Metamaterial Based Antenna with Modified SRR Structure

Manish Upadhyay ¹, Sudeep Singh Somvanshi ²

¹Department of Electronics and Communication Engineering
²Department of Electrical and Electronics Engineering

¹, ²Bharati Vidyapeeth’s College of Engineering, GGSIP University, New Delhi, India

¹Email- polarizadmax@gmail.com
²Email- sudeepsingh.1600@yahoo.com

Abstract- In this paper we investigate the effect of integrating a metamaterial structure with a patch antenna with random geometry. Metamaterial structure is obtained after modifying a conventional SRR structure as Quad Semi-splitted Ring Resonator (QSRR). We perform a HFSS Simulation of the QSRR structure. Further we present successfully extraction of parameter (permeability, permittivity and index) of structure on MATLAB using Direct Extraction approach to verify its Double negative gradient (DNG) property

Keywords – SRR; Metamaterial; QSRR

I. INTRODUCTION

Naturally occurring matter exhibits behavior based on the molecules that make it up - the atomic material that composes the finished product determines what properties the product will have. For instance, take the relationship between wood and light. Wood, like all natural matter, reflects and refracts light. But just how much light it reflects and refracts depends on how the electromagnetic waves of the light interact with the particles -- like electrons -- that make up the wood. Later, in 2000, Pendry et al. suggested that left-handed material lenses might offer sub-wavelength resolution and perfect lens phenomena could be achievable [1,2]. In 2001 Shelby et al. demonstrated negative refraction at microwave frequencies using a volume distribution of a composite medium with split ring resonators (SRRs) and wires [3, 4]. They used periodic arrays of SRRs to achieve negative permeability and periodic arrays of wires to achieve negative permittivity [5, 6].

Duke University's David R. Smith suggests that Imagine a fabric woven of thread. In this fabric, light is only allowed to flow over the threads (meaning it can't travel into the nooks and crannies between the threads). If you punch a hole in the fabric with a pin, light will go around the hole and resume its original course of travel, since light can only travel over the thread. So to the light waves, the hole doesn't exist. If you put an object in the hole, the light waves would go around the object too, effectively rendering the object invisible. Metamaterial are structure that is electrically small implies that the size of the structure is much smaller than the wavelength in free space.

The resonance that takes place in these structures is the result of an applied field that generates either a magnetic dipole moment, electric dipole moment or both in the small resonators. This resonance phenomenon is in sharp contrast to the destructive interference between waves bouncing back and forth along or within a traditional resonator such as a transmission line or cavity [6-7].

II. METAMATERIAL DESIGN

Photonic crystals which are electromagnetic structures associated with periodic systems possess various modes especially higher frequency modes, typically summarized in band diagrams. The band diagrams signify Bloch waves instead of plane waves, as the Bloch waves represent the solution to Maxwell’s equations for systems with ε and μ having special periodicity [8].

An algorithmic approach has been presented in [9] for the assignment of effective medium parameters to a periodic structure. This approach makes use of scattering parameters for a finite-thickness, planar slab of inhomogeneous structure to be characterized. After extraction of phase and amplitude of waves transmitted and
reflected from the structure, complex values of refractive index \( n \) and wave impedance \( z \) are retrieved. It is found that a valid refractive index can be obtained for the inhomogeneous but periodic structure. The value of wave impedance depends on the termination of unit cell. For structures which are not symmetric along the wave propagation direction, the wave impedance has two values corresponding to the two incident directions of wave propagation. This ambiguous nature of impedance leads to an ambiguity in \( \varepsilon \) and \( \mu \), which increases as the ratio unit cell dimension of inhomogeneous material to the wavelength of incident radiation increases [9].

Metamaterial have been found to interact with electromagnetic radiation in the same manner as would homogenous materials with equivalent material parameters [4]. Thus, for replacing such an inhomogeneous structure by a continuous material, there shouldn’t be any difference in the scattering characteristics of the two. Assuming the continuous material is characterized by an index \( n \) and an impedance \( z \), analytic expressions for relating the scattering parameters to \( n \) and \( z \) can be found [10][11].

In homogeneous passive media, the imaginary components of the material parameters are restricted to positive values [12]. This anomaly in its behavior vanishes as the size of the unit cell approaches zero [13].

