Abstract—A metamaterial is introduced into the cover of a patch antenna and its band structure is analyzed. The metamaterial cover with correct selection of the working frequency increases the patch antenna’s directivity. Based on the methodology, optimization of structure is proposed for the application of metamaterials as antenna substrate to primarily enhance directivity by minimizing its refractive index. The experimental results are presented thoroughly and compared with the analytic calculations. This paper aims to review and critically discuss the comparison of a metamaterial included patch and metamaterial cover over the patch. An analytical method is used to predict the features of the simulation results, implying that within a certain frequency range, comparison can be made between these two models. The S-parameters as a performance matrix are obtained from antenna simulations carried on CADFEKO Silverlite version 5.5. Simulations have been carried out for different shapes of microstrip patch antenna in the microwave regime. © 2010 ISRO – Indian Space Research Organisation

Index Terms—Microstrip antenna (MSA), Antennas, Patch cover, Directivity, Negative refractive Index (NRI), metamaterials.

I. INTRODUCTION

Metamaterials are a broader class of materials which enables us to manipulate the permittivity and permeability for optimizing physical properties of radiating patch primarily for improvement in radiation from antenna. Recently, there has been growing interest in both the theoretical and experimental study of metamaterials. Many properties and potential applications of left-handed metamaterials have been explored and analyzed theoretically [10]. Emission in metamaterials using an antenna was presented in 2002 by Enoch et al. [8]. An MSA in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side [7]. The top and side views of a rectangular MSA (RMSA) are shown in Figure 1.1.

Radiation from the MSA can occur from the fringing fields between the periphery of the patch and the ground plane. In 1953, Deschamps first proposed the concept of the MSA [1]. Practical antennas were developed by Munson [2, 3] and Howell [4] in the 1970s. The numerous advantages of MSA led to the design of several configurations for various applications, which includes its low weight, small volume, and ease of fabrication [5, 6]. With increasing requirements for personal and mobile communications, the demand for smaller and low-profile antennas has brought the concept of MSA.

Another objective of this paper is to develop a methodology to analyze, design and compare a metamaterial substrate for a microstrip antenna with a patch cover. We will use numerical simulation and theoretical studies first to design a metamaterial structure that is suitable for the antenna substrate; then use experiments to prove our prediction for the comparison purpose.

II. THEORETICAL BACKGROUND

A. Metamaterials

A metamaterial (or meta material) is a material which gains its properties from its structure rather than directly from its composition.
B. Types of Metamaterial:

<table>
<thead>
<tr>
<th>Permittivity</th>
<th>Permeability</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>&gt;0</td>
<td>&gt;0</td>
<td>DPS</td>
</tr>
<tr>
<td>&lt;0</td>
<td>&gt;0</td>
<td>ENG</td>
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<td>&gt;0</td>
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<td>MNG</td>
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<tr>
<td>&lt;0</td>
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<td>DNG</td>
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</table>

Where,
- DPS - Double Positive material
- ENG - Electrically negative material
- MNG - Magnetically negative material
- DNG - Double Negative material

C. Patch Antenna

MSAs are manufactured using printed-circuit technology, so that mass production can be achieved at a low cost.

Fig 2 Basic structure of a rectangular microstrip patch antenna

Fig 3 Simple Patch

IV. MATHEMATICAL RELATIONS

A. Calculations for Metamaterial:

Permittivity \( \varepsilon \) and the Permeability \( \mu \) measurements:

The constitutive parameters are the permittivity \( \varepsilon \) and the permeability \( \mu \), which are related to the refractive index \( n \) by

\[
\varepsilon = \frac{\varepsilon_0 \varepsilon_r}{1 - \frac{\mu_0 \mu_r}{\varepsilon_0}}
\]

Where, \( \varepsilon_r \) and \( \mu_r \) are the relative permittivity and permeability related to the free space permittivity and permeability by

\[
\varepsilon_0 = \varepsilon / \varepsilon_r = 8.854 \times 10^{-12}
\]

\[
\mu_0 = \mu / \mu_r = 4\pi \times 10^{-7}
\]

Maxwell’s equations:

\[
\nabla \times H = \frac{\partial D}{\partial t}
\]

\[
\nabla \times E = -\frac{\partial B}{\partial t}
\]

From the point of view of Maxwell’s Equations, the material is some collection of objects (whether atoms, molecules, composites or anything else) that can be described by a Permittivity \( \varepsilon \) and a Permeability \( \mu \).

The reflection coefficient (\( \Gamma \)) at the interface is found from the measured reflection (\( S_{11} \)) and transmission (\( S_{21} \)) coefficients.

\[
\Gamma = X \pm \sqrt{(X^2 - 1)}
\]

Where,

\[
X = \frac{S_{11}^2 - S_{21}^2 + 1}{2S_{11}}
\]

The propagation factor \( P \) is found from \( S_{11}, S_{21} \) & \( \Gamma \)

\[
P = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma}
\]

The complex dielectric constant and permeability can be determined from \( P \) and \( \Gamma \):
The resonance frequency of the MSA excited at TM_{mn} mode is obtained using the following expression [12]:

\[ f_0 = \frac{c}{2\sqrt{\varepsilon}} \left[ \left( \frac{m}{L} \right)^2 + \left( \frac{n}{W} \right)^2 \right]^{1/2} \]  

(14)

where \( m \) and \( n \) are the modes along the \( L \approx a_p \), length and \( W b_p \), width of patch, respectively.

