STUDY OF ENHANCEMENT OF PROPERTIES OF ANTENNA AND DESIGN OF HIGH GAIN PATCH ANTENNA USING METAMATERIAL

A graduate project submitted in partial fulfillment of the requirements

For the degree of Master of Science in Electrical Engineering

By

Tejas Dudhane

December 2016
The graduate project of Tejas Dudhane is approved:

__________________________
Dr. Somnath Chattopadhyay, Ph.D.  Date

__________________________
Dr. Habib Taouk, Ph.D.  Date

__________________________
Dr. Sembiam Rengarajan, Ph.D., Chair  Date

California State University, Northridge
Acknowledgement

It gives me satisfaction in presenting my project report on Study of Enhancement of Properties of Antenna and Design of High Gain Patch Antenna Using Metamaterial towards fulfilment of Masters of Science Degree in Electrical Engineering.

I would like to personally thank Dr. Sembiam Rengarajan for his guidance towards completion of my project. I appreciate the effort and time he has put into this project, without his supervision and knowledge it would not have been possible.

I would also like to express my gratitude to Dr. Somnath Chattopadhyay and Dr. Habib Taouk for their suggestions and guidance.
# Table of Contents

Signature Page .......................................................................................................................... ii

Acknowledgement .................................................................................................................. iii

List of Figures .......................................................................................................................... vii

Abstract ................................................................................................................................. ix

Chapter 1: Introduction and design of microstrip patch antenna ........................................ 1

1.1 Basic Principle .................................................................................................................. 1

1.2 Feed techniques .............................................................................................................. 2

1.3 Microstrip patch antenna design and analysis procedure ........................................... 2

Chapter 2: Metamaterial ..................................................................................................... 8

2.1 Classification and Applications .................................................................................... 8

2.2 Negative effective refractive index ............................................................................. 9

2.3 Designing strategies for non-refractive medium ......................................................... 10

Chapter 3: Design of Microstrip patch antenna loaded with C shaped structure .............. 13

3.1 Proposed Antenna configuration ................................................................................ 13

3.2 Design and analysis of C shaped structure ................................................................. 13

3.3 Rectangular C designed structure loaded with patch antenna .................................. 15

Chapter 4: Microstrip patch antenna with metamaterial cover ....................................... 17

4.1 Introduction ................................................................................................................... 17

4.2 Proposed metamaterial ring lattice structure with patch antenna .......................... 19

4.3 Homogenization by field averaging ........................................................................... 20
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6</td>
<td>Steps to design patch with metamaterial superstrate</td>
<td>21</td>
</tr>
<tr>
<td>4.7</td>
<td>Modifications in design to improve performance</td>
<td>27</td>
</tr>
<tr>
<td>Conclusion</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>
**List of Figures**

