A Review on Meta-material based Micro strip Antenna

Shah Shefa
Department of Electronics & Communication
L.J. Institute of Engineering & Technology
Ahmedabad,India
shefashah20393@gmail.com

Nimesh Prabhakar
Department of Electronics & Communication
L.J. Institute of Engineering & Technology
Ahmedabad,India
nimpra28@gmail.com

Abstract— In today's communication Microstrip antenna has been widely used having an advantage of low weight, small size & low cost but it also has a disadvantage of having low gain, directivity, efficiency & has a narrow bandwidth. To overcome the limitation of having narrow bandwidth , a literature review on microstrip antenna using metamaterials has been discussed in this paper. Further paper describes introduction , basics of Metamaterial & its applications, design of various patch antenna using MTM structures & conclusion.

Keywords- *Circular polarisation, Left Handed Materials Microstrip antenna , Metamaterials, SRR.*

*****

I. INTRODUCTION

In today's wireless trends , the designing of an antenna should have a small size as well as easy to integrate with other components. So microstrip patch antenna has choosen for this prime importance. In order to overcome limitations of patch antenna i.e. low Gain & narrow Bandwidth various techniques has been carried out to improve its performance.[1]

In order to enhance the bandwidth various techniques such as increasing the height of substrate, thus lowering the Q factor, using multiple resonators in a single ground plane, using multiple layer configuration etc are used. All these techniques require large area, spurious feed radiations, surface wave production, and complicated structures which are not acceptable. Therefore these complications led to the invention of metamaterials.[2-4]

Metamaterial (MTM) are the material generated from artificial materials that are not found in nature but can be engineered. In the mid 1960s, Victor Veselago studied the behavior of such materials that show negative permittivity and permeability and hence are called double negative materials. These materials exhibit negative refractive index, since the structure consists of a Split Ring Resonators (SRR). SRR consists of two concentric rings with a split on opposite sides of rings. These structures provide high quality factor forming an electrically small LC resonator. Metamaterials find their uses in variety of applications.[3-5]

Section II describes basics of metamaterials , Section III describes design of various microstrip antenna using MTM, Section IV describes , Section IV conclusion made after studying various configuration of patch antenna over MTM structures.

II. BASICS OF METAMATERIALS

Metamaterials are artificially designed materials with properties different from the naturally occurring materials. Electric permittivity (ε) and magnetic permeability (μ) are the two basic parameters which describe the electromagnetic property of a material or medium. Permittivity describes how a material is affected when it is placed in electric field. And permeability describes how a material is affected in presence of magnetic field. Metamaterials may have either negative permittivity or permeability or both may be negative simultaneously. Metamaterial is an arrangement of periodic structures of unit cells in which the average size of a unit cell should be much smaller[6] than the impulsive wavelength of the light.

i.e., $a \ll \lambda$

Metamaterial was first introduced by Victor Veselago [7] in 1967 after the Second World War. He showed that wave propagation in metamaterial is in opposite direction than the naturally occurring materials. John Pendry [6] discovered a realistic way to design a material in which right handed rule is not applied. In this material, group velocity is antiparallel in direction to its phase velocity. Materials with negative permittivity such as ferroelectrics were available in nature but materials with negative permeability did not exist in nature.

In fig 1. Pendry showed that the negative permittivity could be achieved by aligning metallic wires along the direction of a wave whereas negative permeability by placing split ring with its axis along the direction of propagation of wave .

Figure 1. Combination of Alternating Layers of Thin Metallic Wires and Circular Split Rings

1. Properties of Metamaterial

Consider the Maxwell's first order differential equations,

$$\nabla \times E = -j\omega\mu H \qquad (1)$$

$$\nabla \times H = j\omega\epsilon E \quad (2)$$

Where ω is an angular frequency.

