

A Survey of Techniques used for Performance Enhancement of Patch Antenna using Metamaterials

Preet kaur¹, Dr.S.K.Aggarwal², Dr.Asok De³

^{1,2}(Electronics Department, YMCA University of Science and Technology, India) ³(Director, National Institute of Technology Patna(Bihar), India)

Abstract: Metamaterial is a composite material that is artificially designed by arranging its unit cell in a periodic manner that provides it with unusual electromagnetic properties. In addition these materials have broad frequency range coverage making it further beneficial. It is due to these reasons; metamaterials have gained popularity in the recent past. In the last few years, compact and improved performance antennas are designed using metamaterials for microwave frequency range. Patch antenna is one such type and is very much suitable for modern applications in microwave range. Therefore, in this paper we provide a comprehensive study of metamaterial inspired patch antennas used in the last decade. Also, their pros and cons are discussed in this paper. At the last we provide open issues and challenges that may help researchers working in this direction.

Keywords: Metamaterial, Patch antenna, Performance enhancement, SRR(Split Ring Resonator)

I. Introduction

Metamaterials are artificially designed materials with basic properties like permittivity (ϵ) and permeability (μ) which describe the electromagnetic behaviour of a material or medium are different from the naturally occurring materials. These materials can be synthesised by arranging the periodic structures of unit cells. The average size a of unit cell (a) should be much smaller [1] than the impulsive wavelength (λ) of the light.

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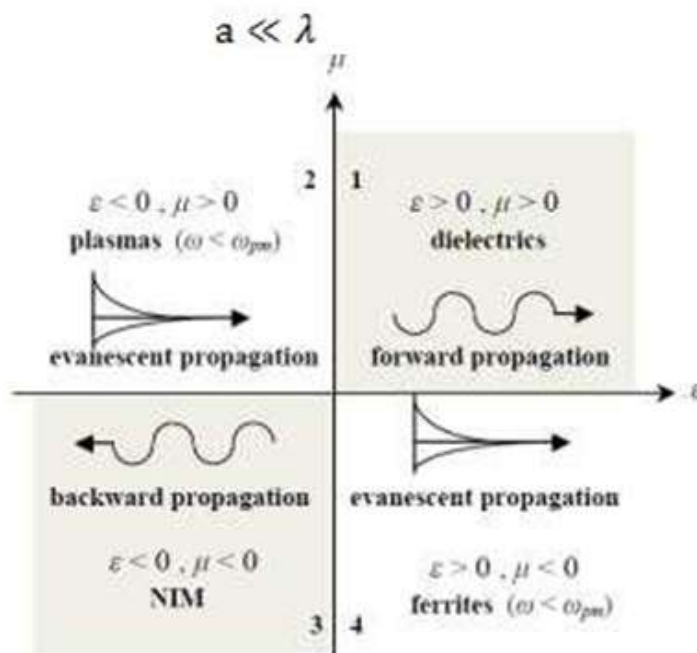


Fig. 1: Material characterized by electric permittivity (ϵ) and magnetic permeability (μ)

Based on the sign of permittivity and permeability, the materials can be divided into four categories. As seen from the Fig. 1, meta-materials may have either negative permittivity or permeability or both.

- Quadrant 1: This region contains dielectric material not meta-materials that are naturally occurring. The region has positive permittivity and permeability.
- Quadrant 2: This region has negative permittivity and positive permeability value. These materials represent the class of meta-materials known as artificial dielectrics. Due its highly negative dielectric value, these materials can be used for reducing the size of antennas.
- Quadrant 3: This region represents the meta-materials with simultaneously negative permittivity and permeability. These are called left handed materials since due to backward wave propagation.
- Quadrant 4: This region represents the materials with negative permeability below plasma frequency and positive permittivity value. This class of meta-materials is called artificial magnetic. These meta-materials can be used to increase the gain and to reduce the size of antenna.

In this paper, use of meta-materials in the patch antennas is presented. In addition, the paper also discusses about the nearby future challenges that needs to be addressed by the researchers. The rest of the paper is organised as follows: Section 2 gives the history of development of meta-materials. Section 3 gives its basic characteristics and types. Section 4 describes the challenges faced in designing the patch antenna. Also, it provides the solution to these designing problems using metamaterials as proposed by various researchers in the last decade. Section 5 gives the open issues and challenges followed by conclusion and references.

