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Parameters Comparison of Miniaturized Symmetric and Asymmetric Inhomogeneous Metamaterials

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Abstract: *This paper gives a comparative study of parameters of symmetric and asymmetric inhomogeneous structures metamaterials, a unit cell of split ring resonator, by using standard retrieval methods that assigns electromagnetic properties electric permittivity and magnetic permeability from the calculation of scattering parameters. Scattering parameters are the means of characterizing the artificially structured metamaterials which are inhomogeneous. Based on this study it is shown that, while the difference in the magnitudes of* S_{11} *and* S_{22} *are modest but there is difference in the phases of* S_{11} *and* S_{22}*, resulting in the difference in the impedance properties of symmetric and asymmetric structures.*

Keywords: *SRR, METAMATERIALS, NIM, DNG*

I. INTRODUCTION

The possibility of the negative refraction of electromagnetic (EM) waves by materials with simultaneous negative permittivity and negative permeability was predicted by Vesalago in 1968 [1]. This proposition was not demonstrated until recently; the main difficulty being in obtaining negative permeability. Negative permittivity is available through metals or the periodic arrangement of metallic wires [2, 3, 4, 5, 6]. On the other hand, obtaining negative permeability was an issue. Pendry et al. proposed several structures in order to obtain negative permeability [7]. Among these structures split-ring resonators (SRRs) have attracted much attention [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. A single SRR is composed of two concentric rings with slits on each of them. The slits on the rings are situated on the opposite sides of the rings with respect to each other. The planar nature of the SRR structure makes it easy to fabricate and integrate into 2 and 3 dimensional structures. Several research groups have demonstrated negative indices of refraction by using the periodic arrangement of metallic wires with SRRs through several methods such as the retrieval of effective medium parameters [19, 20, 21, 22, 23, 24, 25], refraction type experiments and wedge experiments [26, 27, 28, 29, 30, 31, 32, 33, 34]. While SRR structure provides negative permeability and can be used to obtain negative refraction, it has several disadvantages. First of all, it has been shown that a medium consisting of a periodic arrangement of SRRs is bianisotropic [25, 35, 36, 37]. The bianisotropy is a result of the non-zero electric dipole moment of the SRR structure due to the asymmetric placement of slits on the rings. Second, it has been shown that the magnetic resonance of the SRR structure can be excited via electric fields [38, 39]. The excitation of the magnetic resonance of the SRR structure results from the capacitive coupling of the electric field. The capacitive coupling of the electric field creates non-zero current along the rings. These two disadvantages make it difficult to obtain isotropic, homogeneous two or three dimensional negative refraction media by using SRRs for negative permeability.

It is conceptually convenient to replace a collection of scattering objects by a homogeneous medium, whose electromagnetic properties result from an averaging of the local responding electromagnetic fields and current distributions. Ideally, there would be no distinction in the observed electromagnetic response of the hypothetical continuous material versus that of the composite it replaces. This equivalence can be readily achieved when the applied fields are static or have spatial variation on a scale significantly larger than the scale of the local inhomogeneity, in which case the composite is said to form an *effective medium*. The electromagnetic properties of an inhomogeneous composite can be determined exactly by solving Maxwell's equations, which relate the local electric and magnetic fields to the local charge and current densities. When the particular details of the inhomogeneous structure are unimportant to the behavior of the relevant fields of interest, the local field, charge, and current distributions are averaged, yielding the macroscopic form of Maxwell's equations. To solve this set of equations, a relationship must be assumed that relates the four macroscopic field vectors that arise from the averaging—or *homogenization*—procedure. It is here that the electric permittivity and the magnetic permeability tensors are typically defined, which encapsulate the specific local details of the composite medium.

