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Metamaterial based Multiband and UWB Antenna Using Split Ring Resonator Concept

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Abstract: *Electromagnetic metamaterials (MTMs) are artificial effectively homogeneous electromagnetic structures with unusual properties not readily available in nature. Metamaterials are artificial structures which provide engineerable permeability and permeability. This paper gives classification of metamaterial based on available literature. In this paper Split Ring Resonator is used to explain the concept of metamaterials. Further the work is extended to demonstrate the effect of SRR to generate multiband antenna in the frequency band of 1 GHz to 10GHz. By modifying the ground structure of multiband antenna efficient UWB antenna is designed and simulated using EM simulation tool. This paper also demonstrates the effect of placing SRR to particular position on ground changes from multiband antenna operation to ultra wide band.*

Keywords: *Electromagnetic metamaterials (MTMs), UltraWide Band antenna, multiband antenna, Split Ring Resonato*

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I. Introduction

Electromagnetic metamaterials (MTMs) are broadly defined as artificial effectively homogeneous electromagnetic structures with unusual properties not readily available in nature.[1][2]. The concept of artificial materials first introduced by Jagadis Chandra Bose while conducting microwave experiments on twisted structures, these artificial structures are termed as chiral elements by todays terminology. In 1914 Lindman worked on artificial chiral media. In 1948 Kock worked on lightweight microwave lenses by arranging conducting spheres, disks, and strips periodically and effectively tailoring effective refractive index of the artificial media.[3] In 1967, Veselago theoretically proved plane wave propagation in material whose permittivity and permeability both were simultaneously negative.[4] Metamaterials shows negative permittivity and permeability. Many researchers are presently working on metamaterials and they have proposed various terminologies to metamaterials such as Left handed materials, negative refractive index materials, backward wave media(BW media), double negative metamaterials. Many research groups all over the world are now studying various aspects of this class of metamaterials, and several ideas and suggestions for future applications of these materials have been proposed.[2] This paper gives the different classifications of metamaterials based on the different papers published in peer reviewed journals. Author tried to study many papers on metamaterials and classified them according to the techniques used to generate metamaterials which are used to design antennas. In this research paper multiband and UWB antenna using the split ring resonator is designed and simulated in HFSS. Antennas are simulated by considering FR4 substrate of dielectric constant of 4.4, thickness of 1.6mm and loss tangent of 0.02.Use of Split Ring Resonator to design and generate multiband antenna operation is analysed and from the simulation results it is found that Multiband antennas of desired frequency can be achieved. Further the work is extended to analyze the effect of CSRR and SRR to generate Ultra Wide Band antenna from the same multiband antenna by modifying the ground structure of it, and is simulated and presented in this paper.

II. Metamataerial classification

The Metamaterials are artificial structures which produce electromagnetic properties that are not found or difficult to obtain in nature. Metemetrials are able to provide engineerable permittivity, permeability and index of refraction. To determine propagation of waves in matter, dielectric constant and magnetic permeability are the fundamental quantities.[1][2][3] Refractive index of substance is given by(1). [4]

$$n^2 = \varepsilon\mu \qquad (1)$$

Where n, μ and ε are refractive index, permeability and permittivity of material respectively. These are real numbers if losses are not considered. Hence simultaneous change in sign of μ and ε has no effect on properties of substance. If μ and ε both are negative it contradicts fundamental laws of nature and therefore no material with μ and ε values less than zero can exist. Fig.1. shows classification materials based four possible combinations of sign of μ and ε values. [1].