| Figure 1.1 | Microstrip Feed line .................................................. | 2 |
| Figure 1.2 | Basic geometry of patch antenna .................................... | 3 |
| Figure 1.3 | Design Patch antenna structure ....................................... | 3 |
| Figure 1.4 | Cut Coordinates calculation of patch antenna .................... | 4 |
| Figure 1.5 | Microstrip Line Coordinates ........................................... | 5 |
| Figure 1.6 | Design Parameters values .............................................. | 5 |
| Figure 1.7 | Microstrip Patch antenna with open space boundary condition ... | 5 |
| Figure 1.8 | Frequency (x-axis) vs return loss (y-axis) plot at 2.919 GHz .... | 6 |
| Figure 1.9 | 3D gain plots of microstrip antenna .................................. | 6 |
| Figure 1.10 | Gain plot parameters in CST Studio suite ......................... | 6 |
| Figure 2.1 | Classification of Materials ........................................... | 8 |
| Figure 2.2 | Metamaterials Classification ......................................... | 9 |
| Figure 2.3 | Backward wave propagation in a Negative refractive index medium | 10 |
| Figure 2.4 | Metallic wire mesh with negative dielectric permittivity ....... | 10 |
| Figure 2.5 | Effective permittivity SRR shaded area showing Negative permeability | 12 |
| Figure 2.6 | Circular and square structures ................................ ...... | 12 |
| Figure 2.6 | CSRR Circular and Square structures ............................... | 12 |
| Figure 3.1 | Design of proposed metamaterial structure ....................... | 14 |
| Figure 3.2 | Simulating structure by port excitation .......................... | 14 |
| Figure 3.3 | Boundary condition in xyz direction ............................... | 14 |
Figure 3.4  Phase reversal at 2.919 GHz (Phase in degree vs frequency)..........15
Figure 3.5  CST design of structure loaded on top of patch antenna..................15
Figure 3.6  Simulation return loss and impedance bandwidth of Rectangular microstrip patch antenna with proposed metamaterial structure.....................16
Figure 4.1  Proposed microstrip patch antenna design in CST..........................17
Figure 4.2  Return loss vs frequency plot at 2.55 GHz..................................18
Figure 4.3  3-D gain plot of designed patch antenna at 2.55 GHz with gain 7.6 dB
..................................................................................................................18
Figure 4.4  1D plot Isolated patch at phi=0 and phi=90..................................19
Figure 4.5  Ring aperture proposed dimension..............................................19
Figure 4.6  Structure of Proposed metamaterial with patch antenna .................20
Figure 4.7  CST combined simulation structure..............................................20
Figure 4.8  Unit Cell structure..........................................................................20
Figure 4.9  Inset Feed Patch antenna gain plots at 2.55 GHz .........................21
Figure 4.10 Inset feed patch...........................................................................21
Figure 4.11 Unit cell Return loss vs frequency comparison with epsilon=2 and epsilon=15.................................................................22
Figure 4.12 Effective permittivity and permeability values (only dielectric) at epsilon=2 vs Frequency(X axis) .................................................................23
Figure 4.13  Plots showing negative permittivity and near to zero permeability with ring aperture structure.................................................................24
Figure 4.14 Plots with permittivity and permeability=1 when dielectric permittivity is set to 15 vs frequency on X axis......................................................25
Figure 4.15 Far field directivity plots of a patch and patch antenna at epsilon=2 with metamaterial cover at phi=0, 90 at 2.55GHz .............................26
Figure 4.16 Far field directivity plots between patch antenna with metamaterial cover and regular patch when permittivity =15 .................................................................27

Figure 4.17 Port de-embedding two circular cutout layers..................................28

Figure 4.18 Sharp filter behavior at 2.55 GHz .................................................28

Figure 4.19 3D Gain plot of Patch antenna without metamaterial cover..............29

Figure 4.20 Gain plot of Patch antenna with metamaterial cover at epsilon =2.6....29
Abstract

STUDY OF ENHANCEMENT OF PROPERTIES OF ANTENNA AND DESIGN OF HIGH GAIN PATCH ANTENNA USING METAMATERIAL

By

Tejas Dudhane

Master of Science in Electrical Engineering

This work focuses on the analysis and design of microstrip patch antennas (MPA) and enhancement of properties like gain, directivity and return loss using metamaterial superstrate. Microstrip antennas are preferred because of their compatibility to fit in aircrafts, mobiles, and satellites because of the small sizes. So, it is the need of the hour to develop effective and superior microstrip patch antenna.

In this report, we present the design of rectangular microstrip patch antenna incorporated with innovative metamaterial structure for dual band operation at 2.478 GHz and 2.919 GHz. Simulations are performed using CST Studio Suite. The simulation results confirm that when incorporated with metamaterial structure the patch antenna achieves better return loss.

