International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

Antenna Performance Enhancement Using Metamaterial Loading Technique: A Review

Gurveer Kaur [1], Amanpreet Kaur [1], Amandeep Kaur [1]
[1] Department of Electronics and Communication Engineering,
Guru Nanak Dev Engineering College,
Ludhiana, India, 141006,

Abstract: **In the present RF communication scenario there is a great demand of multi band antennas with high gain, large bandwidth for the applications like Wi-Fi, WLAN, MIMO, BAN etc. Gradually, the size of handheld communication devices is becoming portable which ultimately leads to limit the space availability for antenna installation. Thus, it is a challenging task to design a compact size antenna meeting all the requirements regarding number of frequency bands, gain, and bandwidth. Metamaterial loading is found to be a significant technique for size reduction as well as enhancement of antenna performance parameters such as gain, directivity, bandwidth and efficiency.**

I. INTRODUCTION

Microstrip patch antennas due to their numerous advantages like low profile, light weight and ease of fabrication has been proved as suitable elements for these applications. But it is complex to achieve the performance indices such as high gain, large bandwidth and better efficiency in a compact size antenna. Further, different loading techniques like slotting, meandering stacking, shorting pin etc. are used to uplift these indices as well as size reduction. However, these techniques have certain limitations that degrade the other performance parameters of the microstrip patch antennas. Thus, in microstrip patch antennas it is difficult to achieve a better trade-off between the bandwidth, gain and size. Recently, metamaterial is used to load the microstrip patch antennas for size reduction as well as enhancement of gain, bandwidth, directivity and efficiency [1].

Metamaterials are a class of composite materials artificially constructed to exhibit exceptional properties not readily found in nature. In the context of novel artificial materials, an important role is played by metamaterials, which, due to their interesting anomalous electromagnetic features, have attracted a great deal of attention in recent years for several electromagnetic applications. Interest has been focused in particular on the wave interaction of metamaterials with anomalous electromagnetic constitutive parameters, and in particular with negative real part of their permittivity, i.e. ε negative (ENG), of their permeability, i.e. μ negative (MNG) or with both these quantities being negative, i.e. double-negative (DNG) in a specific frequency range [2]. Among the many applications, their use has been proposed to overcome the diffraction limit in various configurations.

The phase compensation properties of DNG metamaterials may allow synthesizing subwavelength cavity resonators , waveguides and scatterers with resonant properties essentially independent on their effective physical size [3].

If both permittivity and permeability are negative at the same frequency, then the composite structure possesses an effective negative index of refraction for isotropic medium and is referred to as a Left Handed Materials (LHMs) or Double Negative Metamaterial (DNG). When an electromagnetic wave passes through these materials, then the electric field(E), magnetic field (H) and wave vector (k) obey left handed rule, whereas in natural materials these vectors obey a right handed rule and they have positive material parameters [4]. Such materials with positive parameters are termed as Right Handed Materials (RHMs). Fig. 1 shows wave vector directions in RHMs and LHMs.

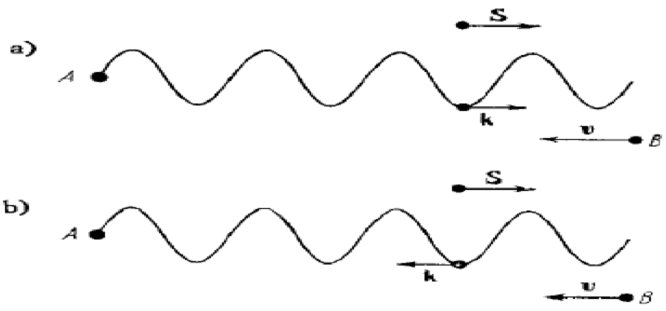


Fig. 1: a) Doppler Effect in a Right-Handed Substance b) Doppler Effect in a Left-Handed Substance. The Letter A Represents the Source of the Radiation, Letter B Represents the Receiver.

