Review on Performance Enhancement Techniques for Microstrip Patch Antenna Using Metamaterials

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Abstract— Various advantages of a patch antenna are light weight, low cost, low power handling capability, easy to integrate and fabricate. Even though it has advantages, it has some limitations like low bandwidth, low gain, spurious radiation, high complexity, mutual coupling and surface wave propagation. Metamaterials are being used to overcome the limitations of microstrip patch antenna. This paper provides the introduction to metamaterials and microstrip patch antenna and how to enhance the performance of microstrip patch antenna using metamaterials.

Keywords— Microstrip Patch Antenna (MPA), Metamaterials (MTM), Mutual Coupling, Spurious Radiation, Surface Wave Propagation.

I. INTRODUCTION
Metamaterials have attracted a great amount of attention in the area of research. These are artificial structures that exhibit characteristics not found in nature and these artificial materials can create negative index of refraction and guide wave in desired direction. They manipulate radiation pattern, can double the frequency range and increase radiated power. These materials gain the properties from structure rather than composition. Depending on the structure, metamaterials may have refractive index less than one and even negative.

II. CLASSIFICATION OF MATERIALS
Materials are classified based on the sign of permittivity (ε) and permeability (μ). Table 1 shows the classification and also it is illustrated graphically in “Figure 1”.

<table>
<thead>
<tr>
<th>Permittivity</th>
<th>Permeability</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε&gt;0</td>
<td>μ&gt;0</td>
<td>Double positive material</td>
</tr>
<tr>
<td>ε&lt;0</td>
<td>μ&gt;0</td>
<td>Epsilon negative material</td>
</tr>
<tr>
<td>ε&gt;0</td>
<td>μ&lt;0</td>
<td>Mu negative material</td>
</tr>
<tr>
<td>ε&lt;0</td>
<td>μ&lt;0</td>
<td>Double negative or Left-Handed Materials (LHMs)</td>
</tr>
</tbody>
</table>

The following figure shows the classification of materials. Out of these four types of materials LHMs are used for improving the performance of microstrip patch antenna and these LHMs are called as metamaterials. The figure also shows how refraction in metamaterials is different compared to conventional material.
III. TYPES OF METAMATERIALS

Different types of Metamaterials are

**Electromagnetic Metamaterials:** These materials have negative refractive index. Normal materials refract waves with positive refractive index.

\[ n = \sqrt{\frac{\varepsilon}{\mu}} \]

The above equation is the definition of refractive index, \( n \). It is a function of electric permittivity and magnetic permeability which are properties relating to the material in the presence of an electric and magnetic field, respectively. Normally, a positive coefficient is assumed for most media; for a metamaterial, both \( \varepsilon \) and \( \mu \) are negative. As Veselago theorized, if both parameters are negative, then a negative coefficient must be used.

One application of electromagnetic metamaterials is in antennas. Because of negative refractive index the wave in antenna is bent to sharper angle. This increases the radiated power of the antenna, doubles the frequency range and also reduces the size of antenna.

Electromagnetic Metamaterials are further classified as Double negative metamaterials, Single negative metamaterials, electromagnetic band gap metamaterials, double positive medium and chiral metamaterials.

The type of electromagnetic metamaterial to be used depends on which parameter of the antenna you need to improve.

**Terahertz Metamaterials:** These kinds of metamaterials are designed for terahertz (THz) frequencies. The terahertz frequency range is 0.1 to 10 THz.

**Photonic Metamaterials:** Photonic metamaterials interact with light. It covers tetra hertz, infrared or visible wavelengths. These kinds of materials employ a periodic structure. These kinds of materials produce negative index of refraction in optical range because which exhibit magnetism at high frequencies, resulting in strong magnetic coupling.
**Tunable Metamaterials:** In these materials the meaning of tunable is to determine whether the Electro Magnetic (EM) wave is transmitted, reflected, or absorbed. In general, the structure of the tunable metamaterial is adjustable in real time, so that we can reconfigure a metamaterial device during operation.

**Frequency Selective Surface (FSS) based Metamaterials:** Depending on the frequency of field it determines whether EM wave is transmitted, reflected, or absorbed.

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**SPLIT RING RESONATOR IN METAMATERIALS**

These are the elements used to fabricate metamaterials. It produces the desired magnetic response in various types of metamaterials up to 200 THz. These also create the necessary strong magnetic coupling to an applied electromagnetic field. With a periodic array of split ring resonators negative permeability is produced.