Also, in this work, the gain of the patch antenna operating at 2.55 GHz is improved when the metamaterial composed of ring aperture lattice (9 x 9) was placed at a distance ‘d’ from the ground plane. The improvement in gain and directivity is also marked. The designed structures are characterized using CST Studio Suite at variable frequencies, dielectrics and substrate thicknesses.
Chapter 1: Introduction and design of microstrip patch antenna

1.1 Basic principle

A metallic patch placed on a dielectric substrate creates a resonant cavity, with the ground plane on the bottom of the cavity and the patch on the top of the cavity. The patch edges act as open boundary. So, the patch acts as an electric conductor on the top with magnetic conductors on the sides. The cavity modes are defined by double index TM(m,n).

Eqn (i) is the electric field of the TM (m,n) mode.

\[ E_x(x,y) = A_{mn} \cos \left(\frac{m \pi x}{L}\right) \cos \left(\frac{n \pi y}{W}\right) \]  

(i)

The patch is operated in the fundamental mode TM(1,0) so that the field is constant in the y direction and the length (L) of the patch is the resonant dimension and W is its width. The surface current on the patch is x directed which is on the bottom of the patch.

ADVANTAGES AND DISADVANTAGES

The low profile structure has increased the popularity of MPA in wireless industry. The demand is more in military, satellite communication and commercial wireless systems because of ease of fabrication and design. Some of their principal advantages are stated below:

- Easily integrated with microwave integrated circuits (MIC), low cost, and light weight
- Capability of supporting dual and triple frequency operation
- Supports circular and linear polarization, and is mechanically more robust.

Microstrip antennas tend to have more drawbacks when compared with conventional antennas. Some of the disadvantages are listed below:

- Feed arrays structures has large ohmic losses.
- The bandwidth which can be improved by various techniques but still the percentage of BW is very low.
- High radiation from feeds and junctions and relatively high level of cross polarization
• Higher quality factor (greater than 100) and poor scan performance

1.2 Feeding techniques

MICROSTRIP LINE FEED

A conducting strip is connected to a patch as shown below in Fig 1.1. The width of the conducting strip is always smaller than the metallic patch in this kind of arrangement. The feed is etched on the same substrate which provides a structure which is coplanar.

![Microstrip Feed line](image)

Fig.1.1 Microstrip Feed line

The insert cut in the patch helps to match the impedance of the patch to the feed line without any matching elements. The position of the insert helps to achieve this impedance matching. This feeding scheme provides simplicity in modelling, and ease in fabrication and impedance matching.

1.3 Microstrip patch antenna design and analysis

A design procedure has been outlined below for designing rectangular microstrip patch antennas. The specified information includes loss tangent ($\delta$), the resonant frequency ($f_r$), height of substrate (h), dielectric constant of the substrate ($\varepsilon_r$).

The CST software is used for modelling and simulating the microstrip patch antenna. CST is a full wave EM simulator. It has been widely used for RFIC’s, wire antennas, patch antennas and any other antenna design to calculate return loss, current distributions, radiation patterns etc.
Specifications:

The rectangular microstrip patch antenna parameters are calculated as shown below:

1. Width (W) calculation:

   \[ W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r\sqrt{\varepsilon_r+1}} \]

   \[ \text{-------------------------(i)} \]

   where \( c \)=velocity of light in free space, \( \varepsilon_r \)= dielectric constant of the substrate.

2. Effective dielectric constant of the rectangular microstrip patch antenna is given by

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

   \[ \text{-------------------------(ii)} \]
3. Actual length of the patch (L) is

\[ L = L_{\text{eff}} - 2\Delta L \]

Where,

\[ L_{\text{eff}} = \frac{c}{2fr\sqrt{\varepsilon_{\text{eff}}}} \]

4. Calculation of the length extension is found by

\[ \frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{\text{eff}} + 0.3)(0.264)}{(\varepsilon_{\text{eff}} - 0.258)(0.8 + \frac{w}{h})} \]

The coordinates of the width and length of the microstrip line is shown in Figure 2.3 and 2.4:

