Subwavelength resonators as metamaterial particles

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Abstract

In this presentation, electrically small metallic elements on planar substrates that operate at the MHz and GHz region and their potential applications in terms of numerical and experimental results will be presented.

1. Introduction

For most solid materials the ions are arranged in a periodic array on the microscopic level [1]. In the presence of an applied electromagnetic field, the materials' response is described by (electric) permittivity (ε) and (magnetic) permeability (μ) parameters. By introducing an artificial periodic array wherein repeated elements of the so-called metamaterial (MTM) are arranged, we can obtain a medium with a controllable linear response. The unit cells of metamaterials are commonly composed of metallic structures of several shapes [2-4]. Electrically small nonmagnetic metallic resonators are proposed as constituting elements of a negative permeability medium [2] and metallic wire mesh structures provide a low frequency plasma system with negative permittivity [3]. Applications of double negative (DNG) and single negative (SNG) media involve the electromagnetic phenomena of reflection, absorption, radiation, cloaking, refraction, and subwavelength imaging. A miniaturized rectangular patch antenna with a μ-negative medium substrate operating at 250 MHz [5] as well as an electrically small circular patch antenna loaded with a μ-negative medium are characterized experimentally and theoretically [6]. A negative permeability medium element loaded monopole antenna was demonstrated experimentally at around 4 GHz in terms of its fundamental limitations [7] and multiple element effects [8]. A negative permittivity shell loaded monopole antenna was developed analytically [9]. In principle, one can enhance the transmission through a subwavelength aperture by utilizing a μ-negative medium cover [10]. One of the critical properties of the μ-negative (MNG) medium elements is their electrical size. In this work, we propose several elements and parametrically study their resonant response.

2. Proposed subwavelength resonators

We studied electrically small MNG materials that can be produced relatively easy in the domain of well developed printed circuit board manufacturing techniques and optical lithography processes [11-12]. The structures are multi split ring resonators (MSRR) and a version of spiral resonators (SRs). The MSRR consists of concentric split rings that are designed in order to increase the distributed capacitance between the strips, Fig. 1(a). The geometrical parameters of the structure are as follows: the side length of the outer ring l = 8 mm, the strip width w = 100 μm, the separation between adjacent strips s = 100 μm, the split width g = 100 μm. In Fig. 1(c) the SR geometry is shown, in which here we also have s = w = 100 μm and l = 8 mm. A parameter of considerable interest for the MSRRs (SRs) is N: number of strips (number of turns). We will present the change of miniaturization factor as we change the structure parameters and propose a novel resonator with strong resonant response: split spiral resonator.

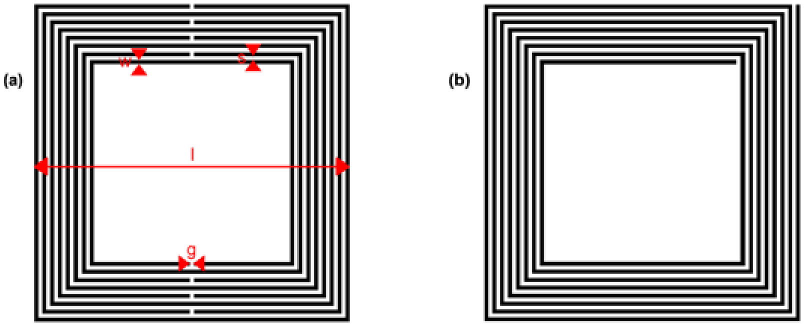

FIG. 1: Geometry of examples of MNG materials: (a) Multi split ring resonator with side length l = 8 mm and number of rings N = 8 (b) Spiral resonator with l = 8 mm and number of turns N = 8.

3. Experimental Results

As we increase the number of rings or number of turns, the resonance frequency shifts towards smaller values. The miniaturization factor for the SRs is higher than the MSRRs. In Fig. 2, we see that increasing the number N above a critical point does not reduce the resonance frequency any more. The resonance frequency of the MSRR can be significantly reduced up to 4-5 rings (N = 5). From Fig. 2 we conclude that it is not necessary to completely fill the inner part of the SR in order to obtain a good reduction of the resonance frequency. Similar to the case of the MSRR, we see that after some point, increasing the number N does not affect the resonance frequency. The reduction of the resonance frequency is comparable with the examples found in the literature. The MNG materials are relatively easy to fabricate, low profile and thereby can be packed into arrays in several dimensions. For the two MSRR examples, we see that increasing the number of rings can reduce the electrical size. This principle is also valid for the SRs. Moreover, using a higher permittivity substrate will lead us to the further reduction of the resonance frequency.

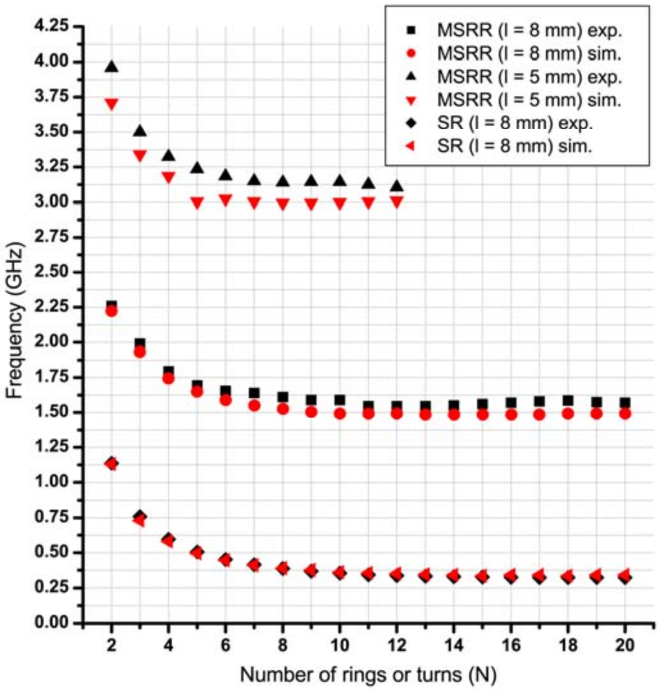

Fig. 2: Resonance frequency as a function of the number of rings and turns (Experiment and simulation).

4. Conclusion

In summary, we experimentally demonstrated electrically small MNG materials. For the MSRR structures, the electrical size of $\lambda_0/17$ and for the SR structures electrical size of $\lambda_0/82$ is achieved. Further size reduction can be realized by increasing the number N or using a higher permittivity substrate. The introduction of splits to the spiral resonator enhanced the response strength, and we obtained a resonator of $\lambda_0/50$ with stopband dip value -50dB. The MNG materials are relatively easy to fabricate, low profile, and can be packed into arrays. Since the electrical size of the metamaterial element limits the resolution of the subwavelength imaging, the MNG materials demonstrated here can be the first step towards the metamaterial based ultra-high resolution imaging systems. Moreover, they establish a solution for the antenna miniaturization problem in wireless systems.

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