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Zero reflection from metamaterial sphere

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ABSTRACT

In this study spherical structure is considered and analyzed with full wave method. The plane wave radiates to the structure and the zero reflection condition is deduced as a closed formula. Two theorems and ideas are proofed mathematically, and finally some examples are presented for validating these theorems. Theorems indicate if the double negative metamaterial sphere (DNG) with an arbitrary radius and parameters ($Re(\varepsilon_2) < 0, Re(\mu_2) < 0$) situate within conventional space with parameters (ε_1, μ_1), and $\varepsilon_2/\varepsilon_1 = \mu_2/\mu_1$ then backscattering radar cross section (RCS) of this metamaterial sphere equals zero whiles the same situation with cylindrical structure has noticeable backscattering. In addition, the bistatic radar cross section of this metamaterial sphere is constant by changing the angle φ. Both theorems are generalized to spherical multilayer structure.

1. Introduction

In recent years, researchers on wave propagation have been interested by applications and properties of metamaterials and proposed interesting applications for such structures. Kerker Has investigated on light scattering of a small spherical particles with arbitrary permittivity and permeability. Kerker condition shows that if in the sphere $\varepsilon_r = \mu_r$, backward light scattering from this sphere is zero, and represent another condition for zero forward light scattering [1]. Ni has derived the zero-forward and zero-backward light scattering conditions for radially anisotropic spheres and their group has found that the near-field intensity can be tuned, while the far-field light scattering diagrams are similar under the zero-forward or zero-backward scattering conditions [2]. In Fu study, directional light scattering by spherical silicon nanoparticles in the visible spectral range is demonstrated. They have shown that directivity of the far-field radiation pattern of single silicon spheres can be strongly dependent on the light wavelength and the nanoparticle size [3]. Geffrin presented unambiguous evidence that a single low-loss dielectric subwavelength sphere of moderate refractive radiates fields, identical to those from equal amplitude crossed electric and magnetic dipoles. Their group has shown that by appropriately tuning the a/λ ratio, zero-backward ('Huygens' source) or almost zero-forward ('Huygens' reflector) radiated power can be obtained [4]. In our study we have analyzed general condition to obtain zero backward scattering of spherical multilayer structures with metamaterials or conventional materials, every domain of frequency has been considered, thus results are valid in all frequencies including low frequencies, microwaves and light domain. In Fig. 1, plane wave radiates to a multilayer spherical structure. So far, different methods are presented for analyzing the multilayer spherical structures. Generally there are three methods for analyzing the electromagnetic waves scattering: (1) analytical, (2) approximation, and (3) numerical [5–7]. We use the full wave method by applying the addition theory to the spherical particular function in which the field in each layer is equal to the total of onward and backward waves.

The radar cross section Reduction is one of the interesting issues in communication engineering which is achieved through different methods [8–12]. In another paper the mathematical formulation to obtain zero reflection from planar multilayer structures has been discussed [11] while In this paper the zero backscattering radar cross section from spherical multilayer structures is achieved. We should notice that because of using different media (conventional and metamaterial), it is necessary to choose correct signs for real and imaginary parts of permeability (μ), permittivity (ε), wave number (k) and characteristic impedance (η) [13–15].

2. The problem structure and formulations

In this section, radiation of planewave to spherical structure and RCS calculation have been considered. Assume that a sphere with parameters (ε_2, μ_2) and the radius of $r = a$ is surrounded by an infinite space of (ε_1, μ_1) which is shown in Fig. 1.

A plane wave with unit amplitude at the direction of axis $z\,(\theta = 0)$ radiates to this sphere:

$$\bar{E}_{inc} = e^{-jk_1 z}\hat{x}$$
$$\bar{H}_{inc} = \frac{1}{\eta_1} e^{-jk_1 z}\hat{y} \qquad (1)$$

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