Research Article

Design and simulation of rectangular microstrip patch antenna loaded with metamaterial structure

Abstract

In this paper we have discussed and analyzed the performance of microstrip patch antenna with and without using the Meta material structure. The return loss of a normal patch antenna designed at the resonant frequency of 2.4 GHz has been compared with that of the same patch antenna along with an additionally stacked Metamaterial structure on to the patch antenna at a height of 1.6 mm from the ground plane. It has been revealed that there is an improvement in return loss of around 6 dB. This rectangular patch antenna is simulated and tested using HFSS Simulator, where an electromagnetic analysis tool is used.

Keywords: rectangular microstrip patch antenna, bandwidth enhancement, rectangular cut shape

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Introduction

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. 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.[2]

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. This resonator is electrically small LC resonator with a high quality factor.[3] Left Handed Metamaterials (LHM) could be used to build a perfect lens with sub-wavelength resolution.[3,4] There are mainly 4 types of metamaterial structures as antenna substrate 1-D Split Ring structure, Symmetrical Ring structure and Omega structures 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.[5] 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.[6] 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.[7] 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.[7]

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. Complex permittivity and permeability of the proposed structures in most investigations has been extracted by Nicolson-Ross-Weir (NRW) approach.[8,9] SRR is not the main component in a making a left handed medium. Sometimes its complementary structure takes the role.[10] Presents a novel patch array antenna mounted with the rectangular Complementary Split Ring Resonators (CSRRs). 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.[11] A size reduction of 61.11% can be achieved with a Mushroom Structured Composite Right/Left Handed transmission line (CRLH-TL) metamaterial.[12] 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.[13] In this paper, we present the possibility of trimness of a rectangular microstrip patch antenna by using a new structure of metamaterial, which is located on the substrate. First of all, the resonance structure of the metamaterial is investigated and analyzed. Then the antenna structure at the presence of this metamaterial in the substrate is investigated and the return loss and radiation pattern of the proposed antenna is compared with the conventional patch antenna with the same aspect.

Antenna design

The basic characteristics of the patch antenna design on the FR-4 substrate with dielectric constant 4.4, with inset feed are shown in Fig.1. The dimension of the antenna is 45 mm and 26 mm respectively. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation.

Design specifications

The proposed patch antenna has been designed using following specifications:

i) Feeding technique: Inset Feed

ii) Substrate material: FR-4

iii) Relative permittivity of the substrate(ε_r): 4.4

iv) Design frequency: 2.4-2.5 GHz (ISM band)

v) Thickness of dielectric substrate: 1.6 mm

vi) Elemental side: 45 X 26 mm

vii) Feed location: 10 mm (from the centre)

In this paper, the design of an inset feed rectangular microstrip patch antenna at 2.4 GHz for wireless communication is presented having length *L1*=26 mm, patch width *L4*=45 mm and transmission line length *L2*=32.5 mm. This antenna is designed on flame retardant 4 (FR-4) substrate and its performance characteristics, which include return loss, voltage standing wave ratio (VSWR), gain, and radiation pattern, were obtained from a simulation using High Frequency simulation Software (HFSS). (Figure 1) shows rectangular patch antenna designed at 2.4 GHz using HFSS version 13. The results of the design (microstrip antenna) using High Frequency simulation Software (HFSS) the parameters return loss, radiation pattern, Impedance and gain are shown in (Figure 2-5) respectively. The comparison between the resonance frequency and gain of the conventional antenna and proposed antenna are depicted in (Table 1).

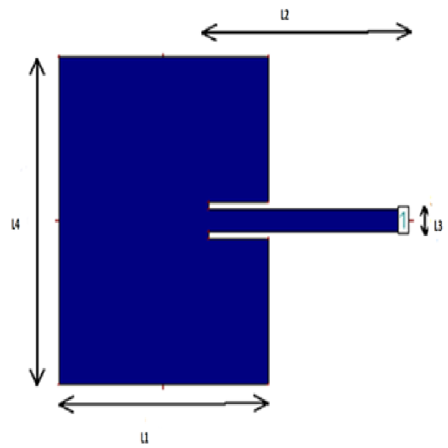

Figure 1 Rectangular Patch Antenna at 2.45 GHz.

