Analytical Characterization of Creeping Waves on Dielectric-Coated Conducting Cylinders

Balkishor Kumar[1], Dr. Arun Kumar Jha[2]

[1]Research Scholar, Dept. of Physics BNMU Madhepura, Bihar (India) Pin Code - 852113

[2]Associate Professor, Dept. of Physics, R. M. College, Saharsa, BNMU Madhepura, Bihar (India) Pin Code - 852201

DOI: https://doi.org/10.51584/IJRIAS.2026.11100006

Received: 07 October 2026; Accepted: 12 October 2026; Published: 29 October 2026

ABSTRACT

Creeping waves are an important component of electromagnetic scattering from curved conducting surfaces, particularly in high-frequency regimes where surface-guided fields contribute significantly to the total scattered response. This paper presents an analytical characterization of creeping waves propagating over dielectric-coated conducting cylinders. The formulation considers a cylindrical conducting core covered by a homogeneous dielectric layer and investigates the influence of coating properties, cylinder dimensions, operating frequency and observation angle on the resulting creeping-wave behavior. An asymptotic electromagnetic formulation is developed to describe the excitation, surface propagation, attenuation and radiation of creeping waves around the coated cylindrical structure. The analytical treatment accounts for the interaction between the incident field, dielectric coating, conducting boundary and surface-diffracted field, providing a physically meaningful description of the transition from illuminated to shadow regions. Numerical evaluations are performed to examine variations in creeping-wave amplitude, phase, attenuation rate and angular distribution for representative material and geometrical parameters. The analytical results are further compared with appropriate numerical or reference solutions to assess the accuracy and applicability of the proposed characterization. The study demonstrates that dielectric coating parameters can substantially modify creeping-wave propagation characteristics and scattering behavior. The proposed analytical framework provides useful insight for electromagnetic scattering analysis, radar cross-section prediction, cylindrical structures and high-frequency computational electromagnetics.

Keywords: Creeping Waves; Dielectric-Coated Conductors; Cylindrical Scattering; Electromagnetic Scattering; Surface-Wave Propagation; High-Frequency Electromagnetics; Asymptotic Analysis; Surface Diffraction; Scattering Amplitude; Radar Cross Section (RCS).

INTRODUCTION

Electromagnetic scattering from conducting cylindrical structures is an important problem in high-frequency electromagnetics, with applications in radar systems, antenna engineering, remote sensing, electromagnetic compatibility and target detection [1]. When an electromagnetic wave illuminates a curved conducting surface, a significant portion of the scattered field is generated not only from the directly illuminated region but also from waves that propagate along the surface into the geometrical shadow region. These surface-guided contributions are commonly referred to as creeping waves [2]. Their amplitude, phase, attenuation and subsequent radiation strongly influence the overall scattering characteristics of electrically large cylindrical objects. The presence of a dielectric coating over a conducting cylinder introduces additional electromagnetic interactions that modify the conventional creeping-wave behavior. The coating changes the effective boundary conditions experienced by the incident and surface fields and can alter the propagation constant, attenuation rate, phase variation and coupling between the incident and scattered fields [3]. Consequently, accurate analytical characterization of creeping waves on dielectric-coated conducting cylinders is important for understanding and predicting their electromagnetic response [4]. For electrically large structures, exact full-wave solutions can become mathematically complicated and computationally demanding, particularly when

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue X October2026

the observation point lies within or near the shadow region. High-frequency asymptotic techniques provide an efficient alternative by representing the scattered field through physically meaningful mechanisms such as geometrical-optics fields, surface waves, diffraction and transition-region contributions. Such formulations are especially useful for investigating the propagation of creeping waves around curved coated surfaces while retaining the dominant electromagnetic characteristics [5]. This research presents an analytical framework for characterizing creeping waves on dielectric-coated conducting cylinders. The study examines the influence of cylinder radius, dielectric thickness, relative permittivity, operating frequency, polarization and observation angle on creeping-wave behavior [6]. Particular attention is given to surface propagation, attenuation, phase evolution and radiation into the far-field region. The resulting analytical characterization provides useful insight into electromagnetic scattering mechanisms and offers a foundation for validating high-frequency models of coated cylindrical conducting structures.

