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Design of 8 - Shaped DNG Metamaterial for GSM 1.8 GHz Applications

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Abstract

In this modern science era, compact sized patch antenna which can exhibit excellent characteristics is in great demand. Metamaterials may be the good solutions to meet all the requirements of this present technological world. Metamaterial features have been used to improve the characteristics of antennas for last many years. Many reasearchers have utilized metamaterial properties to reduce the overall size of patch antennas. An 8-shaped DNG (double negative) metamaterial for GSM 1.8 GHz applications has been represented in this.This metamaterial structure is designed on low cost FR4 substrate. To calculate the complex values of permittivity and permeability Nicolson-Ross-Weir (NRW) approach is used with the help of MATLAB. The challenging tasks of designing and simulating the matematerial are carried out using CST Microwave studio 2010.

Keywords: *DNG Metamaterial, Matlab, CST Microwave studio, NRW approach*

1. Introduction

Invention of metamaterial structures has brought tremendous revolution in the modern technology. Metamaterial (MTMs) are artificial structure, not available in nature [1]-[6].In fact, these are the artificial structures which are made up of several periodic unit cells from various materials like copper, perfect electric conductor and even plastics. The geometrical designed structure of metamaterial has great impact on its various features and applications. Different kinds of figures, standards, forms and orientation methods of metamaterial can change the direction of light that passes through it. All these properties are not found in natural materials. Dimensions of metamaterial are much smaller than the wavelength of electromagnetic wave passing through it.Negative refractive index is the most essential feature in metamaterial design and fabrication. Metamaterials have the ability to imbibe the state where we can get both the permittivity (ε) and permeability (μ) negative. This result gives an extraordinary index of negative refraction. There are several types of metamaterial structures. A metamaterial which has both the permittivity and permeability negative is known as DNG (double negative) metamaterial. It is also known as left handed metamaterial structure. Both the permittivity and permeability should resonate at the same frequency and only then it will be known as left handed materials.

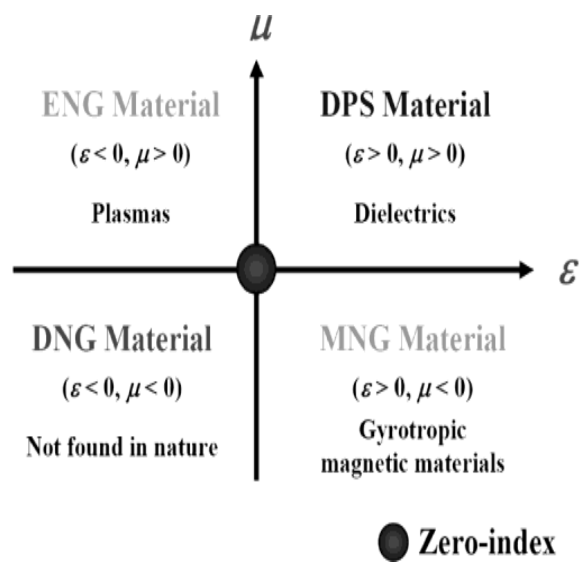

Figure 1: Different Types of Materials based on the values of Complex (ε) and (μ).

Metamaterials can be divided into different categories by their two important parameters i.e. complex values of both the permittivity and permeability. Figure 1 helps to identify the various kinds of metamaterial structures. If permittivity (ε_r) and permeability (μ_r) are real and positive then these are known as double positive materials i.e. dielectrics. If either of permittivity or permeability is negative, they exist in second and fourth quadrant respectively. These kind of materials are known as single negative (SNG) i.e. permittivity negative (ENG) and permeability negative (MNG) material respectively. On the other hand, if both ε and μ have negative and real values then this kind of material structures are known as double negative or Left-handed metamaterials. When an electromagnetic wave passes through double negative material, it develops left handed triad. The left handed materials (LHM) are related with backward wave and anti parallel wave because when electromagnetic wave travels through this kind of material, Power goes away from the source due to this group velocity become positive and simultaneously phase front travels towards the source and the phase front becomes negative. This backward waveform principle results permittivity and permeability negative.

