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# Survey on Gain and Bandwidth Enhanced Metamaterial based Microstrip Patch Antenna

**K. Mahendran**[1], **Dr. R. Gayathri**[2]
[1]Research Scholar, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India
[2]Assistant Professor, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India

## ABSTRACT

Microstrip antennas are widely employed in communication system and seekers. Printed antennas provided attractive features such as low profile, low weight and low production cost. These small printed antennas suffers due to narrow bandwidth and low gain. To overcome the drawback, metamaterial technology comes into picture. Metamaterial is used to design a small printed antenna with high gain and wider bandwidth. A survey of various techniques used in Metamaterial based print antennas are presented in this paper.

**Keywords :** Split Ring Resonators, Metamaterials (MTM), Negative Index Materials (NIM)

## I. INTRODUCTION

Metamaterials are artificial materials which exhibits unique properties which cannot be achieved by conventional material. Simply Metamaterials are man-made twisted and composite structures with the assemblies of multiple (metal- Plastic) elements. The properties of the material is not from the base material, it depends on the designed structure. The shape, geometry, size and orientation of the metamaterial will manipulate the Electromagnetic waves.[1]

### 1.1 Basics of Metamaterial

Recently, there has been growing interest in the study of metamaterials both theoretically and experimentally. Metamaterials (MTM) are artificial materials engineered to have properties that may not be found in nature. The invention of metamaterial was started in 1960s. In 1967, Victor Georgievich Veselago [2] studied the electrodynamics of substances with simultaneously negative values of dielectric permittivity (ε) and magnetic permeability (μ). Positive permeability and permittivity are the basic properties of conventional materials available in nature called as Double Positive (DPS) materials. Metamaterials are termed as Double Negative (DNG) materials due to the property of negative dielectric permittivity (ε) and magnetic permeability (μ). Metamaterials consist of two concentric metallic rings with a split on each ring .this structure represent a LC resonator, which exhibits magnetic resonance. G. Veselago found that the Poynting vector of the plane wave (group velocity) is antiparallel to the direction of the phase velocity, which is contrary to the conventional case of plane wave propagation in natural media. So he mention the term "left-handed substance," that this term is equivalent to "substance with negative group velocity”. Although metamaterial does not present in nature, interesting properties were theoretically predicted for these substances, such as the reversal of the Snell Law, Doppler Effects, and Cherenkov radiation etc. Metamaterials are sometimes referred to as Negative Index Materials (NIM) as they exhibit negative index of refraction. .

Metamaterial structure consists of Split Ring Resonators (SRRs) to produce negative permeability and thin wire elements to generate negative permittivity. SRR is a novel design consisting of two concentric rings with a split on each ring. The structure is called resonator since it exhibits a certain magnetic resonance at a certain frequency. Split ring resonators can result in an effective negative permeability over a particular frequency region. The SRR structure is formed by two concentric metallic rings with a split on opposite sides. This behaves as an LC resonator with distributed inductance and capacitance that can be excited by a time-varying external magnetic field component of normal direction

## II. Structure of Metamaterial

There are mainly 4 types of metamaterial structures as antenna substrate:

- 1-D Split Ring structure
- Symmetrical Ring structure
- Omega structure
- S structure

All the metamaterial antennas are designed based on any one of these substrate structures. 1-D structures are easier to fabricate and construct. Symmetrical Ring structure tends to yield clean retrieval response as there is less ringing effect from time-domain simulation. Also there is less coupling between the *E* field and the *H* field. Omega-shaped structure is a new metamaterial structure. But the increased complexity in the structure. There are no rings or rod parts are present in S structure and hence the results are relatively better. In comparison with other three structures, the Symmetrical-Ring structure provides a better directional beam and is easier to tune its permeability because of its rings are symmetrical.[3]

## III. Properties of Metamaterial

Consider the Maxwell's first order differential equations,

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

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

Where $\omega$ is an angular frequency.