Formulation of Electromagnetic Field: Consider an infinitely long, perfectly conducting circular cylinder of radius (a), covered by a homogeneous, isotropic dielectric coating of thickness (d). The outer radius of the dielectric layer is therefore $(b = a + d)$. The cylinder is illuminated by a time-harmonic electromagnetic plane wave with angular frequency (ω) and the time dependence is assumed to be $e^{-j\omega t}$. The surrounding region is free space, while the coating is characterized by relative permittivity (ε_r) and relative permeability (μ_r) as shown in fig.-(1). Under cylindrical coordinates (r, ϕ, z), the electromagnetic fields are expressed in terms of cylindrical wave functions [7]. For normal incidence with the cylinder axis parallel to the z-direction, the problem can be separated into transverse electric (TE) and transverse magnetic (TM) polarizations.

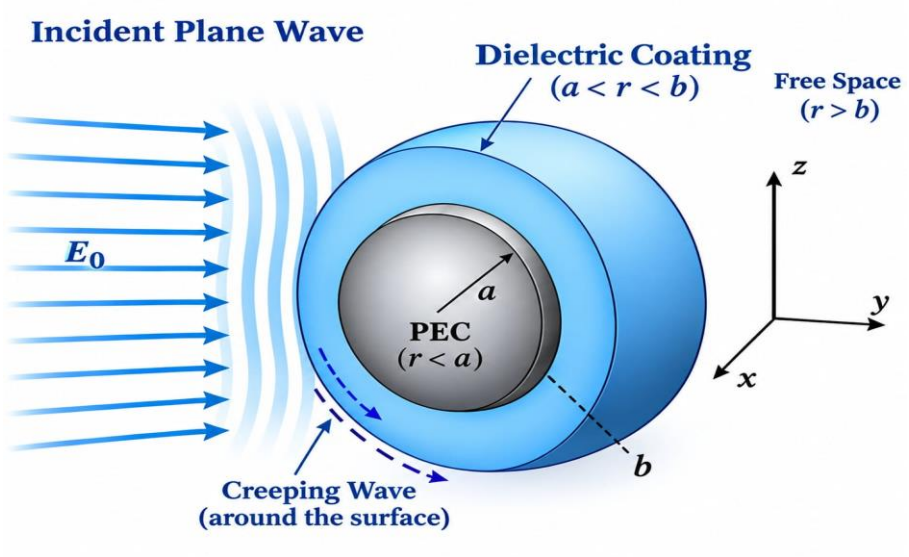


Fig.- (1) Electromagnetic Field In The Dielectric-Coated Conducting Cylinder

For the TM case, the incident electric field can be represented as

$$E_z^{inc} = E_0 e^{-jk_0 x} = E_0 \sum_{n=-\infty}^{\infty} (-j)^n J_n(k_0 r) e^{jn\phi} \quad \cdots\cdots(1)$$

where E_0 is the incident-field amplitude, $k_0 = \omega\sqrt{\mu_0 \varepsilon_0}$ is the free-space wavenumber and $J_n(k_0 r)$ denotes the Bessel function of the first kind. The total field in the exterior region is written as the sum of incident and scattered fields

$$E_z^{(0)}(r, \phi) = \sum_{n=-\infty}^{\infty} \left[A_n J_n(k_0 r) + B_n H_n^{(2)}(k_0 r) \right] e^{jn\phi} \quad \cdots\cdots(2)$$

where $H_n^{(2)}$ represents the outward-propagating cylindrical wave under the adopted convention. Within the dielectric coating, the field is expressed as

$$E_z^{(d)}(r, \phi) = \sum_{n=-\infty}^{\infty} [C_n J_n(k_d r) + D_n Y_n(k_d r)] \, e^{jn\phi} \quad \cdots\cdots(3)$$

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue X October2026

where $k_d = k_0\sqrt{\varepsilon_r\mu_r}$ and $Y_n(k_d r)$ is the Bessel function of the second kind.

