Loss Effects on the RCS of a Conducting Circular or Elliptic Cylinder with a Metamaterial Coating

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Abstract

The problem of electromagnetic scattering by a lossy metamaterial coated circular or elliptic cylinder is analyzed using elliptic waves expressed in terms of Mathieu functions with complex arguments. Numerical results are obtained for the far scattered field for different axial ratio, lossy metamaterial coating and angles of incidence. The numerical results show a significant reduction in the backscattering echo pattern width due to the presence of a lossy metamaterial coating when it is compared with losseless conventional dielectric and metamaterial coatings.

1. INTRODUCTION

The problem of electromagnetic scattering by dielectric elliptic cylinders provides a useful model to study the electromagnetic scattering by the fuselage of aircrafts. On the other hand, analytical solutions can be used to check the accuracy of approximate and numerical solutions of similar geometries.

Analytical solution to the problem of a plane electromagnetic wave scattering by a lossless homogeneous dielectric coated elliptic cylinder was investigated by many authors [1-2], and the solution is later extended to the nonconfocal dielectric case [3]. Axial slot antenna on a dielectric-coated elliptic cylinder was solved by Richmond [4]. Sebak obtained a solution to the problem of scattering from dielectric-coated impedance elliptic cylinder [5]. The scattering by mutilayered lossless dielectric elliptic cylinders was studied by many authors [6-8]. The scattering by a weakly lossy multilayer elliptic cylinder was obtained by Caorasi et al using a first order truncation of the Taylor expansion of each Mathieu function of real argument [9-10]. Recently, lossy and lossless metamaterials have gained considerable attention by many researches [11-14].

In this paper, numerical results of the electromagnetic wave scattering by a lossy metamaterial coated conducting elliptic cylinder is presented. These results are obtained for different configurations and compared with published data for the special case of a lossless conventional dielectric coated elliptic cylinder.

2. Numerical Results

Consider the case of a linearly polarized electromagnetic plane wave incident on a lossy metamaterial coated elliptic cylinder at an angle ϕ_i with respect to the x axis, as shown in Figure 1, with e^{jwt} time dependence. The complete formulation of this problem may be found in [16].

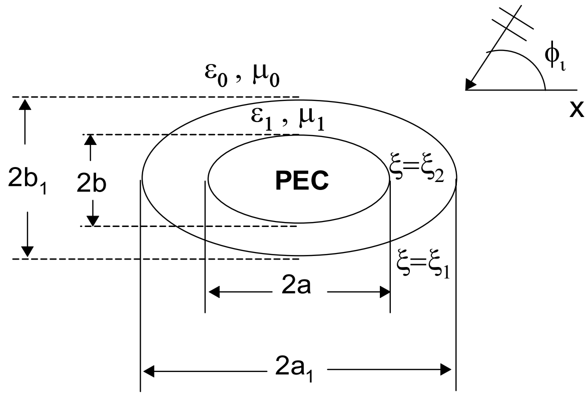

Fig. 1. Geometry of a lossy metamaterial coated elliptic cylinder.

Fig. 2 shows the echo width pattern for a dielectric coated elliptic cylinder against the scattering angle ϕ with an incident angle $\phi_i = 0^o$. The numerical results are plotted for the case of conventional dielectric, lossless metmaterial and lossy metamaterial coatings. The electrical dimensions of the elliptic cylinder are $k_o a = 2.50$, $k_o a_1 = 3.51$, $k_o b = 1.25$, and $k_o b_1 = 2.76$. The numerical results show a significant reduction in the echo width pattern especially at the scattering angles between 170 and 200 degrees due to the presence of the metamaterial, and the loss has little effect on the echo pattern in this range. The effect of the loss can be observed at the other scattering angles where the echo pattern decreases and the resonances vanish by increasing the loss of the metamaterial coating. Fig. 3 has the same electrical dimensions as in Fig. 2 except with $\phi_i = 90^o$.

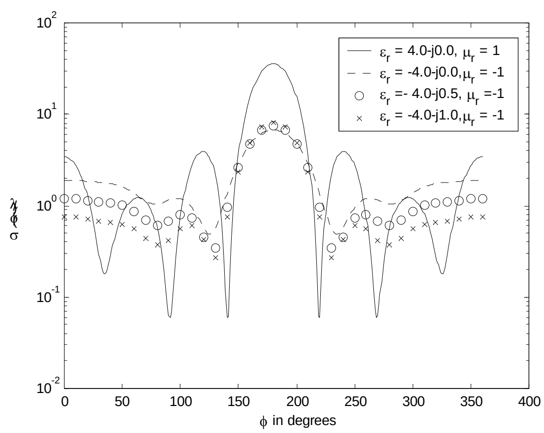

Fig. 2. Echo width pattern against the scattering angle ϕ of a lossy metamaterial coated elliptic cylinder with $k_o a = 2.5$, $k_o a_1 = 3.51$, $k_o b = 1.25$, and $k_o b_1 = 2.76$, and $\phi_i = 0^o$

