Extraction of Material Parameters of Z-Shaped Split Resonator Metamaterial Atom

Prahlad Kumar Rahul, Garima Tiwari

***Abstract:** In today's scenario an artificially constructed meta-materials have become the topic of significant interest, because these material shows the electromagnetic characteristics. In order to achieve negative electrical permittivity and negative magnetic permeability NRW method is presented. The propagation of electromagnetic waves is determined by a two fundamental characteristic quantities such as the electrical permittivity ε and the magnetic permeability µ. In this paper, by the use of CST simulator which is based on Finite element method, S parameters are extracted. By the use of MATLAB script, the permittivity and permeability curves are calculated. Perfect electric and perfect magnetic (PE-PM) boundary conditions methods are employed in CST to extract the S parameters. To excite the structure, wave ports are used.*

***Index Terms:** permeability, permittivity, S11 parameter, S21 parameter.*

I. INTRODUCTION

In recent years due to the novel properties of the metamaterial, many researchers are interested in it. Metamaterials have been the most innovative concept in electromagnetic and materials fields [1].Generally; metamaterial are periodic or nonperiodic composite materials. The electromagnetic properties of metamaterial depend on material composition as well as on the inclusion of macroscopic structures which are specially designed to obtain a specific response. By introducing different structures within it, the properties of a material can be modified. Due to this behavior of metamaterials, it can be used in a wide frequency ranges, ranging from microwaves to optics. For improving the performance of microwave devices metamaterials are widely used. Metamaterials are employed in filters [2-3], power dividers [4-5] and amplifier [6-7]. Apart from that, metamaterials are widely used in antenna miniaturization [8] and also modify the characteristics of antennas [9].

To enhance the isolation between closely packed MIMO antenna systems [10], metamaterial are used because they

Can provide bandgaps. Analytical Drude-Lorentz model [11] and S-parameter-retrieval method [12] are the two methods which are used to evaluate the electromagnetic properties such as Complex permeability (µ), the permittivity (ε) and refractive index (n). If the unit element of the metamaterial is a complex structure, the Drude-Lorentz method is not accurate. On the other hand, the S-parameter-retrieval method depends on the S parameter extracted from the actual structure, And hence provides more accurate values for the permittivity, Permeability and refractive index. In this paper a new split resonator of Z shape has been presented. We use CST High Frequency Structure Simulator (CST 16.0) which uses Finite-Difference Time- Domain (FDTD) method for the extraction of S parameter. MATLAB scripts are used,

For the calculation of permittivity, permeability and Refractive index curves.

II. MATHEMATICAL FORMULATION

In electromagnetic, the material's characteristics are defined by the permittivity, permeability, and Conductivity. The propagation profile of the material at a different frequency is defined by the extraction of permittivity, permeability at that frequency. To extract the permittivity and permeability of the material the refractive index and impedance of the material are used. To extract permittivity, permeability, consider the unit element of a metamaterial with lattice vectors in all three dimensions. For the simulation of the periodic metamaterial and excitation of this metamaterial in order to extract the S parameters, appropriate boundary conditions and excitations are assigned to the different surface of the three-dimensional unit element. Figure.1. Shows a normally incident plane wave on the metamaterial cube [13].

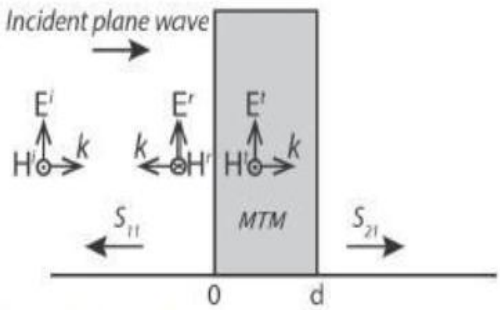

Figure 1. A normally incident plane wave on a metamaterial (MTM), placed in free space.

$$S_{11} = \frac{R_{01}(1-e^{i2nk_0d})}{1-R_{01}^2 e^{i2nk_0d}} , \tag{1}$$

$$S_{21} = \frac{(1-R_{01}^2)e^{i2nk_0d}}{1-R_{01}^2 e^{i2nk_0d}} \tag{2}$$

Solving Equation (1) and (2) gives

$$z = \pm\sqrt{\frac{(1+S_{11})^2-S_{21}^2}{(1-S_{11})^2-S_{21}^2}} , \tag{3}$$

$$e^{ink_0d} = \frac{S_{21}}{1-S_{11}\frac{z-1}{z+1}} , \tag{4}$$

$$n = \frac{1}{k_0 d}\left[\{[\ln(e^{ink_0d})]'' + 2m\pi\} - i[\ln(e^{ink_0d})]'\right], \tag{5}$$

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Where (•) shows the complex component, (•)' real component of the complex number, S_{11} is the reflection coefficient, S_{12} represents the transmission coefficients, R01 is $\frac{z-1}{}$, n is the refractive index, z is the impedance, k_0 is equal to the wave number, d is equal to the maximum length of the unit element, E is the electric field component, H is the magnetic field component and $(\bullet)^I$, $(\bullet)^r$, $(\bullet)^t$ are the incident, reflected and transmitted component of the fields, respectively.