2. Metamaterial Design

Metamaterials are artificially made electromagnetic structures .Their features are based on the formation of magnetic resonators and long conducting wires at sub wavelength scale, which have the negative permittivity and the negative permeability simultaneously at a certain frequency. A number of different LHM or DNG structures (SSR, Omega, CRR, S-shaped etc) have been introduced for the last few years, having the same behavior [7]-[10]. In this work, a novel method has been introduced for the implementation of DNG metamaterial at 1.8 GHz .This method allows to tune complex values of permittivity and permeability individually, as there is less coupling between electric and magnetic fields.
The design procedure of a material with desired properties is an extremely demanding synthesis process. But the proposed work involves an efficient design consists of accurate field solvers that can analyze any possible metamaterial and derive the corresponding macroscopic properties with an efficient numerical optimizer that designs the cell that establish the metamaterial. First, in this novel method of designing two symmetrical rings are designed to give the form of digital number '8' .This metamaterial is designed on the FR4 substrate with PEC (perfect electric conductor) is used for rings and wire. The ring structure tried to exhibit relative permeability (μ_r) at a certain frequency. Similarly, conducting wire is polarized to the electric field, to have the relative permittivity (ε_r) at a specified resonant frequency. All the geometrical dimensions are shown in Table I. The combination of rings and wire result in double negative (DNG) material which has both negative permeability and permittivity. The dimensions of all the metallic inclusion (strip width, gap, unit cell dimensions etc), are varied in order to select the desired resonant frequency. However, variations in the length of rings and wire have great impact on the simulated results.

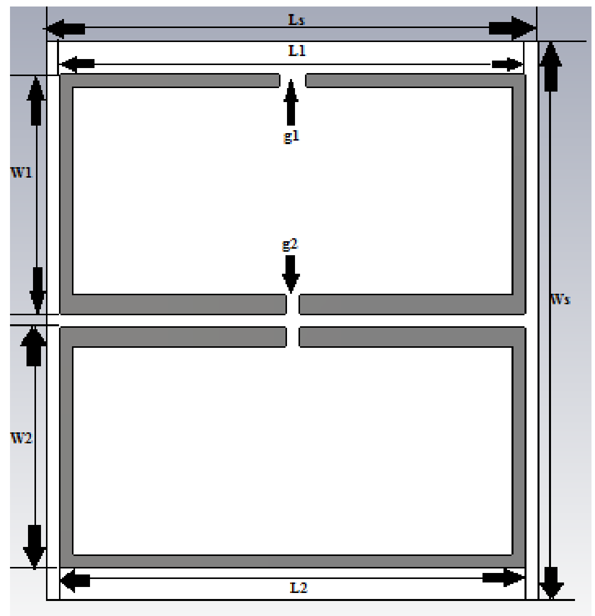

Figure 2 Front view of DNG Metamaterial

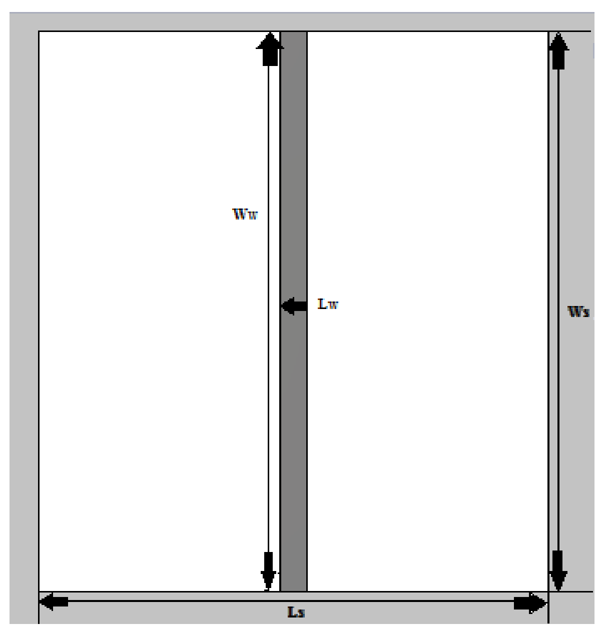

Figure 3 Back View of DNG Metamaterial

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Table I: Dimensions of Metamaterial Structure