It is also seen that the poynting vector (S) and wave vector (k) are in opposite directions in LHM i.e. the poynting vector of the plane wave is antiparallel to the direction of the phase velocity (v), which is in contrast to the conventional case of plane wave propagation in natural medium. When an electromagnetic wave is obliquely incident on a LHM slab then it is seen that the direction of wave refraction at the first interface is upward (inside the slab) with respect to the normal in the RHM slab and downward in the LHM slab, as shown in Fig. 2 [5].

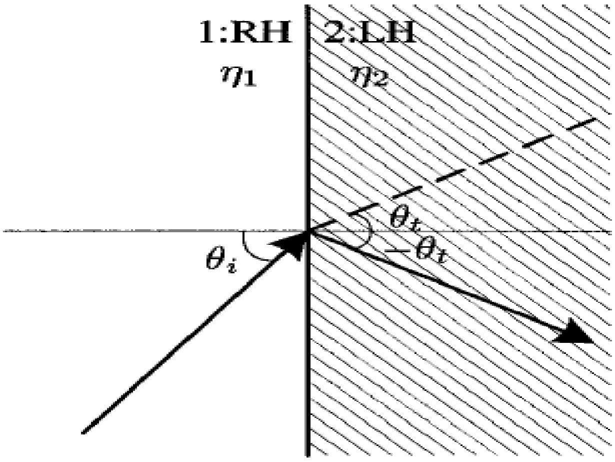


Fig. 2: Interface RH/LH with a Negative Angle of Refraction

It has been found that a composite structure of split ring resonators (SRRs) and conducting wires behave as a medium, an array of split rings gives rise to effective negative permeability and an array of wires exhibit negative effective permittivity [6].

Negative permittivity can be obtained from some naturally available materials. It can be achieved from metals at frequencies near their plasmonic resonance. Free electron gas with permittivity $\varepsilon = 1- w^2_p / w^2$ is negative when the frequency $w < w_p$, where w_p is the plasma frequency and w is the frequency of propagating electromagnetic wave. Some crystals such as SiC, LiTaO3, LiF and ZnSe also have negative permittivity at certain frequencies governed by their dispersion relations. Materials with negative permeability do not occur in nature. They have to be constructed artificially.

Fig. 3 illustrates a graphical representation of different material possibilities for electromagnetic applications based on the signs of their permittivity and permeability values and refraction and reflection at the interface between air and each medium.

