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Multiband Microstrip Patch Antenna for Wireless Applications Using Metamaterial

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***Abstract*—A U-slot microstrip patch antenna loaded with metamaterial substrate is presented. The metamaterial substrate consists of an array of 5×6 split ring resonators. Each split ring resonator is made up of two concentric circular copper rings patterned on a substrate of FR4, with slits diametrically opposite each other. This work is mainly focused on increasing potential parameters of antenna and analyzing the multiband operation of proposed antenna. The antenna covers the frequency range of 2-4 GHz. For simulation purpose CST microwave studio software has been used.**

Keywords: metamaterial, patch antenna, Split ring resonators (SRRs)

I. INTRODUCTION

With a rapid development of wireless communication, the demand for low cost, minimal weight, low profile antenna that can operate in different frequency bands is on the increase. The future development of the personal communication devices will aim to provide image, speech and data communication at any time anywhere around the world.

This indicates that the future communication terminal antennas must meet the requirements of multi band or wide band operation to sufficiently cover the possible operating bands and compact size of antenna is a demand factor. Microstrip patch antennas are good candidate for these requirements because of their many merits, such as the low profile, light weight and conformity.

However, patch antennas have some disadvantages like narrow bandwidth, surface wave excitation etc. With the properties of negative permittivity and negative permeability LHM material mainly used to focus on radiation of an antenna .Metamaterial certainly deserve more than an increased gain in microstrip antennas, miniaturize patch antenna size, adjust the bandwidth and also find its applications in filtering the unwanted signals.

Metamaterial is a combination of “meta” and “material”, meta is a Greek word which means something beyond, altered, changed or something advance [1]. Metamaterial or left handed materials (LHM) are manmade artificial materials, whose permeability and permittivity are simultaneously negative. In 1986, Veselago studied the novel electromagnetic properties of substance with simultaneously negative permittivity (ε) and negative permeability of material (μ)[2]. Veselago found that pointing 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 to term “left handed substance,” keeping in mind that this term is equivalent to the term “substance with negative group velocity”. Metamaterial consist of many unique properties especially the backward wave and negative refraction. The negative refraction has been proven by [3], [4], and the backward wave propagation has been verified by [5].

After Veselago, Pendry proposed that long metallic wire lattices had effectively negative permittivity and split ring resonator had effectively negative permeability in specified frequency band [6] and later Smith made the first experimental realization of left handed material [7]. The Metamaterial or left handed material is a combination of thin wires and split ring resonators (SRR). Many new structures have been proposed for LHM such as Omega shape, spiral multi –split, fishnet and S-shape they exhibit the properties of a LHM [8-10]. In the recent years, for microwave applications Metamaterial have been studied. To improve the performance of antenna in the microwave range of frequencies several works have been aimed [6, 7, and 11].

II. METHODOLOGY

The multiband microstrip patch antenna is etched on FR4 substrate of thickness h=1.2mm, and dielectric constant =4.4. The proposed design for metamaterial substrate is based on “Split Ring resonators” shaped structure.

III. DESIGN SPECIFICATIONS

The parameters of multi band microstrip patch antenna are calculated from the formulas given below.

Desired parametric analysis [12]

III (a) Resonant Frequency

$$f_0 = \frac{c}{2W\sqrt{\varepsilon_r+1}} \tag{1}$$

Where

Fo = Resonance Frequency

C = Speed of light

W = Width of Patch

ε_r = Relative dielectric constant

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III (b) Length [L]

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{2}$$

ε_{reff} = Effective dielectric constant

III(c) Effective dielectric constant

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{3}$$

H=height of substrate

W=width of patch

III (d) Width [W]

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{4}$$

IV.

V. ANALYSIS OF MULTIBAND MICROSTRIP PATCH ANTENNA

The multiband microstrip patch antenna is designed using FR-4 substrate. The antenna is fed by 50 ohm microstrip line. The size of patch is 40×47mm.
Dimensional view of multiband microstrip patch antenna is shown in figure 1