II. History of Meta materials

In 1946, Kock was first to suggest an artificial dielectric antenna lens [1]. In 1962 rotman and in 1968 smith has presented the work on artificial electric plasma produced using parallel plate and wire media respectively. In 1968, Victor Veselago [2] published the work about the electrodynamics of material with negative permittivity and permeability without practical realization and application of these material. J.B.pendry et.al. had shown firstly the realization of negative permittivity medium at microwave frequency using 2D matrix of thin wire medium [3] and in the subsequent paper[4], Pendry and his co-workers extended this idea to 3D wire net, by which the isotropic behaviour was achieved . In 1999 , pendry et.al published[5] the most significant publication in metamaterial, in which they had proposed the split ring resonator (SRR) , a resonant practical, which is constituent of artificial negative permeability media. SRR practical is equivalent to an LC oscillator consisting of a magnetic coil with inductance L and a capacitor with capacitance C. if the frequency of incident wave is slightly higher than the LC- resonance frequency, the effective permeability of SRR array will be definitely negative.

After this pivotal work, Smith et al. [6] had presented the first implementation of left handed (LH) media by superimposing the SRRs with negative permeability and metallic wires with negative permittivity and subsequently the experimental demonstration of negative refraction was demonstrated in [7] by Shelby et al.

After these work, medium with negative permittivity and negative permeability has attracted a great attention of researchers with the emphasis on subject of electromagnetics. They have been considered for use in wide variety of radiating and guiding structures [8-10]. In this paper, we have focused on the potential application of metamaterial to resolve the designing issues of patch antenna and its array. The brief overview of properties and types of metamaterials is presented and the technical literature presenting the patch antenna design and its performance enhancement using these materials is also discussed.

III. Basic characteristics of Metamaterial

The electromagnetic properties of the materials, the dielectric permittivity (ϵ) and the magnetic permeability (μ) determine how the electromagnetic waves propagate through a material. To understand the propagation of electromagnetic waves through the metamaterial, let start with the Maxwell's first order differential equations.

$$\nabla \times \mathbf{E} = -j\omega\mu \mathbf{H} \tag{1}$$

$$\nabla \times \mathbf{H} = -j\omega\mu\mathbf{E} \tag{2}$$

where ω is the angular frequency. For plane-wave electric and magnetic fields like

$$\mathbf{E} = \mathbf{E}_0 e^{(-jk \cdot r + j\omega t)} \tag{3}$$

$$\mathbf{H} = \mathbf{H}_0 e^{(-jk \cdot r + j\omega t)} \tag{4}$$

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

$$\mathbf{k} \times \mathbf{E} = \omega\mu\mathbf{H} \tag{5}$$

$$\mathbf{k} \times \mathbf{H} = -\omega \epsilon \mathbf{E} \tag{6}$$

For simultaneous positive values of ϵ and μ , the vectors \mathbf{E}, \mathbf{H} and \mathbf{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

$$\mathbf{k} \times \mathbf{E} = -\omega |\mu| \mathbf{H} \tag{7}$$

$$\mathbf{k} \times \mathbf{H} = \omega |\epsilon| \mathbf{E} \tag{8}$$

vectors \mathbf{E}, \mathbf{H} and \mathbf{k} make a left handed orthogonal system. Energy flow is determined by the real part of the Poynting Vector \mathbf{S}

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

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 vacuum.

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 as shown in Fig 2(a).

For left handed system, n is negative, thus the phase velocity is negative. Hence the direction of energy flow and wave will be opposite resulting in backward wave propagation [12] as shown in Fig 2(b). Backward waves may commonly appear in non-uniform waveguides [13][14].

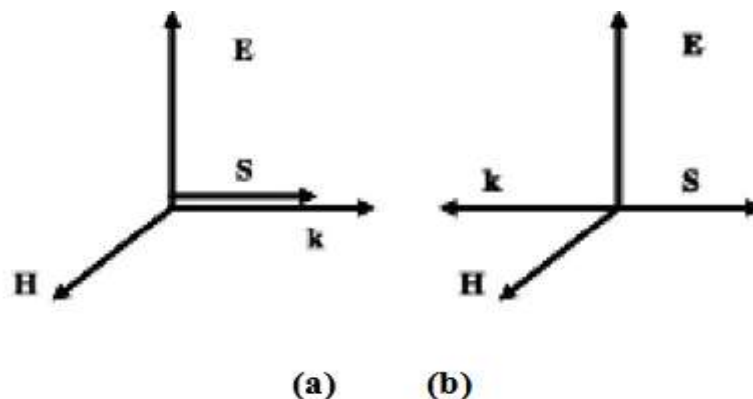


Fig. 2 (a) Right handed system (b) Left handed system

IV. Types of Metamaterial

Depending upon the sign of permittivity and permeability, metamaterials are broadly classified into artificial dielectric, artificial magnetics and left handed materials. Chiral metamaterials are also the type of metamaterial which lacks mirror symmetry in its structure. All these types of metamaterial are discussed in detail below.