Depending on the symmetry and complexity of the scattering objects that comprise the composite medium, the permittivity and permeability tensors may not provide sufficient information to obtain a solution from Maxwell's equations, and additional electromagnetic material parameters must be introduced f6g. Such media, including chiral and bianisotropic, can couple polarization states and are known to host a wide array of wave propagation and other electromagnetic phenomena

II. S RETRIEVAL METHODS

If an inhomogeneous structure can be replaced conceptually by a continuous material, there should be no difference in the scattering characteristics between the two. A procedure, then, for the assignment of effective material parameters to an inhomogeneous structure consists of comparing the scattered waves i.e., the complex transmission and reflection coefficients, or *S parameters* from a planar slab of the inhomogeneous material to those scattered from a hypothetical continuous material

A. S-parameter retrieval for a symmetric structure

Negative index metamaterials, which have been of recent interest, pose a significant challenge to retrieval methods because they utilize resonant elements and exhibit both an electric and magnetic response. A single unit cell of a typical symmetric in the propagation direction metamaterials structure is shown in Fig. 1. This particular structure is composed of two types of conducting elements—a split ring resonator SRR and a wire—that have been designed to yield a band of negative refractive index at microwave frequencies. We note in passing that the SRR generally exhibits bianisotropy, since an applied magnetic field induces both an electric as well as a magnetic response. This material response should properly be accounted for in a complete characterization procedure. The unit cell is cubic, with a cell dimension of *d*=2.5 mm. A 0.25 mm thick substrate of FR4 ε =4.4, loss tangent of 0.02d is assumed. A copper SRR and wire are positioned on opposite sides of the substrate. The copper thickness is 0.017 mm. The width of the wire is 0.14 mm, and it runs the length of the unit cell. The outer ring length of the SRR is 2.2 mm and both rings have a line width of 0.2 mm. The gap in each ring is 0.3 mm, and the gap between the inner and outer rings is 0.15 mm.

The *S* parameters for the symmetric unit cell of Fig. 2 are computed using HFSS (Ansoft), a commercial finite-element-based electromagnetic mode solver. Both the *S* parameters and the Z parameters are presented in Fig. 3 and Fig. 4.Note the dip in the phase of *S*21, which indicates the presence of a negative index band. The retrieved index in confirms the negative index band that lies between roughly 9 and 12 GHz. The structure was designed so as to be roughly impedance matched. The retrieved impedance, shown in Fig. 4, shows that the structure is indeed roughly matched at the frequency where *n*=−1.

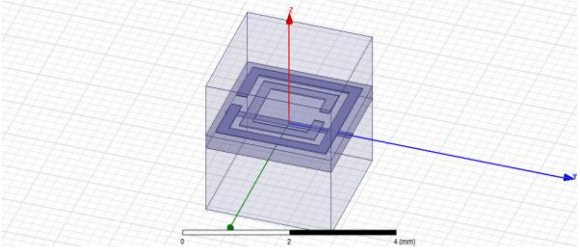

Fig 1 symmetric SRR

B. S-parameter retrieval for asymmetric structure

The unit cell in Fig. 1 can be made asymmetric by moving the wire, for example, off of the symmetry axis. The unit cell shown in Fig. 2 is identical to that of Fig. 1, except that the wire has been shifted a distance of 0.75 mm along the propagation direction. Figures 5 and 6 show the *S* parameters and Z parameters computed for an infinitely repeated asymmetric unit cell, one cell thick in the direction of propagation. While the differences between the magnitudes of S_{11} and S_{22} are modest, there is a great contrast in the phases of S_{11} and S_{22}, implying very different impedance properties for the structure depending on which side of the unit cell faces the incoming wave both the phases and magnitudes of S_{12} and S_{21} are identical.

The retrieved indices for the symmetric and asymmetric unit cells are compared, illustrating that, aside from a shift in frequency, the refractive properties of the two structures are very similar. The frequency shift is not surprising, as there is likely an interaction between the SRR and wire that leads to somewhat different material properties depending on their relative positions. While the index is nearly the same for the structures having symmetric and asymmetric unit cells, the impedance is clearly different, as indicated in Fig. 5 and Fig. 6. So different are the two solutions for *z* for the asymmetric structure that in general the assignment of values of ε and μ to the composite becomes counterproductive. Thus, although a well-defined refractive index exists for the composite, the manner in which a wave scatters from this material can depend strongly on how the surface is terminated.

