Calculation Method of Electromagnetic Waves Scattering by Dielectric Toroid Meteorological Formations

Oleg Sukharevsky[1*]**, Vitaliy Vasilets**[1**]**, and Vitalii Misailov**[1***]

[1]*Ivan Kozhedub National Air Force University, Kharkiv, Ukraine*
*ORCID: 0000-0002-4607-5361, e-mail: sukharevsky@euro.dinos.net
**ORCID: 0000-0002-3614-559X, e-mail: rainbow.dome@gmail.com
***ORCID: 0000-0002-5307-5474, e-mail: misaylov@ukr.net

Abstract—One of the possible physical mechanisms of so-called "angel" echoes, not visually observed radar discrete reflections from objects, is considered. The vortex flows can be the cause of "angel" echoes. They take out some volume of air with certain radiophysical parameters into the region of space with other radiophysical parameters of the air. Toroidal vortices (vortex rings) have a fairly long lifetime and can move to considerable distances without destruction. The calculation of radio wave scattering diagrams by vortex rings by modern universal programs designed to solve electrodynamic problems and based on the method of moments requires significant computational and time resources. The asymptotic calculation method of the electromagnetic waves scattering by dielectric toroidal formations of large radius is developed. Simulation and comparison of its results with calculations in Altair Feko is carried out, and their well coincidence is shown. The monostatic and bistatic effective scattering areas of vortex rings are calculated for interesting cases in practice. The calculation results for the monostatic location good enough coincide with the results of known experimental works.

1. INTRODUCTION

The radio wave propagation environment is an integral part of any radio engineering system (RES). There are various radiophysical models, describing the dependence of the electrical properties of environment via coordinates and time, to assess the influence of radio wave propagation conditions on the quality of RES operation. These can be general models of the atmosphere or its separate parts (ionosphere, troposphere, boundary planetary layer) depending on the scope of RES.

Since the atmosphere is the gaseous shell of the Earth, and the relative magnetic permeability of atmospheric gases is very close to 1 with insignificant changes in terrestrial conditions, usually we talk about the dielectric permittivity of the air ε. In general case, ε depends on time and coordinates, is a complex quantity described stochastically, with average quasi-constant and variable components. Their average values are determined by the averaging scale in time and space and, in turn, depend on the motion scale in the atmosphere [1].

The dynamic structure of the atmosphere leads to spatiotemporal inhomogeneities of its radiophysical properties. Slow vertical movement and the air stratification in the boundary planetary layer can lead to occurrence of the tropospheric radio waveguides, and significantly increase the RES range. And active air mixing in the troposphere averages its characteristics, reduces vertical refraction, and as a result, the RES range [2].

The appearance of the coherent discrete reflections from not observed visually objects ("angel" echoes) is a separate problem in radar [3]. Classification of the received marks remains rather difficult even for modern radar equipment [4].

As a result of processing a large amount of experimental data and analysis of concomitant factors (season, time of day, temperature near the Earth surface), one part of the "angel" echoes (AE) is attributed to the reflections from individual large birds or flocks of small one, and other part of AE is attributed to the reflections from swarms of insects. Another part of the reflections is caused by inhomogeneities of the