1. Artificial dielectrics:

These materials have negative permittivity and positive permeability (Quadrant II in Fig. 1) and these are also called epsilon negative material (ENG). Noble materials like gold or silver have a negative permittivity at very high frequencies but these materials also have an extremely large conductivity (or imaginary part of permittivity). There is a substantial absence of materials with largely real and negative permittivity in the microwave regime. The metamaterial with negative permittivity in microwave and other regions can be generated artificially by arranging thin rods or cylinders in cubic lattice structure such that lattice constant of the structure and diameter of rods are small as compared to operating wavelength as shown in Fig 2. When the electric field is applied parallel to the axis of rods, structure shows the negative permittivity below plasma frequency as shown in Fig. 3 and plasma frequency $\omega_{p,eff}$ is given by

$$\omega_{p,eff}^2 = \frac{2\pi c^2}{d^2 \ln(\frac{d}{r})} \quad \epsilon_{eff} = 1 - \frac{\omega_{p,eff}^2}{\omega(\omega + i\gamma_{eff})}$$

Where γ_{eff} the effective damping factor, p is distance between rods and r is the radius of rod. The effective permittivity [19] of such medium is given as

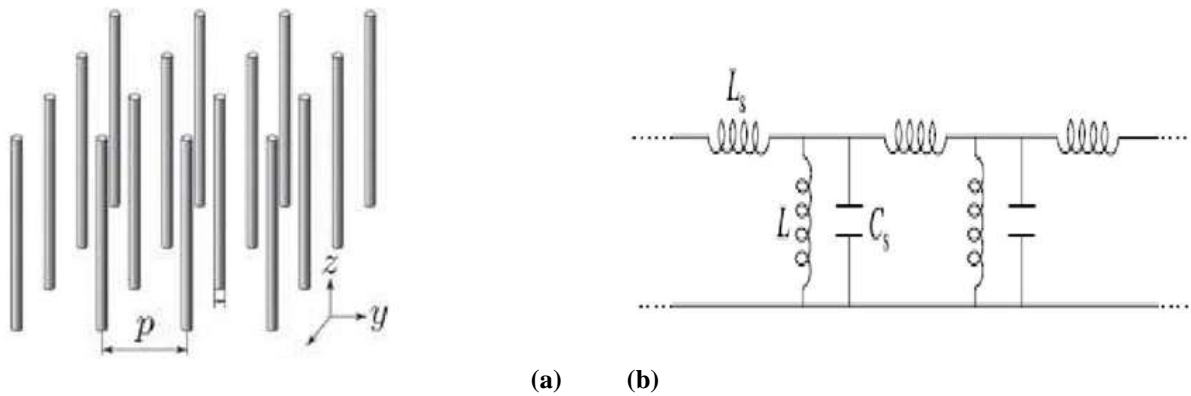


Fig. 3 (a) An array of metallic cylinders (b) transmission line model of rodded medium (c) plot of ϵ_{eff} versus frequency

The modified structure of SRR [11] as shown in Fig. 4(a) also gives negative permittivity. The equivalent circuit of this proposed structure consist of two symmetric inductive loop connected to common capacitor as shown in Fig. 4(b). At resonance, magnetic moment associated with currents in both loop cancel each other and have a large electric polarizability.

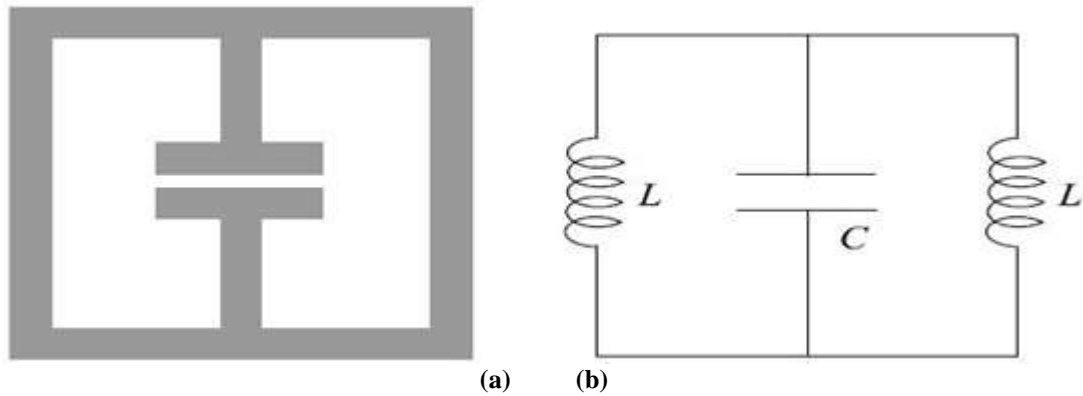


Fig4: (a) Electric coupled field resonator (b) Equivalent structure of electric coupled resonator

2. Artificial magnetics: These materials have negative permeability and positive permittivity (Quadrant IV in Fig. 1) and these are also called mu negative material (MNG). Artificial magnetics exhibits negative permeability below plasma frequency.