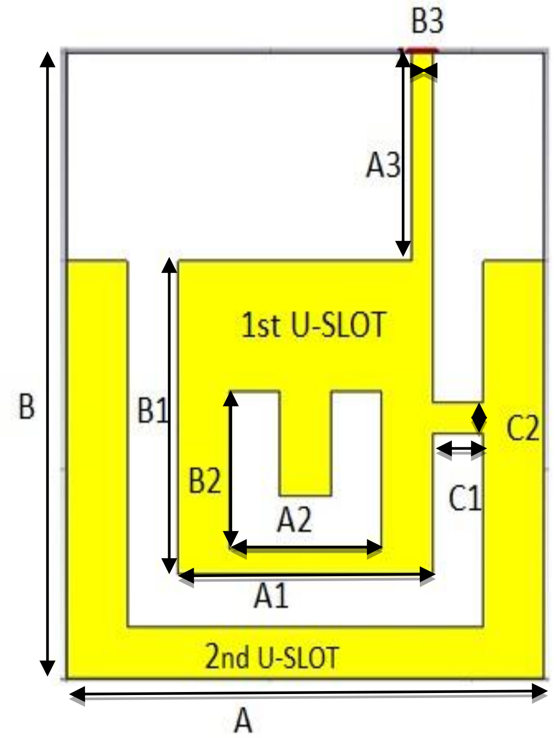


Fig.1 U slot microstrip patch antenna

The parametric specifications of Rectangular microstrip patch antenna are mentioned in table 1.

Parameters	Dimensions (mm)
Dielectric constant	4.4
Thickness	1.2
A	47
A1	30
A2	15
A3	20
B	60
B1	25
B2	15
B3	2
C1	5
C2	3

Table1. Parameters of U-slot microstrip patch antenna.

The return loss is a main parameter in almost all antenna analysis. It is also known as the S_{11} parameter in the two port network. It measures the antennas absorption of the fed power over the total power. A good antenna should indicate a return loss of less than -10 dB, which indicates that the antenna absorbs more than 90% of the fed power. Return loss of multiband microstrip patch antenna is shown. Figure shows only one band at frequency 2.43 GHz with return loss -12.831 dB.

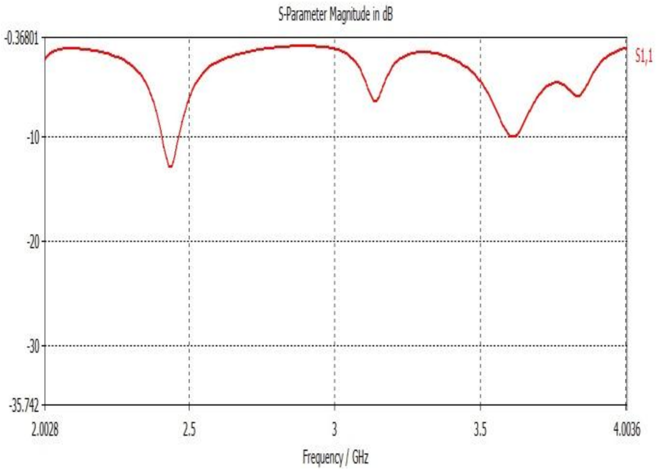


Fig.2 Return losses

PATCH ANTENNA LOADED WITH METAMATERIAL

VI. METAMATERIAL UNIT CELL STRUCTURE

Split ring resonator design is used to produce the negative dielectric constant (permittivity) and negative permeability. Sometime this structure is known as double negative material or DNG. In its original form as proposed by Pendry [6], the split ring resonator (SRR) is composed of two concentric circular metallic rings each interrupted by a small gap, hence the name “split -rings”. In split ring resonators external magnetic field penetrates through the rings and currents are induced. The gap between the rings prevents flow of current around the rings. Which considerably increase the resonance frequency of the structure. Split ring resonator (SRR) provides a resonant structure which is much smaller than the resonance wavelength.

The figure shows the split ring resonator, which consist of two concentric rings of copper with thickness 0.035mm patterned on FR4 substrate of dielectric constant $\varepsilon = 4.4$. The other geometric parameters of split ring resonator are: width of ring w=0.5mm, radius of inner ring r=2.5mm, spacing between inner and outer ring d =0.5mm, side a= 9mm.

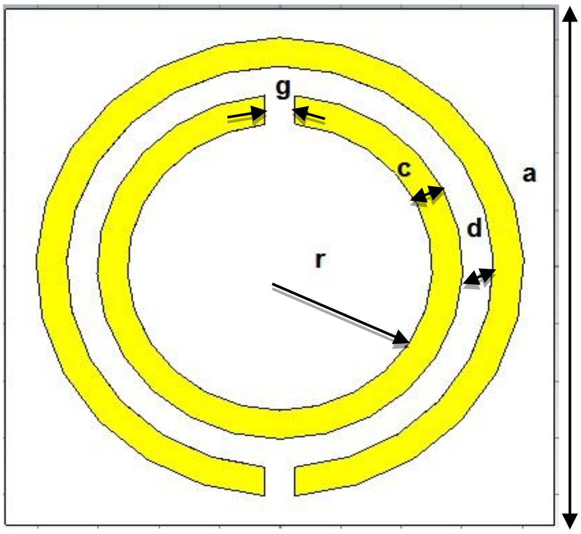


Fig.3 Split Ring Resonator unit Cell.