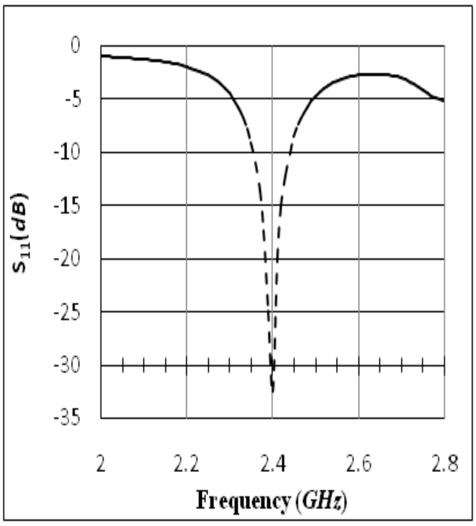

Figure 2 Return Loss of Simple Microstrip Patch Antenna using HFSS.

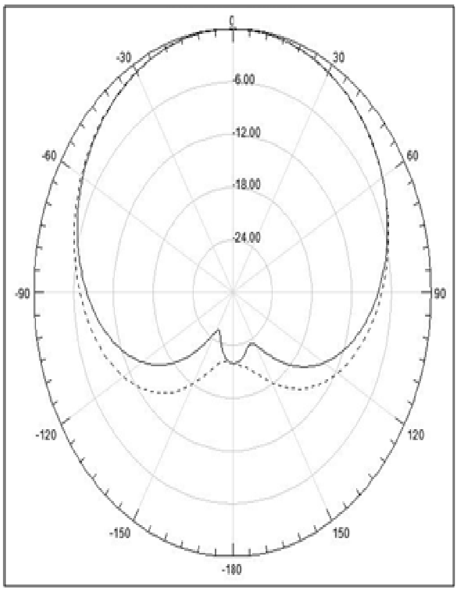

Figure 3 Radiation Pattern of Simple Microstrip Patch Antenna using HFSS.

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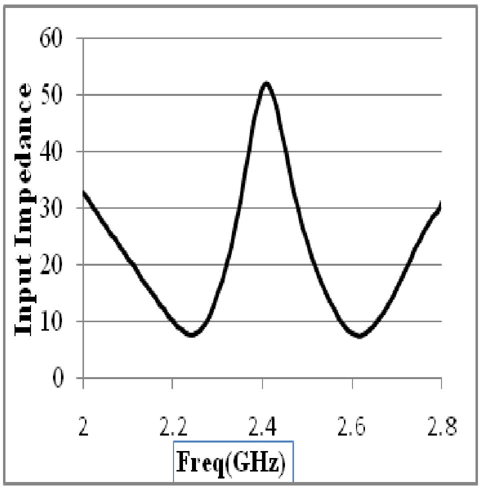

Figure 4 Input Impedance of simple Microstrip Patch Antenna using HFSS.

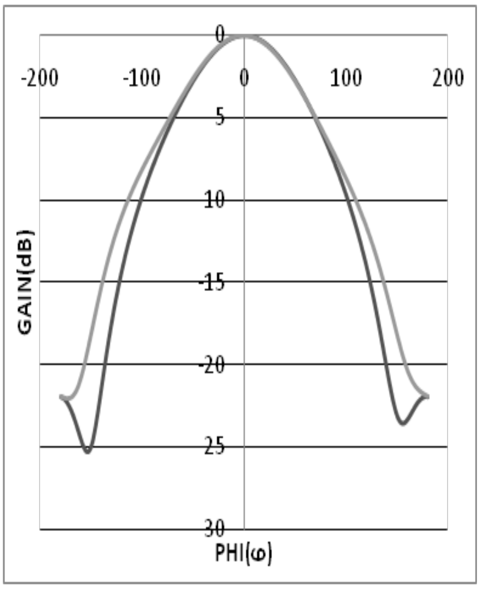

Figure 5 Gain for the simple rectangular patch antenna using HFSS.