A stack of edge-coupled split rings (EC-SRR) displays negative permeability as shown in Fig. 5.

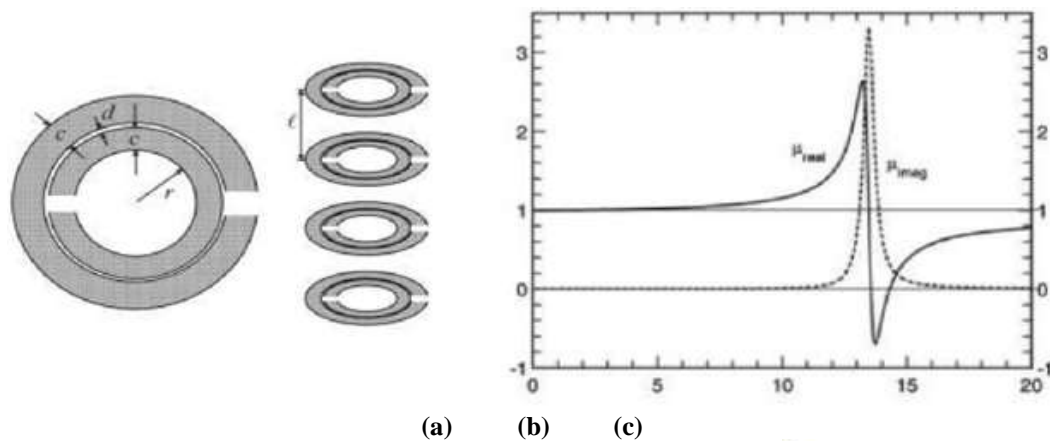


Fig. 5 (a) Simple View of Split Ring (b) Split Rings in Stack (c) Plot of μ_{eff} versus frequency[1]

EC-SRR consist of two concentric metallic split rings are printed on a dielectric substrate [11] as shown in Fig. 6. When a time varying external magnetic field is applied to it along the z-direction, the electric current starts flowing from one ring to another through slots between them. The slots between the rings acts as distributed capacitance. The equivalent circuit is shown in Fig. 6(b), where C is the capacitance associated with each EC-SRR half and L is self-inductance of EC-SRR.

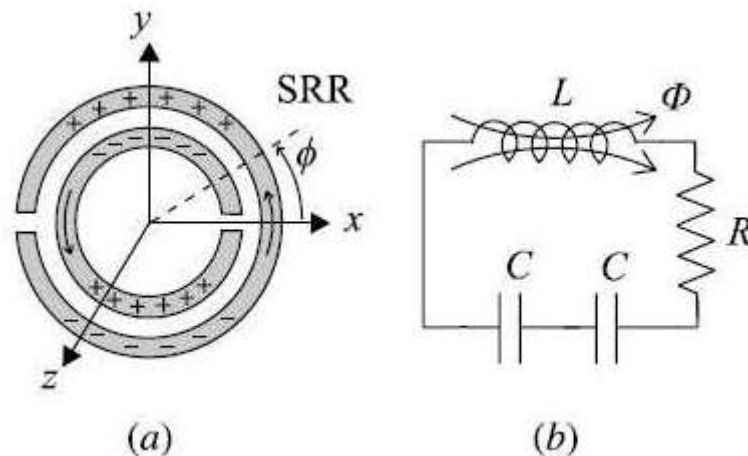


Fig. 6 (a) EC-SRR (b) Equivalent Circuit

Effective permeability [19] of stack of EC-SRR is given as

$$\mu_{eff} = 1 - \frac{F \omega^2}{\omega^2 - \omega_0^2 + i\Gamma\omega}$$

where F represents the filling ratio of split ring resonator and l is lattice constant.

$$F = \frac{\pi r^2}{l^2}$$

ω_0 is the resonance frequency

$$\omega_0 = \sqrt{\frac{3lc^2}{\pi^2 r^3}}$$

and Γ represents the damping term

$$\Gamma = \frac{2}{r\sigma\mu_0}$$

To avoid bi-anisotropy of EC-SRR, broadside-coupled (BC-SRR) is proposed. It consists of metallic rings printed on the both sides of the dielectric substrate as shown in Fig 7(a). Since the charge distribution in it does not form a net electric dipole, therefore, it is non bianisotropic. Thus it eliminates EC-SRR bianisotropy. It has smaller electrical size than EC-SRR. Equivalent circuit of BC-SRR as shown in Fig 7(b) is same as that of EC-SRR.

