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Review Paper on Microstrip Patch Antenna using Metamaterials

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Abstract —*Microstrip antenna has many advantages, since the light weight, small size, low cost, but there are some drawbacks, such as low-gain, narrow frequency bandwidth of these two important parameters. This review article describes how to use metamaterials or how we can improve the gain bandwidth and increase the performance of the patch antenna. Here, we first provide after-sales service, the introduction of microstrip patch antenna metamaterial described microstrip patch antenna can be improved through the use of metamaterials and discusses the scope and parameters of future applications of metamaterials.*

Keywords-*Microstrip Patch Antenna (MSA); Metamaterials; SRR; LHM.*

I. INTRODUCTION

There has been a lot of studies published on the improvement of performance of microstrip patch antenna and where metamaterial provides the improvement in desired characteristics without changing in resonant frequency. Paper published in 1968 [1], the concept of a medium having both negative permittivity and permeability was theoretically given and predicted that electromagnetic plane waves in such a medium would have dramatically different characteristics. However there was not much progress until the year 1999. Then Prof. J.B.Pendry proposed the design of thin wire structure that exhibits the negative value of permittivity and split ring resonator (SRR) exhibits the negative permeability [2]. After that Dr. Smith combined the two structures and also fabricated the first structure of metamaterial [3]. In fact many researches were done to increase the response of microstrip antenna as this type of antenna is desired for its low cost properties but compromises in gain and directivity. According to few studies done the LH MTM could actually increase the directivity [4]. The planar metamaterial-based transmission line has attracted much attention since it can be designed to have unusual characteristics (negative phase constant and so on) with abroad pass band and can also be easily constructed on PCBs.

II. MICROSTRIP PATCH ANTENNA

The most common type of antenna used today is Microstrip Patch Antenna, especially between 1 to 6 GHz frequency range antennas are popular. Deschamps first proposed the concept of microstrip antenna (MSA) in 1953, but the actual antenna developed by Manson and Howell in the 1970s. Often also called microstrip antenna microstrip patch antenna, or simply patch antenna. The microstrip patch antenna of the unique nature of its two-dimensional structure [5]. A microstrip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. The radiating elements and the feed lines are usually photo etched on the dielectric substrate. The microstrip antenna radiates relatively broad beam broadside to the plane of substrate. Thus the microstrip antenna has a very low profile and can be fabricated using printed circuit (photolithographic) technology [6]. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular or any other configuration. There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling and proximity coupling. There are mainly two analysis methods for patch antennas- transmission line model and cavity model [7]. Figure 1 shows the configuration of a patch antenna.

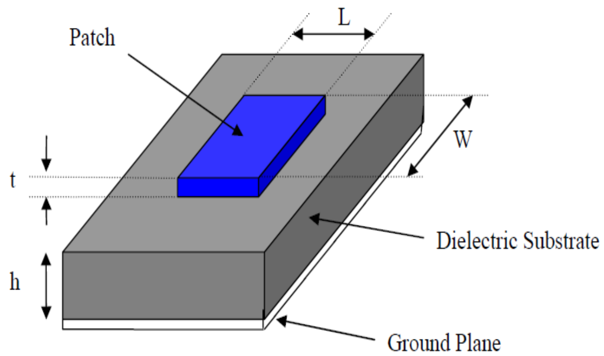

Figure 1. Microstrip Patch Antenna Configuration

The principle of operation behind the patch antenna can be explained as follows. The electric field is zero at the center of the patch, maximum at one side, and minimum (negative) at the opposite side. According to the instantaneous phase of the applied signal, the sign of field on the sides of patch continuously changes. The electric fields extend the outer periphery of the patch which is known as fringing fields and cause the patch to radiate. The fundamental mode in a rectangular patch is TM10 mode. Resonant length, ground plane size, metal (copper) thickness, patch (impedance) width, and dielectric constant are the several parameters which influence the resonant frequency.