Equations for calculating negative permittivity and negative permeability:

Negative permeability is given by

$$\mu_{eff} = 1 - \frac{\pi r^2/a}{1 + \frac{2\sigma_i}{\omega r \mu_0} - \frac{3d}{\pi^2 \mu_0 \omega^2 \varepsilon_0 \varepsilon r^2}} \qquad (6)$$

And negative permittivity is given by

$$\varepsilon_{eff} = 1 - \frac{\omega_p}{\omega - [\omega - i(\omega_p{}^2 a^2 \varepsilon_0)/\sigma\pi r^2]} \qquad (7)$$

$$\varepsilon_{eff} \approx 1 - \frac{\omega_p{}^2}{\omega^2} \qquad (8)$$

$$\omega_p{}^2 = \frac{2\pi c^2}{a^2 \ln(a/r)} \qquad (9)$$

Where
a =unit cell length
r=radius and r<<a
σ= electrical conductance
ω_p= plasma frequency
μ_0= permeability of free space
ε_0 = permittivity of free space

The obtained negative value of permeability and permittivity with in the operating frequency range by using MATHCAD is shown below.

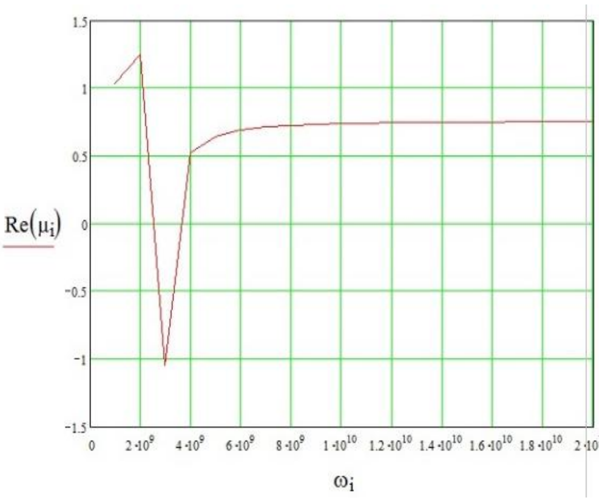


Fig.4 Permeability versus Frequency Graph.

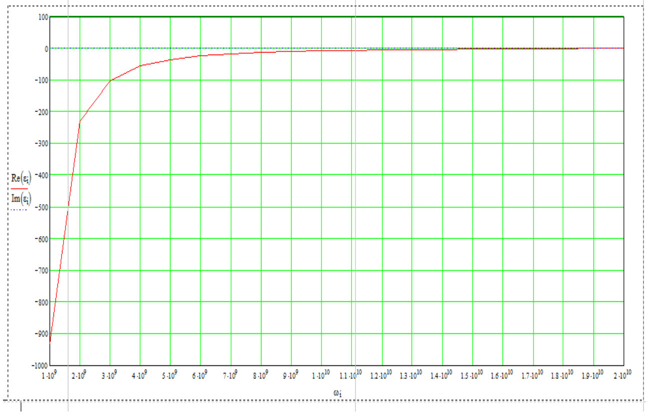


Fig.5 Permittivity versus Frequency Graph.

VII. ANTENNA DESIGN

Figure show the geometry of proposed antenna. A 5×6 array of Metamaterial is placed in the substrate of a patch antenna. The Metamaterial substrate has been constructed by using two layer of FR4 with relative electric permittivity of $\varepsilon_r = 4.4$. On the lower layer of 40 mm an array of 5×6 metallic SRRs is printed and on upper layer of 30mm the U-slot patch antenna is printed. The metallic part of antenna is considered copper. When the patch antenna is loaded with this metamaterial, its resonance frequency depends on metamaterial constitutive parameters. It mean that antenna resonates when the constitutive parameters becomes negative. Therefore the antenna resonance frequency shifts to the metamaterial resonance frequency.