For an RMSA to be an efficient radiator, \( W \) should be taken equal to a half wavelength corresponding to the average of the two dielectric mediums (i.e., substrate and air) [13].

\[ W = \frac{c}{2f_0 \sqrt{\varepsilon + \frac{1}{2}}} \]  

(15)

The expressions for approximately calculating the percentage BW of the RMSA in terms of patch dimensions and substrate parameters is given by

\[ \% BW = \frac{A h}{\lambda_0 \sqrt{\varepsilon_r}} \frac{W}{L} \]  

(16)

Where,

\[ A = 180 \text{ for } \frac{h}{\lambda_0 \sqrt{\varepsilon_r}} < 0.045 \]  

\[ A = 200 \text{ for } 0.045 < \frac{h}{\lambda_0 \sqrt{\varepsilon_r}} < 0.075 \]  

V. PARAMETRIC STUDY OF MSAS

A. Effect Of \( b_p \)

The width \( b_p \) of the RMSA has significant effect on the input impedance, BW, and gain of the antenna. With an increase in \( b_p \) the following effects are observed: The resonance frequency decreases from 3.14GHz to 2.46 GHz. The BW of the antenna increases by 8.7%. The aperture area of the antenna increases resulting in an increase in the directivity, efficiency, and gain.

B. Effect Of \( \varepsilon_r \)

With an increase in \( \varepsilon_r \), the following effects are observed: BW increases due to a decrease in \( \varepsilon_r \) and an increase in \( h/\lambda_0 \), because the resonance frequency has increased. A better comparison of effect of \( \varepsilon_r \) is obtained when the antenna is designed to operate in the same frequency range for different values of \( \varepsilon_r \).

C. Effect Of Finite Ground Plane

The finite ground plane effect can be taken into account by numerical techniques. However, it should be noted that the simulation time is least when the ground plane is infinite because then only the patch is analyzed with its perfect image. For the finite ground plane, on the other hand, both the patch and the ground plane are divided into number of segments and hence the simulation time increases. Also, as the size of the ground plane increases, the simulation time increases [7].

VI. DESIGN AND METHODOLOGY

Objective: To obtain the response of slotted patch within desired frequency band. To compare the response of metamaterial include patch, which is used as artificial substrate with the patch cover.

VII. COMPARATIVE ANALYSIS

A. Slotted Patch with metamaterial.

For different dimensions of patch: After simulating various models, best results are displayed below.

- \( d_1 \times w_1 = 7 \text{mm} \times 0.5 \text{mm} \),
- \( d_1 \times w_2 = 8 \text{mm} \times 0.5 \text{mm} \)
Design and Comparative analysis of a Metamaterial included Slotted Patch Antenna with a Metamaterial Cover over Patch

\[ a_p = 45.9 \text{ mm}, \quad b_p = 30 \text{ mm}; \]

| TABLE II |
| --- | --- | --- | --- |
| \( a_p \) (mm) | No. of Bands | Band-1 | Band-2 |
| Max Freq (GHz) | \( S_{11} \) (dB) | Max Freq (GHz) | \( S_{11} \) (dB) |
| 45.9 | 3 | 1.4450 | -17.9261 | 2.1000 | -16.3489 |
| 2.4100 | -35.1532 | |

Simulated Result:

Return loss/ S-parameter:

RESULT ANALYSIS: Slotted Patch with metamaterial responds between 1.4450 - 2.4100 GHz for patch dimensions 30mm x 45.9mm. Tribands are further shifted towards left of the frequency axis with good results of return loss.

B. Metamaterial Cover over Patch

Fig 8 Results for slotted patch with metamaterial cover dimension 45.9mm x 30mm

TABLE V
SHOWS OPTIMUM DESIRED BAND 1.3-2.2GHz

<table>
<thead>
<tr>
<th>( \alpha_p ) (mm)</th>
<th>No. of Bands</th>
<th>Band-1</th>
<th>Band-2</th>
<th>Band-3</th>
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VIII. FUTURE SCOPE
Task to be performed includes the implementation of multilayer patch, using one or two layers of metamaterial over patch cover. To introduce the concept of Fractal Antenna and Array of metamaterial inclusions in patch substrate.
IX. CONCLUSION
Triband Operation of slotted patch antenna for 1 to 4 GHz of frequency band is obtained with optimized results in terms of return loss. It can be concluded that after appropriate slotting the patch the triband is shifted more towards left of the frequency axis i.e. upto 1.4910 GHz. Moreover all the three bands are obtained between 1.4450-2.4100GHz. This paper has demonstrated two ways to simulate a patch antenna. The return loss is obtained for metamaterial include slotted patch and compared with the patch cover response. Applying metamaterial to patch antenna is an important development of new high-directivity patch antenna. The results showed that the metamaterial cover, which works like a lens, could effectively improve the patch antenna’s directivity. The physical reasons for the improvement are also given. The important factors that are considered are the difference in solution time and the deviation in the results. With increase in width of the patch from 25mm to 30 mm 8.71% increase in bandwidth is observed. Miniaturization of the patch antenna is to the core of our effort and the enhancement of bandwidth is obtained by slotting of the patch. After inclusions of the metamaterial the bandwidth increment is 11.13% as compared to the substrate with tetol as the dielectric. Future scope of metamaterials hold great promise for new applications in the megahertz to terahertz bands, as well as optical frequencies which includes super-resolution imaging, cloaking, hyperlensing, and optical transformation.

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