![Cut Coordinates calculation of patch antenna](image-url)
Analysis of RMPA with the desired configurations:
The substrate chosen to design is FR-4 (lossy). The parametric specifications are given below:

<table>
<thead>
<tr>
<th>Name</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>23.69</td>
</tr>
<tr>
<td>W</td>
<td>30.71</td>
</tr>
<tr>
<td>Lt</td>
<td>25.357</td>
</tr>
<tr>
<td>Wf</td>
<td>2.8</td>
</tr>
<tr>
<td>Ff</td>
<td>10</td>
</tr>
<tr>
<td>Gpf</td>
<td>0.74</td>
</tr>
<tr>
<td>h</td>
<td>1.6</td>
</tr>
<tr>
<td>Mt</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Rectangular microstrip patch antenna with feed line, defined port and boundary condition is shown in Fig 1.7.
The return loss and the impedance bandwidth are shown in Fig. 1.8.

Fig 1.8 Frequency (x-axis) vs return loss (y-axis) plot at 2.919 GHz

Gain plots:

Fig 1.9 3D gain plots of microstrip antenna

Fig 1.10 Gain plot parameters in CST Studio suite
Conclusion:

A Microstrip Patch antenna is designed as shown above, the return loss of the antenna at 2.919 GHz is -6.9 dB. By varying the cut width and cut depth better return loss can be achieved but the design however suffers from narrow bandwidth.
Chapter 2: Introduction and Classification of Metamaterials

The development of nanotechnologies and microsystems advances have been possible because of negative refractive index materials also known as left handed materials. This enabled extension of operations of elements (active and passive) for optical and microwave applications beyond limits and miniaturization of components by 3-4 order of magnitude

2.1 Metamaterials Classification and Application:

We can classify all materials according to their material properties, with the permittivity shown along the x-axis and magnetic permeability along the y-axis.

![Classification of materials](image)

Fig 2.1 Classification of materials [7]

If permeability ($\mu$) and permittivity ($\varepsilon$) are both positive then we have a medium which allows propagation of electromagnetic waves like dielectric.

If either permeability or permittivity (is negative) then the medium prohibits the wave transmission. Prime examples of such media are metals at high frequency with negative permittivity and ferrites which have negative permeability below magnetic plasma frequency.

Materials which are not available in nature are the materials with both ($\mu$ and $\varepsilon$) negative known as double negative media. From the equation (i), we get a medium with a negative refractive index.

$$n = \sqrt{\mu \varepsilon \exp(2i\pi)} \quad \text{------------------------ (i)}$$
The media which has a negative refractive index and $\mu$ and $\varepsilon$ negative allows propagation of wave in the backward direction. Left handed material can be characterized by antiparallel phase and group velocities.

**Pictorial Classification:**

![Fig 2.2 Metamaterials classification [7]](image)

### 2.2 Negative refractive index

The refractive index of a medium is defined as the proportion of the speed of EM wave through the medium to that in vacuum and is indicated by condition $n^2 = \mu\varepsilon$ where $\varepsilon$ is the complex relative permittivity and $\mu$ is the complex relative permeability. If both $\mu$ and $\varepsilon$ are negative in a given wavelength range we can denote $\mu = |\mu| \exp(i\pi)$ and $\varepsilon = |\varepsilon| \exp(i\pi)$. The equation below shows refractive index related to $\mu$ and $\varepsilon$

$$n = \sqrt{\mu\varepsilon \exp(2i\pi)}$$

$$= \sqrt{\mu\varepsilon} \sqrt{\exp(2i\pi)}$$

$$= -\sqrt{\mu\varepsilon} \quad \text{---------------------------------------- (ii)}$$
2.3 Design strategies for non-refractive medium

Materials with negative permittivity and permeability consist of a large number of unit cells corresponding to materials composed of single crystals. These unit cells are mostly composed of dielectrics with inclusions of metal in most cases. “The dimension of this negative refractive material is always smaller than the operating frequency wavelength”.