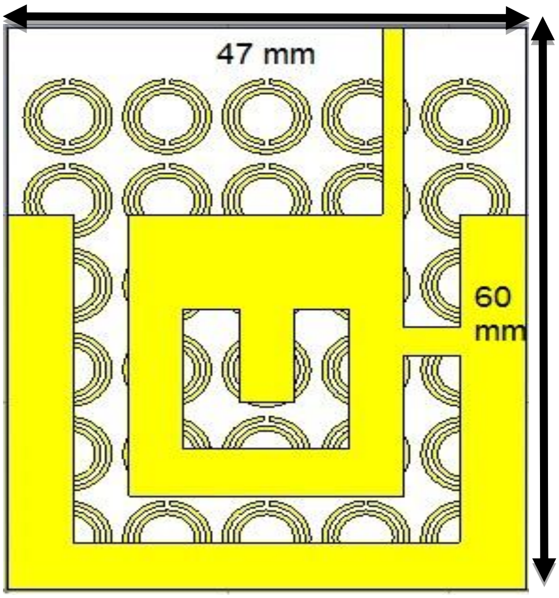


Fig.6 Microstrip patch antenna with metamaterial substrate.

VIII. SIMULATION RESULTS AND COMPARISIONS

Simulation results of proposed antenna are shown below. Theses simulations are obtained by using CST microwave software.

[A] RETURN LOSSES

The return losses of multiband antenna with or without metamaterial are shown in the above figure. It has been noted that the antenna with metamaterial achieves the low return losses.

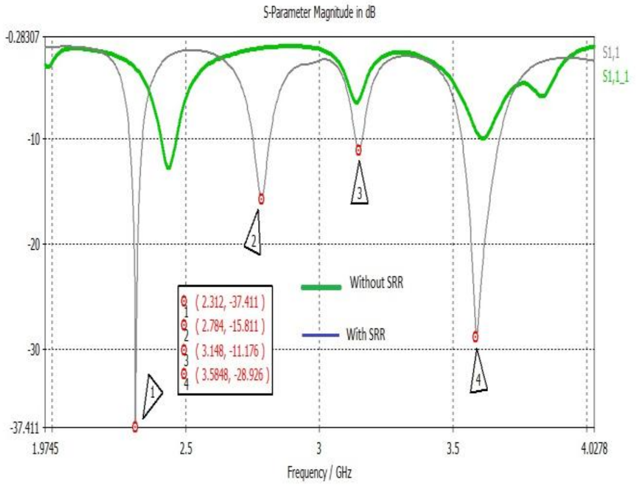


Fig.7 Return losses of antenna with or without metamaterial substrate.

The graph shows that there is a slight variation in operating frequencies. Antenna with metamaterial achieves four band at frequency 2.312GHz , 2.784GHz, 3.148GHz ,3.584GHz with return losses -37.41dB,-15.8 dB,-11.17dB,-28.96dB respectively.

[B] VSWR

VSWR is an indication of the quality of the impedance match. A VSWR under 2 is considered suitable for most antenna applications. Figure show the VSWR values for antenna without metamaterial substrate and with metamaterial substrate.

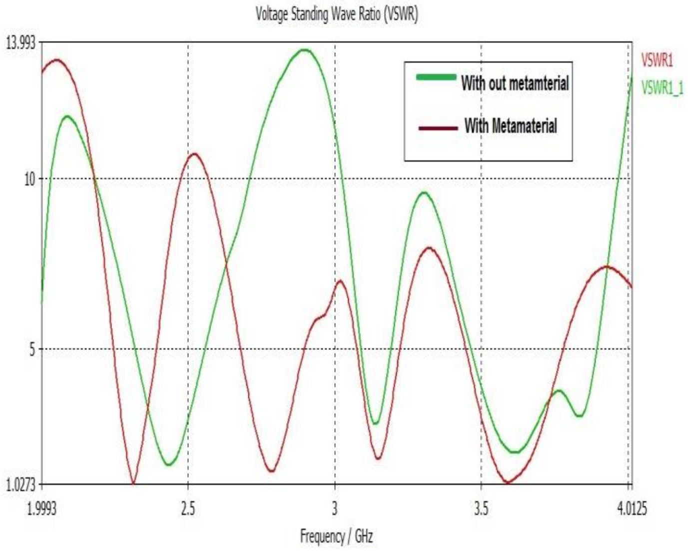
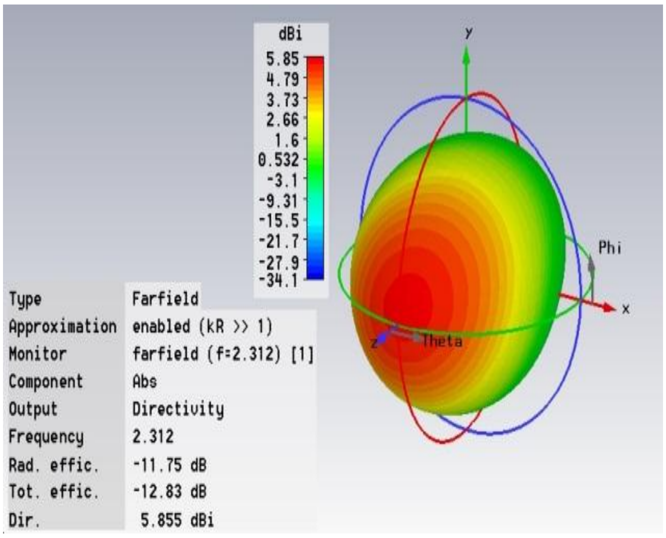