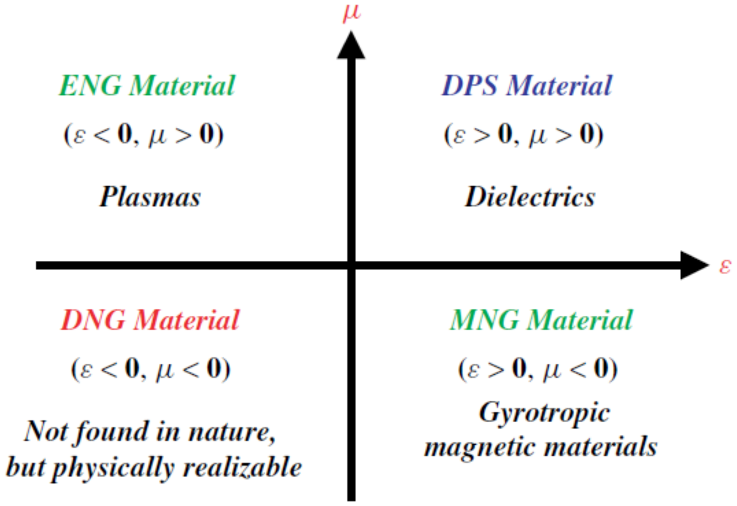


Fig. 1. Metamaterial classification based on $\varepsilon - \mu$ [1]

I quadrant shows both μ and ε are positive i.e. (DPS) double positive mediums do occur in nature. II quadrant is Epsilon negative (ENG) and IV quadrant is mu negative (MNG) materials. This concept is used to design metamaterial based antennas. III quadrant shows material with both μ and ε are negative called as (DNG) double negative which are not available in nature but can be physically realized.[7] We use metamaterial antenna as it has benefits of small physical size, low cost, broad bandwidth, and good efficiency.[1][2][8] Metamaterials received great attention in research areas of physics and engineering. Microwave and milimiter wave applications of metamaterials are as couplers, resonators, negative refractive index lenses, small antennas, leaky wave antennas and absorbers.[9] Some interesting application of metamaterials is cloaking and invisible metamaterials. Here we will discuss some of its application in multiband and UWB antennas. Antennas which work in more than one frequency band for transmitting and receiving electromagnetic waves are called as multiband antennas. Multiband antennas are complex in design, structure and operations as compared to single band antenna [7][10] This paper reviews the development of metamaterial based antenna and are classified in the following categories.[7][10]

1. Composite Right Left Handed Transmission Line (CRLH-TL) based or dispersion engineered resonant multiband antennas which includes the antennas with negative-order modes and zeroth-order resonators.
2. Multiband antennas based on the metamaterial loadings
3. Multiband and UWB antennas using Split Ring Resonators.
4. Multiband antennas loaded with metasurfaces.

III. Concept of Metamaterial Slip Ring Resonator

A. Split Ring Resonator concept

The SRR shown in Fig. 2 is a metamaterial structure that produces both electric and magnetic responses.

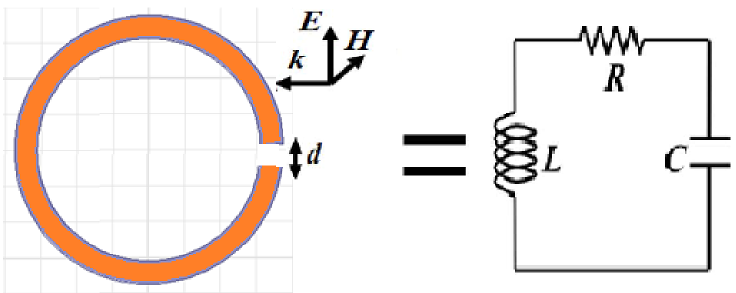


Fig. 2 Split Ring Resonator

Split Ring resonator can be of any shape circular, square, triangular etc. An SRR element is the electromagnetic analog of an *LC* circuit, in which the ring acts as an inductor and the gap as a capacitor. When the axis of the ring is parallel to the *H*-field, the *H*-field generates a current in the SRR, which gives rise to a strong magnetic dipole and, hence, a magnetic resonance. If the gap of the SRR is parallel to the *E*-field, the *E*-field generates voltage variation at the gap, leading to a strong electric dipole, and this gives rise to an electric resonance. The modified SRR with both electric and magnetic resonances at two closely spaced frequencies is used to improve the bandwidth of the antenna. [11]

B. Concept of negative permeablity in microwave band

According to Drudes relation (1) metals at optical frequencies are characterized by an electric permittivity that varies with frequency.[3]

$$\varepsilon(\omega) = \varepsilon_0 \left(1 - \frac{\omega_p^2}{\omega(\omega + i\gamma)}\right) \quad (2)$$

Where

$\omega_p^2 = \frac{N_c^2}{m\varepsilon_0}$ is the plasma frequency. i.e. frequency with which the collection of free electrons oscillates in the presence of an external driving field. N, e, and m are electron density, charge and mass respectively. γ is the rate at which the amplitude of plasma oscillation decreases.