Sr. No.	Name of Parameters	Values
1.	Length of Substrate(Ls)	36mm
2.	Width of Substrate(Ws)	44mm
3.	Length of rings(L1=L2)	16.5mm
4.	Width of rings(W1=W2)	18.5mm
5.	Gap(g1)	2mm
6	Gap(g2)	1mm
7.	Length of wire (Lw)	36mm
8.	Width of wire(Ww)	1mm
9.	Dielectric Constant(ϵ)	4.3
10.	Substrate height(h)	1.574mm

The effective properties of the DNG material can be determined by simulating a single cell with appropriate boundary conditions. These act as effective periodic boundaries. Figure 4 shows the detail of all the boundaries and ports as well. Built in optimizers can be used with a parameterized set of material properties to match a simplified cell's S-parameters to the full structure of metamaterial.

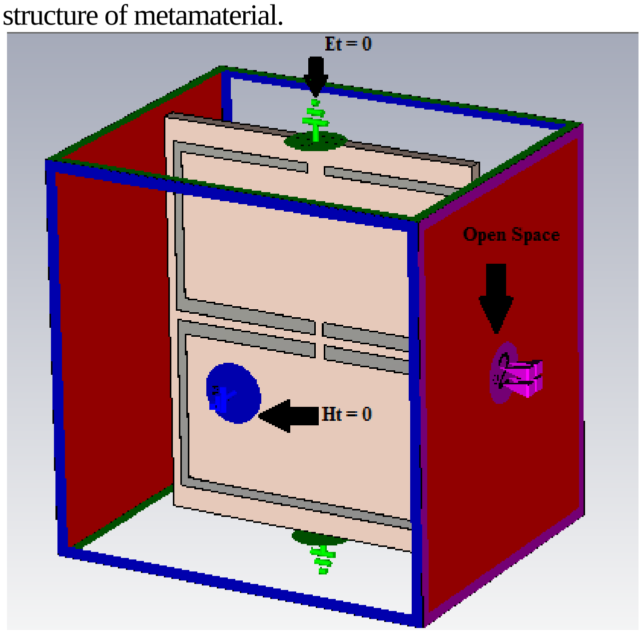

Figure 4. DNG Metamaterial with Boundary conditions.

3. Nicolson-Ross-Weir Method to determine complex parameters.

Many methods have been developed to measure the complex properties from s-parameters [11]-[14]. The selection of the method depends on several factors such as the measured s-parameters, sample length, the desired dielectric properties, speed of conversion and accuracies in the converted results. Table-2 gives an overview of the conversion methods utilizing various sets of s-parameters to determine the dielectric properties.

Table 2-Comparison between the conversion Methods

Conversion Techniques	S-parameters	Dielectric Properties
NRW	S11,S21,S12,S22 or S11,S21	(ε_r, μ_r)
NIST iterative	S11,S21,S12,S22 or S11,S21	μ_r, ε_r=1
New non-iterative	S11,S21,S12,S22 or S11,S21	ε_r, μ_r=1
SCL	S11	ε_r

Every method is limited to specified frequencies, materials and applications by its own constraint measurement of dielectric properties involves measurement of the complex relative permittivity (ε_r) and complex permeability (μ_r) of the materials. In this work, we have used the Nicolson-Ross-Weir (NRW) method to measure the dielectric properties because this only method to determine both the values of permittivity and permeability. It is the most commonly used method for performing such conversion. Measurement of reflection coefficient and transmission coefficient requires all four (S11, S21, S12, S22) or a pair (S11, S21) of s parameters of the material under test to be measured. The procedure proposed by NRW method is deduced from the following equations.

