NUMERICAL ANALYSIS OF ELECTROMAGNETIC SCATTERING FROM A DIELECTRIC ROUGH SURFACE CYLINDER

Toshitaka Kojima and Hiromi Arita
Department of Electronics, Faculty of Engineering, Kansai University
3-3-35, Yamate-cho, Suita-shi, Osaka 564-80, Japan
E-mail:kojima@ipcku.kansai-u.ac.jp

1.Introduction

The wave scattering from rough surfaces is an important problem which closely relates to the measurement technology or diagnosing techniques by using microwave, millimeter wave, light wave or acoustic wave (1). Various kinds of theoretical models and methods for analyzing the wave scattering from random rough surfaces have been proposed so far. However, they have often used approximated boundary conditions(2), for example Kirchhoff approximation, perturbation approximation, or impedance boundary approximation. Moreover, in many cases, the rough surfaces considered in them have infinite extent and also the plane-wave incident cases are treated. However, in order to measure the scattering characteristics from rough surfaces in a laboratory system, the condition of finite area illumination by the incident wave such as a beam wave is more or less inevitable. The author has analyzed the scattering of a focused beam from random rough surfaces by computer simulation(3).

In the present paper, the scattering of a focused beam from a dielectric cylinder with a random rough surface is analyzed by computer simulation. Such a scattering problem can be applicable to the measurement of microscopic surface roughness of optical fibers. A sample cylinder with Gaussian radius distribution and periodic radius correlation function is numerically generated by a computer. The scattered field from a realized sample cylinder is numerically calculated by using the boundary-element method (BEM) based on the integral equation(4). The mean intensity of the scattered field and its coherent component are obtained by calculating the mean square value of the scattered fields from all computer-generated sample cylinders. The dependence of the scattering characteristics on the roughness parameters is examined.

2. Simulation

In the present analysis, we consider the cases where a plane electromagnetic wave and a two dimensional Gaussian beam with the spot size w_0 are incident on a rough surface dielectric cylinder with the permittivity $\varepsilon_r \varepsilon_0$ and the permeability μ_0. ε_0 and μ_0 are the permittivity and the permeability of free space. In the previous paper $^{(5)}$, the rough surface profile was generated numerically by a computer using the moving average process with weights based on a Gaussian distribution of zero mean and specified RMS value. However, the periodicity of the generated surface was not necessarily guaranteed mathematically. Therefore, in the present analysis, we use the periodic correlation function with a period 2π for generating the periodic rough surface numerically. At an arbitrary angle $\phi \in [0, 2\pi]$, the radius of the cylinder is expressed by

$$r(\phi) = r_0 + \varepsilon(\phi) \tag{1}$$

where r_0 is the average radius and $\varepsilon(\phi)$ is realization of a stationary stochastic process with zero mean ,standard deviation σ and a correlation function

$$c(\phi - \phi') = \sigma^{-2} \langle \varepsilon(\phi) \varepsilon(\phi') \rangle \tag{2}$$

which must be a periodic function with the period 2π. The function $c(\phi)$ can be expanded into a Fourier series

$$c(\phi) = \sum_n C_n \, \mathbf{exp}(jn\phi) \tag{3}$$

In the present analysis, the following correlation function $^{(6)}$ is used:

$$c(\phi) = \mathbf{exp}\left(-2\alpha \, \mathbf{sin}^2(\phi/2)\right), \quad \alpha \geqq 0 \tag{4}$$

For this correlation function, the coefficient C_n is given by

$$C_n = \mathbf{exp}(-\alpha) I_n(\alpha) \tag{5}$$

where I_n is the first modified Bessel function of order n.

The function $\varepsilon(\phi)$ can be realized numerically by a set of $\varepsilon(\phi_n)$ at n-th sampling angle ϕ_n , where each $\varepsilon(\phi_n)$ can be given by the finite summation of the series with weighted random variables$^{(7)}$ with normal distribution.

An example of the computer-generated rough surface cylinder is shown in Fig.1. This cylinder has the mean radius r_0=2.0λ, the standard deviation of the radius profile σ=0.1λ and the correlation parameter α=0.5, where λ is the wave length. In Fig.2, we can observe a good agreement between the correlation of the realized sample cylinder and theoretical correlation function in (4).

