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An Analytical Approach to Modifying the Properties of Dielectric Substrates Composed of Nanomaterials

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I. Introduction

The aim of this research is to fabricate antennas and dielectrics out of nanomaterials. This method has the potential of integrating the whole antenna structure into one process. Since nanomaterials are extremely small, larger structures (~mm) can be created by suitably arranging many such particles (metallic and/or non-metallic), and thus resonance at microwave frequencies can be achieved. Fabrication and physical advantages include potentially faster fabrication processes and reduced production costs [1]. Using nanomaterial fabrication methods will enable novel and bespoke substrate properties, by controlling the size and volume ratio of the particles. Electromagnetic advantages (bandwidth, size and efficiency) can be achieved by varying the local permittivity with the local electric field strength, or by creating substrates with equal permittivity and permeability.

II. Literature Review

Lord Rayleigh [2] examined how the properties of a medium are affected when obstacles are placed in it. However, more commonly cited and used for related problems is the analysis carried out by Lewin [3]. Lewin studied a homogenous medium within which were embedded spherical particles, with uniform spacing, s and radius, a, in order to determine the effective permittivity (ε) and permeability (μ) of the mixture. The validity of his study is restricted to high frequencies where the size of the particles is much smaller than the wavelength and the particles are not too densely packed. Also, the analysis assumes that the particles are arranged in a cubic lattice with uniform spacing. The effective properties of the mixture are defined in (1) while those of the particle are defined in (2).

$$\mu = \mu_1\left(1+\frac{3f}{\frac{\mu_p+2\mu_1}{\mu_p-\mu_1}-f}\right); \quad \varepsilon = \varepsilon_1\left(1+\frac{3f}{\frac{\varepsilon_p+2\varepsilon_1}{\varepsilon_p-\varepsilon_1}-f}\right) \qquad (1)$$

where $(\varepsilon,\mu), (\varepsilon_1,\mu_1)$ and (ε_p,μ_p) are the effective permittivity and permeability of the mixture, host medium and the particles respectively, and $f=\frac{4}{3}\pi a^3/s^3$ is the particle volume ratio. Also,

$$\frac{\varepsilon_p}{\varepsilon_2}=\frac{\mu_p}{\mu_2}=\frac{2(sin\theta-\theta cos\theta)}{(\theta^2-1)sin\theta+\theta cos\theta}=F(\theta) \qquad (2)$$

where ε_2 and μ_2 are the parameters of the particle's bulk material, $\theta = ka\sqrt{\mu\varepsilon}$, vacuum wave number, $k=2\pi/\lambda$.

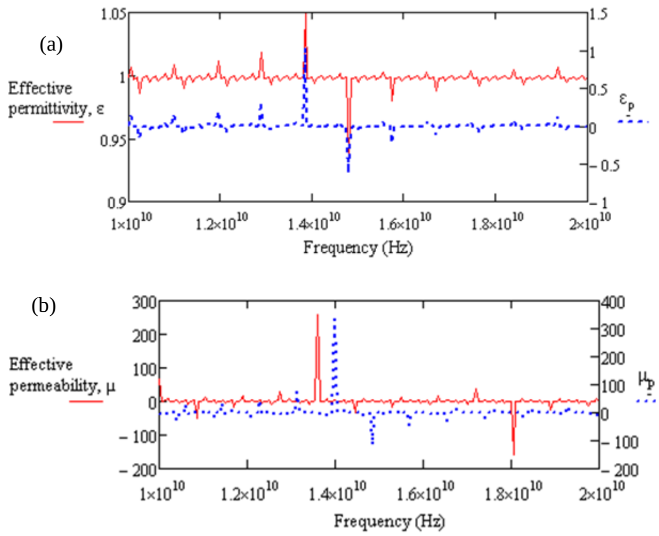

Figure 1: Effective (a) permittivities and (b) permeabilities of the mixture (—) and the particle (·····)

III. Results

The equations were analysed using MathCAD. For example, by adding spheres composed of many Cobalt particles (ε_2 = 1, μ_2 = 250) to a Polymer host (ε_1 = 1.05) with a/s = 0.2, over a frequency range of 10-20 GHz, the effective ε and μ of the mixture, in (1) varies with frequency as shown in Fig. 1. By controlling the dielectric properties of the host and the inserted spheres, and also the size and spacings of the spheres, we can theoretically create any mixture of ε and μ.

IV. Conclusions and Future Work

By fabricating antennas and substrates using nanomaterials, the effective substrate properties can be controlled by varying the fractional particle volume and the type of inserted particle. These bespoke substrates are good for antenna design. Future work will compare these results with simulations and measurements, and extend this theoretical model to design novel substrates at microwave frequencies.

References

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