The reflection co-efficient can be written as:

$$\Gamma = X \pm \sqrt{X^2 - 1} \quad \text{--------- (1)}$$

Where X in terms of s-parameter is given by

$$X = \frac{s_{11}^2 - s_{21}^2 + 1}{2s_{11}} \quad \text{-------- (2)}$$

The transmission coefficient can be written as:

$$T = \frac{s_{11} + s_{21} - \Gamma}{1 - (s_{11} + s_{21})\Gamma} \quad \text{-------- (3)}$$

The permeability is calculated as:

$$\mu_r = \frac{1 + \Gamma_1}{\Lambda(1-\Gamma)\sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}} \quad \text{------- (4)}$$

Where λ_0 is free space wavelength and λ_c is cut-off wavelength and

$$\frac{1}{\Lambda^2} = \left(\frac{\varepsilon_r * \mu_r}{\lambda_0^2} - \frac{1}{\lambda_c^2}\right) \quad \text{------- (5)}$$

The permittivity iscalculated as:

$$\varepsilon_r = \frac{\lambda_0^2}{\mu_r}\left(\frac{1}{\lambda_c^2} - \left[\frac{1}{2\pi L}\ln\left(\frac{1}{T}\right)\right]^2\right) \text{------- (6)}$$

Where
L is Material length.
ε_r = Relative permittivity.
μ_r =Relative permeability.
Γ = Reflection Coefficient
T = Transmission Coefficient
λ_c= Cut-off Wavelength

4. Results and Discussion

The simulated s-parameters (magnitude) of the 8-shaped DNG Metamaterial are further used for the verification of DNG material properties.

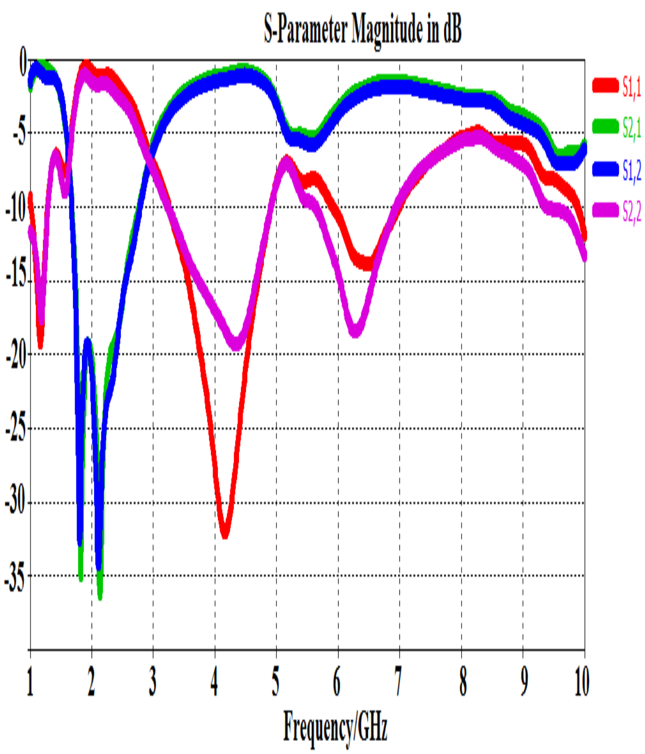

Figure 5 Return loss for all the S-parameters.

Plot of all the reflection and transmission coefficients are shown in figure 5. It can be observed that response is achieved at multiple frequencies for S11, S21, S12 and S22 parameters. But in this proposed work our main concern is around the frequency of 1.8 GHz. However, these results give an idea that permittivity and permeability can also be made negative in other specified range of frequencies

The simulated S-parameters obtained from the CST Microwave Studio 2010 are exported to Microsoft Excel sheet and then MATLAB software is used for the retrieval of complex dielectric parameters using NRZ approach. Permittivity and permeability should be negative at desired frequency in order to control directions of electromagnetic waves passing through the metamaterial structure. From figure 6 and 7 it can be observed that the permittivity and permeability are negative at frequency of 1.8 GHz.