Fig.8 VSWR of antenna with or without metamaterial substrate.

[C] DIRECTIVITY

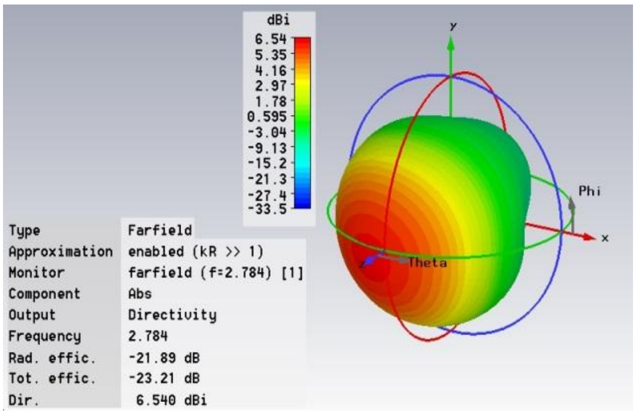
Directivity is the ability of antenna to measure the power density the antenna radiates in the direction of its strongest emission versus the power density radiated by an ideal isotropic radiator radiating the same total power. The directivity of antenna with metamaterial at different frequencies is shown below:



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.312) [1]
Component	Abs
Output	Directivity
Frequency	2.312
Rad. effic.	-11.75 dB
Tot. effic.	-12.83 dB
Dir.	5.855 dBi

Fig.9(a) Directivity of multiband antenna with metamaterial at frequency 2.312 GHz is 5.855 dBi.

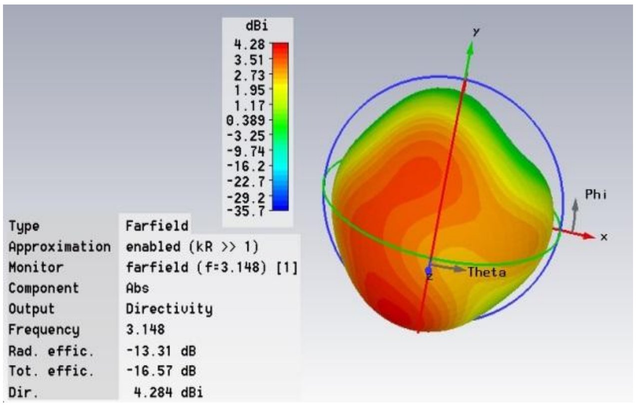
The directivity observed in the Fig 9(a) comes out to be 5.855dBi at frequency 2.312 GHz.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.784) [1]
Component	Abs
Output	Directivity
Frequency	2.784
Rad. effic.	-21.89 dB
Tot. effic.	-23.21 dB
Dir.	6.540 dBi

Fig.9(b). Directivity of multiband antenna with metamaterial at frequency 2.784 GHz is 6.540 dBi.