Design of metamaterial loaded microstrip patch antenna

The proposed design is based on rectangle shape. As the name state that there are several cut in rectangle so we take a rectangle with length of 26 mm and width of 45 mm. Then we take a cut width of 30 mm and cut depth of 4 mm. To make a first cut in both side of the original width. And take a gap of cut length and cut width 5.5 mm and 5.6 mm. respectively. Finally we make a cut of *L* of 5.5 mm and *W* of 5.5 mm on both top & bottom side. The patch antenna structure in the presence of Metamaterials (Split Ring Resonators to produce negative permeability and thin wire elements to generate negative permittivity) is shown in (Figure 6). The obtained results of return loss, radiation pattern, Impedance and gain of the rectangular patch Antenna Loaded with metamaterial structure are as shown in (Figure 7-10) respectively. The comparison between the resonance frequencies, gain, directivity, radiated power, efficiency, bandwidth and VSWR of the conventional antenna and proposed antenna are tabulated in (Table1).

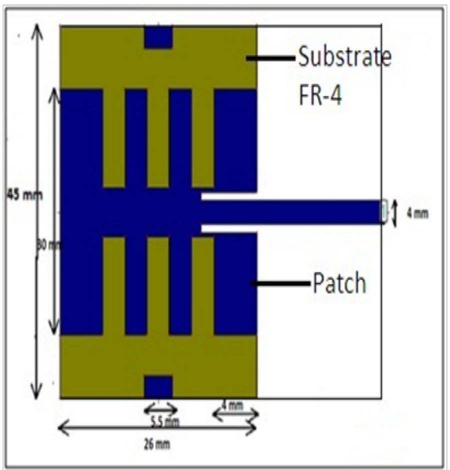

Figure 6 The patch antenna structure in the existence of metamaterial.

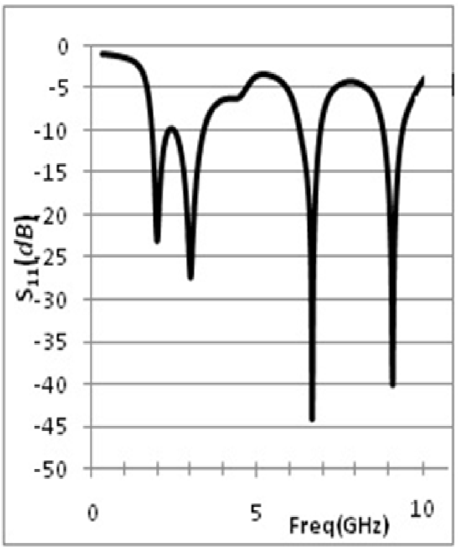

Figure 7 Return Loss of The Metamaterials Loaded Rectangular Microstrip Patch.

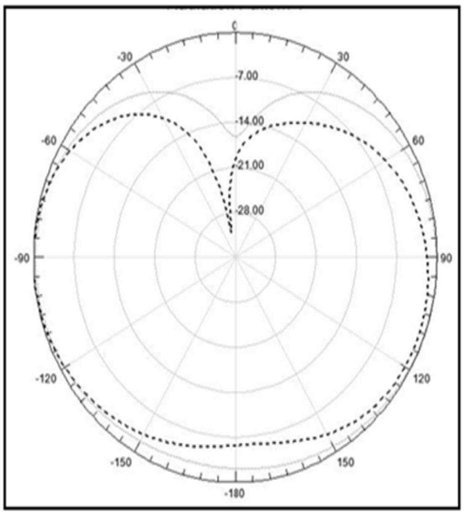

Figure 8 Radiation Pattern of the Rectangular Patch Antenna Loaded With Metamaterials.