In these expressions, with appropriate boundary conditions and excitations, the metamaterial is represented by the cube which is formed by unit element. Here we assume that,

The material is homogeneous, possessing an effective refractive index and impedance. Since, the dimensions of the unit element are usually less than one-tenth of the wavelength in the material; hence we can say that our assumption is valid.

The relationship between the permittivity (ε), permeability (μ) and refractive index, impedance is shown by the following expressions.

$$\varepsilon = \frac{n}{z} \tag{6}$$

$$\mu = nz \tag{7}$$

III. NICOLSON-ROSS-WEIR (NRW) METHOD

Nicolson- Ross-Weir (NRW) approach was implemented to extract effective medium parameters from the normal incidence scattering parameter data. While many of the difficulties discussed in the literature are associated with sample sizes and the need for care when they are near a multiple of a half-wavelength, other problems were encountered when trying to apply these techniques to the MTMs under consideration here. The NRW approach begins by introducing the composite terms[14].

$$V_1 = S_{11} + S_{21} \tag{8}$$

$$V_1 = S_{21} - S_{11} \tag{9}$$

And deriving the following quantities

$$X = \frac{1+V_1V_2}{V_1+V_2} = \frac{1+Z^2}{2Z} \tag{10}$$

$$Y = \frac{1-V_1V_2}{V_1-V_2} = \frac{1+\Gamma^2}{2\Gamma} \tag{11}$$

Consequently,

$$Z = X \pm \sqrt{X^2-1} \tag{12}$$

$$\Gamma = Y \pm \sqrt{Y^2-1} \tag{13}$$

|Z|≤1 and | |≤1, In the case of the metamaterial the values of the S11 and S21 are highly frequency dependent and achieve values near zero and unity. Many other expressions for and Z are given below. Many other expressions for r and Z are given below.

$$Z = \frac{V_1 - \Gamma}{1 - ZV_2} \tag{14}$$

$$\Gamma = \frac{Z - V_2}{1 - ZV_2} \tag{15}$$

From equation (14) and (15),

$$1\text{-}Z = \frac{(1-V_1)(1+\Gamma)}{1-\Gamma V_1} \tag{16}$$

$$\eta = \frac{1+\Gamma}{1-\Gamma} = \frac{(1-V_2)(1+Z)}{(1-Z)(1+V_2)} \tag{17}$$

Assuming………

$$k \sim \frac{(1-V_1)(1+\Gamma)}{1-\Gamma V_1}\frac{1}{jd} \tag{18}$$

$$\mu_r \sim \frac{(1-V_2)}{(1+V_2)}\frac{2}{jk_0 d} \tag{19}$$

The permittivity and index of refraction can then be obtained simply as

$$\varepsilon_r = \left(\frac{k}{k_0}\right)^2 \frac{1}{\mu_r} \tag{20}$$

$$n = \frac{k}{k_0} = \sqrt{\varepsilon_r \mu_r} \tag{21}$$

The square of the wave impedance can also be obtained as

$$\eta^2 = \frac{\varepsilon_r}{\mu_r} = \frac{1+Y}{1-Y} = \frac{(1-V_2)(1+V_1)}{(1-V_2)(1+V_2)} \tag{22}$$

$$\varepsilon_r \sim \frac{(1-V_1)}{(1+V_1)}\frac{2}{jk_0 d} \tag{23}$$

$$S_{11} \sim \frac{(\eta^2-1)2jkd}{(1+\eta)^2-(\eta-1)^2} = \frac{(\eta^2-1)}{4}\frac{2jkd}{\eta} \tag{24}$$

$$\varepsilon_r = \mu_r + j\frac{2S_{11}}{k_0 d} \tag{25}$$

IV. EXTRACTION OF THE S PARAMETERS

Metamaterial is required to be realized for extracting the S parameters. Infinite repetition of the unit element in the direction of the lattice vectors is required for the realization of the metamaterial. By dignifying boundary conditions on the unit element, this requirement is accomplished. Periodicity is realized by the use of boundary conditions. There are two types of boundary conditions first one is the combination of perfect electric (PE) and perfect magnetic (PM) boundary conditions. The Z-shaped resonator structure is shown in fig.2. The metamaterial is fabricated with FR4 epoxy dielectric substrate which has relative permittivity εr = 4.4, dielectric loss tangent tan δ = 0.02, with a thickness of 1.6 mm. Table 1 shows the dimensions of the metamaterial.