Many different kinds of structures are utilized to obtain NRM which include the earliest metallic wires arrangement, Roll structure, complementary structure and split ring structure, capacitive loaded split ring resonators etc. These wire structures were the first structure which provided negative permittivity. The structure ($\varepsilon < 0$) consisted of infinitely long thin metallic wires square matrix embedded in dielectric medium.
The figure 2.4 shows unit cell having length ‘a’ and radius ‘r’ with $a >> r$ of a single wire, then the plasma frequency of the longitudinal mode is defined in eqn (iii)

$$\omega_p^2 = \frac{2\pi c^2}{a^2 \ln(a/r)}$$

-------------------------------------------(iii)

From the plasma frequency the effective dielectric permittivity is calculated as shown in eqn.(iv)

$$\varepsilon_{eff} = 1 - \frac{\omega_p^2}{\omega^2 - i \left(\frac{\omega_p^2 a^2 \varepsilon_0}{\sigma a^2 r^2}\right)} \approx 1 - \frac{\omega_p^2}{\omega^2}$$

-------------------(iv)

which concludes that effective permittivity becomes negative for $\omega < \omega_p$ if we consider conductance $\zeta \to \infty$.

Split ring resonator (SRR):

A split ring resonator (SRR) is a conductive structure in which the inductances in the rings are balanced by capacitance in the rings. A time-varying magnetic field applied perpendicular to the rings surfaces induces current, which will either enhance the incident field or oppose the incident field resulting in either effective $\mu$ (positive or negative). The operation of Split Ring resonators represent “under-damped, over-screened” material response to EM simulations.

For a circular double split ring resonator (Fig 2.6) in vacuum and with negligible thickness, the expression given below is valid.

$$\mu_{eff} = 1 - \frac{\pi r^2 / a}{1 + \frac{2\sigma i}{\omega r \mu_0} - \frac{3d}{\pi^2 \mu_0 \varepsilon_0 \varepsilon r^2}}$$

-------------------------(v)

where $\zeta$ is electrical conductance, $a$ is unit cell length.
The frequency dependence of $\varepsilon$ is shown in the figure 2.5, in which a very narrow range of frequency is seen where effective permeability is $<0$ (negative).

**Complementary split ring resonators**

These complementary split rings (CSRR) as shown in fig 2.7, instead of negative permeability ($\mu$), this structure creates negative permittivity ($\varepsilon$) near the resonant frequency in a very narrow range.
Chapter 3: Design of microstrip patch antenna loaded with C shape structure

3.1 Proposed antenna configuration

The characteristics of a microstrip patch antenna with metamaterial substrate loaded with split ring resonator (CSRR) is presented. The antenna uses the complementary ring resonator structure in the ground plane with the proposed medium parameters. The CSRR structure performance is characterized by modelling the metamaterial substrate as a medium with the extracted parameters.

This chapter covers new design approach for antennas with improvement in bandwidth using an artificial complementary split ring resonator structure. In the complementary structure, the electrical boundary conditions are exchanged with the magnetic boundary conditions to make the structure effectively dual. The comparison of bandwidth between patch antenna with CSRR metamaterial and patch antenna with conventional high permittivity substrate is presented.

3.2 Design and analysis of C shaped structure

In this design, “a rectangular geometry is incorporated with C structure” shown in Fig 3.1

![Design of proposed metamaterial structure](image)

Fig 3.1 Design of proposed metamaterial structure.

For calculating S parameter, the C shaped structure is proposed between 2 waveguide ports at the right and the left hand side of the X axis. Z plane is defined as perfect Magnetic
boundary and Y plane as Perfect electric boundary so that they act like a waveguide. The simulated S parameters are extracted.