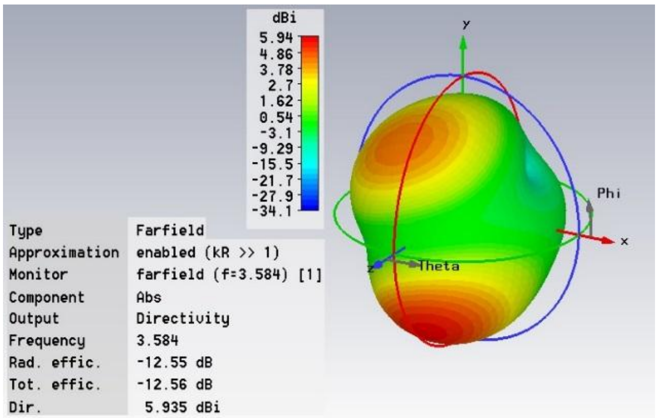
The directivity observed in the Fig 9(b) comes out to be 6.540 dBi at frequency 2.784 GHz.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.148) [1]
Component	Abs
Output	Directivity
Frequency	3.148
Rad. effic.	-13.31 dB
Tot. effic.	-16.57 dB
Dir.	4.284 dBi

Fig.9(c) Directivity of multiband antenna with metamaterial at frequency 3.148 GHz is 4.284 dBi.

The directivity observed in the Fig 9(c) comes out to be 4.482 dBi at frequency 3.148 GHz.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.584) [1]
Component	Abs
Output	Directivity
Frequency	3.584
Rad. effic.	-12.55 dB
Tot. effic.	-12.56 dB
Dir.	5.935 dBi

Fig.9 (d) Directivity of multiband antenna with metamaterial at frequency 3.584 GHz is 5.935 dBi.

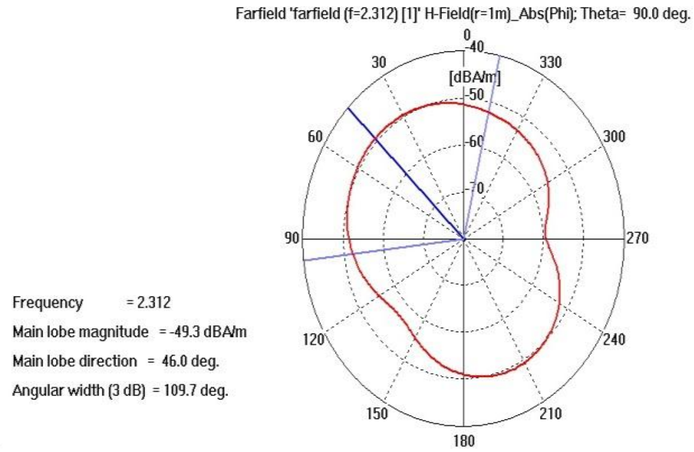
The directivity observed in the Fig 9(d) comes out to be 5.935 dBi at frequency 3.584 GHz.

[D] RADIATION PATTTERN

The radiation pattern is a graphical depiction of the relative field strength transmitted from or received from by the antenna. In microstrip patch antenna the source of radiation of the electric field at the gap of the edge of the microstrip elements and ground plane is the key factor to accurate calculation of the pattern for the patch antenna. Antenna radiation patterns are taken at one frequency, one polarization, and one plane cut. The patterns are usually presented in polar or rectilinear from with a dB strength scale. The radiation pattern is three dimensional, but usually the measured radiation patterns are a two dimensional slice of the three dimensional pattern, in horizontal or vertical planes.

H-Plane Radiation Patterns

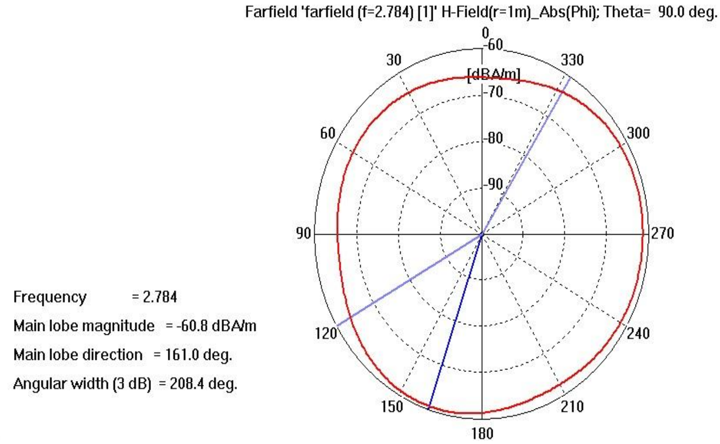
The H- plane radiation pattern of multiband microstrip patch antenna for different frequency bands is shown below:


Farfield 'farfield (f=2.312) [1]' H-Field(r=1m)_Abs(Phi); Theta= 90.0 deg.