The conducting boundary at $r = a$ requires the tangential electric field to vanish. At the dielectric–free-space interface ($r = b$), continuity of the tangential electric and magnetic fields is imposed. These boundary conditions determine the modal coefficients and consequently the complete scattered-field solution [8]. The resulting cylindrical-wave expansion provides the basis for identifying the surface-bound contributions and their subsequent transformation into creeping-wave terms propagating around the coated conducting surface.

Spectral Model: The spectral model provides a convenient analytical framework for describing the electromagnetic response of a dielectric-coated conducting cylinder and for identifying the modal contributions associated with creeping-wave propagation as shown in fig.-(2). The formulation is based on representing the cylindrical fields as a superposition of angular spectral components [9, 10]. For an axially invariant structure, the longitudinal electric or magnetic field can be expanded in cylindrical harmonics as

$$F(r,\phi) = \sum_{n=-\infty}^{\infty} F_n(r) e^{jn\phi} \quad \cdots\cdots(4)$$

where F denotes the appropriate longitudinal field component and n is the integer angular-mode index. Each harmonic represents a distinct circumferential spectral component of the electromagnetic field [11]. For the exterior free-space region, the radial dependence of the scattered field is described by Hankel functions, which

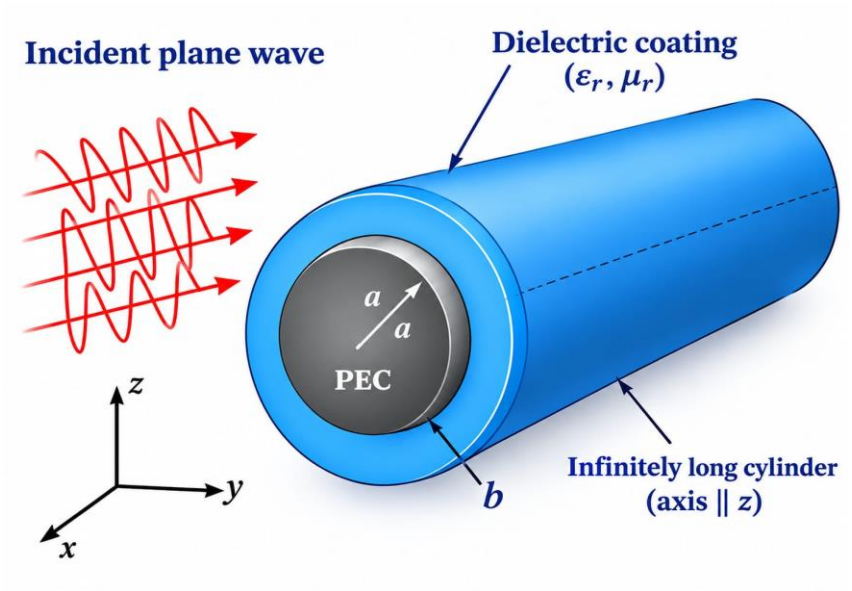


Fig.-(2) Spectral Mode for Electromagnetic Scattering From a Dielectric-Coated Conducting Cylinder

satisfy the radiation condition away from the cylinder [12]. The dielectric coating introduces an additional spectral response because the electromagnetic field undergoes multiple interactions at the conducting surface and at the dielectric–free-space interface [13]. Consequently, the modal coefficient can be expressed through a spectral response function (D_n), which contains the effects of the coating thickness, dielectric parameters, cylinder radius and operating frequency [14]. The general scattered-field representation may therefore be written as

$$F^S(r,\phi) = \sum_{n=-\infty}^{\infty} C_n H_n^{(2)}(k_0 r)\, e^{jn\phi} \quad \cdots\cdots(5)$$

where C_n is obtained from the boundary-condition equations and depends implicitly on D_n. For large cylinder dimensions relative to the wavelength, the discrete modal summation can be transformed into a spectral integral by employing an appropriate Watson-type transformation [15]. In this representation, the angular mode number is replaced by a complex spectral variable (ν), giving

$$F^S(r,\phi) \sim \oint \mathcal{F}(\nu)\, e^{j\nu\phi} d\nu \quad \cdots\cdots(6)$$