For a plane-wave electric & magnetic fields like

$$E = E_0 e^{(-jk.r+j\omega t)} \quad (3)$$

$$H = H_0 e^{(-jk.r+j\omega t)} \quad (4)$$

where k is a wave vector, the equations (1) and (2) will become

$$k \times E = \omega\mu H \quad (5)$$

$$k \times H = -\omega\epsilon E \quad (6)$$

For simultaneous positive values of ε and μ, the vectors E, H and **k** make a right handed orthogonal system[11]. There will be forward wave propagation in this medium.
For simultaneous negative values of ε and μ, equations (5) and (6) can be rewritten as

$$k \times E = \omega|\mu|H \quad (7)$$

$$k \times H = \omega|\epsilon|E \quad (8)$$

And the vectors E, H and **k** make a left-handed orthogonal system.
Energy flow is determined by the real part of the Poynting Vector.

$$S = \frac{1}{2} E \times H^*$$

For simultaneous change of sign of permittivity and permeability, the direction of energy flow is not affected, therefore, the group velocity will be positive for both left-handed and right-handed system. Refractive index is given as

$$n = \pm\sqrt{\epsilon\mu}$$

And phase velocity is given as

$$v_p = \frac{c}{n}$$

where c is the velocity of light in vaccum.

For right handed system, n is positive, thus the phase velocity will be positive. Therefore, energy and wave will travel in same direction resulting in forward wave propagation.

For left-handed system, n is negative, thus the phase velocity is negative. Hence the direction of energy flow and the wave will be opposite resulting in backward wave propagation [9]. Backward waves may commonly appear in non-uniform waveguides [10,11]. Figure 2 shows the right-handed system and left-handed system in left and right respectively.

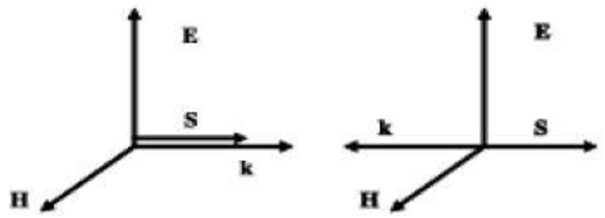


Figure 2. Left: Right Handed System and Right: Left Handed System [8]

2. Types of Metamaterials:

The metamaterials are classified on the basis of permittivity and permeability as shown in Figure 3.

In Figure 3, Quadrant 1 represents the materials with simultaneously positive value of permittivity and permeability both. It covers mostly dielectric materials. Quadrant 2 represents the materials with negative permittivity below plasma frequency and positive permeability. It covers metals [12-15], ferroelectric materials, and extrinsic semiconductors. Quadrant 3 represents the materials with simultaneously negative value of permittivity and permeability both. No such material is found in nature. Quadrant 4 represents the materials with negative permeability below plasma frequency and positive permittivity. It includes ferrite materials.

In recent trends, Metamaterials are used for making invisible cloak. Metamterial control the propogation such that it can bend light around object. If the light is not reaching at the object , we can't see the object & it becomes invisible to us. The incident waves are guided around object & it is still present in its location but we can't see it. The incident rays recover their original path at the other end.

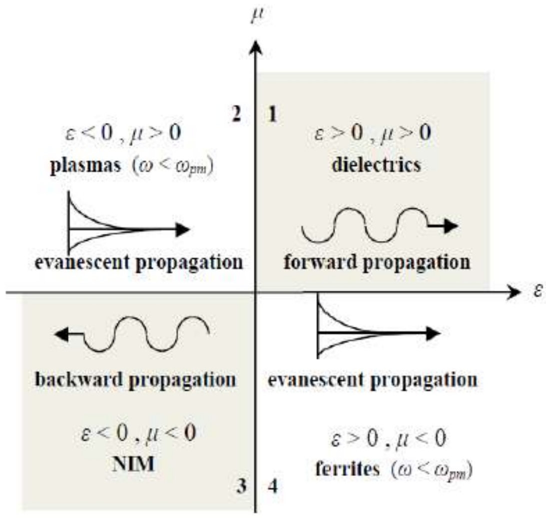


Figure 3. Classification of Metamaterial on the Basis of Permittivity and Permeability

Figure 4. Example of Cloaking Effect

There are various issues while designing a path antenna like compact size, gain improvement, directivity enhancement , increased bandwidth, suppressed side lobes etc. Metamaterial are being used for improving the performance of conventional patch antennas.