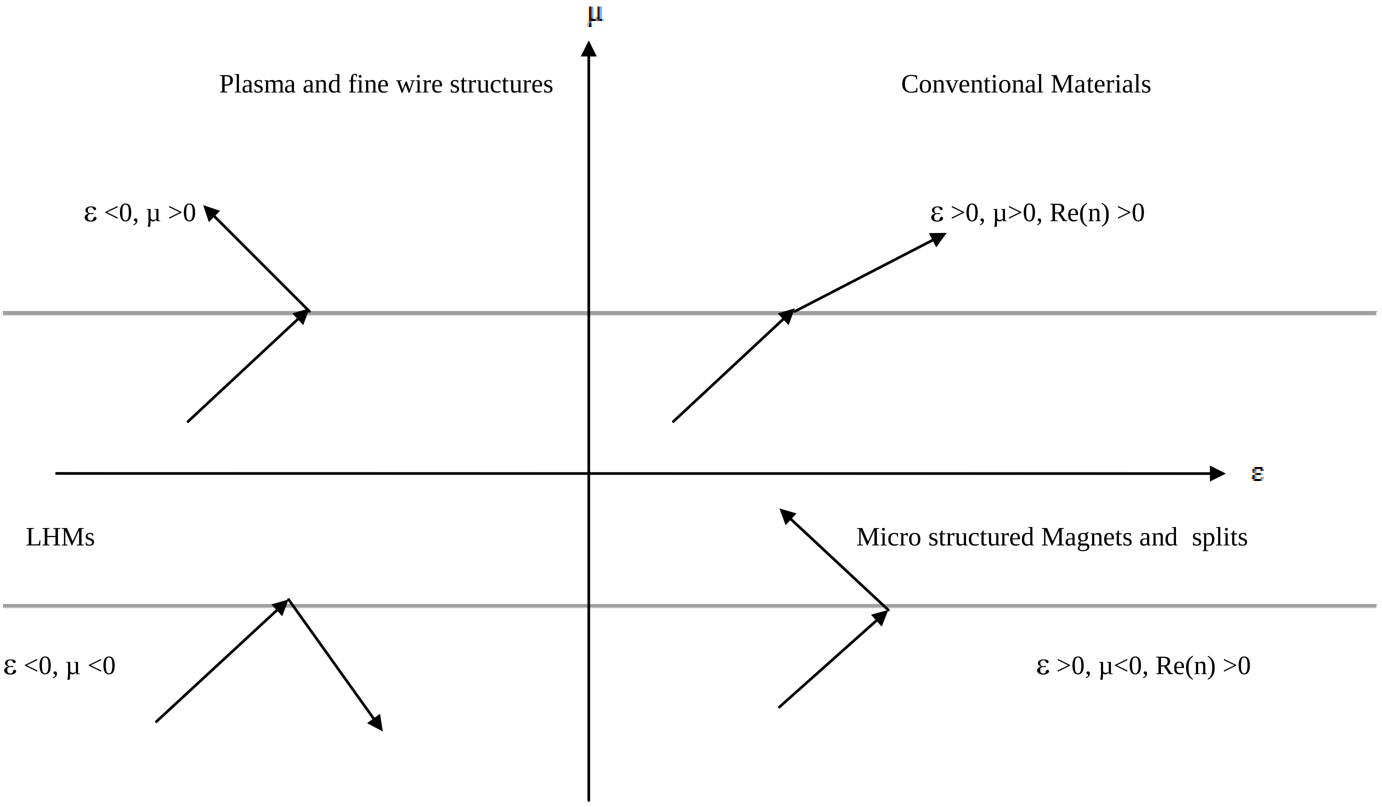


Fig. 3: Wave Reflection or Refraction Directions Based upon the Signs of ε and μ

There are four regions and plasma belongs to the region with negative permittivity and positive permeability. Split rings belong to the region of negative permeability and positive permittivity.

Fig. 4 shows all the possible combinations of ε and μ.

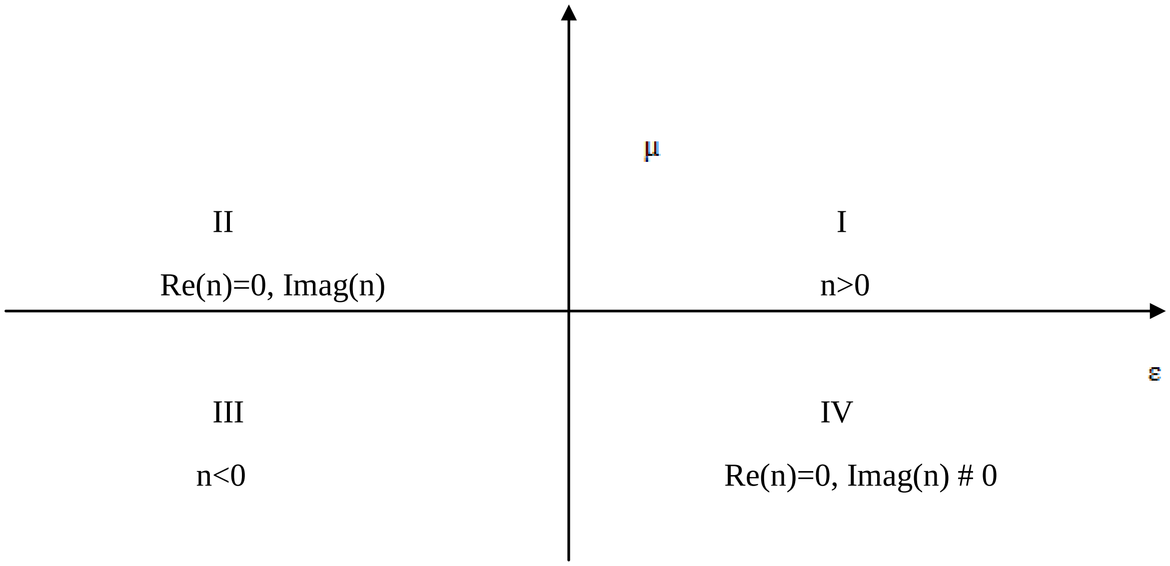


Fig. 4: Quadrant Wise Representation of ε and μ

It is clear that there is wave transmission when both parameters are of same sign. However if these two parameters are of opposite sign then refractive index will become imaginary and wave transmission will stop. It is also observed that wave is refracted positively in conventional materials and negatively in LHMs.