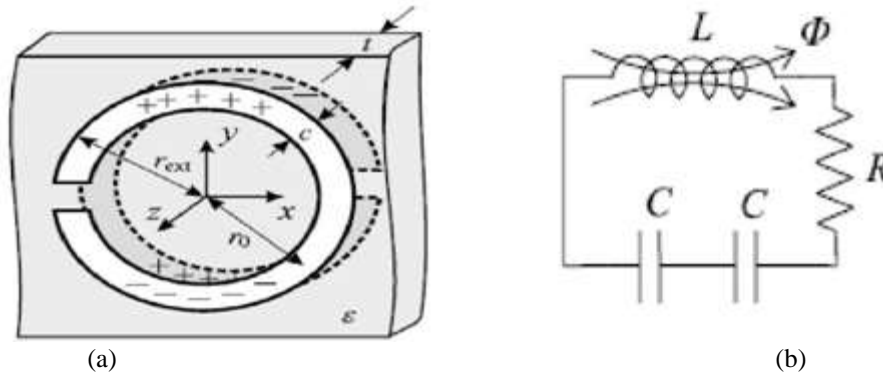


Fig. 7 (a) BC-SRR (b) Equivalent Circuit

3. Negative-index material (NIM):

Refractive index of an electromagnetic responsive material mainly depends on its permittivity and permeability.

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

When either ϵ or μ is negative, then refractive index will be purely imaginary resulting in evanescent waves. When both the parameters are positive, the refractive index is positive and thus results in forward wave propagation. When both the parameters are negative, the refractive index will be negative resulting in backward wave propagation. The materials with simultaneous negative permittivity and permeability (Quadrant III in Fig. 1) are called Negative-index materials(NIM). These are also called left handed materials.

The combination of alt alternating layers of thin metallic wires and circular split rings, Omega shaped [20], S shaped structures[20], I shaped structures[21], Double H shaped[22]structures etc. as shown in Fig 8 exhibits negative index Of refraction.

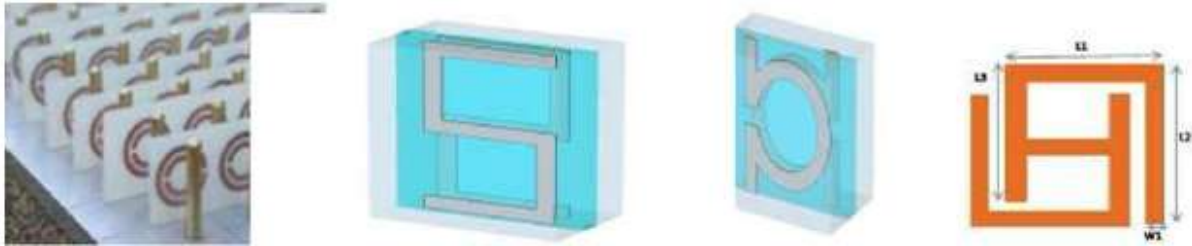


Fig.8 Negative refractive index metamaterials

4. Chiral materials:

Chiral material is comprised of particles whose mirror images cannot be superimposed as shown in Fig. 9. It is different from electromagnetic metamaterials in which both ϵ and μ are required to be negative for achieving negative index of refraction. But in chiral materials, either ϵ or μ or both are not required to be negative. We can achieve negative refraction in chiral materials

by having strong chirality.

For chiral material, refractive index \tilde{n} is

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

where κ is chirality parameter. It defines the cross coupling effect between the electric field and magnetic field when going through chiral material. Because of its chiral asymmetry property, it reacts different for left circularly polarized and right polarized waves[23].

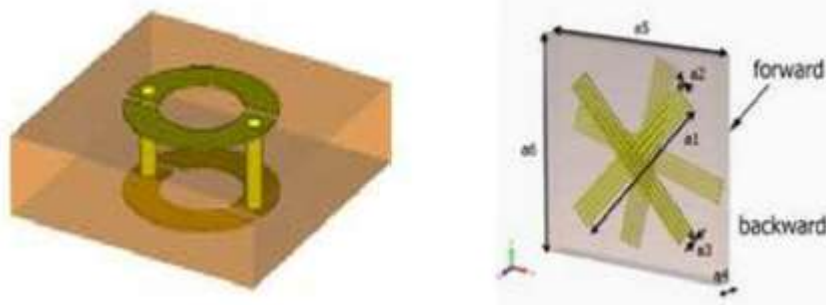


Fig 9: Chiral Metamaterial

V. Challenges faced in designing of microstrip patch antenna and performance enhancement using metamaterials

4.1 Challenges in designing of patch antenna

Microstrip patch antenna is suitable for modern communication application. These antennas are easy to fabricate, but there are some challenges in designing of patch antennas as discussed below.