MSAs have several advantages compared to the conventional microwave antennas. The main advantages of MSAs are listed as follows [8]:

- They are lightweight and have a small volume and a low-profile planar configuration
- They allow both linear polarization and circular polarization
- Their ease of mass production using printed-circuit technology leads to a low fabrication cost
- They are easier to integrate with other MICs on the same substrate
- They allow for dual- and triple-frequency operations
- They can be made compact for use in personal mobile communication

Amid these benefits, MSAs suffer from some disadvantages also as compared to conventional microwave antennas which are the following [8]:

- Narrow bandwidth
- Lower gain
- Low power-handling capability

MSA's have narrow bandwidth, typically 1–5%, which is the major limiting factor for the widespread application of these antennas. Increasing the BW of MSAs has been the major thrust of research in this field. Investigations have come out with a lot of solutions to this issue.

Various techniques used to increase the bandwidth of a microstrip patch are described in as a) Decreasing the Q factor of the patch by increasing the substrate height and lowering the dielectric constant, b) Use of multiple resonators located in one plane, c) Use of multilayer configurations with multiple resonators stacked vertically and d) Use of impedance matching networks [9]. The problems associated with the use of multi resonator configurations are larger area requirement and the variation in radiation pattern. The difficulty with application of wide band impedance matching network approach is the need for larger substrate area required for incorporating matching network. The most direct method of increasing the bandwidth of the microstrip element is to use a thick, low dielectric constant substrate [6] [10]. But, this inevitably leads to unacceptable spurious feed radiation, surface wave generation, or feed inductance. Thus, a reasonable thickness should be considered in the selection of substrate and the bandwidth would be enhanced using additional techniques. The most common and effective of them, are: a) the loading of the surface of the printed element with slots of appropriate shape b)the texturing of narrow or wide slits at the boundary of the microstrip patch [8] [10]. However, these methods also have the demerits as explained above and leads to the formation of complicated structures.

III. METAMATERIALS

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 the late 1960s. In 1967, Victor Georgievich Veselago studied the electrodynamics of substances with simultaneously negative values of dielectric permittivity (ε) and magnetic permeability (μ) [1]. 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 ε and μ. V. G. Veselago found that the Poynting vector of the plane wave is antiparallel to the direction of the phase velocity, which is contrary to the conventional case of plane wave propagation in natural media. He used the term "left-handed substance," keeping in mind that this term is equivalent to the term "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. A composite medium of conducting, non-magnetic elements can form a Left-Handed frequency band, as the electric field (**E**), magnetic intensity (**H**) and propagation vector (**k**) are related by a left-hand rule [3].

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 of resonator. This resonator is electrically small LC resonator with a high quality factor [2]. Left Handed Metamaterials (LHM) could be used to build a perfect lens with sub-wavelength resolution [1] [2].

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 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. The increased complexity of the structure is the problem of this structure. There are no obvious rings or rod parts any more in S structure and hence the retrieval results are relatively clean. In comparison with other three structures, the Symmetrical-Ring structure shows better directional beam and is easier to tune its permeability since its rings are symmetrical [11].

Metamaterials have a wide variety of applications. Metamaterial Surface Antenna Technology (MSAT) offers an affordable and efficient way to connect various mobile customers-airborne broadband communications, broadband Internet services on any rail system etc. Metamaterials can be used to construct wearable antenna - Metamaterial Embedded Wearable RMPA [12].

Metamaterial structures can be used along with patch antennas in order to improve the performance parameters. A study on high gain circular waveguide array antenna with metamaterial structure is presented in [13].The metamaterial is composed of copper grids with a square lattice. When electromagnetic wave propagates in free space, the electric field is enhanced by using metamaterial structure. The gain of antenna with metamaterial structure increases from the original 9.053 dB to 17.34 dB. The gain of the circular waveguide aperture antenna with metamaterial structure is already very close to the theoretical maximum value of antenna with the same size and operating frequency. The array structure combining with metamaterial-mantled technology is a more effective method to improve gain. The simulation results, which validate the theoretical analysis, show an about 7 dB addition in the antenna array gain in comparison with the conventional antenna array, so the radiation characteristics of antenna array with metamaterial structure are remarkably improved.