In a slab of conventional material (having positive refractive index), i.e. right handed material, the wavefront is transmitted away from the source. In a LHM the wavefront travels towards the source. Light incident on a LHM will bend to the same side as the incident beam and for Snell's law to hold, the refraction angle should be negative. In a metamaterial medium this determines negative real and imaginary part of the refractive index as shown in Table 1.

Table 1: Microwave Permittivity and Permeability Characteristics of Homogeneous Materials

ε>0, μ>0	**ε<0, μ>0**	**ε>0, μ<0**	**ε<0, μ<0**
Right Handed Medium	Metal like characteristics at optical frequencies.	Ferrimagnetic material characteristics	Left Handed Medium
Re(n)>0	Re(n)>0	Re(n)>0	Re(n)<0
-Forward wave propagation	-Evanescent Waves (No Transmission)	-Evanescent Waves (No Transmission)	-Backward wave propagation

II. REALIZATION OF LEFT HANDED METAMATERIALS

Metamaterials are artificial materials that consists of a collection of repeated objects whose size and spacing are much smaller than the electomagnetic wavelength of interest. As long as the wavelength of operation for any radiation in the structure is much larger than the inclusion size and spacing, an array of inclusions behaves like a continuous material.

LHM are realized in many ways, out of which the most common method is by embedding periodic metallic patterns in dielectric substrate [7]. Various theories have been given for LHM realization from composite media. The actual design of metamaterials consists of scattered elements arranged or patterned in a periodic manner. This method of forming a metamaterial is convenient in terms of design and analysis because a complete numerical solution Maxwell's equations can be obtained by considering single unit cell of a large periodic structure.

For the metamaterials, the effective response of the periodic structures can be utilized much beyond the limits of conventional effective medium theory, even to the point where the free space wavelength is of the order of the unit cell dimension. Some of the potential factors effecting these material parameters in a metamaterial are inclusion geometry, element spacing in the array, material composition of inclusions and electric sources used for the excitation.

Sir J.B. Pendry gave the analogy on effective permeability ,stating that a conventional material is a composite material with periodic arrays of structure called atoms or molecules. Long wavelengths are invisible to such small structures and hence composite medium composed of periodic structures appears as a homogeneous medium to the waves, with bulk composite parameters forming the effective parameters [8].

III. REALIZATION OF NEGATIVE PERMITTIVITY

As we know negative permittivity can be obtained from some naturally available metals at frequencies which are close to the plasmonic resonances. Also some crystals such as SiC, LiTaO3, LiF and ZnSe have negative permittivity at certain frequencies governed by their dispersion relations. However the plasma frequency w_p of a metal is usually in ultraviolet region of the spectrum. Also when the frequencies approach lower end, the effective permittivity gets dominated by its imaginary part and thus will cause absorptive resonance resulting in increased dissipation. So it is required to reduce the plasma frequency of the metal so as to achieve negative permittivity with low absorption. In order to achieve the reduction in plasma frequency of metals, J.B Pendry [8] proposed a periodic structure that consists of thin and straight conducting wires. Since it is known that the density of electrons confined with a certain periodic lattice decides the plasma frequency of lattice, therefore due to the confinement of thin and straight metal wire in relatively bigger lattice as background, the density of electrons in the lattice is reduced to a great extent. Besides this, thin metal lines also have their mass enhanced because of the self inductance possessed by the wire array. These two factors contribute together to bring effective plasma frequency down to 6 orders of magnitude, thus making it to fall into the GHz range. And when the operating frequency falls below the plasma frequency, permittivity effectively becomes negative.