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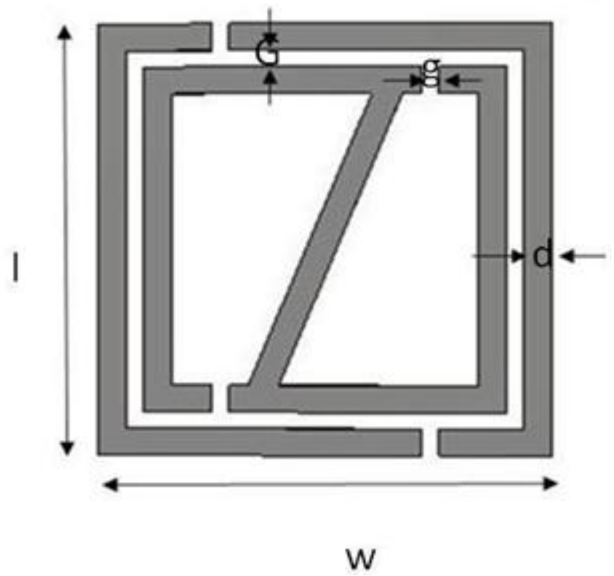

Figure 2: The top view of Metamaterial Atom

Table 1 Dimensions of Metamaterial

Symbol	Dimension (mm)	Description
l	8	Length
w	8	Width
G	0.3	Gap b/w ring
g	0.3	Cut
d	0.5	Width of conductor

Fig. 3 shows the Waveports excitation after applying (PE-PM) boundary condition. After the boundary condition, to excite the structure, the excitation Waveports are required. Due to the excitation ports, the incident waves transmit from (25) the left to right in x direction of the unit element. Two Waveports are used to excite the structure.

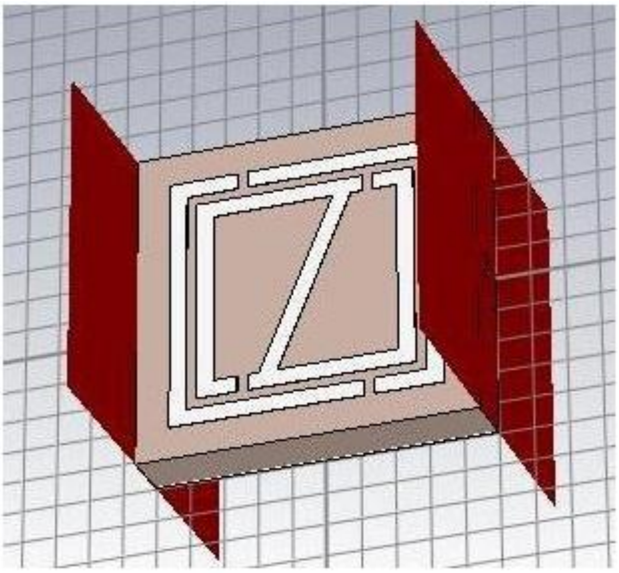

Figure 3: Waveguide port are using to excite the Z shape structure Metamaterials

Two Waveports are used to excite the structure; it is used to excite the structure when we applying perfect electric (PE) and perfect magnetic (PM) Boundary condition.

V. OBTAINING THE MATERIAL PARAMETER CURVES FROM THE EXTRACTED S

A. Parameters

The parameters are obtained using a MATLAB script. To derive the complex permittivity, permeability and Refractive index curves MATLAB script uses the expressions presented in the mathematical formulation. The MATLAB script uses the S parameters as input files. From the CST simulations, S parameters are extracted and saved in csv format. Two different files are needed one for S11 and the other for S21.The Real part and Imaginary part are extracted from the csv files of S11 and S21.The magnitude of S11 and S21 are plotted in dB using matlab script, the graph is shown in figure 4, the value of S11 is having lowest at a particular frequency and the value of S21 is having higher value at that frequency. Using the equation of NRW method, we converted equations into MATLAB script. The Electrical permeability and Electrical permittivity and Refractive index are plotted in figure5, figure 6, and figure 7 respectively. The electrical parameters (□ and μ) are showing left handed properties of metamaterial at 4.55 GHz.