III. SURVEY OF VARIOUS MICROSTRIP ANTENNA USING MTM

This section describes a various configuration of MTM structures with patch antenna to increase the performance of an conventional patch antenna. Later comparison is made between antenna parameters such as gain & bandwidth of an patch antenna with Metamaterial and without Metamaterial.

Y.Dong *et al*., used a RIS reactive impedance surface on a substrate as a Metamaterial[16]. He has discussed a Metamaterial inspired low profile patch antenna for CP circular polarized radiation in his paper. The antenna has a single feed configuration and loaded with composite left /right handed (CRLH) mushroom like structure & RIS structure for miniaturization purpose. RIS unit cell is placed at an height of 2.6mm on “Megtron 6” substrate. Using a single fed patch antenna is loaded with RIS & CRLH resonators and radiation characteristics are carefully investigated. The proposed antenna exhibit at 2.58GHz frequency.

The measured 10 dB return loss and 3-dB axial ratio bandwidths of an antenna was found to be 4.62% and 1.46%.the gain of an antenna is 2.98dBic.The proposed antenna is applicable for wireless networks such as WLAN.

Y.Dong *et.al*., used a same structure as in [16] but instead of CRLH mushroom structure , pair of CSRR complementary split ring resonators are used for proposed CP antenna. CSRR worked as a shunt LC resonator providing a low resonance frequency and able to miniaturize the antenna size. The measured 10 dB return loss and 3-dB axial ratio bandwidths of an antenna was found to be

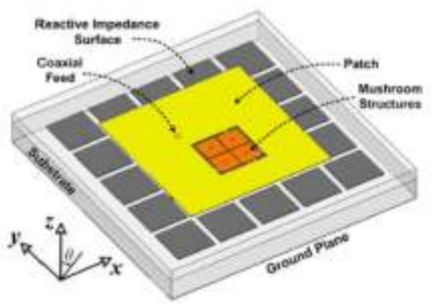


Figure 5. Perspective view of a proposed CP patch antenna with RIS & mushroom like CRLH[16]

4.9% and 1.68% and Gain is 3.7dBic. The proposed antenna exhibit at 2.8GHz frequency. [17]

H.X.Xu et al., proposed a single feed CP patch antenna based on strategy of combining meta-surfaces and meta-resonators owing strong filling capability. Antenna comprise a slot loaded square patch printed over a well designed reactive impedance surface for improved antenna performance and size reduction. The antenna is designed at a frequency of 3GHz exhibit a comparable impedance and axial ratio bandwidth over 1.05% and a high gain of more than 4.15dBic[18]. The proposed antenna is applicable for portable and handheld communication systems.

The complementary crossbar fractal tree (CCFT) slot and three-turn complementary spiral resonators (TCSRs) with asymmetric gap orientation are employed as meta-resonators to render the antennas to radiate CP waves in single-band or dual-band operation and to facilitate further miniaturization.[18]

K.Agarwal et al., in his paper showed a compact asymmetric/symmetric slotted/slit microstrip patch antenna on RIS was presented and studied for CP radiation. The antenna is made on FR4 substrate at 2.5GHz frequency having overall volume is $0.292\lambda_0 \times 0.292\lambda_0 \times 0.0308\lambda_0$.[19]

The measured results of the compact asymmetric cross slotted square patch antenna are 1.6% for 3-dB axial ratio bandwidth, 5.2% for 10-dB return loss bandwidth and 3.41dBic for gain over 3-dB axial ratio bandwidth.

