OPTIMIZATION OF RECTANGULAR MICROSTRIP PATCH ANTENNA PARAMETERS IN L BAND BY EMPLOYMENT OF PROPOSED COMPOSITE NEGATIVE INDEX METAMATERIAL STRUCTURE

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ABSTRACT

In this paper work, a patch antenna and our proposed metamaterial patch antenna are simulated and compared. A rectangular microstrip patch antenna along with the innovative metamaterial structure is proposed at a height of 3.2mm from the ground plane. This work is mainly focused on increasing the potential parameters of microstrip patch antennas and analyzing the operation of proposed antenna. This structure produces a better performance compared to simple RMPA. The implementation of the metamaterial as the substrate in a rectangular microstrip patch antenna produces high value of return loss. Rectangular Microstrip Patch antenna loaded with metamaterial (MTM) is proposed for better improvement in the impedance bandwidth and reduction in the return loss at operating frequency 1.812 GHz. The proposed antenna is designed at a height 3.2 mm from the ground plane. At 1.812 GHz, the bandwidth is increased up to 20.4 MHz in comparison to RMPA alone of bandwidth 8.2 MHz. The Return loss of proposed antenna is reduced by -14.7dB. Microstrip Patch antenna has advantages over other antennas as it is lightweight, inexpensive, easy to fabricate and achieve radiation characteristics with higher return loss. CST MICROWAVE STUDIO is used to design the metamaterial based rectangular microstrip patch antenna. The result of our work suggest the proposed structure could be used in L band for wireless communications.

Keywords- Rectangular microstrip patch antenna (RMPA), Metamaterial (MTM), Impedance Bandwidth, Return loss, Nicolson-Ross-Weir (NRW) approach.
I. INTRODUCTION

In modern wireless communication systems, the microstrip patch antennas are commonly used in the wireless devices. Therefore, the miniaturization of the antenna has become an important issue in reducing the volume of entire communication system [1]. Microstrip antennas are largely used in many wireless communication systems because of their low profile and light weight [2].

The “patch” is a low-profile, low-gain, narrow-bandwidth antenna. Aerodynamic considerations require low-profile antenna on aircraft and many kinds of vehicles. Typically a patch consists of thin conducting sheet about 1 by 1/2 \( \lambda \) mounted on Substrate. Radiation from the patch is like radiation from two slots, at the left and right edges of the patch. The “slot” is the narrow gap between the patch and the ground plane. The patch to ground plane spacing is equal to the thickness “t” of the substrate and is typically about \( \lambda /100 \). The electric field is zero at the center of patch, maximum at one side, minimum on the opposite side. The important parameters of any type antenna are impedance bandwidth and return loss. The impedance bandwidth depends on parameters related to the patch antenna element itself and feed used. The bandwidth is typically limited to a few percent. This is a disadvantage of basic patch antenna. Metamaterial based rectangular microstrip patch antenna improves the bandwidth and return loss in significant way [14]. CST MICROWAVE STUDIO is a software package for the electromagnetic analysis and design, used to design the metamaterial based rectangular microstrip patch antenna. The software contains four different simulation techniques like transient solver, frequency domain solver, integral equation solver, Eigen mode solver and most flexible is transient solver.

V.G. Veselago in 1968 provided a theoretical report on the concept of metamaterial (MTM) [3]. A Left- Handed metamaterial or Double-Negative Metamaterial exhibits negative permittivity and permeability [4]. The currently popular antenna designs suitable for the applications of wireless local area network (WLAN) and world-wide interoperability for microwave access (Wi-MAX) have been reported [5].

II. DESIGN SPECIFICATIONS

The RMPA parameters are calculated from the following formulas. Desired Parametric Analysis [6] [7].