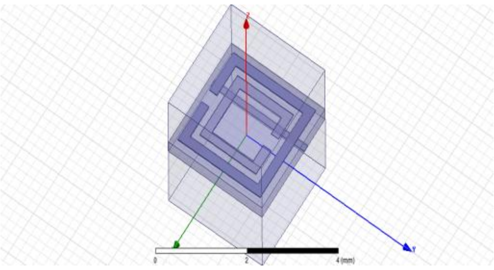

Fig 2 Asymmetric SRR

III. RESULTS

A. For symmetric structure

A.1 S PARAMETERS

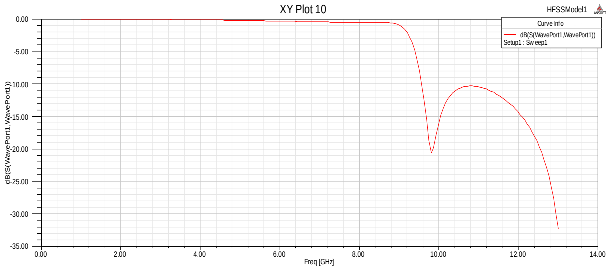

Fig 3.1 S_{11} for symmetric SRR

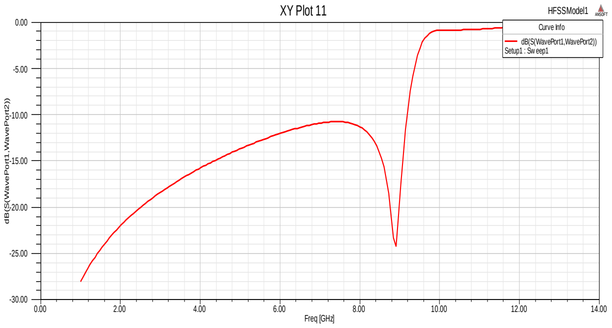

Fig 3.2 S_{12} for symmetric SRR

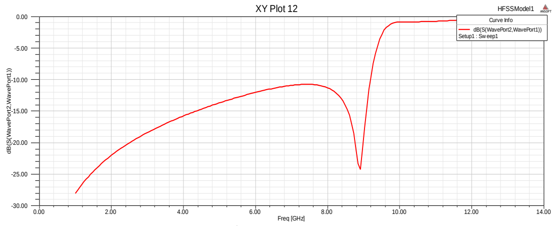

Fig 3.3 S_{21} for symmetric SRR

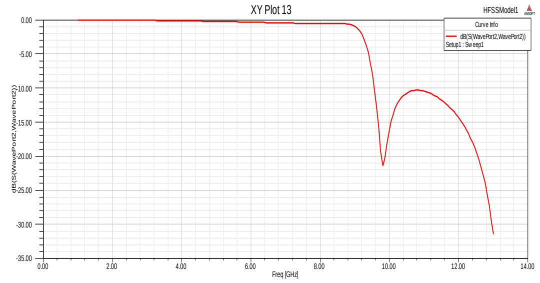

Fig 3.3 S_{22} for symmetric SRR

A.2 Z PARAMETERS

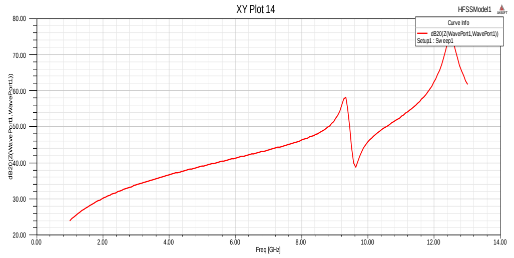

Fig 4.1 Z_{11} for symmetric SRR

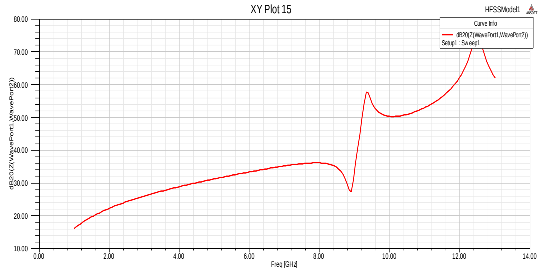

Fig 4.2 Z_{12} for symmetric SRR

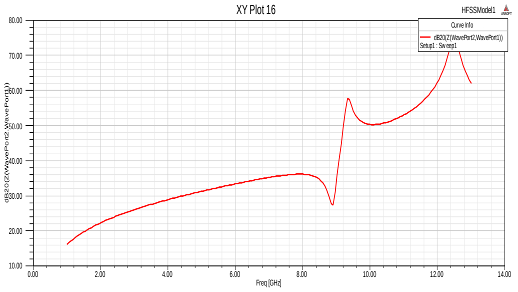

Fig 4.3 Z_{21} for symmetric SRR

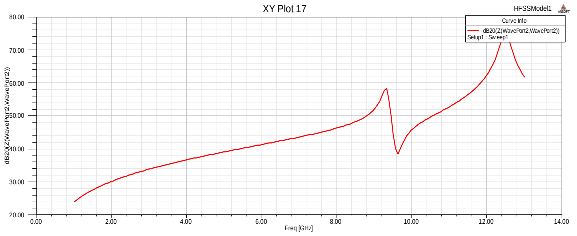

Fig 4.4 Z_{22} for symmetric SRR

B. For Asymmetric structure

B.1 S PARAMETERS