![Figure 2. Structure of split ring resonator](image)

External magnetic field penetrates through the rings and currents are induces. Gap prevents current from flowing around the ring, which considerably increases the resonance frequency of the structure. This kind of structure gives simultaneous enhancement in the bandwidth and gain of antenna.

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**IV. MICROSTRIP PATCH ANTENNA**

MPA consists of metallic patch on one side and dielectric substrate on another side. The length of the patch (L) is equal to one half of the dielectric wavelength which corresponds to the resonant frequency.

The dielectric substrate material determines the size and bandwidth of an antenna. Larger dielectric constant smaller is the size of antenna but reduces the bandwidth and efficiency of the antenna while decreasing the dielectric constant increases the bandwidth therefore increase in size of antenna. But there is limit on increasing the value of dielectric constant.

The width \( W \) of the Microstrip antenna determines the input impedance and radiation pattern. Larger width indicates an increase in bandwidth. As shown in Figure 3, \( t \) is thickness of patch and \( h \) is the height of dielectric substrate.

![Figure 3. Geometry of MPA](image)

The patch of MPA can have different shapes like rectangle, square, circular, elliptical, triangular etc. The most commonly used is rectangular Microstrip patch antenna.
There are various methods for improving the bandwidth and gain of MPA like changing the shape of patch, using multilayer structures, different feeding techniques, array method, using different dielectric substrates etc. Comparative analysis of few methods is given in Table 2.

### Table 2. Comparative analysis of performance enhancement techniques of Microstrip Patch Antenna

**Methods Used**

1) **Defected Ground Structure**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psi Shape in ground plane</td>
<td>The bandwidth of rectangular microstrip patch antenna was 67 MHz which got improved to 302 MHz This bandwidth is suitable for different applications of WLAN [2]</td>
</tr>
<tr>
<td>Asymmetric Sai Shape in ground plane</td>
<td>The bandwidth is improved and it can be used for wide band applications [3]</td>
</tr>
<tr>
<td>In ground rectangular shaped strips are cut in the form of inter digital Capacitor</td>
<td>95% improvement in bandwidth without increase in antenna size. This can be used for C-band and X-band wireless applications [4]</td>
</tr>
<tr>
<td>Two different defected ground structures are used which are complement of each other</td>
<td>Four different frequencies of operation (10 GHz, 12 GHz, 16 GHz and 16.6 GHz) are achieved with 22% enhanced bandwidth [6]</td>
</tr>
</tbody>
</table>

2) **Slots on patch surface and ground plane**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slots are in rectangular and fractal U shape which are imposed on the patch surface and there is slot on the ground plane in cylindrical shape</td>
<td>18.6% improvement in gain and about 100% in bandwidth [7]</td>
</tr>
<tr>
<td>13 slots are etched on the patch</td>
<td>70.8% improvement in bandwidth. It is designed for GPS application to operate at 1.6 GHZ center frequency [8]</td>
</tr>
<tr>
<td>Parasitic patch placed adjacent to the radiating patch along with the slots</td>
<td>Parasitic Patch gives 6.52% improvement in bandwidth. It is suitable for X-band applications [9]</td>
</tr>
<tr>
<td>Square shaped ground plane is having U shaped slot</td>
<td>Using this configuration maximum impedance bandwidth 12.5% of can be obtained. This is suitable for wireless communications [10]</td>
</tr>
</tbody>
</table>

### V. METHODS FOR IMPROVING THE PARAMETERS OF MPA USING METAMATERIALS

After studying various methods, we observe that there is an improvement in either bandwidth or gain. So, in order to simultaneously increase bandwidth and gain we go for metamaterial. The major limitation of MPA is narrow bandwidth and low gain. Increasing bandwidth of antenna is important research area. Using MTM we can increase bandwidth as well as gain with reduction in
size of an antenna. The techniques for performance enhancement of Microstrip patch antenna are using metamaterial as substrate and superstrate, Defected Ground Structure etc.