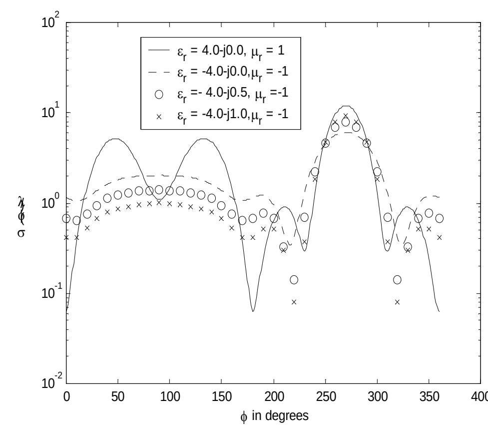

Fig. 3 Echo width pattern against the scattering angle ϕ of a lossy metamaterial coated elliptic cylinder with $k_o a = 2.5$, $k_o a_1 = 3.51$, $k_o b = 1.25$, and $k_o b_1 = 2.76$, and $\phi_i = 90^o$.

The effect of the metamaterial coating on the echo pattern at $\phi_i = 90^o$ is similar to that in Fig. 2. The echo pattern of a lossy metamaterial coated circular cylinder is also shown in Fig. 4 with $k_o a = 1.0$, $k_o a_1 = 2.0$, $k_o b = 1.0$, $k_o b_1 = 2.0$, and $\phi_i = 90^o$.

Fig. 5 shows the backscattering echo width pattern of a lossy metmaterial elliptic cylinder verses the incident angle ϕ_i. The electrical dimensions of the elliptic cylinder are $k_o a = 2.50$, $k_o a_1 = 3.08$, $k_o b = 0.63$, and $k_o b_1 = 1.88$. It can be seen that a significant reduction in the echo pattern occurs between 60 and 120 degrees due to the presence of the metamaterial coating and the reduction increases with an increase of the coating loss.

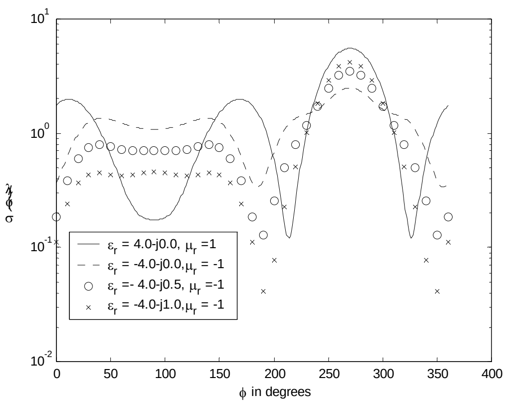

Fig. 4. Echo width pattern against the scattering angle ϕ of a lossy metamaterial coated circular cylinder with $k_o a = 1.0$, $k_o a_1 = 2.0$, $k_o b = 1.0$, and $k_o b_1 = 2.0$, and $\phi_i = 90^o$.

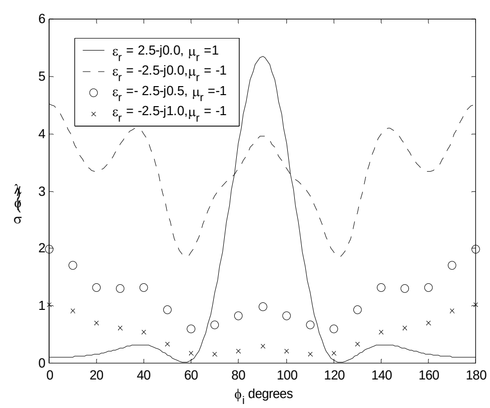

Fig. 5. Backscattering pattern against the incident angle ϕ_i of a lossy metamaterial coated elliptic cylinder with $k_o a = 2.5$, $k_o a_1 = 3.08$, $k_o b = 0.63$, and $k_o b_1 = 1.88$.

Fig. 6 shows the backscattering echo pattern of a lossy metamaterial elliptic cylinder versus the major axis of the dielectric coating (ka_1) with $k_o a = 0.63$, $k_o b = 0.50$ and $\phi_i = 0^o$. It can be seen that presence of the metamaterial coating reduces the number of resonances and a significant reduction in the echo pattern width also occurs at values of ka_1 greater than 2.0 with $\varepsilon_r = -4 - j1.0$. Fig. 7 is similar to Fig. 6 except for a lossy metamaterial coated circular cylinder with $k_o a = 0.63$. It can be seen that the echo pattern of a circular cylinder behaves similar to the elliptic cylinder with metamaterial coatings.

