}\right)\hat{r}\right] e^{-jk\vec{r}'\cdot\hat{r}} dv' + O\left(\frac{1}{r^2}\right). \quad (5)$$

Consider that an equivalent homogeneous volume of width w, depth d, and thickness h is illuminated by a uniform plane wave, as shown in Fig. 1. The media is bounded on both sides by air. The propagation direction of the incident plane wave and the direction of the observation point are assumed to be parallel to the x-axis and are defined by $\hat{k}_i = \hat{x}$ and $\hat{k}_s = -\hat{x}$. Thus, the incident field is given by

$$E^i = E_0 \exp(-jk_1 x). \quad (6)$$

The ratio between the wave number of the effective medium and that of free space, k_1/k_0, is as close to $1-js/2$ as desired by making the non-dimensional parameter, s, sufficiently close to zero [5]. Substituting (3) and (6) into (5), we obtain

$$\begin{aligned} E_{incoh}^{s} &\approx \frac{-j\omega\mu e^{-jk_0 r}}{4\pi r} \iiint_V \left(\omega\varepsilon s E_0 e^{-jk_1 x'}\right)\cdot e^{-jk_0 x'} dv' \\ &= \frac{-jk_0^2 e^{-jk_0 x} s}{4\pi x} \int_0^h\int_0^w\int_0^d E_0 \cdot e^{-j(k_1+k_0)x'} dv' \\ &= \frac{-jk_0^2 e^{-jk_0 x} s}{4\pi x} \int_0^h\int_0^w\int_0^d E_0 \cdot e^{-k_0\left(2j+s/2\right)x'} dv' \end{aligned} \quad (7)$$

We suppose that a number of scatterers N divide the equivalent homogeneous volume into N_d, N_w, and N_h in the x-, y-, z-directions, as shown in Fig. 1. such that N equals the total number of total sub-volumes ($N_d \times N_w \times N_h$). The integral in (7) can be expressed in the following Riemann summation form:

$$E_{incoh}^{s} = -\frac{jk_0^2 e^{-jk_0 x} s}{4\pi x} \Delta x \Delta y \Delta z \sum_{n_h=1}^{N_h}\sum_{n_w=1}^{N_w}\sum_{n_d=1}^{N_d} e^{-k_0(2j+s/2)m\Delta x}, \quad (8)$$

where Δx, Δy, and Δz are d/N_d, w/N_w, and h/N_h, respectively. In addition, $\Delta x\Delta y\Delta z = V/N$ is the reciprocal of the scatterers density. Then, (8) becomes

$$E_{incoh}^{s} = -\frac{jk_0^2 e^{jkx} s}{4\pi x\rho}\left(N_h \cdot N_w\right)\sum_{n_d=1}^{N_d} e^{-k_0(2j+s/2)m\Delta x}. \quad (9)$$

Therefore, the incoherent RCS can be estimated as follows:

$$\sigma_{incoh} = \frac{2\pi^2}{\lambda}\frac{sA}{\rho}\left(1-e^{-k_0 sd}\right). \quad (10)$$

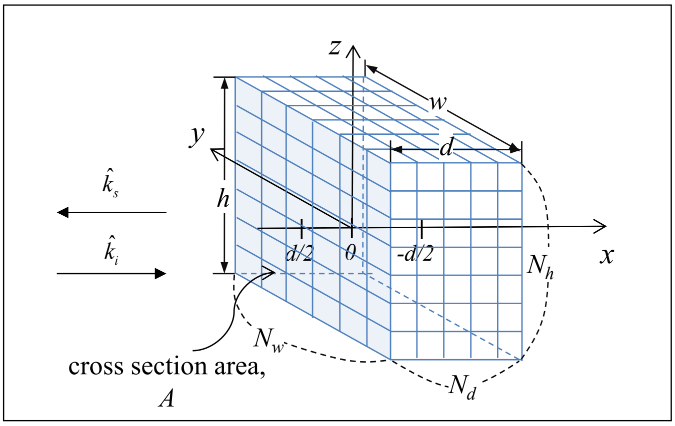

Fig. 1. Geometry of a equalized homogeneous media of $w \times d \times h$ m^3 with N sub-blocks.

III. Simulation Results

To validate the proposed method, the simulation results are compared with the incoherent RCS obtained from the Monte-Carlo analysis using the MoM with 50 realizations. The coherent RCS, meanwhile, is obtained from the GEC method [6] and the Monte-Carlo analysis. The multiple identical scatterers are assumed to be thin, perfectly conducting wire with a half-wavelength long. These scatterers are also assumed to be uniformly distributed in volume V ($w \times d \times h$ m^3), as shown in Fig. 1. The scatterers have a uniformly random orientation for all directions. The cross sectional area of the random medium is fixed as A = 10λ × 10λ, and its depth, d, varies from 0.1 to 4 λ. Although the total volume V is varied, the density of the scatterers is kept to be 1.0 [no./λ^3], and thus the total number of scatterers is varied.