L.Bernard et al., presented a wideband antenna based on RIS having CP radiation. A reduced-size wideband single-feed circularly polarized patch antenna is introduced for telemetry applications in-band around 2300 MHz. The proposed structure consists of a slot-loaded patch antenna printed over an optimized Metamaterial-inspired reactive impedance substrate (RIS). They demonstrated, step by step, the main role of each antenna element by comparing numerically and experimentally the performance of various antenna configurations: antenna over a single- or dual-layer substrate, standard patch or slot-loaded patch, antenna with or without RIS. The final optimized structure exhibits an axial-ratio bandwidth of about 15% and an impedance bandwidth better than 11%, which is much wider than the conventional printed antenna on the same materials.[20]

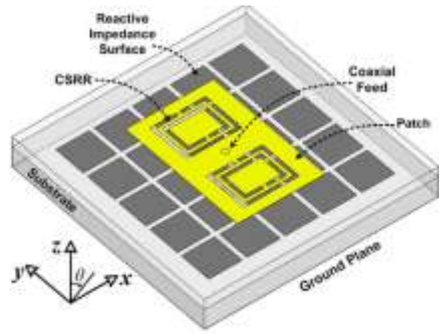
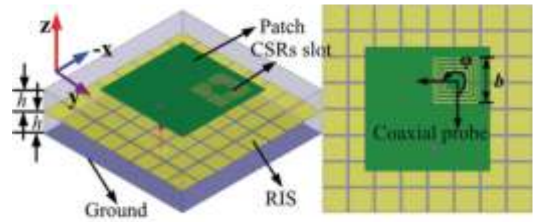
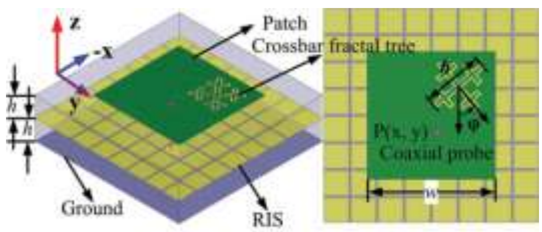


Figure 6. Perspective view of a proposed CP patch antenna with RIS and CSRR[17]



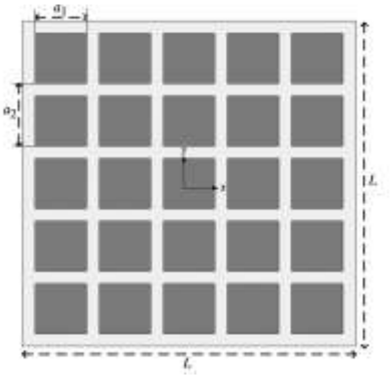
(a)



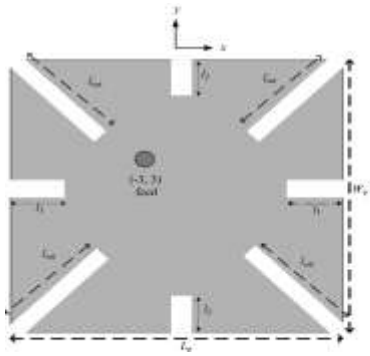
(b)

Figure 7. Perspective view of proposed MTM antenna based on (a)TCSRs (b)CCFT[18]

ISSN: 2321-8169
123 – 127



(a)



(b)

Figure 8. (a) Top view of 5*5 unit cell of RIS and (b) configuration of asymmetric-slit nearly square patch[19]