Fig. 8 shows the backscattering echo width pattern against $\varepsilon_r^{'}$ of a lossy and lossless metamaterial coated elliptic cylinder. The electrical dimensions of the elliptic cylinder are $k_o a = 1.25$, $k_o a_1 = 2.18$, $k_o b = 0.62$, $k_o b_1 = 1.88$ with $\phi_i = 0^o$. There is only one strong resonance occurs at small values of $\varepsilon_r^{'}$ for the case of lossels metamaterial coating and it vanishes due to the presence of the lossy coatings. Further, the loss has little effect on the echo pattern at larger values of $\varepsilon_r^{'}$, namely at $\varepsilon_r^{'}$ greater than -8.0. Fig. 9 is similar to Fig. 8 except for $\phi_i = 90^o$. It can be seen that changing the incident from 0 degree to 90 degrees has little effect on the echo pattern width.

3. CONCLUSIONS

Numerical results of the electromagnetic waves scattering by a lossy metamaterial coated circular or elliptic cylinder was obtained for the first time in the case of TM polarization. It was shown that a conducting cylinder coated with a lossy or lossless metamaterial has different backscattered cross section when compared to that coated with conventional dielectric material. The lossy and lossless metamaterials may be used to reduce the backscattered cross section over a certain lossy or lossless metamaterial coatings range.

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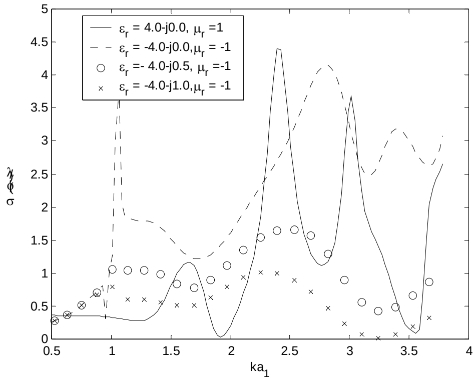

Fig. 6. Backscattering pattern against ka_1 of a lossy metamaterial coated elliptic cylinder with $k_o a = 0.63$, $k_o b = 0.50$, and $\phi_i = 0^o$.

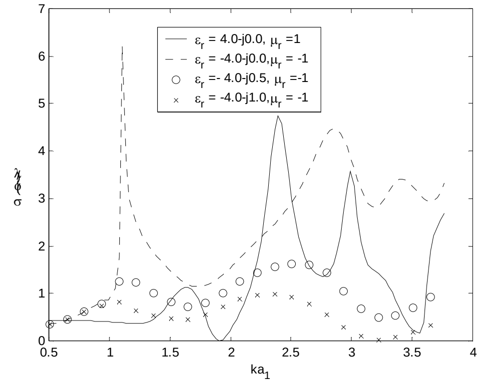

Fig. 7. Backscattering pattern against ka_1 of a lossy metamaterial coated circular cylinder with $k_o a = 0.63$ and $\phi_i = 0^o$.

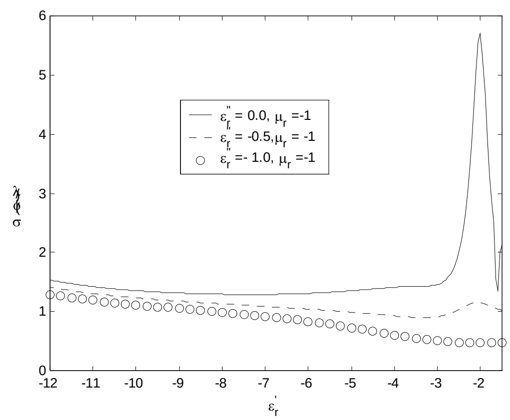

Fig. 8. Backscattering pattern against ε_r' for a lossy metamaterial coated elliptic cylinder with $k_o a = 1.25$, $k_o a_1 = 2.18$, $k_o b = 0.62$, $k_o b_1 = 1.88$ and $\phi_i = 0^o$.

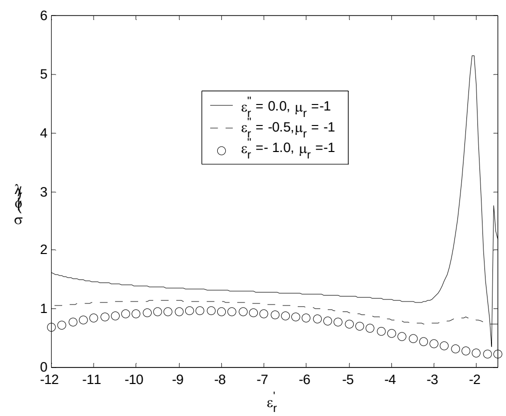

Fig. 9. Backscattering pattern against ε_r' for a lossy metamaterial coated elliptic cylinder with $k_o a = 1.25$, $k_o a_1 = 2.18$, $k_o b = 0.62$, $k_o b_1 = 1.88$ and $\phi_i = 90^o$.

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