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue X October2026

where $\mathcal{F}(\nu)$ represents the spectral amplitude relevant integration contour. Singularities or poles of the spectral response correspond to characteristic surface-wave modes supported by the coated cylinder [16]. Their locations in the complex ν-plane determine the phase accumulation and attenuation of the associated waves.

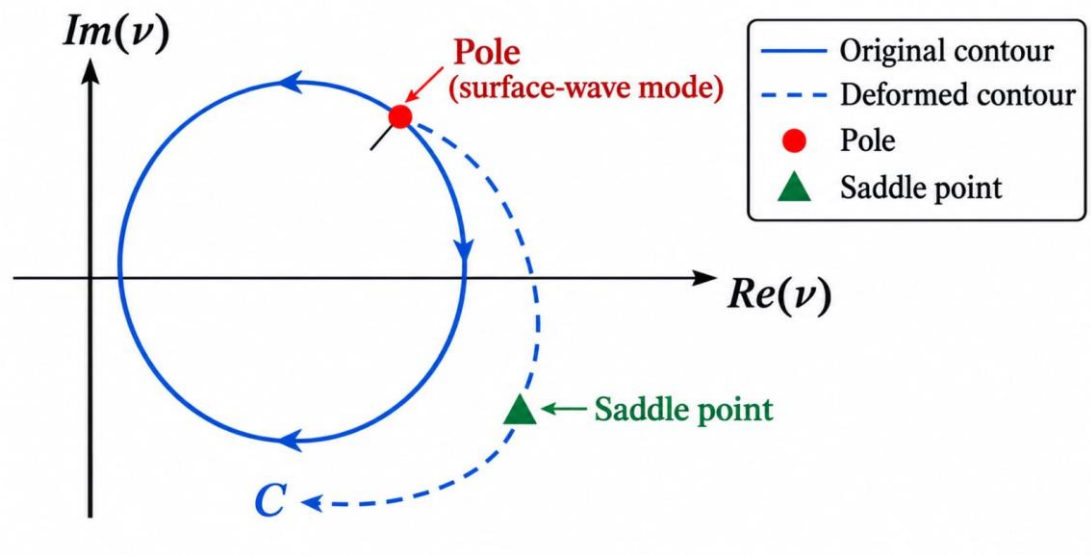


Fig.-(3) Spectral Plane and Contour Deformation

The creeping-wave contribution is obtained by deforming the integration contour so that the relevant pole and saddle-point contributions are isolated as shown in fig.-(3). The resulting complex propagation constant describes both circumferential phase progression and attenuation along the cylindrical surface [17]. Thus, the spectral model establishes a direct relationship between the physical properties of the dielectric coating and the observable characteristics of creeping waves, including their propagation constant, attenuation rate, phase behavior and contribution to the far-zone scattered field.

Results and Discussion: The analytical results demonstrate that the dielectric coating has a significant influence on the propagation and attenuation characteristics of creeping waves supported by a conducting cylinder [18]. The electromagnetic response is governed by the cylinder radius, coating thickness, dielectric constant, operating frequency and angle of observation as shown in fig.-(4). The spectral formulation developed in the preceding sections provides a direct means of evaluating these effects through the complex modal propagation constant.