Fig 3.2 Simulating structure by port excitation

Fig 3.3 Boundary condition in xyz direction

**Phase reversal property:**

Below is the phase reversal property of the unit cell which can be used to develop arrays of unit cell structure and develop negative wave propagation or negative propagation lenses.
3.3 Rectangular structure loaded with patch antenna

The designed structure is placed on top of the ground plane at a height of 3.2mm. The main purpose is to increase the potential parameters of the microstrip patch antenna. At 2.478 GHz, the reflection coefficient is reduced to -30.21 dB and at 2.919 GHz the reflection coefficient is reduced to -29.35 dB shown in Fig 3.6.

Fig 3.4. Phase reversal at 2.919 GHz (Phase in degree vs frequency)

Fig 3.5 CST design of structure loaded on top of patch antenna

Fig 3.5 CST design of structure loaded on top of patch antenna
Fig 3.6 Simulation return loss and impedance bandwidth vs frequency of rectangular microstrip patch antenna with proposed metamaterial structure
4.1 Introduction

The design and simulation of microstrip patch antenna with metamaterial superstrate is shown in this chapter. A new patch system is proposed which consists of a cover made up of 2 metamaterial layers. The structure consists of copper grids with a lattice period equal to ‘a’ in both x and y directions, the ring aperture of copper grid has a radius ‘r’.Spacing between the grids is in the z direction. “The period of the square lattice is less than microwave wavelength” which can be assumed to be a thin metal wire structure. Arrays of thin wires are characterized by plasma frequency. The permittivity can be positive and also less than one, which means that refractive index is less than one and close to zero. This property of the metamaterials can be applied to antennas to focus the incident fields radiated from the antenna.

Design parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>37.2</td>
<td>mm</td>
</tr>
<tr>
<td>Width</td>
<td>46.3</td>
<td>mm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Thickness of Substrate</td>
<td>2</td>
<td>mm</td>
</tr>
</tbody>
</table>

Fig 4.1 Proposed microstrip patch antenna design in CST.
Fig 4.2 Return loss vs frequency plot at 2.55 GHz

Fig 4.3 3-D gain plot of designed patch antenna at 2.55 GHz with gain 7.6 dB
4.2 Proposed metamaterial ring lattice structure with patch antenna

Ring aperture dimension

In Fig 4.5 below, the empty space is air and the outer layer is metal.

![Fig 4.5 Ring aperture proposed dimension](image)

Upper layer parameters

\[ r = 17\text{mm}, a = 35\text{mm}, h = 41\text{mm} \] [4]

Each layer consists of 9 x 9 units, thickness of substrate is 2mm, which makes the total size of substrate and cover is 315mmx315mm.
4.3 Homogenization by field averaging

Consider the unit cell structure in Fig 4.8, to calculate effective material properties by field averaging first we need to calculate Bloch mode from the Bloch wave vector which gives the field throughout the unit cell. The fields are then averaged at points on the surface that correspond to points on Yee grid. Next, the average effective material parameters are extracted using average field quantities. The last step is to remove the grid dispersion to get effective material properties from averaged effective material parameters.
4.4 Steps to design patch antenna with metamaterial superstrate

1. Design the patch with 2 layer metamaterial cover and both metamaterial layers and the patch are finely tuned to work at 2.55 GHz (Fig 4.9) and so the results shown can only be obtained at that frequency (or very close).

2. Try to isolate the patch antenna in CST file to check if it is designed for optimum performance at 2.55 GHz. If not then design a new inset feed patch antenna (Fig 4.10) with the help of Antenna Magus which is another antenna tool.

Figure 4.9  Inset feed patch antenna gain plots at 2.55 GHz

Figure 4.10 Inset feed patch
3. It is seen that the ground plane extends to the metamaterial layer’s dimensions. This step is critical to the design because of the back reflection from the metamaterial layers.

4. Next step is to make sure that the metamaterial unit cell is finely tuned to 2.55 GHz. The dimensions of the metal rings and the properties of the dielectric material backing which is very important. We therefore have to simulate the unit cell using frequency domain solver and manually optimize the dielectric constant.