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ADDITIONAL INFORMATION

REFERENCES

1. N. L. Byzova, V. N. Ivanov, and E. K. Garger, *Turbulence in Atmospheric Boundary Layer* [in Russian] (Hydrometeoizdat, Leningrad, 1989).
2. R. ITU, *Handbook on Radiometeorology* (ITU, 2014). URL: https://www.itu.int/dms_pub/itu-r/opb/hdb/R-HDB-26-2013-OAS-PDF-E.pdf.
3. A. A. Chernikov, *Radar Reflections from Clear Sky* [in Russian] (Hydrometeoizdat, Leningrad, 1979).
4. W. J. Martin and A. Shapiro, "Discrimination of bird and insect radar echoes in clear air using high-resolution radars," *J. Atmos. Ocean. Technol.* **24**, No. 7, 1215 (2007). DOI: 10.1175/JTECH2038.1.
5. S. Fukao and K. Hamazu, *Radar for Meteorological and Atmospheric Observations*, in *Radar For Meteorological And Atmospheric Observations* (Springer, Tokyo, 2014), Vol. 9784431543. DOI: 10.1007/978-4-431-54334-3.
6. J.-I. Yano, "Basic convective element: bubble or plume? A historical review," *Atmos. Chem. Phys.* **14**, No. 13, 7019 (2014). DOI: 10.5194/acp-14-7019-2014.
7. D. G. Akhmetov, *Vortex Rings*, in *Vortex Rings* (Springer-Verlag, Berlin, 2009). DOI: 10.1007/978-3-642-05016-9.
8. U. Yusupaliev, S. A. Shuteev, E. E. Vinke, and P. U. Yusupaliev, "Vortex rings and plasma toroidal vortices in a homogeneous infinite medium. I. Maximum vortex path," *Bull. Lebedev Phys. Inst.* **37**, No. 8, 227 (2010). DOI: 10.3103/S1068335610080014.

9. D. C. Tzarouchis, P. Ylä-Oijala, and A. Sihvola, "Resonant scattering characteristics of homogeneous dielectric sphere," *IEEE Trans. Antennas Propag.* **65**, No. 6, 3184 (2017). DOI: 10.1109/TAP.2017.2690312.
10. D. Tzarouchis and A. Sihvola, "Light scattering by a dielectric sphere: Perspectives on the Mie resonances," *Appl. Sci.* **8**, No. 2(2018). DOI: 10.3390/app8020184.
11. A. A. Kucharski, "The FIT-MoM hybrid method for analysis of electromagnetic scattering by dielectric bodies of revolution," *IEEE Trans. Antennas Propag.* **66**, No. 3, 1384 (2018). DOI: 10.1109/TAP.2018.2796721.
12. B.-B. Kong and X.-Q. Sheng, "A discontinuous Galerkin surface integral equation method for scattering from multiscale homogeneous objects," *IEEE Trans. Antennas Propag.* **66**, No. 4, 1937 (2018). DOI: 10.1109/TAP.2018.2803133.
13. L. Huang, Y.-B. Hou, H.-X. Zhang, L. Zhou, and W.-Y. Yin, "Time-domain discontinuous Galerkin PMCHW integral equation method with MOD scheme for simulating electromagnetic pulse responses of arbitrarily shaped dielectric objects," *IEEE Trans. Electromagn. Compat.* **61**, No. 4, 1157 (2019). DOI: 10.1109/TEMC.2018.2853261.
14. X.-W. Huang and X.-Q. Sheng, "A discontinuous Galerkin self-dual integral equation method for scattering from IBC objects," *IEEE Trans. Antennas Propag.* **67**, No. 7, 4708 (2019). DOI: 10.1109/TAP.2019.2905670.
15. K. Shariff and A. Wray, "Analysis of the radar reflectivity of aircraft vortex wakes," *J. Fluid Mech.* **463**, 121 (2002). DOI: 10.1017/S0022112002008674.
16. M. M. Bibby, C. M. Coldwell, and A. F. Peterson, "A high order numerical investigation of electromagnetic scattering from a torus and a circular loop," *IEEE Trans. Antennas Propag.* **61**, No. 7, 3656 (2013). DOI: 10.1109/TAP.2013.2258316.
17. L. A. Vainshtein, *Electromagnetic Waves* [in Russian] (Radio i Svyaz', Moscow, 1988).
18. M. V. Fedoryuk, *Pass Method* [in Russian] (Nauka, Moscow, 1977).
19. I. S. Gradstein and I. M. Ryzhik, *Tables of Integrals*, *Sums*, *Series and Products* [in Russian] (State Publishing House Physics-Math. Literature, Moscow, 1963).
20. A. N. Vulfson and O. O. Borodin, "The system of convective thermals as a generalized ensemble of Brownian particles," *Uspekhi Fiz. Nauk* **186**, No. 2, 113 (2016). DOI: 10.3367/UFNr.0186.201602a.0113.