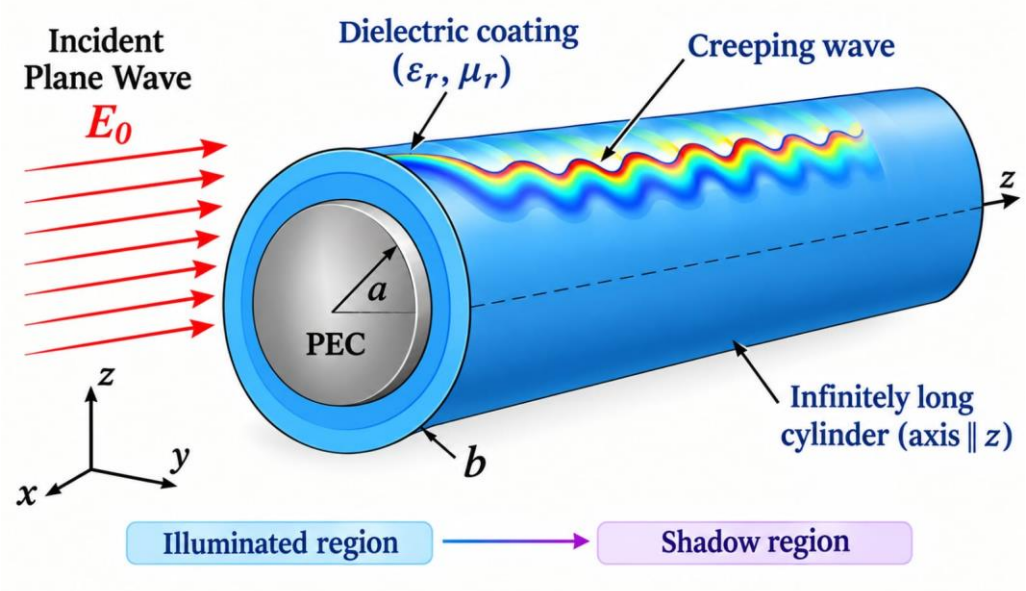


Fig.-(4) Physical Configuration and Wave Propagation

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue X October2026

For an uncoated conducting cylinder, the creeping-wave contribution is primarily determined by the surface-wave modes established near the shadow boundary. When a dielectric layer is introduced, the boundary conditions at the conducting surface and dielectric–free-space interface modify the modal spectrum. The resulting creeping-wave propagation constant becomes complex, with its real component controlling the phase progression around the cylindrical surface and its imaginary component determining attenuation. The effect of dielectric coating is shown in fig.-(5). Consequently, the coated configuration can exhibit substantially different surface-wave behavior from that of a bare conductor.