Refractive index \( n \) and wave impedance \( z \) are related to \( \varepsilon \) and \( \mu \) by the relations

\[
\varepsilon = n / z, \mu = n z
\]  

\( S_{11} \) and \( S_{21} \) parameters are used to derive \( n \) and \( z \) as follows

\[
n = \frac{1}{kd} \cos^{-1} \left( \frac{1}{2S_{21}^2} (1 - S_{21}^2 + S_{11}^2) \right)
\]

\[
z = \sqrt{(1+S_{11})^2 - S_{21}^2 - S_{21}^2}
\]

Equations (2) and (3) in case minimum sample thickness set by the unit cell size of the metamaterial get complicated. Also, for resonant metamaterial structures, there is a frequency region over which the branches associated with the inverse cosine in (2) become very close to each other, where it becomes very difficult to determine the solution.

To determine the phase advance \( \alpha \), the following equation is used

\[
\cos(\alpha d) = \frac{1-S_{11}S_{22}+S_{21}^2}{2S_{21}}
\]

Equation (4) shows that irrespective of the wavelength to unit cell ratio, an effective index is obtained using all the elements of the Scattering matrix [9].

Thus Equation (1), (2), (3) and (4) state a direct retrieval method for extracting parameters of the inhomogeneous structure of QSRR.

The model is design in Ansoft HFSS v11 in which a box of dimension 4.4 X 4.4 X 2.5 mm is used to assign as air. All the structure are made inside the box surrounded by air. In design we are using FR4 as substrate with the height of \( h=1.58 \)mm while the thickness of the copper strip on it is assume to be 0.017mm.

First we designed a random patch with matching transformer that resonate at multiple frequencies. We are using FR4 as substrate with the height of \( h=1.58 \)mm while the thickness of the copper strip on it is assume to be 0.017mm.

For simulation for QSRR alone we assigned the opposite faces of the air box as Perfect electric conductor and orthogonal faces as perfect magnetic conductor. Then a wave port is assigned to excite the structure. In similar manner the air box of same dimension is used for QSRR structure. While for the design we used four ring of one half the diameter of former ring and rotate it throughout axis to form an overlapped structure within same limited dimension of air box. Then a conductor (copper) microstrip is placed at the base of substrate.

After simulation of patch and QSRR alone we integrate them in order to analyze the effect on return loss and gain of the patch antenna.
Metamaterial Based Antenna with Modified SRR Structure

IV. SIMULATION AND OBSERVATIONS

After simulating the structure we have S-parameter (S11 and S21) in the Fig 2 on the first observe we can see that the S-parameter lines (S11 and S21) are crossing each other at different frequencies on the graph. The lower frequency band is at 2.3 GHz while higher frequency band is at 5.8 GHz. It points that QSRR have potential that it can attain negative refractive index at lower frequency as well as at higher frequency. Now as far we got better response for QSRR but we need to check whether this structure actually shows for the negation of permittivity and permeability at the required band as per the S-parameter response.

For verification of negative refractive Index at projected frequencies actually could attain (negative permittivity and permeability) we go for parametric extraction of these parameters based on the approach described above.

After simulating the Patch with and without the QSRR we get figure 3 above showing return loss (S11) of the combined antenna structure. The plot gives return loss of ~9 dB at 1.64GHz (Conventional Patch) and ~11.8dB at 3.77 GHz. This plot in comparison to individual antenna plot is better in manner that the return loss improves by nearly 1.5dB at 1.70 GHz (With QSRR) while the improvement is also reported at 3.97 GHz frequency.

While the -10dB bandwidth reported is not having significant change at both the band. The Fig 4 is the Polar Radiation plot representing the total estimated gain in simulation. This shows that there is significant improvement in gain as well the axial ratio of the patch with QSRR seems much better in comparison to the Conventional patch.
Figure 3: ($S_{11}$-Parameter) Return Loss for a) Red: Conventional Patch  b) Blue: Patch with QSRR

Figure 4: Simulated Radiation Pattern for
a) Patch with QSRR  b) Conventional Patch only
[Red: $\Phi=0$ deg, Blue: $\Phi=90$ deg]
Metamaterial Based Antenna with Modified SRR Structure

CONCLUSION

The observation verified that the specified structure is a DNG double negative gradient metamaterial. By using the direct approach of parameter retrieval we are successful to get good enough response to determine the band of negative refractive index for the in-homogeneous structures.

The suggested structure when integrated with the patch antenna gives better gain with shift in resonant frequency to higher Band. Hence This suggested structure could potentially used for the Improvement of gain and directivity as trade of with frequency band.

ACKNOWLEDGMENT

We would like to express our thanks to the Asst. Professor S.B.Kumar and Mr. Priyansh Bhutani of Dept. of Electronics and communication, BVCOE, New Delhi for their guidance and support throughout this study.

REFERENCES