Metamaterials are used for further miniaturization of microstrip patch antennas. Patch antennas using metamaterials can be used for C band applications. The size of such an antenna reduces by a factor of 2.4 and the gain directivity increases from 4.17 dBi in conventional design approach to 5.66 dBi in metamaterial design [14].

Several shapes can be considered to make the metamaterial substrate in order to operate in different frequencies. Framed Square rings, different C patterns, square and circular patterns, etc. are considered to make metamaterial antenna substrate. All these shapes are designed with the intention to ameliorate the bandwidth and return loss along with size reduction. There are several methods to find out the permeability and permittivity of an antenna. They are Wave perturbation method, Nicolson Ross Wier method, NIST iterative technique, new non-iterative technique and short circuit technique. Complex permittivity and permeability of the proposed structures in most investigations has been extracted by Nicolson-Ross-Weir (NRW) approach [15] [16].

SRR is not the main component in a making a left handed medium. Sometimes its complementary structure takes the role [17].Presents a novel patch array antenna mounted with the rectangular Complementary Split Ring Resonators (CSRRs). The antenna consists of two patch arrays. Based on the Babine principle and the duality concept, the CSRR is the negative images of SRR. It is shown that addition of the CSRRs has shifted resonant frequency 5 GHz of typical patch array antenna to 3.8 GHz without changing the size of radiating patch. Also a size reduction of 47% is observed with the new structure.

A circuit design which has a broader range of material parameters resulting in negative refractive index has resulted in antennas that are innovative. Combining a left-handed transmission line segment with a conventional (right- handed) transmission line results in novel configurations with advantages over conventional antenna designs. The left- handed transmission lines are essentially a high-pass filter with phase advance. Conversely, the right-handed transmission lines are a low-pass filter with phase lag. This configuration is designated composite right/left-handed (CRLH) metamaterial. Broad band antenna design is one of the major applications of metamaterials. Composite Right/Left Handed Transmission Line approach is used with metamaterial antenna design to enhance the antenna performance [18]. A size reduction of 61.11% can be achieved with a Mushroom Structured Composite Right/Left Handed transmission line (CRLH - TL) metamaterial [19]. In addition, a wideband also can be obtained by reducing the ground plane of the antenna. A compact ultra Wide Band (UWB) antenna can be designed using metamaterial structure. The antenna exhibits a wide bandwidth of 189%. The bandwidth of a single patch antenna can be raised by placing a number of metamaterial unit cells [20].

IV. CONCLUSION

Microstrip antennas have been one of the most innovative topics in antenna theory and design for many years, and are increasingly finding application in a wide range of modern microwave systems. Like any other system or invention in this world till now, microstrip patch antennas also have some limitations amongst its numerous advantages. Several investigations are going on to improve the gain and bandwidth of patch antenna. Existing solutions leads to the problems of spurious radiation and high complexity. The studies have come up with a new solution called metamaterial.

Metamaterials have attained a major role in antenna design due to its interesting and unusual properties. From this survey, it is clear that antennas using metamaterials can be used for performance enhancement of microstrip antennas. A metamaterial antenna is created by reactively loading the metamaterial structure over the substrate. There are various types of metamaterial substrates. Any changes to the metamaterial substrate will result in changes in the parameters of antenna. A broadband antenna can be constructed using a number of metamaterial unit cells together. Gain of a patch antenna increases by a value of 1.5dB to 7dB with the addition of metamaterial structures. Miniaturization is the primary function of metamaterial. In all the works mentioned here shows that use of metamaterials results in about 50% reduction in the size of a patch antenna. Narrow bandwidth and lower gain are the two main drawbacks of microstrip patch antenna. Metamaterial antenna is a good solution to overcome the above mentioned problems of microstrip patch antenna along with miniaturization.

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