Figure 2 shows the backscattering incoherent, coherent, and average RCSs of the random medium normalized to λ_0^2, in terms of the resonance frequency of the scatterers as a function of the depth of the slab. In terms of the value of peak, null, and level, the proposed method shows good agreement with the Monte-Carlo analysis performed using the MoM.

The coherent RCSs shown in Fig. 2 have nulls at points where the depth of media are multiple half-wavelengths, but maintain constant peak value. When a plane wave is incident normally on the random medium, the phase difference between the field reflected from the front and rear of the equivalent media generates nulls and peaks. These patterns mean that the coherent RCS can be calculated from the equivalent homogeneous medium of the random medium, as mentioned earlier. On the other hand, as the number of scatterers increases. The incoherent RCS even increases. The incoherent RCS even becomes larger than the coherent RCS when there is an increase of the depth of the equivalent homogeneous medium. Therefore, as illustrated in Fig. 2, the average RCS, which is the sum of the coherent and incoherent RCS, has the increasing value with oscillating form as a function of depth. For a uniformly oriented distribution, the $\hat{\theta}\hat{\theta}$-polarization RCS is equal to the $\hat{\phi}\hat{\phi}$-polarization RCS.

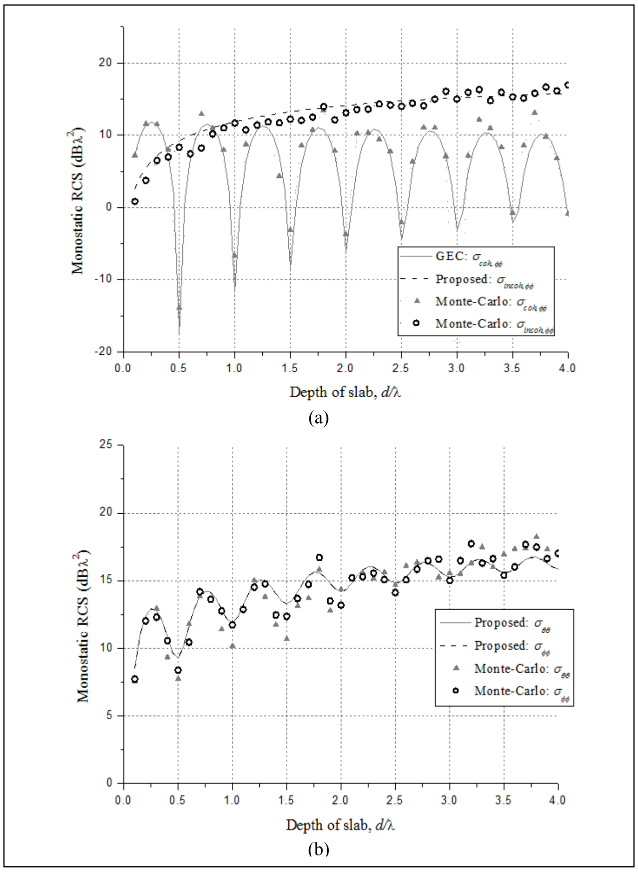

Fig. 2. Monostatic RCS of the scatterers with uniform orientation: (a) incoherent and coherent RCSs, and (b) the average RCS.

ACKNOWLEDGMENT *(Heading 5)*

This work was supported by the Agency Specific Research Program of MSIP, Rep. of Korea (Development of Multi-Sensor Platform Technology for Context Cognitive Smart Car).

REFERENCES

[1] C.-J. Kim and H.-J. Lee, “Performance Analysis of the Clutter Map CFAR Detector with Noncoherent Integration,” *ETRI J.*, vol. 15, no. 2, Oct. 1993, pp. 1-9.

[2] Y. Kim, M, Jeong, and Y. Han, “Rake-Based Cellular Radar Receiver Design for Moving Tartget Detection in Multipath Chaennel,” ETRI J., vol. 36, no. 5, Oct. 2014, pp. 799-807

[3] Y. Hwang, B.-S. Lee, Y.-R. Kim, K.-M. Roh, O.-C. Jung, and H. Kim, “GPS-Based Orbit Determination for KOMPSAT-5 Satellite,” *ETRI J.*, vol. 33, no. 4, Aug. 2011, pp. 487-496.

[4] K. Sarabandi, and P. R. Siqueira, “Numerical Scattering Analysis for Two-Dimensional Dense Random Media: Characterization of Effective Permittivity,” *IEEE Trans. Ant. Propagat.*, vol. 45, no. 5, May 1997.

[5] S. W. Marcus, “Incoherent Scattering from Dense Clouds of Wire Dipoles,” *IEEE Ant. And Propagat. Society Int. Symposium*, San Diego, CA, USA, 5-11 July 2008, pp. 1-4.

[6] D. W. Seo, J. H. Yoo, K. I. Kwon, and N. H. Myung, "Generalized Equivalent Conductor Method for a Chaff Cloud with an Arbitrary Orientation Distribution," *Progress In Electromagnetics Research*, Vol. 105, pp. 333-346, 2010.