IV. REALIZATION OF NEGATIVE PERMEABILITY

In 1999, Sir John Pendry proposed a way to realize the negative permeability in the microwave regime by using Split Ring Resonator (SRRs) [8]. They are called so because they are metallic rings with a capacitive gap. When the SRR is much smaller than the wavelength of radiation used to illuminate it, then it is equivalent to LC circuit, with L being the self inductance of the ring and C being the capacitance of the gap. A diagram of SRR along with its equivalent circuit is shown in Fig. 5 where L is the equivalent inductance, C_g is the gap capacitance at the splits and C_m is the mutual capacitance between inner and outer split rings.

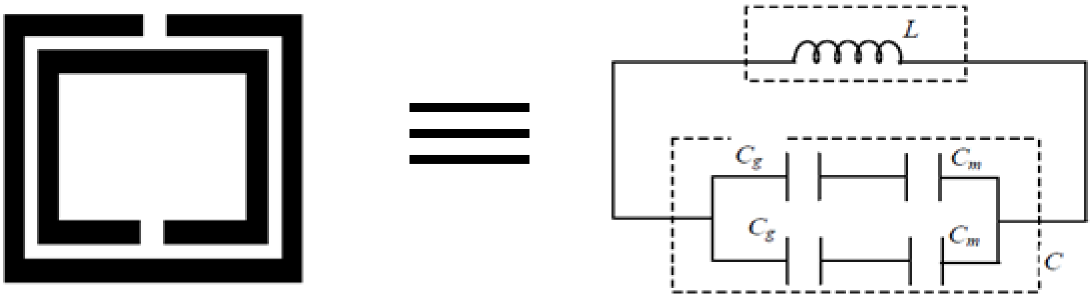


Fig.5 : SRR and its Equivalent Circuit Model

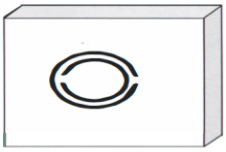
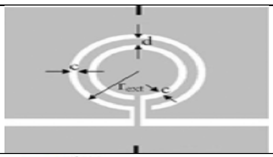
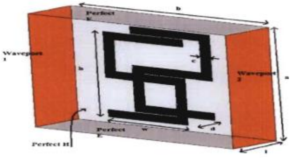
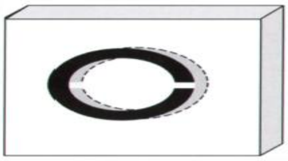
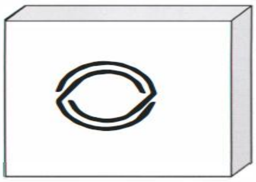
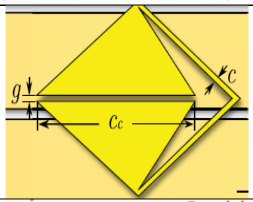
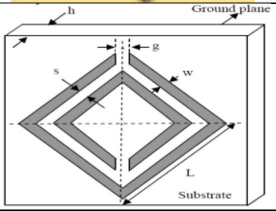
In a SRR there are two rings both having a split. By having splits in the ring, the SRR unit can be made to resonate at wavelengths much larger than the diameters of the ring.

The purpose of second ring inside and whose split is oriented oppositely to the outside split is to generate a large capacitance in the small gap region which support strong electric field. Electric fields further interact with magnetic fields oriented with normal to cut-plane of the rings. As a result currents are excited on both inner and outer ring though the gap between the rings prevents current from flowing around any one ring. Thus significant capacitance between the two rings enables the current to flow.

V. SOME EXISTING METAMATERIAL STRUCTURES

With advances in manufacturing technologies, the realization of metamaterials, which achieve all the desired properties, has become quite easy. Some of the recently developed left handed metamaterial structures are Smith Structure, Pendry Structure, Omega Structure and S Structure. The Table 2 shows some of the metamaterial structures known till date.

Table 2: Some Commonly Used Metamaterial Structures

S.No.	**Nomenclature**	**Geometry**
1	Edge-coupled SRR [9]	
2	Omega SRR [10]	
3	S Shaped SRR [11]	
4	Broadside SRR [9]	
5	Non Bianisotropic SRR [9]	
6	Diamond Shaped Tapered SRR [12]	
7	Offset-cut Diamond shaped SRR [13]	

VI. CONCLUSION

Different loading techniques used to uplift antenna performance indices like slotting, meandering stacking, shorting pin etc. have certain limitations that degrade the other performance parameters of the microstrip patch antennas. Thus, in microstrip patch antennas it is difficult to achieve a better trade-off between the bandwidth, gain and size. Thus metamaterial is used to load the microstrip patch antennas for size reduction as well as enhancement of gain, bandwidth, directivity and efficiency.