From equation (2) it is clear that when $\gamma = 0$ and $\omega < \omega_p$ value of ε will be less than zero, it means the medium is characterized by a negative permittivity. [3]

IV. Monopole Antenna design

A general purpose dipole antenna (long thin wire antenna) shown in Fig 3.[5] From dipole antenna concept monopole antenna is designed and is as shown in Fig. 4. Monopole radiates only half as much power as the dipole.[6]

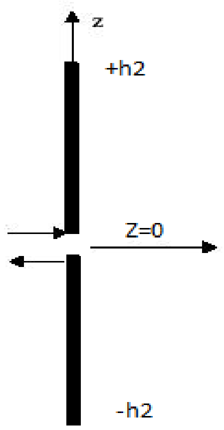


Fig. 3. Dipole antenna total length of h1+h2.

The current of the center fed antenna of length *L* at any point *z* on the antenna is

$$I(z) = I_0 sin\left[\frac{2\pi}{\lambda}\left(\frac{L}{2} - |z|\right)\right] \quad (3)$$

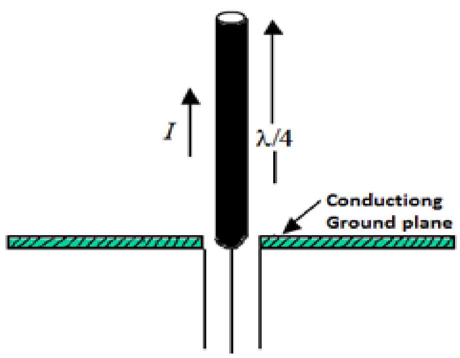
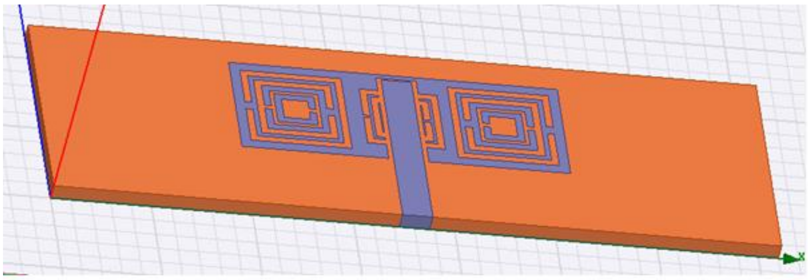


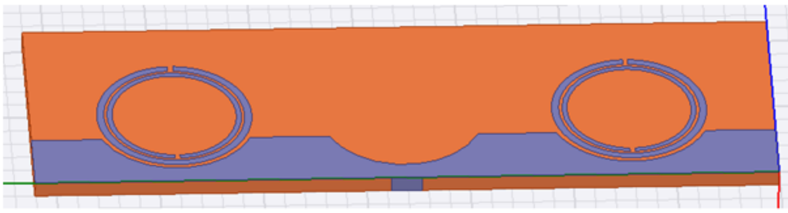
Fig. 4. λ/4 monopole antenna

V. Use of Srr to design Multiband Antenna And UWB Antenna

A Monopole antenna structure is modified using the concept of metamaterials i.e. by modifying the monopole antenna using SRR coupling. Monopole antenna is now coupled with Complementary Split Ring Resonators (CSRR) on the top surface as in Fig. 5 (a). Ground also modified with double split ring resonators on both ends as shown in Fig. 5(b). The said antenna is simulated in HFSS and is as shown in Fig. 6 and its frequency response in Fig.7.