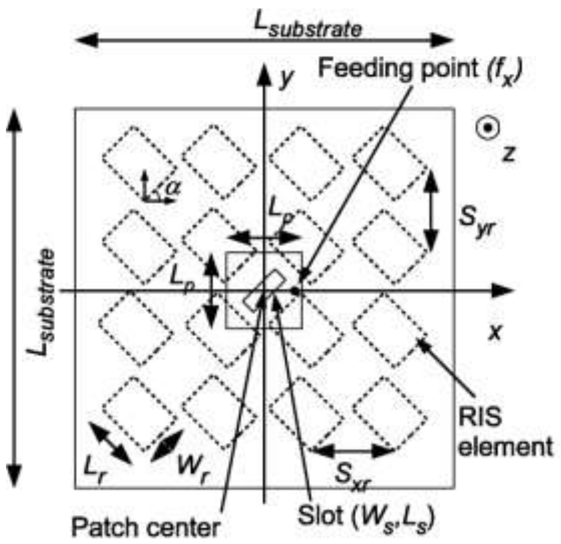
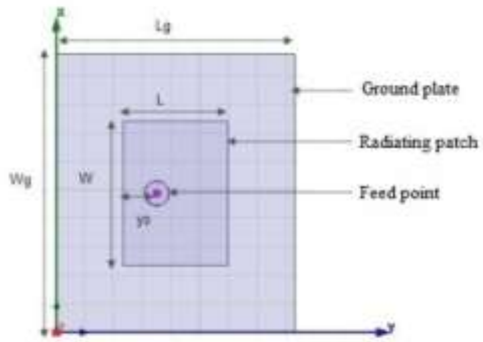
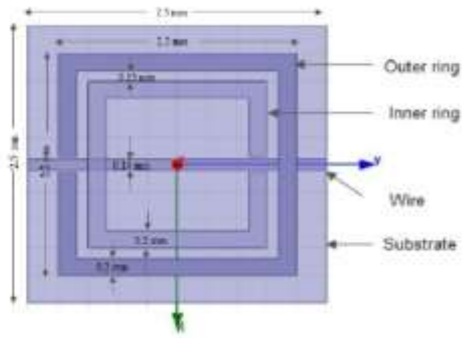


Figure 9. Top view of proposed slot antenna on RIS [20]



(a)



(b)

Figure 10. (a)Top view of patch antenna (b) SRR+ Thin wire unit cell[21]

Fig 10 shows that P.Paswan et.al., presented coaxial feed rectangular microstrip patch antenna along with left-handed metamaterial (LHM) cover.[21] The Proposed metamaterial cover increases the gain and directivity of the antenna in comparison to conventional microstrip patch antenna alone. The antenna has been designed for 8-10 GHz, hence it can be used for X-band application. S-Parameters ($S11$ and $S22$) are used for verifying the double-negative properties of the proposed metamaterial cover. The proposed antenna is simulated by using Ansoft HFSS

IV. CONCLUSION

In this review paper, the basics of Metamaterial with its properties have been studied. Also the application of Metamaterial- cloaking has been discussed . In this paper, various configuration of MTM structures over patch antenna has been discussed which improves performance of various antenna parameters such as gain , bandwidth, efficiency, directivity. From the survey carried on microstrip patch antenna using MTM found very promising in achieving the better performance of patch antenna over conventional antenna. It shows very attractive feasibility in radiation characteristics of an antenna.

REFERENCES

[1] Anisha Susan Thomas, Prof A.K. Prakash, "A Survey on Microstrip Patch Antenna using Metamaterial", International Journal of Advanced Research in Electrical, Electronic and Instrumentation Engineering, pp. 6289-6294, 2013.

[2] Atul Kumar, Nitin Kumar, Dr. SC Gupta, "Review on Microstrip Patch Antennas using Metamaterials", International journal of Engineering Research and General Science Vol. 2, Issue 4, pp.678-682, 2014.

[3] Kushwaha R S, Srivastava D K, Saini J P and Dhupkariya S. Bandwidth enhancement for microstrip patch antenna with microstrip line feed. 2012 3rd IEEE International conference on computer and communication technology (ICCCT), Allahabad, 183-185, 2012.

[4] Rupleen Kaur, Satbir Singh, Naveen Kumar, "A Review of Various Fractal Geometries for Wireless Applications", International Journal of Electronics and Electrical Engineering, pp. 34-36, 2015.

[5] G.K. Pandey, H.S. Singh, P.K.Bharti, M.K. Meshram, " Metamaterial based Ultra Wideband Antennas", IEEE Electronic Letters, pp. 1266-1268, 2014.