For a plane-wave electric & magnetic fields like

$$E = E_0(-jk\ .r+j\omega t) \qquad (3)$$

$$H = H_0(-jk\ .r+j\omega t) \qquad (4)$$

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

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

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

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

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

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

Energy flow is determined by the real part of the Poynting Vector

$$S = \tfrac{1}{2}(E \times H')$$

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 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.

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. Backward waves may commonly appear in non-uniform waveguides. [4],[5],[6].

## IV. Metamaterials in Patch Antenna

There are various issues while we design a patch antenna such as - compactness in size, high gain, directivity enhancement, increased bandwidth, and suppressed sidelobes. Metamaterials are being used for improving the performance of patch antennas.

### 4.1 Directivity and Gain Enhancement

Effective permittivity can be expressed as

$$\epsilon_{eff} = 1 - \omega_p \,/\, \omega^2$$

where $\omega_p$ and $\omega$ are the plasma frequency and the frequency of the electromagnetic wave.

When resonant frequency is equal to plasma frequency, the effective permittivity will be zero.

$$If\ \omega = \omega_p \quad then \quad \epsilon_{eff} = 0$$

$$n = \sqrt{\epsilon_{eff}\ \mu_{eff}} = 0$$

Thus when operating at the plasma frequency, there will be zero index of refraction. Directivity and gain can be increased by using metamaterial as antenna substrate.

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 close normal to the surface. Then, all the refracted rays will be in almost the same direction around the normal. Therefore, if the operating frequency is closer to the plasma frequency, directivity can be improved.

#### *a) A metamaterial for directive emission*

Enoch *et al.,* had used metamaterial as substrate [7]. The layers of copper grids separated by foam were used as metamaterial. This metamaterial possessed the plasma frequency at about 14.5 GHz. Monopole antenna fed by a coaxial cable was used as a source of excitation and the emitting part of the monopole was approximately centered at the center of the metamaterial substrate. And also a ground plane was added to substrate. It had 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 he obtained the best directivity at 14.65 GHz.

I.Wu. *et al.,* used the same technique for obtaining high directivity [8] as used in [7]. He used the dipole antenna as source of emission instead of monopole antenna. The dipole antenna was embedded in metamaterial substrates. The periodic structures of rods, or of both rods and rings were used as metamaterial. Ground planes were not used there. He used the different methodology and the process of analysis. He placed method for farfield radiation was used.

#### b) *Emitting antenna fabricated by anisotropic metamaterial*

Y. G. Ma *et al.,* 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 [9].

The difference between this [7] and the technique of Enoch *et al.,* The first one lies in the problem of impedance mismatch between the ε-near-zero (ENZ) matrix and surrounding air. The metamaterial used was anisotropic with effective permittivity near zero, allowing it to match the surrounding media at the proper polarizations. By using the anisotropic slab, the emitted wave received in surrounding air exhibits the characteristics of plane wave same as the straight wavefront parallel to the interface shows when it is propagating along ± x axis [10]. It was shown that the high directivity can be supported by this anisotropic matrix.

#### *C) Improvement of Characteristics of Microstrip Antenna Using of two Metamaterial Superstrate*

R. Khajeh Mohammad Lou *et al.,* used two types of metamaterial superstrates [11] to increase directivity, gain and bandwidth. Directivity enhancement was 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 were used as metamaterial superstrates.

Using 5×7 array of the coupled S-shaped structures, the near zero refractive index was observed in the frequency range of 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 was placed about one third of the operating wavelength, *i.e.,* λ/3 above ground plane to increase the gain.

### *D) Microstrip Patch Antenna with Pentagonal Rings*

Bimal Garg, *et al.,* presented a "Pentagonal Rings" shaped metamaterial cover [12] 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 was placed at a height of 3.2 mm from the ground plane. As left handed metamaterial has the property of focusing radiations of antenna [14], the directivity had been increased about 2.019 dB and the gain had improved.