1. Size of patch antenna: Transverse dimension of patch antenna depends on resonant frequency and hence these cannot be made arbitrarily small.
2. Narrow bandwidth
3. Low gain and directivity
4. Low efficiency
5. Side lobe level

4.2: Performance enhancement of patch antenna using metamaterials

Metamaterials can provide the solution to above design problems and can be used to improve the performance of conventional patch antennas. In following section, technique used by various researchers for improving the performance parameters like gain, directivity, bandwidth, suppression of side lobe & back lobe, efficiency etc. and compactness of patch antenna using metamaterial is discussed and explained.

4.2.1 Directivity and Gain Enhancement:

Metamaterials have the interesting feature of controlling the direction and power of emission of patch antenna in small solid angle. The technique for directivity and gain enhancement is that when the resonant frequency is equal to plasma frequency, the effective permittivity or permeability will be zero and hence the refractive index n will also become zero.

$$\text{Refractive index } n = \sqrt{\epsilon_{\text{eff}} \mu_{\text{eff}}} = 0$$

If a source is embedded in a substrate with zero index of refraction, then according to Snell's law, the exiting ray from substrate will be very close normal to the surface. Then all the refracted rays will be in almost the same direction around the normal. Therefore, the closer the operating frequency is to the plasma frequency, the better directivity can be achieved.

Enoch et al. has used metamaterial as substrate [24] and has showed how the characteristics of metamaterial can change the emission of an embedded source. The layers of copper grids separated by foam were used as metamaterial. This metamaterial possessed the plasma frequency at about 14.5 GHz. It has the best directivity at 14.65 GHz. Since the metamaterial has a plasma frequency at about 14.5 GHz, the index of refraction is close to zero at this frequency. According to Snell's law, the refracted ray from the metamaterial will be very close to the normal of it. Hence we obtain the best directivity at 14.65 GHz.

I. Wu. used the same technique for obtaining high directivity[25] as used in [24]. The periodic structures of rods, or of both rods and rings are used as metamaterial. Ground planes are not used there. He used the different methodology and the process of analysis than [24].

Y. G. Ma represented that the directivity of an EM emission could be more improved by embedding the source in an anisotropic metamaterial with either effective permittivity or effective permeability nearly zero [26]. The difference between this[26] and the technique of Enoch et al. [24] lies in the problem of impedance mismatch between the ϵ -near-zero (ENZ) matrix and surrounding air. The metamaterial used is anisotropic with effective permittivity near zero, allowing it to match the surrounding media at the proper polarizations. It is shown that the high directivity can be supported by this anisotropic matrix [27].

R. Khajeh Mohammad Lou used two types of metamaterial superstrates [28] to increase directivity, gain and bandwidth. Directivity enhancement is based on zero index refraction phenomenon. The radiation energy of patch antenna is concentrated near zero index refraction. The S coupled and Double split rings are used as metamaterial superstrates. Using 5×7 array of the coupled S- shaped structures, the near zero refractive index is observed in the frequency range 13.5-17.5 GHz. Hence the radiated energy will be concentrated in this frequency range and directivity will be maximum. A 6×7 array of Double split ring structures near zero refractive index was also used. The metamaterial superstrate layer is placed about one third of operating wavelength i.e. $\lambda/3$ above ground plane to increase the gain. Bandwidth can be improved by using two metamaterial superstrate layers. The gap between the first layer and second layer is from $\lambda/3$ to $\lambda/2$.

Bimal Garg presented a "Pentagonal Rings" shaped metamaterial cover[29] to enhance the gain and directivity of microstrip patch antenna. The designed metamaterial has negative values for both effective permittivity and permeability. The metamaterial cover is placed at a height of 3.2 mm from the ground plane. As left handed metamaterial has the property of focusing radiations of antenna [30][31], the directivity has been increased about 2.019 dB and the gain has improved.

H. Attia represented magneto-dielectric superstrates[32] to improve gain of microstrip antenna array. The gain was improved without any substantial increase in antenna size. The superstrate was designed of SRR unit cells. The effective permittivity and permeability both are positive for this superstrate material. A 4×1 antenna array is used with magneto dielectric superstrate to achieve gain enhancement of about 3.5 dB. The gain enhancement depends on the distance between the patches and superstrates. This technique is better than the techniques which used EBG based superstrates [33][34] as it resulted low antenna profile.