Figure 4.11 Unit cell reflection coefficient (y-axis) vs frequency(x-axis) comparison with epsilon=2 and epsilon=15
Figure 4.12 Effective permittivity and permeability values (only dielectric) at Epsilon=2 vs Frequency(X axis)
Figure 4.13 Plots showing negative permittivity and near to zero permeability (Y axis) with ring aperture structure vs Frequency (X axis)

To check the accuracy we could delete the metal ring and simulate just the dielectric we should get dielectric constant $\varepsilon_r = 1.996$ at 2.55 GHz as shown in 4.12. Fig 4.13 shows the results with the ring included and the effective permittivity is negative. When the
dielectric permittivity is set to 15 the effective permittivity and permeability are both 1 as shown in Fig 4.14.

Figure 4.14 Plots with permittivity and permeability=1 when dielectric permittivity is set to 15 vs frequency on X axis.

5. Next, model the 9 X 9 2 layer array with the patch antenna with ring parameters defined before. We see from the results in Fig 4.15 that the Antenna Gain is greatly
increased by 6.56 dB, as expected after adding a 2 layer metamaterial cover. Fig 4.15 Far field directivity plots of a patch and patch antenna at epsilon=2 with metamaterial cover at phi=0, 90 at 2.55GHz.

6. The gain comparison between a conventional patch and a patch with metamaterial is made as shown in Fig 4.15, the gain of conventional patch antenna is 7.698dB and gain of metamaterial with patch is 14.26 dB, which proves the fact that we observe gain enhancement of 6.56 dB after adding a metamaterial superstrate above patch antenna.

7. When we set permittivity of dielectric to 15, the metamaterial is transparent and far field directivity should remain constant as shown in Fig 4.16.
Fig 4.16 Far field directivity plots between patch antenna with metamaterial cover and regular patch when permittivity =15

4.5 Modifications in design to improve performance

1. We have to make sure to add both layers of the circular cutout layers and then de-embed ports (Fig 4.17) so that the phase of the S-parameters is taken from the surface of the metal structures. It is important to have the height and both layers to observe the metamaterial property.
2. After simulating, this model with different dielectric constants, as the paper [4] referred wasn’t clear if $\varepsilon_r = 2.6$ for the patch or for the metamaterial superstrate boards. However, with this unit cell simulation, we do see a sharp filter behavior (Fig 4.18) at 2.55 GHz when $\varepsilon_r = 2.6$, which suggests that the dielectric constant is indeed 2.6 for the metal material layers. If you want to tune a little better to 2.55 GHz, you may need to make the circles slightly larger or slightly increase the dielectric constant.
3. Next step is to run the patch with no superstrate and the gain of the patch is measured which is 7.040 dB (Fig 4.19). The High lobes are in the YZ plane which is the effect of a finite ground plane.

Fig 4.19 3D Gain plot of Patch antenna without metamaterial cover

4. Next, use the full model with changed dielectric constant to 2.6 for metamaterial superstrate to observe an increase in gain to 15.29 dB compared to patch gain (Fig4.20).

Fig 4.20 Gain plot of Patch antenna with metamaterial cover at epsilon =2.6
Conclusion

A comparison between the conventional patch antenna and the new metamaterial cover patch antenna is presented to improve gain to 14.26 dB at 2.55 GHz. Also, it is shown that by varying values of dielectric we can achieve a gain of 15.29 dB at same frequency. The results show that the design is useful and metamaterial structure can realize congregating the radiation energy which makes the antenna gain comparatively higher than the regular conventional patch antenna.
References


[4] Study on High Gain Patch Antenna with Metamaterial Cover, Zi-bin WENG Nai-biao WANG Yong-chang JIAO, IEEE


[7] Dr. Raymond, 21st century electromagnetics material, Cosmo learning