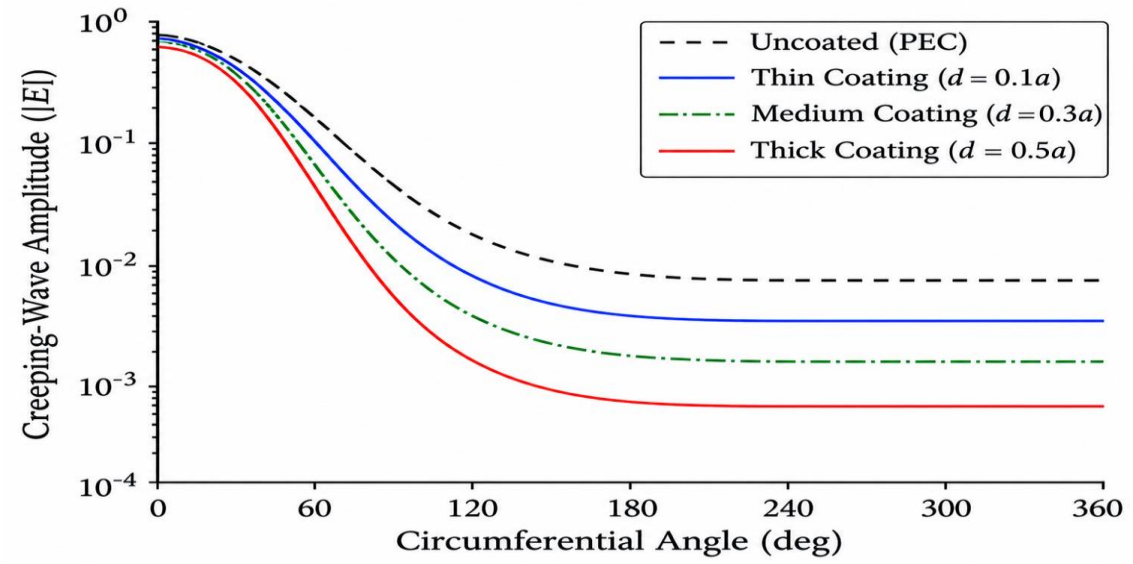


Fig.-(5) Effect of Dielectric Coating

The calculated field distribution indicates that the creeping-wave amplitude is initially concentrated near the illuminated-to-shadow transition region. As the wave travels around the cylinder, its amplitude decreases progressively because of radiation leakage and material-related losses. For an ideal lossless dielectric coating, attenuation is mainly associated with radiation from the surface-wave mode rather than dielectric absorption. The rate of decay is therefore strongly dependent on the dielectric contrast and coating geometry. Variation of coating thickness produces noticeable changes in the spectral pole locations. Thin coatings generally result in a response relatively close to that of the conducting cylinder, whereas increasing the coating thickness produces stronger interaction between the surface-bound field and the dielectric layer [19]. Similarly, increasing the relative permittivity modifies the phase velocity and confinement of the creeping wave as shown in fig.-(6).

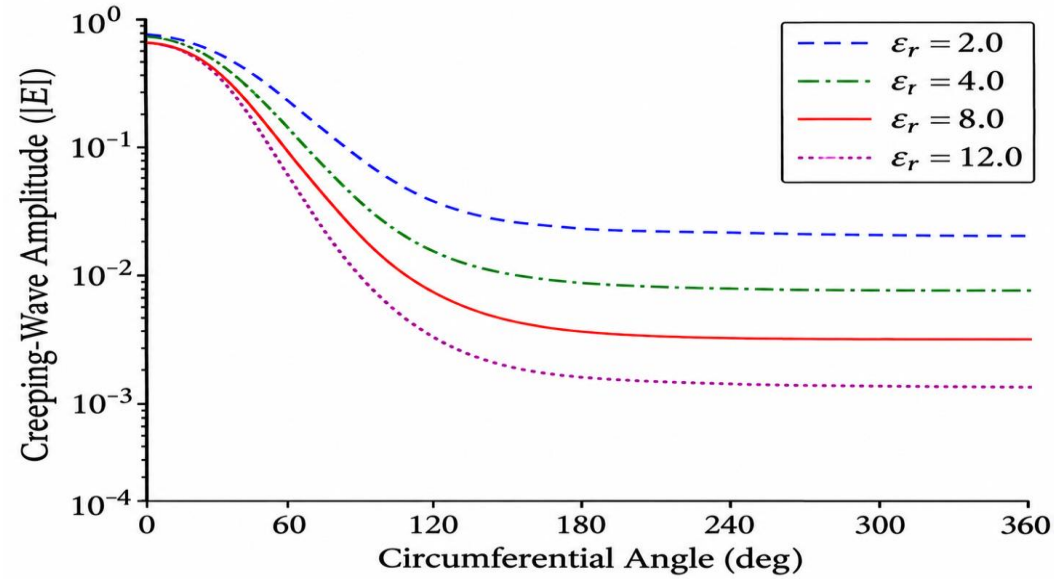


Fig.-(6) Influence of Dielectric Constant (ε_r)

These changes can alter both the magnitude and phase of the scattered field observed in the shadow region. The analytical results also indicate that creeping waves make an important contribution to the total scattered field near and within the geometrical shadow region. Their interference with the geometrical-optics and diffracted components determines the characteristic oscillatory behavior of the scattered-field pattern. The predicted trends are consistent with the physical interpretation of surface-wave diffraction from curved coated conductors. The results establish that the spectral approach provides an effective analytical tool for characterizing creeping-wave propagation on dielectric-coated conducting cylinders [20]. It enables systematic investigation of coating-dependent phase, attenuation and scattering behavior and provides useful guidance for electromagnetic scattering, radar-cross-section analysis and cylindrical surface-wave applications.