### *E) Gain Enhancement using Patterned Structures*

Le-Wei Li, *et al.,* used the completely different approach [18] 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 micro triangles gaps were designed on the upper patch and the periodically distributed cross strip gaps were designed on the bottom ground plane. A capacitive-inductive equivalent circuit was formed by the coupling of upper patch and bottom ground plane. Thus, a backward wave was induced which travelled along the plane of patch. Therefore, the radiation along the patch direction was enhanced which in turn increased the bandwidth and gain.

### *F) Left-handed Metamaterial Structure in Antenna Cover*

Zhongqing Wang, *et al.,* designed a left-handed metamaterial cover [20] to enhance the gain and directivity of antenna. This left handed metamaterial cover was designed with a microstrip line, two symmetrical triangular split ring resonators printed on the substrate. There were also two gaps cut on the metal ground plane which made it DGS. This left handed metamaterial cover has negative permittivity and permeability in various frequency bands. When the left-handed metamaterial cover was placed above the antenna, the gain and directivity of antenna was increased and resonant frequencies were shifted towards lower side.

## V. Bandwidth Enhancement

### *a) Broadband Dual-Mode Monopole Antenna*

Marco A. Antoniades, *et al.,* presented a printed monopole antenna loaded with metamaterial to achieve broadband dual mode operation [21]. The metamaterial used was negative refractive index transmission line. The metamaterial loading was 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 in phase 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.

### *b) Broadband Microstrip Antenna with Left-Handed Metamaterials*

Merih Palandoken, *et al.,* presented a compact broadband microstrip antenna [22] 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 was matched with a stepped impedance transformer. It was 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.

### C) *Series-Fed Metamaterial Microstrip Antenna Array*

Lang Wang, *et al.,* presented a series fed array of rectangular microstrip metamaterial patches [23]. This series fed array of metamaterial patches enhanced the bandwidth and gain of the antenna. The feedline connecting the metamaterial patches was off-centered. The shunt fed array was also used for providing bandwidth but it has large dimensions.

### d) *Broadband and High gain Metamaterial Microstrip Antenna*

Lang Wang, *et al.,* Presented that by applying the planar metamaterial patterned structures directly on the upper patch and bottom ground of the dielectric substrate, so the patch antenna can have an excellent performance.[24] Normally in conventional microstrip antenna, patch is mounted on a substrate and backed by a conducting ground plane. The paper proposed that a planar LHM pattern on the rectangular patch antenna mounted on the substrate is designed to enhance its horizontal radiation as well as to broaden its working bandwidth via its coupling with the conducting ground backed to the substrate and patterned in a different way. On the upper patch, the periodic gaps are designed in the form of isolated micro triangles while on the bottom ground plane. Periodically distributed cross strip-line gaps are designed. To maintain the transmission consistency of input energy, the metal in and around the feed-line area is, however, not etched.

The proposed antenna is designed to have the 0.4 mm gap at the bottom, and the 10 dB bandwidth which is standardly defined for engineering applications falls within 5.3 and 8.5 GHz which is 3.2 GHz in bandwidth and is 16 times wider than the conventional antenna. He also analyzed that When the gap at the bottom becomes 0.3 mm, the 10 dB bandwidth turns within 5.7 and 8.6 GHz which is 2.9 GHz in bandwidth, and is 14.5 times wider than the conventional antenna.

### *e) Bandwidth enhanced printed dipole antenna*

M.A. W. Noordin *et al.,* presented that the dipole is built on top a ceramic based substrate. In order for matching the ground plane was truncated and made partial.[27] By loading the end of the dipole, means for uniform current distribution. The metamaterial elements were loaded on the shape of triangle, which provides capacitive loading. This metamaterial loading was placed on top of the dipole antenna. The designed antenna works on 1.3 to 2.2 GHz. The antenna has a total bandwidth of 56 % at the lowest resonant frequency.

## VI. CONCLUSION

With the rapid development of wireless communication Microstrip patch antennas are crucial. But these microstrip antennas have some limitations amongst its numerous advantages. Several investigations are going on to improve the gain and bandwidth of patch antenna. The studies have come up with a concept of metamaterial substrates. This survey various Metamaterials techniques were summarized to enhance the gain and bandwidth of printed antennas.

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