REFERENCES:

[1] Joshi, J.G., Pattnaik, S.S. and Devi, S. (2011), "Metamaterial Loaded Square Slotted Dual Band Microstrip Patch Antenna", Proceedings of IEEE Applied Electromagnetic Conference (AEMC-2011), Kolkata, pp. 1-4.

[2] Chen, P.Y. and Andrea, A. (2010), "Dual-Mode Miniaturized Elliptical Patch Antenna with μ Negative Metamaterials", IEEE Antennas and Wireless Propagation Letters, vol. 9, pp. 351-354.

[3] Andrea, A., Bilotti, F., Engheta, N. and Vegni, L. (2007), "Subwavelength, Compact, Resonant Patch Antennas Loaded with Metamaterials", IEEE Transactions on Antennas and Propagation, vol. 55, 1, pp. 13-25.

[4] Veselango, V.G. (1968), "Electrodynamics of Substances with Simultaneously Negative Values of ε and μ", Soviet Physics Uspekhi, vol. 10, 4, pp. 509-514.

[5] Caloz, C., Chang, C.C. and Itoh, T. (2001), "Full-Wave Verification of the Fundamental Properties of Left-Handed Materials in Waveguide Configurations", Journal of Applied Physics, vol. 90, 11, pp. 5483-5486.

[6] Smith, D.R., Padilla, W.J., Vier, D.C., Nasser, S.C., and Schultz, S. (2000), "Composite Medium with Simultaneously Negative Permeability and Permittivity", Physical Review Letters 1, vol. 84, 18, pp. 4184-4187.

[7] Lim, J.S., Kim, C.B., Jang, J.S., Lee, H.S., Jung, Y.H., Kim, J.H., Park, S.B., Lee, B.H. and Lee, M.S. (2008), "Design of a Subwavelength Patch Antenna Using Metamaterials", Proceedings of 38th European Microwave Conference (EuMC 2008), Amsterdam, pp. 1246-1249.

[8] Pendry, J.B., Holden, A.J., Robbins, D.J. and Stewart, W.J. (1999), "Magnetism from Conductor and Enhanced Non-Linear Phenomena", IEEE Transaction on Microwave Theory & Techniques, vol. 47, 11, pp. 2075-2084.

[9] Pradeep, A., Mridula, S. and Mohanan, P. (2011), "Design of an Edge -Coupled Dual-Ring Split-Ring Resonator", IEEE Antennas and Propagation Magazine, vol. 53, 4, pp. 45-54.

[10] Sindreu, M.D., Velez, A., Aznar, F., Siso, G., Bonache, J. and Martin, F. (2009), "Applications of Open Split Ring Resonators and Open Complementary Split Ring Resonators to the Synthesis of Artificial Transmission Lines and Microwave Passive Components", IEEE Transactions on Microwave Theory and Techniques, vol. 57, 12, pp. 3395-3403.

[11] Chen, H., Ran, L., Huangfu, J., Zhang, X. and Chen, K. (2004), "Left-Handed Materials Composed of Only S-Shaped Resonators", Physical Review, vol. 70, 5, pp. 1-4.

[12] Horestani, A.K., Fumeaux, C., Al-Sarawi, S.F. and Abbott, D. (2013), "Displacement Sensor Based on Diamond-Shaped Tapered Split Ring Resonator", IEEE Sensors Journal, vol. 13, 4, pp. 1153-1160.

[13] Joshi, J.G., Pattnaik, S.S., Devi, S., Lohokare, M.R. and Vidyasagar, C. (2009), "Offset Fed Diamond Shaped Split Ring (DSSR) Planar Metamaterial Antenna", Proceedings of IEEE Applied Electromagnetic Conference (AEMC-2009), Kolkata, pp. 1-4.