Reducing Resonator Dimensions with the Use of Metafilms

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In recent years, there has been a great deal of attention devoted metamaterials—novel synthetic materials (i.e., engineered or man-made) designed to achieve unique properties not normally found in nature. One particular class of metamaterials that is being studied extensively are the so-called double negative (DNG) materials, which have the property that their effective permittivity and effective permeability are simultaneously negative in a given frequency band. This has not been observed in naturally occurring materials. These materials have a wide range of potential applications in electromagnetics and optics. Of interest in the present paper are electromagnetic resonators. It is well known that a conventional resonator must be at least $\lambda/2$ in size, where λ is the wavelength in the medium filling the resonator. Recently, it has been demonstrated that partially filling a resonating structure with DNG material can relax this size limit [N. Engheta, *IEEE Antennas and Wireless Propag. Lett.*, vol. 1, pp. 10-13,, 2002]. The use of gangbuster surfaces for such a purpose has also been studied [M. Caiazzo, et al., *IEEE Antennas and Wireless Propag. Lett*., Vol. 3, pp. 261-264, 2004.].

Metamaterials are commonly engineered by arranging a set of scatterers in a regular array throughout a region of space so as to obtain some desirable bulk behavior. DNG materials have been achieved by using scatterers composed of metallic or magneto-dielectric materials (e.g., metallic rings and rods or spherical magneto-dielectric particles). This concept can be extended by judiciously placing scatterers in a two-dimensional pattern at a surface or interface (see Fig. 1). This surface version of a metamaterial has been given the name metafilm. Specifically, a metafilm is a surface distribution of electrically small scatterers characterized by electric and magnetic polarizabilities. A theoretical study of the field behavior at a metafilm is given in [E. F. Kuester, et al., *IEEE Trans. Antennas and Propag*., vol. 51, pp. 2641-2651, 2003] (where boundary conditions known as generalized sheet transition conditions (GSTCs) are presented), while reflection and transmission properties of metafilms and their applications to smart/controllable surfaces are given in [C.L. Holloway, et al., *IEEE Trans. on Electromag. Compat.*, vol. 47, no. 4, 2005]. In the present paper, we show that a metafilm can be used in the same way that a DNG material is used for circumventing the $\lambda/2$ resonator size limit. In fact, it is shown that if a metafilm is placed in the resonator, the resonator can be made as small as desired so long as the polarizability densities of the scatterers are chosen appropriately. We will show that the use of the GSTC provides an analytical relationship between the resonator dimensions and the polarizability densities needed to achieve an arbitrarily sized resonator. To validate the analytical results of this paper, we show comparisons to full-wave simulations of a resonator with a metafilm. The results in this paper can be scaled; that is, the dimensions of the scatterers can range from relatively large to relatively small, depending on the frequencies of interest.

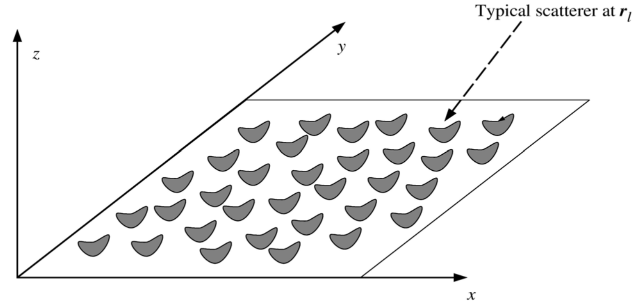

Fig. 1: Illustration of a Metafilm