Le-Wei Li used the completely different approach[35] to enhance the bandwidth and gain of a conventional patch antenna. He applied the planer metamaterial patterned structures directly on the upper patch and bottom ground of the substrate. Periodically distributed isolated microtriangles gaps are designed on the upper patch and the periodically distributed cross strip gaps are designed on the bottom ground plane. A capacitive-inductive equivalent circuit is formed by the coupling of upper patch and bottom ground plane. Thus, a backward wave is induced which travels along the plane of patch. Therefore, the radiation along the patch direction is enhanced which in turn increases the bandwidth and gain.

Osama M. Haraz presented the two different techniques for gain and directivity enhancement[36]. In first technique, the metallic ground is suspended underneath the monopole antenna. Gain of the monopole antenna can be increased by controlling the dimensions of suspended ground. Using appropriate dimensions, it can work as a reflector and produce a unidirectional broadside radiation patterns. Gain is increased about 3 dB using suspended ground as compared to that of conventional antenna. There is also a shift of resonance frequencies towards lower frequencies, so it has also become compact. In second technique, a metamaterial superstrate with metallic printed strips is used to increase the gain and directivity. A metamaterial superstrate with metallic printed strips on its lower side is placed above the monopole antenna at a distance about 11 mm above the ground. Gain enhancement about 3 dB is achieved by adding superstrate.

Zhongqing Wang designed a left handed metamaterial cover[37] to enhance the gain and directivity of antenna. This left handed metamaterial cover is designed with a microstrip line two symmetrical triangular split ring resonators printed on the substrate. There are also two gaps cut on the metal ground plane which makes it DGS. This left handed metamaterial cover has negative permittivity and permeability in various frequency bands. When the left handed metamaterial cover is placed above the antenna, the gain and directivity of antenna increases and resonant frequencies are shifted towards lower side.

4.2.2 Size Reduction of Patch antenna

Microstrip patch antenna size can be reduced considerably by loading it with metamaterial. Patch antenna produces subwavelength resonance due to modification of resonant modes under loading condition.

Using metamaterial loading Mohmoud Abdalla presented a compact and triple band metamaterial [38] antenna for all WiMAX applications. The antenna is designed using a monopole rectangular patch antenna with CPW feed and two metamaterial LH transmission line cells. These two metamaterial LH transmission line cells are loaded on monopole rectangular patch antenna. Each unit cell is formed of inductive slot and interdigital capacitor. Each cell can be designed separately to resonate at different frequency so that it can introduce two different antenna bands. The monopole patch antenna contributes to obtain the third band. The designed antenna has 66% size reduction as compared to conventional antenna at lower band (2.4GHz), whereas 50% size reduction at 3.5 GHz and 25% at 5.5 GHz is also achieved.

Yuchu he presented a compact metamaterial-inspired circular monopole antenna[39]. The circular patch antenna design is based on the design in [40]. In the circular patch, an arced T-shaped slot is cut out. The designed antenna is covering the 2.3 GHz band with 220 MHz bandwidth. For achieving the wideband, the circular shape is exalted by the design in [41].

R. Pandeewari presented a compact sized antenna[42] by loading it with square shaped multi split ring resonator (MSRR). MSRR with four rings is used and it has negative permeability. Rectangular patch of size 0.5mm×5mm×1.6mm is used and MSRR is placed close to it. When patch is excited, then according to Faraday's law of electromagnetic induction, the emf is induced in the rings and it caused flow of current in it. Thus, the resonant frequency shifts to lower side. It was shifted at 8.51 GHz when MSRR was placed at a distance of 0.25mm from patch whereas it was 17.89 GHz before MSRR loading. Thus the resonant frequency was reduced by 52% by using MSRR.

Surbhi Dwivedi proposed metamaterial inspired patch antenna[43] for size reduction. The rod and split ring resonator is used as metamaterial. The substrate dimensions are varied for optimization. Size reduction is obtained upto 36.7 %. Bandwidth is also increased by 12.43% by using metamaterial. Multiband operation is obtained by using slotted and chopped patch antenna.

Jaegeun Ha presented a compact and wideband patch antenna [44]. Patch antenna is loaded with planer metamaterial. The unit cell of the metamaterial is comprised of an interdigital capacitor and a complementary split ring resonator slot to have CRLH properties. The interdigital capacitor inserted in the patch provides series capacitance. The SRR slot etched on the ground plane provides shunt admittance. The series capacitance increases on increasing the interdigital finger length. It causes decrease in the half wavelength resonance frequency, thus the size of the antenna has been reduced by 55%. The increase in the interdigital finger length also generates TM_{10} mode in addition. This TM_{10} mode can be combined with normal TM_{11} mode to achieve a wideband.

Wanquan Cao. proposed a compact patch antenna[45] with CSRR loaded on ground. This antenna was used for beam steering.