Calculation of Width (W):

\[
W = \frac{1}{2f_r \sqrt{\mu_0 \varepsilon_r}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{C}{2f_r \sqrt{\varepsilon_r + 1}} \quad (1)
\]

where

\( C = \) free space velocity of light,

\( \varepsilon_r = \) Dielectric constant of substrate

Effective dielectric constant of the rectangular microstrip patch antenna:

\[
\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{1 + \frac{12h}{W}} \right) \quad (2)
\]

Actual length of the patch (L):

\[
L_e = L + 2\Delta L \quad (3)
\]

Calculation of length extension:

\[
\frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{reff}^{0.3}}{h} \right) \left( \frac{W + 0.264}{h} \right) \quad (4)
\]
III. ANALYSIS OF RECTANGULAR MICROSTRIP PATCH ANTENNA AND METAMATERIAL STRUCTURE WITH SIMULATED RESULTS

The Rectangular Microstrip Patch Antenna is designed on FR-4 (Lossy) substrate at 50Ω matching impedance dielectric constant $\varepsilon_r = 4.3$ and height from the ground plane $d=1.6$mm. The parameter of rectangular microstrip patch antenna are $L= 35.8462$ mm, $W= 46.0721$ mm, Cut Width= 6 mm, Cut Depth= 10mm, length of transmission line feed= 29.58 mm, with width of the feed= 3mm shown in figure 1.

The simple RMPA is inspired by metamaterial structure at 1.812 GHz.

**TABLE 1: RECTANGULAR MICROSTRIP PATCH ANTENNA SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dimension</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant</td>
<td>4.3</td>
<td>-</td>
</tr>
<tr>
<td>Loss tangent($\tan \delta$)</td>
<td>.02</td>
<td>-</td>
</tr>
<tr>
<td>Thickness (h)</td>
<td>1.6</td>
<td>Mm</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>1.812</td>
<td>GHz</td>
</tr>
<tr>
<td>Length L</td>
<td>35.84</td>
<td>Mm</td>
</tr>
<tr>
<td>Width W</td>
<td>46.07</td>
<td>Mm</td>
</tr>
<tr>
<td>Cut width</td>
<td>6</td>
<td>Mm</td>
</tr>
<tr>
<td>Cut depth</td>
<td>10</td>
<td>Mm</td>
</tr>
<tr>
<td>Path length</td>
<td>29.58</td>
<td>Mm</td>
</tr>
</tbody>
</table>

**Figure 1.** Rectangular microstrip patch antenna at 1.812 GHz

CST-software is used to design the Rectangular microstrip patch antenna (RMPA) at operating frequency 1.812 GHz.
However, their employment raises some problems, such as, difficulty impedance matching or increasing of surface waves in the substrate that could decline the radiation efficiency and the radiation pattern. Bandwidth of the antenna may be considerably becomes worse [8].

Simulated result of Return loss and bandwidth of Rectangular Microstrip Patch antenna(RMPA) are shown in fig 2.

![Simulation of return loss and bandwidth of RMPA](image)

**Figure 2.** Simulation of return loss and bandwidth of RMPA

The bandwidth of simple RMPA is 8.2 MHz and Return loss is -10.3 dB.

The Rectangular microstrip patch antenna has 3D Radiation pattern at 1.812 GHz as shown in figure 3. The radiation pattern shows the directivity of simple RMPA is 6.859 dB.

![Radiation pattern of RMPA at 1.812 GHz](image)

**Figure 3.** Radiation pattern of RMPA at 1.812 GHz
Figure 4. Delivered power to RMPA. The maximum power delivered to patch antenna is above 0.90 watt.

Figure 5. Design of proposed metamaterial structure at the height of 3.2 mm from ground plane.

In this metamaterial design as shown in fig 5, composition of many figures like circles, triangles, rectangles along with cuts are loaded on the patch antenna. This design gives the better improvement in impedance bandwidth and reduction in return loss.
Figure 6. Rectangular microstrip patch antenna with proposed metamaterial structure

The simulation result of Return loss and bandwidth of Rectangular microstrip patch antenna loaded with proposed composite metamaterial structure is shown in Fig 7.

Figure 7. Simulation of Return loss and impedance bandwidth of RMPA with proposed metamaterial structure at operating frequency 1.812 GHz

The simulated result of RMPA loaded with proposed composite metamaterial is showing return loss of -25 dB and bandwidth of 20.4 MHz.
It is clear that the directivity of proposed antenna is almost unaffected in comparison to simple RMPA alone.