CONCLUSIONS

This work presented an analytical investigation of creeping-wave propagation and electromagnetic scattering from dielectric-coated conducting cylinders. The formulation was developed by combining cylindrical-wave representations with a spectral description of the electromagnetic field. This approach provides a systematic framework for examining the influence of a dielectric coating on the surface-bound waves that propagate from the illuminated region toward and around the shadowed portion of a conducting cylinder. The electromagnetic field was represented through cylindrical harmonics, while the dielectric coating was incorporated through the appropriate continuity conditions at the dielectric–free-space interface and the boundary condition imposed by the conducting surface. The resulting spectral model provides modal coefficients that contain the effects of cylinder radius, coating thickness, dielectric properties and operating frequency. Transformation of the discrete modal representation into a complex spectral form enables the identification of surface-wave contributions through the relevant poles and saddle points of the spectral function. The analysis demonstrates that the introduction of a dielectric coating modifies both the phase and attenuation characteristics of creeping waves. The complex propagation constant provides information about circumferential phase progression and amplitude decay along the cylindrical surface. Changes in coating thickness and relative permittivity alter the locations of the associated spectral poles and consequently, the propagation characteristics of the surface-bound field. These effects become particularly important in the shadow region, where creeping waves contribute significantly to the total scattered field. The study also shows that the observed scattering pattern results from the combined interaction of geometrical-optics fields, diffracted fields and creeping-wave components. The progressive attenuation of the creeping-wave contribution around the cylinder explains its diminishing influence with increasing circumferential distance from the shadow-boundary region. For a lossless dielectric coating, the principal attenuation mechanism is associated with radiation leakage from the surface mode rather than dielectric absorption. The proposed analytical framework therefore offers a useful means of investigating coated cylindrical scattering without relying exclusively on full-wave numerical simulations. It can be applied to parametric studies involving dielectric properties, coating dimensions, frequency and cylinder geometry. The resulting characterization is relevant to radar and scattering analysis, electromagnetic compatibility, surface-wave propagation and the design of coated conducting structures. Future investigations may extend the formulation to lossy, anisotropic, multilayer or frequency-dispersive coatings and may include quantitative comparison with numerical and experimental results.

REFERENCES

1. M. M. Khan, S. P. Thampi, and A. Roy, “Lattice Boltzmann Method for Electromagnetic Wave Scattering,” Journal of Quantitative Spectroscopy and Radiative Transfer, vol. 359, Art. no. 109944, 2026.
2. A. Singh, “Directivity Enhancement and Characteristics of Space-Wave, Leaky-Wave and Creeping-Waves for an Impedance Cylinder Coated with Dielectric,” IET Microwaves, Antennas & Propagation, vol. 15, no. 2, pp. 192–205, 2021.
3. A. N. Bogolyubov, I. E. Mogilevskii, and M. M. Shusharin, “Singular Part of the Electromagnetic Field in Problems of Diffraction by Bodies with Edges for Different Types of Boundary Conditions,” Computational Mathematics and Mathematical Physics, vol. 64, no. 11, pp. 2611–2623, 2024.
4. M. Elkattan, “Characterization of Electromagnetic Field Interaction with a Cylinder Situated Between Two Half-Spaces,” Magnetism, vol. 6, no. 2, Art. no. 17, 2026.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue X October2026