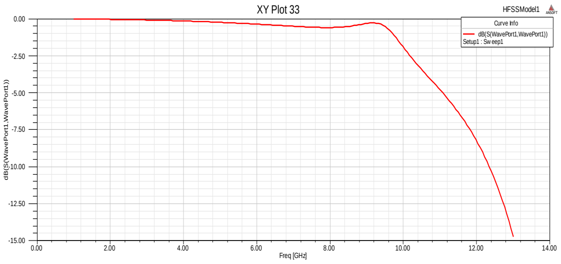

Fig 5.1 S_{11} for Asymmetric SRR

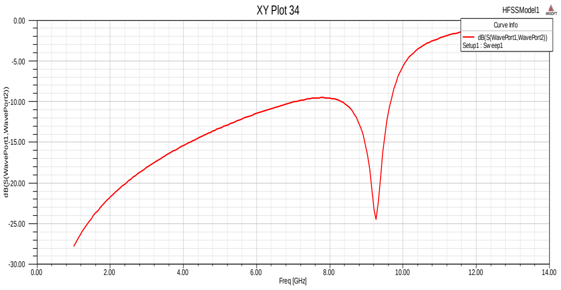

Fig 5.2 S_{12} for Asymmetric SRR

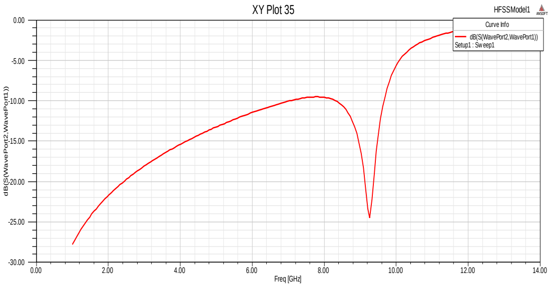

Fig 5.3 S_{21} for Asymmetric SRR

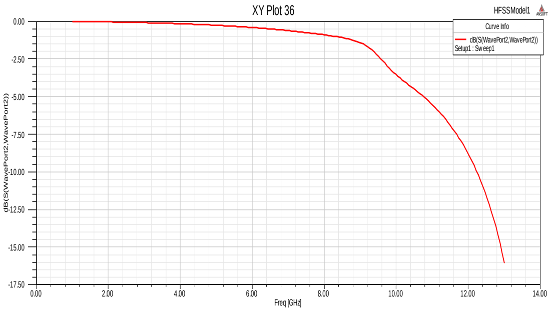

Fig 5.4 S_{22} for Asymmetric SRR

B.2 Z PARAMETERS

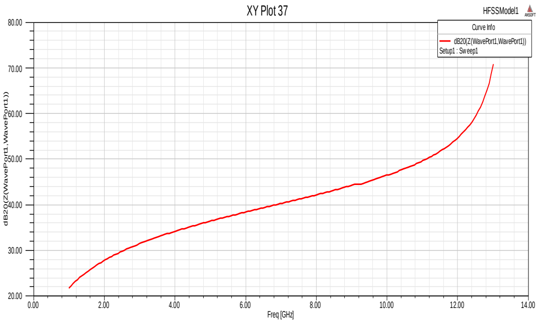

Fig 6.1 Z_{11} for non symmetric SRR

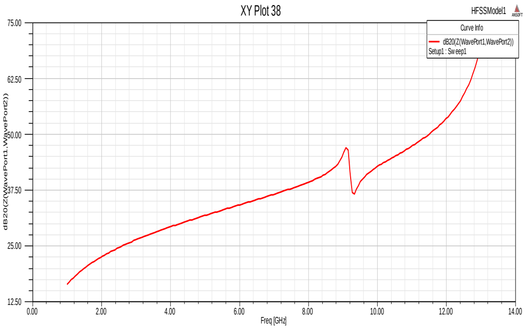

Fig 6.2 Z_{12} for non symmetric SRR

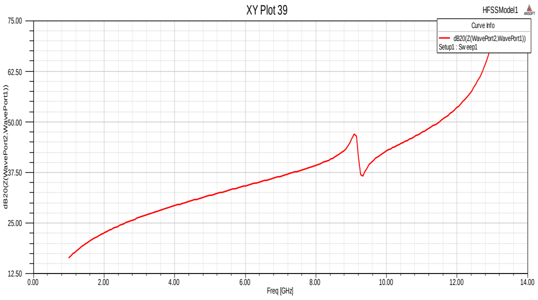

Fig 6.3 Z_{21} for non symmetric SRR

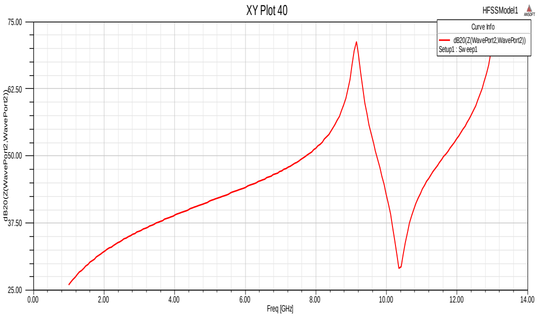

Fig 6.4 Z_{22} for non symmetric SRR

IV. CONCLUSION

It is shown that metamaterials based on periodic structures occupy conceptually a special position between effective media and photonic crystals. The *S*-parameter retrieval techniques that have been utilized recently to characterize metamaterials have been shown to be valid for metamaterials having symmetric unit cells, even when the optical path length is on the order of the unit cell size. The retrieved indices for the symmetric and asymmetric unit cells are compared, illustrating that, aside from a shift in frequency, the refractive properties of the two structures are very similar While the differences between the magnitudes of S_{11} and S_{22} are modest, there is a great contrast in the phases of S_{11} and S_{22}, implying very different impedance properties for the structure depending on which side of the unit cell faces the incoming wave both the phases and magnitudes of S_{12} and S_{21} are identical.

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