The scattered field from this sample cylinder can be numerically calculated by the boundary-element method. In the present analysis a hundred sample cylinders with the same stochastic parameters are realized by rotating the computer-generated cylinder by 3.6 degree continuously. The relative permittivity of the cylinder ε_r is assumed to be 4.0.

The coherent components of the scattered field calculated by the present method, perturbation theory to second order, and its Padé approximation are shown in Fig.3 for the case where a plane wave is incident on the perfectly conducting cylinder with r_0=2.0

λ, σ=0.15λ ,and α=0.5. This figure shows the present method gives a reasonable result for relatively large roughness. Fig.4 is an example of the calculated results for E-polarized incident beam. This result is almost same as the previous one (5) calculated for the computer-generated cylinder with an approximated periodicity.

3. Conclusion

The present paper has described the numerical results of the electromagnetic wave scattering from the rough surface dielectric cylinders. The rough surface of the cylinder has been generated numerically by the computer and the scattered field from the rough surface cylinder has been calculated by the boundary-element method. It has been shown that the present numerical method is valid for a random rough surface dielectric cylinder with relatively large roughness.

References

(1) A. Ishimaru, ”Wave propagation and scattering in random media”, Academic Press, New York (1978).

(2) P. Beckmann and A. Spizzichino, “The scattering of electromagnetic waves from rough surfaces”, Pergamon Press, Oxford (1963).

(3) T. Kojima and Y. Yamazoe, “Scattering of a focused beam from random rough surfaces-analysis by computer simulation”, Abstracts of XXIVth General Assembly of International Union of Radio Science, B9-7, p.68 (Aug. 1993).

(4) T. Kojima and J. Ido, “The boundary-element method analysis of light-beam scattering analysis and the sum and differential signal output by DRAW type of optical disk models”, IEICE Trans. C-I, Vol. J.73-C-I, No.9, pp.551-558 (Sept. 19990).

(5) T. Kojima, “Numerical analysis of focused beam scattering from a dielectric cylinder with a rough surface”, Proc. of Int. Symp. on Electromagnetic Theory, Vol. 4, pp.316-318 (May 1998).

(6) C. Eftimiu, ”Electromagnetic scattering by rough conducting circular cylinders-I: angular corrugation”, IEEE Trans. Antennas Propagat., Vol. 36, No.5, pp.651-658 (May 1988).

(7) E. I. Thorosos, “The validity of the Kirchhoff approximation for rough surface scattering using a Gaussian roughness spectrum”, J.Acoust.Soc.Am.Vol.83 pp.79-82 (Jan. 1988).

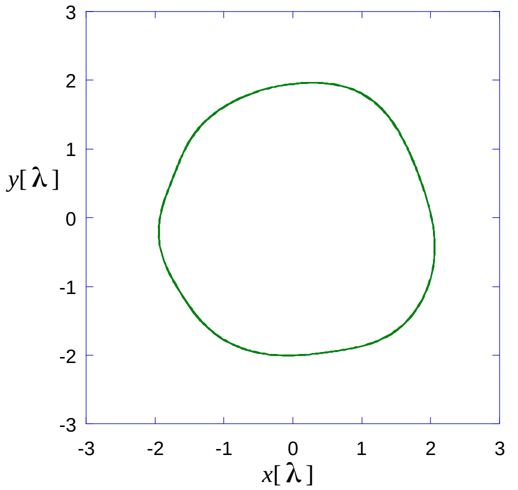


Fig. 1 Generated cylinder.