[6] J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, ‘‘Magnetism from Conductors and Enhanced Non- Linear Phenomena", IEEE Trans. Microwave Theory Tech., vol. 47, **(1969)**, pp. 2075-84.

[7] V. G. Veselago, "The Electrodynamics of substances with simultaneously negative value of epsilon and mu", Soviet Phys. Usp., vol. 10, no. 4, **(1968)**, pp. 509-514.

[8] R. Marques, F. Martin and M. Sorolla, "Metamaterials with Negative Parameters: theory, Design and Microwave Applications, Wiley Series in Microwave and Optical Engineering", Wiley-Blackwell, **(2008)**.

[9] C. Caloz, H. Okabe, H. Iwai and T. Itoh, "Transmission line approach of left-handed metamaterials", Proc. USNC/URSI Nat. Radio Sci. Meeting, **(2002)**, pp. 39, San Antonio, TX.

[10] P. A. Belov, R. Marque´s, S. I. Maslowski, I. S. Nefedov, M. Silveirinha, C. R. Simovski and S. A. Tretyakov, "Strong spatial dispersion in wire media in the very large wavelength limit", Phys. Rev. Lett., vol. 67, paper 113103, **(2003)**.

[11] L. D. Landau, E. M. Lifshitz and L. P. Pitaevskii, "Electrodynamics of Continuous Media Pergamon", New York, **(1984)**.

[12] J. B. Pendry, A. J. Holden, W. J. Stewart and I. Youngs, "Extremely Low Frequency Plasmons in Metallic Meso Structures", Phys. Rev. Lett., vol. 76, **(1996)**, pp. 4773-4776.

[13] J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, "Low Frequency Plasmons in Thin Wire Structures," J. Phys. [Condensed Matter], vol. 10, **(1998)**, pp. 4785-4809.

[14] D. F. Sievenpiper, M. E. Sickmiller and E. Yablonovitch, "3D Wire mesh photonic crystals", Phys. Rev. Lett., vol. 76, **(1996)**, pp. 2480-2483.

[15] D. F. Sievenpiper, E. Yablonovitch, J. N. Winn, S. Fan, P. R. Villeneuve and J. D. Joannopoulos, "3D Metallo-Dielectric Photonic Crystals with Strong Capacitive Coupling between Metallic Islands", Phys. Rev. Lett., vol. 80, **(1998)**, pp. 2829-2832.

[16] Y. Dong, H. Toyao, and T. Itoh, "Compact circularly polarized patch antenna loaded with metamaterial structures," *IEEE Trans. Antennas Propagat.*, vol. 59, no. 11, pp. 4329–4332, Nov. 2011.

[17] Y. Dong, H. Toyao, and T. Itoh, "Design and characterization of miniaturized patch antennas loaded with complementary split-ring resonators," *IEEE Trans. Antennas Propagat.*, vol. 60, no. 2, pp. 772−785, Feb. 2012.

[18] H. X. Xu, G. M. Wang, J. G. Liang, M. Q. Qi, and X. Gao, "Compact circularly polarized antennas combining metasurfaces and strong space-filling meta-resonators," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 7, pp. 3442−3450, July 2013.

[19] K. Agarwal, N. Nasimuddin, and A. Alphones, "RIS based compact circularly polarized microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 2, pp. 547–554, Feb. 2013.

[20] L. Bernard, G. Chertier, and R. Sauleau, "Wideband circularly polarized patch antennas on reactive impedance substrates," *IEEE Antennas Wireless Propagat. Lett.*, vol. 10, pp. 1015−1018, Oct. 2011.

[21] Pradeep Paswan, Vivekanand Mishra, P. N. Patel, Surabhi Dwivedi, "Performance Enhancement of Coaxial Feed Microstrip Patch Antenna Using Left-Handed Metamaterial Cover," IEEE Students' Conference on Electrical, Electronics and Computer Science., 2014.

[22] D. Smith, D. Vier, T. Koschny, and C. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Physical Review E*, vol. 71, no. 3, p. 036617, 2005.