(a)



(b)

Fig.5. Multiband antenna using SRR and CSRR a) Top view b) Ground plane

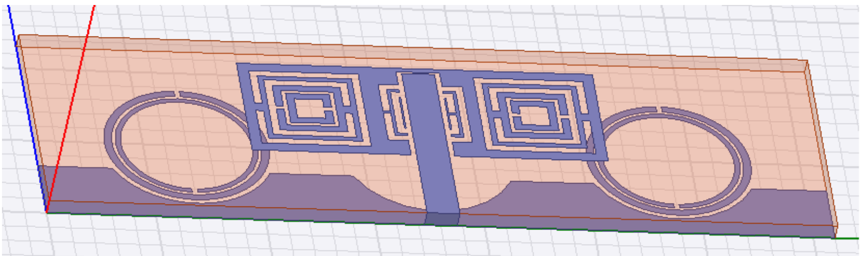


Fig. 6 Multiband antenna prototype using SRR and CSRR Simulated in HFSS

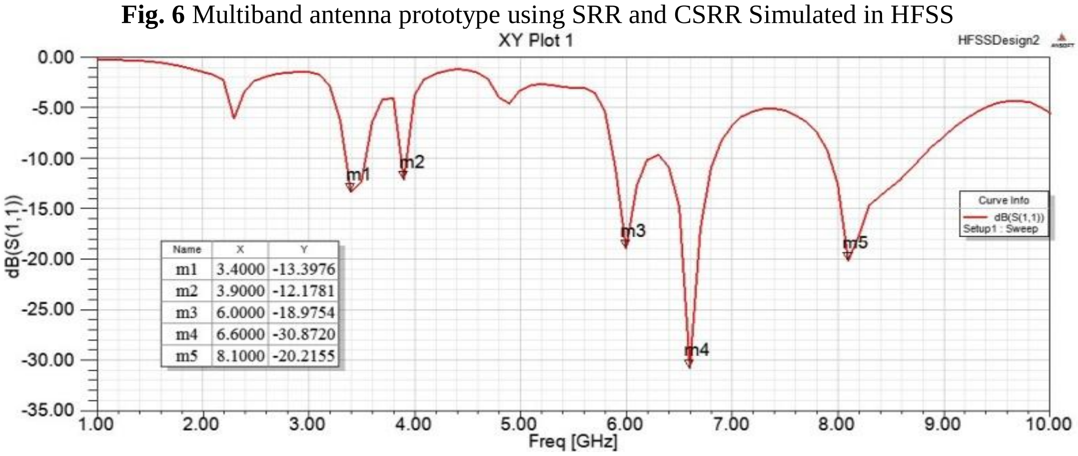


Fig.7. S11 verses frequency response for antenna

A. Effect of Split Ring Resonastor on Multiband Operation

The ground structure of antenna shown in Fig. 5 b. is modified as shown in Fig.8.

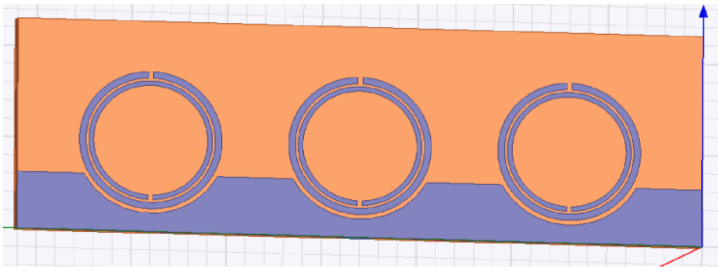


Fig.8. modified ground structure of antenna

It is observed that the after placing SRR at the center of ground plane the antenna behaves as that of UWB antenna in the frequency range of 6GHz to 9.5 GHz range as shown in Fig. 9. From the simulation results and the author concludes that Multiband to UWB antenna conversion is possible by modifying the SRR and CSRR structures.