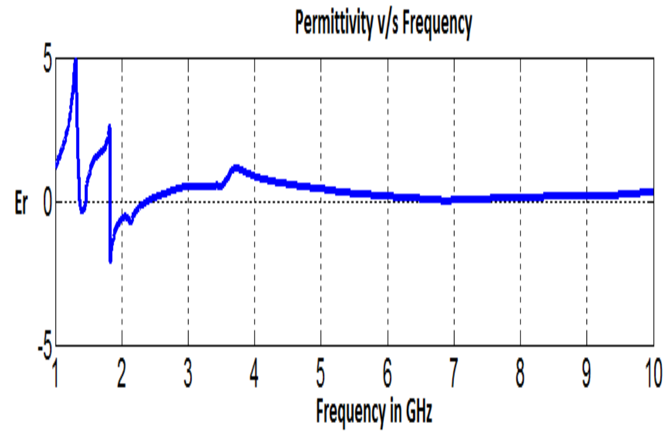

Figure 6. Retrieval results of 8-shaped DNG MTM for Permittivity (ε_r)

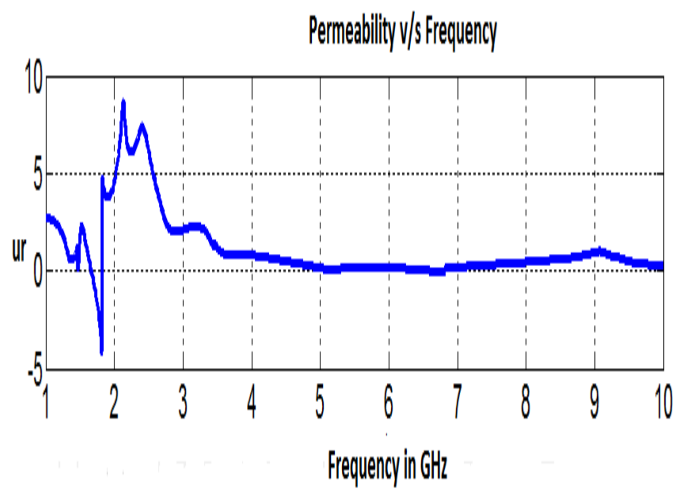

Figure 7. Retrieval results of 8-shaped DNG MTM for Permeability (μ_r)

This structure tends to yield clean retrieval response as there is less ringing effect from the time domain simulation.

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6. Conclusion

An 8-shaped DNG Metamaterial for GSM 1.8 GHz applications has been successfully designed.The measured results for the dielectric parameters ($\varepsilon_r\ \mu_r$) shown in this paper validate the basic principle of metamaterial to control the direction and behaviour of electromagnetic waves passing through it. After the designing and simulation process, it is noted that the variation in geometrical dimensions and boundary conditions has significant role in obtaining negative complex values at a certain frequency or in the range of frequencies. The simulated results shown in figure 5 verify this observation that in future research work, proposed single band structure can be transformed in to a dual band or multi-band DNG metamaterial structure. When we compare the optimized dimensions illustrated in table I with the calculated values at 1.8 GHz, it is observed that the designed structure exhibits atleast 45 % size reduction. The 8-shaped DNG Metamaterial inspired antenna can present excellent characteristics (return loss, directivity, bandwidth etc) as compare to conventional antenna with FR4 substrate. In another technique, this designed single unit cell can be used as a combination of unit cells to build up a metamaterial cover for any microstrip patch antenna. In this method, the cover is placed at a certain distance from the patch antenna and the variation of the distance between patch and MTM results excellent characteristics at a desired range of frequencies. Finally, the structure presented in this paper has verified the properties of DNG or left –handed material.

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