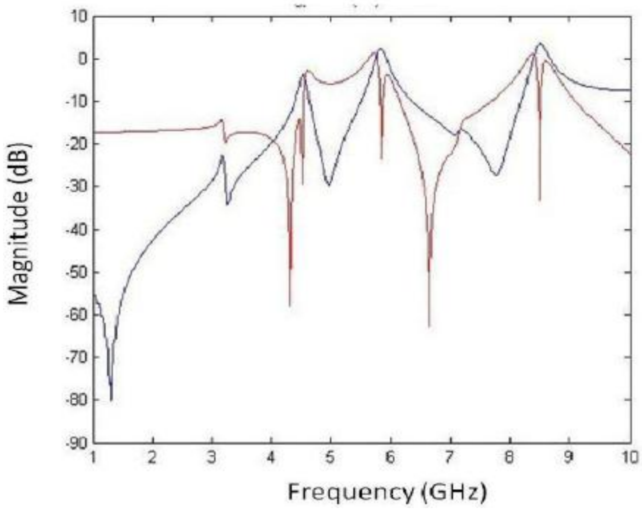

Figure 4: Magnitude of S Parameters of Metamaterial Atom

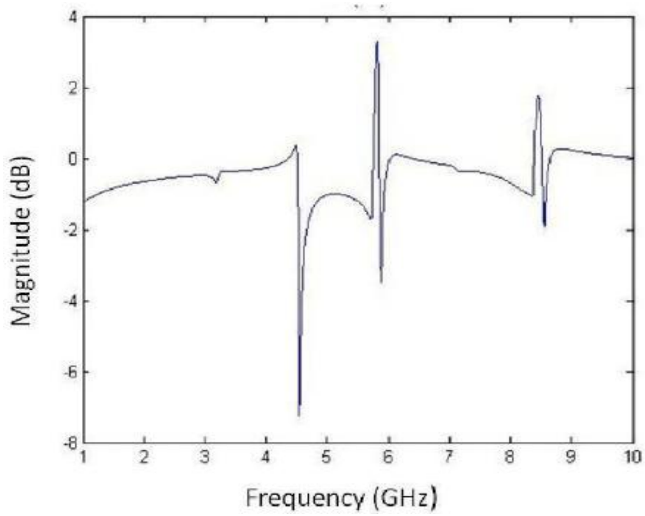

Figure 5: Electrical Permeability (μ) of Metamaterial Atom

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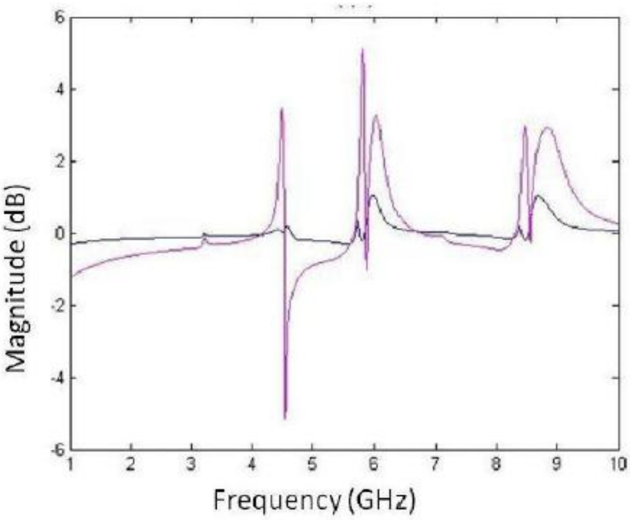

Figure 6: Electrical permittivity ( ) of Metamaterial Atom

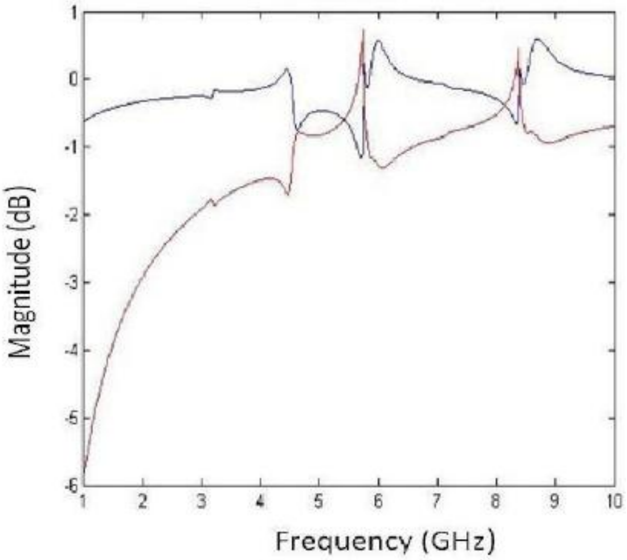

Figure 7: Refractive Index of Metamaterial Atom

VI. CONCLUSION

A Z-shaped metamaterial was presented. For the extraction of S parameter CST software was used. Permittivity, permeability and Refractive index curves were calculated by MATLAB script. Boundary conditions were presented. Perfect electric and perfect magnetic (PE-PM) boundary conditions method was presented. In addition to the periodic boundary conditions, wave ports are used for the excitation of Z shaped structure Metamaterials.

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