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Table 1 Parameters of various proposed metamaterials antennas

Parameters	Simple microstrip patch antenna	Metamaterial loaded microstrip rectangular patch antenna	Comparison between the two (%)
Resonant Frequency (GHz)	2.4	2.4	47.54%
		2.7	
			56.94%
		0.0139	
Peak Gain (dB)	0.46		96.97%
	1.22		
Peak Directivity		0.0169	98.61%
Radiated Power(mW)	80	695.78	88.50%
Radiation Efficiency	0.37	0.82	45.173%
Return Loss (S_{11} in dB)	-32.42	-23.12	40.23%
		-27.42	18.23%
Bandwidth (GHz)	0.09	1.02	91.18%
VSWR	1.91	1.150	39.79%
		1.08	43.45%

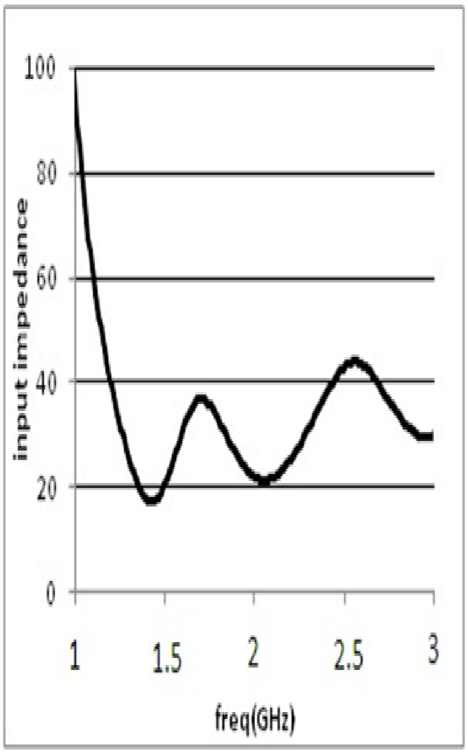

Figure 9 Input Impedance of the Rectangular Patch Antenna Loaded With Metamaterials.

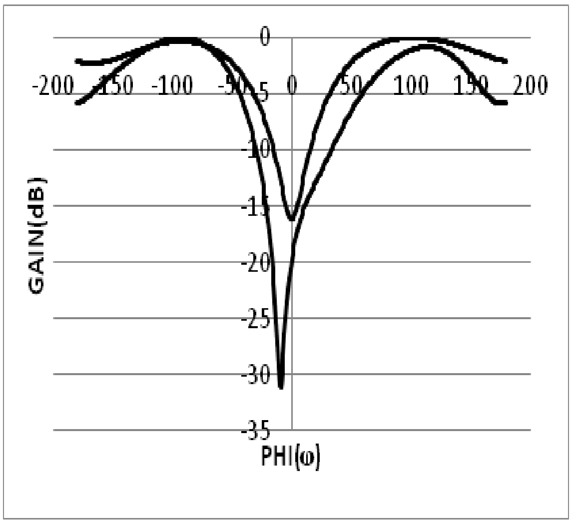

Figure 10 Gain of the Rectangular Patch Antenna Loaded With Metamaterials.

Conclusion and future work

A compact microstrip antenna with an improved bandwidth using a metamaterial substrate has been presented. For the characterization of the microstrip antennas on metamaterial substrates, the effective medium approach was employed. The new design help achieve the reduction of the antenna size and the improvement of the bandwidth for microstrip patch antennas. The results presented in this work are promising for the design of compact antennas achieving a size reduction without having to sacrifice the antenna bandwidth, which makes the antenna useful for various applications.

Acknowledgments

None.

Conflict of interest

The author declares no conflict of interest.

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