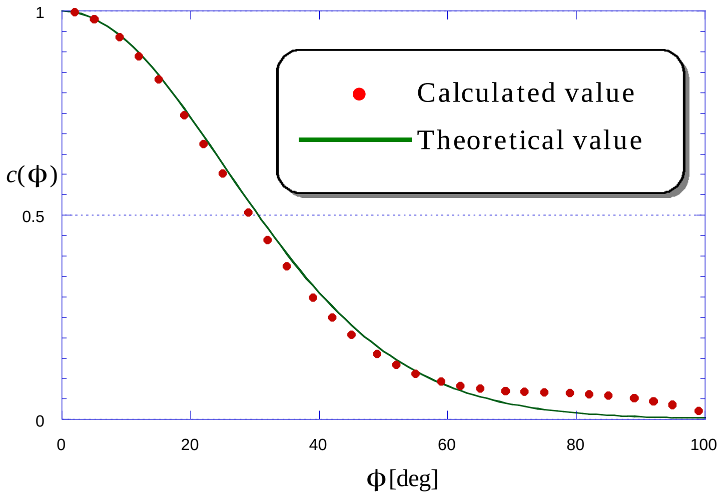
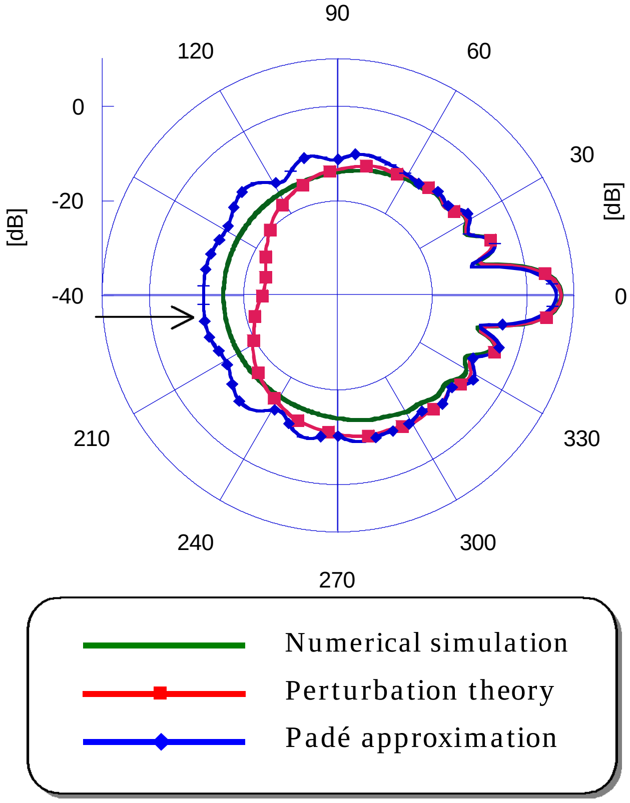


Fig. 2 Correlation function



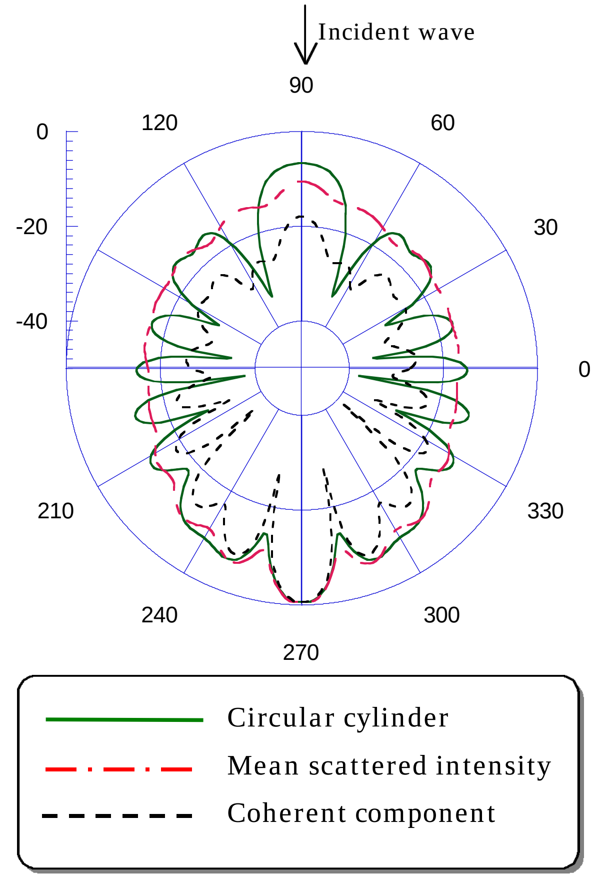


Fig.3 Coherent component from conducting cylinder.

Fig. 4 Scattering pattern for dielectric cylinder.