Saimoom Ferdous proposed a method to obtain reduced size with multiband operation and multiband operation for convention antenna[46]. Size reduction is obtained by loading μ negative metamaterial as a substrate in circular microstrip patch antenna. Triple band operationed by loading it with epsilon negative metamaterial.

Filiberto Bilotti proposed a compact circular patch antenna[47] loaded with metamaterial. in his previous work, he assumed the matamaterial as an ideal isotropic material. Here he presented the same structure with its cavity model analysis to optimize the position and orientation of the unit cell structures. The

metamaterials unit cells are embedded underneath the patch. These metamaterials are μ negative metamaterials. The patch is designed to resonate at 0.5 GHz using the formulas given in [48]. Magnetic field is very high between metamaterial and dielectric whereas it is zero at the centre of the patch. After SRR incisions, antenna resonates at 0.565 GHz with electrically small dimensions of the patch.

He also proposed [49] again miniaturized patch antenna with μ negative loading. A theoretical analysis of magnetic field distribution underneath the patch is done. This helps to find out the position, arrangement and alignment of magnetic unit cell underneath the patch.

4.2.3 Bandwidth Enhancement of Patch Antenna

Broadband patch can also be designed using metamaterial loading. Marco A. Antoniadis presented a printed monopole antenna loaded with metamaterial to achieve broadband dual mode operation [50]. The metamaterial used is negative refractive index transmission line. The metamaterial loading is adjusted to support even mode current at 5.5 GHz which transforms the antenna into short folded monopole. At 3.55 GHz, the ground plane radiates due to inphase current along its top edges. The ground plane radiates a dipole mode orthogonal to folded monopole mode, thus resulting a wideband of 4.06 GHz.

Merih Palandoken presented a compact broadband microstrip antenna [51] loaded with left handed metamaterial and dipole. The proposed antenna consists of six unit cells of negative refractive index metamaterials fashioned in 2×3 antenna array, and a dipole. The impedance of antenna is matched with a stepped impedance transformer.

It is also matched with rectangular slot cut in the truncated ground plane. The phase compensation and the coupled LH resonance properties resulted into its broad bandwidth (63 %) over the band 1.3-2.5 GHz.

Lang Wang presented a series fed array of rectangular microstrip metamaterial patches [52]. This series fed array of metamaterial patches enhances the bandwidth and gain of the antenna. The feedline connecting the metamaterial patches is off-centered. The shunt fed array [35][53]-[55] is also used for providing bandwidth but it has large dimensions.

4.2.4 Efficiency:

Efficiency of patch antenna can be improved using metamaterial. In [29], [32] efficiency is improved. Very high Efficiency about 90 % is also achieved in [50] along with bandwidth enhancement.

4.2.5 Patch antenna design using chiral metamaterial:

Chiral metamaterials are the alternate route towards the negative refraction. These materials has two important properties, besides negative refraction

- (1) it can rotate the polarization plane of linearly polarized wave
- (2) Circular dichroism,

These materials can improve the performance of circularly polarized antenna and also provide a simple means to design a circularly polarized antenna.

Ye .et.al [56] proposed a circularly polarized antenna using a wheel like chiral metamaterial and linearly polarized antenna. when the chiral metamaterial is placed above the conventional linearly polarized antenna, its polarization changes from linear to circular and thus provide a simple method for designing CP(circular polarized) antenna.

M.Malathong.et.al [57] has enhanced the performance of circularly polarized antenna using a chiral metamaterial. Unwanted polarized waves are filtered out using the chiral metamaterial which results in enhanced axial ratio, transmitted bandwidth and return loss of conventional circularly polarized antenna.

D.zafiri et.al.[58] had investigated the influence of semi-planar chiral metamaterial structures on the important characteristics of CP(circularly polarized) antenna and found that CMM (chiral metamaterial) at optimized distance from circularly polarized antenna significantly improves its axial ratio and gain.

VI. Conclusion

By proper tailoring and using the metamaterials in designing of patch antenna , performance of these antennas can be enhanced significantly and subwavelength antenna can be designed as presented in this review . Chiral metamaterial provides a simple and new method of designing circularly polarized patch antenna. These materials can also improve the axial ratio, directivity and gain of circularly polarized antenna.

VII. Future Challenges

Fabrication of complex metamaterial structure based antenna is a challenge, but with the advancing progress in fabrication techniques, one may anticipate that this technological hurdle should not be an issue in future. Narrow bandwidth response of is one of the major drawback of metamaterial. The limited bandwidth makes its designing complex and prevents its use in ultra-wide band antenna designing and performance enhancement. Substantial theoretical progress is also required for the antennas made from MTMs based on NIM or chiral materials at microwave frequencies .

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