NICOLSON-ROSS-WEIR (NRW) APPROACH

In this work Nicolson-Ross-Weir (NRW) technique [9]-[10] has been used to obtain the values of permittivity and permeability as this is a very popular technique to convert S-parameters due to the fact that this technique provides easy as well as effective formulation and calculation. Here in this work for extracting the S-Parameters, proposed metamaterial structure is placed between the two waveguide ports [11] [12] at the left and right hand side of the X axis as shown in Fig.4. In Fig 9, Y-Plane is defined as Perfect Electric Boundary (PEB) and Z-Plane is defined as the Perfect Magnetic Boundary (PMB), which creates internal environment of waveguide. The simulated S-Parameters are then exported to Microsoft Excel Program for verifying the Double-Negative properties of the proposed metamaterial structure [13].

![Figure 8. Radiation pattern of proposed antenna showing Directivity of 6.856 dBi](image1)

![Figure 9. Proposed metamaterial structure between the two waveguide ports](image2)
Equations used for calculating permittivity and permeability using NRW approach [10]-[11].

\[
\mu_r = \frac{2c(1-\nu_1)}{\omega d i(i+\nu_2)} \tag{1}
\]

\[
\varepsilon_r = \mu_r + \frac{2S_{11} c i}{\omega d} \tag{2}
\]

Where,

- \( \nu_1 = S_{21} - S_{11} \)
- \( \omega \) = Frequency in Radian
- \( d \) = Thickness of the Substrate
- \( i \) = Imaginary coefficient
- \( c \) = Speed of Light
- \( \nu_2 \) = Voltage Minima

For satisfying Double Negative property, the values of permeability and permittivity should be negative within the operating frequency range. The obtained values of these two quantities from the MS-Excel Program are given in Table 2 whereas Fig. 10 & Fig. 11 shows the graph between permeability & frequency and permittivity & frequency respectively.

**Figure 10:** Permeability versus Frequency Graph

**Figure 11:** Permittivity versus Frequency Graph
The maximum power delivered to proposed rectangular microstrip patch antenna is 1 watt in figure 12.

![Table 2](image)

**Table 2**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Re[Er]</th>
<th>Re[μr]</th>
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<tbody>
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<td>1.791</td>
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<td>1.827</td>
<td>-5.33052</td>
<td>-1.73665</td>
</tr>
</tbody>
</table>

![Figure 12](image)

**Figure 12.** Delivered power to reduced size RMPA loaded with metamaterial structure
Figure 13. E Field of the reduced size RMPA loaded with Metamaterial

Figure 14. H Field of the reduced size RMPA loaded with Metamaterial

Figure 15. Smith chart of simple Rectangular microstrip patch antenna
The smith chart is very useful when solving transmission problems. The real utility of the Smith chart, it can be used to convert from reflection coefficients to normalized impedances (or admittances), and vice versa.

Above figure shows the impedance variation in the simulated frequency range and received impedance matching for proposed antenna at characteristic impedance.

IV. SIMULATION RESULTS

In this paper, Rectangular microstrip patch antenna loaded with composite structure along with cuts metamaterial structure is simulated using CST-MWS software. The proposed design in comparison to RMPA alone, found that the potential parameters of the proposed antenna is increased. This is clear from Fig.7 that the return loss is reduced to -25.0 dB and bandwidth is increased to 20.4 MHz. From Fig.9, it is clear that the Directivity of proposed antenna design is almost unaffected. The maximum power delivered to proposed rectangular microstrip patch antenna is 1 watt.

V. CONCLUSION

The main drawback of Patch Antenna was impedance bandwidth. For this purpose, Rectangular microstrip patch antenna loaded with composite structure along with cuts metamaterial structure has been proposed and analyzed in this paper. The simulated results provide that improvement in the bandwidth is 12.2 MHz and the Return loss of proposed antenna is reduced by -14.7 dB. It is clear that we can easily overcome the drawbacks of RMPA by using the properties of Metamaterial (MTM). By using metamaterial, the maximum power delivered to proposed antenna is 1 watt as compared to the RMPA delivered power of 0.9 watt.

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REFERENCES