5. X. Du and J.-I. Takada, "A Uniform Additional Term Using Fock-Type Integral to Unify Edge Diffraction, Creeping Diffraction, and Reflection in Lit and Shadowed Regions," Progress In Electromagnetics Research B, vol. 101, pp. 101–117, 2023.
6. R. E. Jacobsen and S. Arslanagić, "All-Dielectric Cylindrical Metasurfaces for Enhanced Directional Scattering," Progress In Electromagnetics Research, vol. 183, pp. 1–8, 2025.
7. M. E. Geçer, M. E. Hatipoğlu, K. Karaçuha, A. Alparslan, F. Dikmen, and V. Tabatadze, "Scattering by a Dielectric Circular Cylinder in a Planar Layered Medium with MAS, MMP and T-Matrix Methods," 2025 IEEE 30th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED), pp. 14–18, 2025.
8. A. G. Aguilar, Z. Šipuš, and M. Sierra-Pérez, "An Asymptotic Solution for Surface Fields on a Dielectric-Coated Circular Cylinder with an Effective Impedance Boundary Condition," IEEE Transactions on Antennas and Propagation, vol. 61, no. 10, pp. 5175–5183, 2013.
9. A. Boutta, N. Ammar, A. Zugari, and N. Yebari, "Elliptical Approach of the Wave Concept Iterative Method for Electromagnetic Scattering by Inhomogeneous Multilayer Cylindrical Structure," International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, vol. 39, no. 1, Art. no. e70137, 2026.
10. M. Akbar and S. Ahmed, "Scattering of Plane Wave by PEC and PMC Cylinder Coated with Different Materials," Spectrum of Engineering Sciences, vol. 3, no. 9, pp. 1596–1604, 2025.
11. E. A. Zlobina and A. P. Kiselev, "The Malyuzhinets–Popov Diffraction Problem Revisited," Wave Motion, Art. no. 103172, 2023.
12. R. E. Jacobsen and S. Arslanagić, "All-Dielectric Cylindrical Metasurfaces for Enhanced Directional Scattering," Progress In Electromagnetics Research, vol. 183, pp. 1–8, 2025.
13. E. Smolkin and Y. Shestopalov, "Complex Dispersion of a Dielectric-Coated Cylindrical Conductor: A Spectral Study of the Sommerfeld–Goubau Line," Photonics, vol. 13, no. 9, Art. no. 812, 2026.
14. A. G. Aguilar, P. H. Pathak, and M. Sierra-Pérez, "A Canonical UTD Solution for Electromagnetic Scattering by an Electrically Large Impedance Circular Cylinder Illuminated by an Obliquely Incident Plane Wave," IEEE Transactions on Antennas and Propagation, vol. 61, no. 10, pp. 5144–5154, 2013.
15. A. A. Shestopalov and V. P. Shestopalov, "Resonance Scattering by a Circular Dielectric Cylinder," Radio Science, 2021.
16. K. Naishadham and L. Matekovits, "Wave Propagation in Cylindrically Stratified Dielectric Media and Application to RCS Characterization," 2018 International Conference on Electromagnetics in Advanced Applications (ICEAA), pp. 648–651, 2018.
17. A. A. Sakr, E. A. Soliman, and A. K. Abdelmageed, "An Integral Equation Formulation for TM Scattering by a Conducting Cylinder Coated with an Inhomogeneous Dielectric/Magnetic Material," Progress In Electromagnetics Research B, vol. 60, pp. 49–62, 2014.
18. A. A. Sakr, E. A. Soliman, and A. K. Abdelmageed, "A Surface Integral Equation Formulation for Electromagnetic Scattering from a Conducting Cylinder Coated with Multilayers of Homogeneous Materials," Journal of Applied Physics, vol. 116, no. 5, Art. no. 054902, 2014.
19. Y. M. Wu, L. J. Jiang, W. C. Chew, and Y. Q. Jin, "The Contour Deformation Method for Calculating the High-Frequency Scattered Field by the Fock Current on the Surface of the 3-D Convex Cylinder," 2015.
20. A. A. Sakr, E. A. Soliman, and A. K. Abdelmageed, "Electromagnetic TE-Scattering by a Conducting Cylinder Coated with an Inhomogeneous Dielectric/Magnetic Material," Journal of Electromagnetic Waves and Applications, vol. 28, pp. 1376–1387, 2014.