**Table 3. Comparative analysis of performance enhancement techniques of Microstrip Patch Antenna using metamaterial**

**Methods Used**

1) **Metamaterial Superstrate**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>metamaterial superstrate is in the form of coupled square-shape split ring resonators</td>
<td>The antenna gain and bandwidth is increased to 8.1 dB and 9.96%. It is suitable for WIFI 2.4 GHz operation [11]</td>
</tr>
<tr>
<td>The configuration is in the form of diagonally connected square split ring resonator</td>
<td>Improves the return loss by 18 dB and enhances the gain by 1.2dBi, bandwidth by 28 MHz and radiation efficiency by 17.5%. It finds the applications in the field of satellite communications, highly sensitive radar and missiles systems [12]</td>
</tr>
<tr>
<td>Split Ring Resonator Superstrate</td>
<td>It enhances the gain of a conventional patch antenna array by 86%, improves the bandwidth by 60% maintaining almost same profile and cost. It is used in Wi-MAX applications</td>
</tr>
<tr>
<td>Multiple Split Ring Resonators</td>
<td>An improvement in gain by 8 dBi and bandwidth by 680 MHz</td>
</tr>
<tr>
<td>Omega Shaped metamaterial is used as superstrate</td>
<td>Multi-frequency operations at 5.125 GHz, 11.34 GHz, 12.43GHz and Simultaneous enhancement on antenna gain and bandwidth [19]</td>
</tr>
</tbody>
</table>

2) **Defected Ground Structure**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-shaped DGS metamaterial</td>
<td>Compared to the conventional design there is enhancement of 118% bandwidth. Also gain and return loss of 17.6% and 71.89%, respectively. Reduction in Size of the radiating patch for about 21%. Used for S-band application [13]</td>
</tr>
</tbody>
</table>

3) **Metamaterial Substrate**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criss - Cross Shaped Metamaterial-Substrate</td>
<td>An increase in gain of around 2 dB has been achieved as well as bandwidth up to 86%</td>
</tr>
<tr>
<td>S Structure</td>
<td>Improvement in bandwidth is 10.7-10.8 GHz</td>
</tr>
<tr>
<td>Omega Structure</td>
<td>Improvement in bandwidth is 13.7-14.1 15.6-17.2 GHz</td>
</tr>
<tr>
<td>Symmetrical Ring Structure</td>
<td>Improvement in bandwidth is 16.1-18 GHz</td>
</tr>
<tr>
<td>1-D Split Ring Structure</td>
<td>Improvement in bandwidth is 12-12.3 GHz [16]</td>
</tr>
</tbody>
</table>
4) **Electromagnetic Band Gap (EBG) Structure**

<table>
<thead>
<tr>
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<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna without EBG</td>
<td>These three methods are compared and observation is made that there is improvement in the bandwidth from 2.4% to 2.9% and then to 3.2% as well as improvement in gain is also observed [20]</td>
</tr>
<tr>
<td>Antenna with EBG Substrate</td>
<td></td>
</tr>
<tr>
<td>Antenna with EBG substrate and superstrate</td>
<td></td>
</tr>
<tr>
<td>Rogers RO3003 substrate with EBG Structures in ground plane</td>
<td>There is an increase in bandwidth of the antenna by 39.63% and reduction in size by 22.38% [22]</td>
</tr>
</tbody>
</table>

5) **Metamaterial Radome**

<table>
<thead>
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<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metamaterial superstrate, is constructed by stacking three layers of Jerusalem cross structure with the use of sub wavelength holes</td>
<td>The number of holes affects the performance of antenna. Here 9 sub wavelength holes can improve the gain by about 3.4 dB. Can be used for wireless communication and industrial manufacturing [21]</td>
</tr>
</tbody>
</table>

6) **Metamaterial Surfaces**

<table>
<thead>
<tr>
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<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mushroom Shaped Metamaterials</td>
<td>All these methods provide various advantages such as wide bandwidth, lower specific absorption rate value, high gain and increased efficiency</td>
</tr>
<tr>
<td>Architecture based on patch, wire and loop elements</td>
<td></td>
</tr>
<tr>
<td>Pi-Shaped Metamaterial</td>
<td></td>
</tr>
<tr>
<td>Split Ring Resonators Metamaterial</td>
<td></td>
</tr>
<tr>
<td>Cut Wire Metal Rod based Metamaterial</td>
<td></td>
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</tbody>
</table>

VI. **CONCLUSION**

Use of Metamaterials to overcome the limitations of Microstrip patch antenna is an interesting research area. The researchers from various disciplines are being attracted towards metamaterials because of its unique properties. In this paper, introduction to metamaterials, various types, and methods to overcome the limitations of microstrip patch antenna have been discussed. From comparative analysis we observe that use of metamaterials in MPA have resulted in surprising improvements in various parameters like gain, bandwidth, VSWR etc.

**REFERENCES**


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