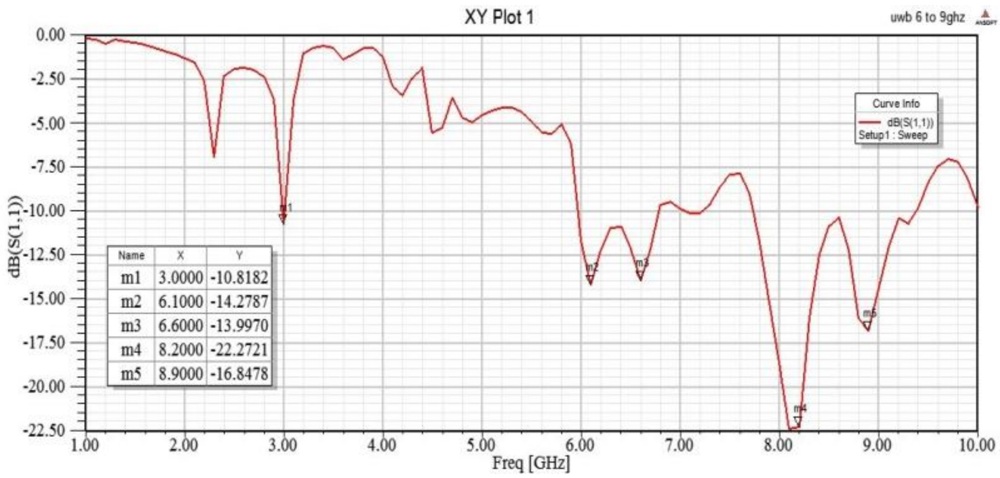


Fig.9. S11 verses frequency response after modification in ground structure.

Comparative results for the antenna in with ground structure for multiband antenna and modified ground structure as shown in Fig. 10.

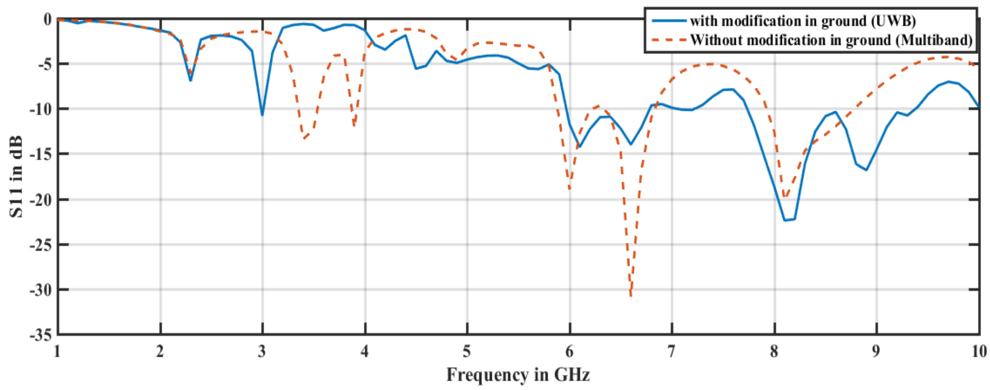


Fig. 10 comparative results before and after modification of ground structure with SRR

From the Fig. 10 it clear that after modifying the ground structure which is combination of Split ring resonators, frequency response of antenna changes. In this paper after modifying the arrangements of split ring resonator on ground plane multiband operation changes to ultra wide band (UWB) operation.

VI. Conclusion

Now days metamaterials and its application as antenna is growing field in the area of research. This paper reviews the recent development of multiband antennas using different types of metamaterial concepts. In this paper author have discussed metamaterials based on concept of SRR and CSRR. Split Ring resonators are used to design multiband antennas as well as UWB antennas of desired frequency. In this paper effect of SRR on monopole antenna is analyzed. It is observed that SRR can be used to design the multiband antenna and

UWB antennas with smaller size compared with others. Presently many communication systems needs multiband antennas with smaller size and this growing need can be fulfilled with the help of this technique. Metamaterials find its applications in various fields such as satellite communications, WLAN / Mobile communications, and on-body communications. Metamaterials received great attention in research areas of physics and engineering. Microwave and millimeter wave applications of metamaterials are as couplers, resonators, negative refractive index lenses, small antennas, leaky wave antennas and absorbers. Some interesting application of metamaterials is cloaking and invisible metamaterials. Fabricating the same structure using the FR4 or any other substrate and testing with VNA will be future scope for this paper.

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