Frequency = 2.312
Main lobe magnitude = -49.3 dBA/m
Main lobe direction = 46.0 deg.
Angular width (3 dB) = 109.7 deg.

Fig.10(a) H-plane radiation pattern for frequency 2.312 GHz.

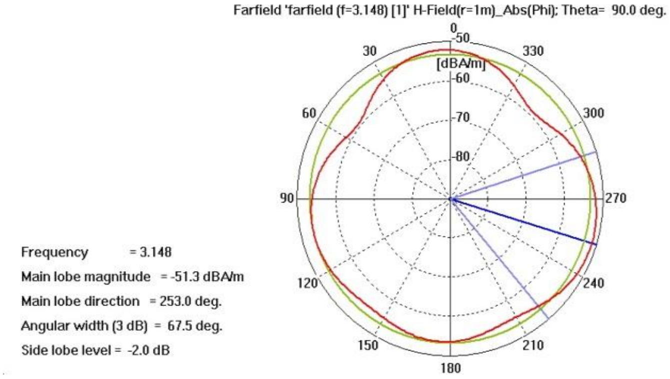
Figure 10(a) show H-plane (theta=90º, phi=varying) radiation patterns for proposed antenna configuration at the resonating frequency of 2.312 GHz.


Farfield 'farfield (f=2.784) [1]' H-Field(r=1m)_Abs(Phi); Theta= 90.0 deg.

Frequency = 2.784
Main lobe magnitude = -60.8 dBA/m
Main lobe direction = 161.0 deg.
Angular width (3 dB) = 208.4 deg.

Fig.10(b) H-Plane radiation pattern for frequency 2.784 GHz.

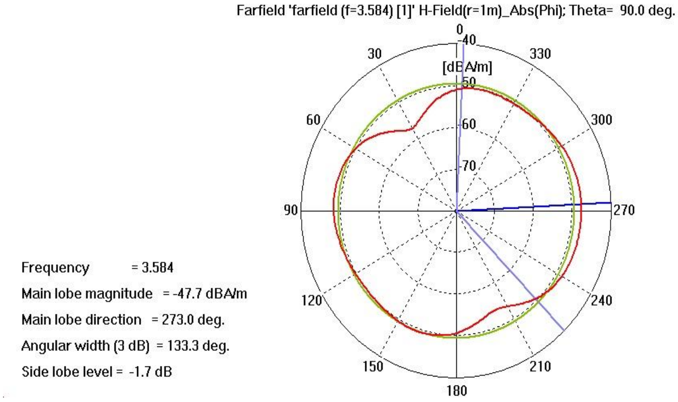
Figure 10(b) show H-plane (theta=90º, phi=varying) radiation patterns for proposed antenna configuration at the resonating frequency of 2.784 GHz.



Frequency = 3.148
Main lobe magnitude = -51.3 dBA/m
Main lobe direction = 253.0 deg.
Angular width (3 dB) = 67.5 deg.
Side lobe level = -2.0 dB

Fig.10(c) H-Plane radiation pattern for frequency 3.148 GHz.

Figure 10(c) show H-plane (theta=90º, phi=varying) radiation patterns for proposed antenna configuration at the resonating frequency of 3.148 GHz.



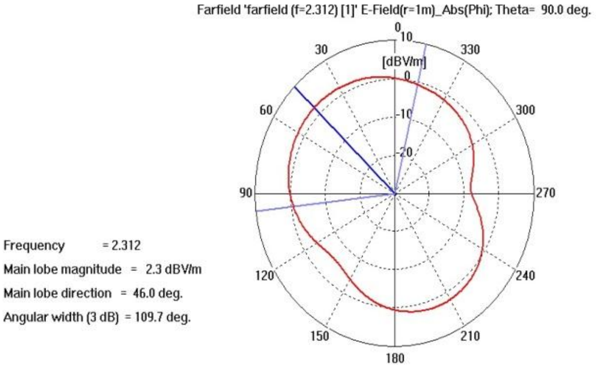
Frequency = 3.584
Main lobe magnitude = -47.7 dBA/m
Main lobe direction = 273.0 deg.
Angular width (3 dB) = 133.3 deg.
Side lobe level = -1.7 dB

Fig.10(d) H-Plane radiation pattern for frequency 3.584 GHz.

Figure 10(d) show H-plane (theta=90º, phi=varying) radiation patterns for proposed antenna configuration at the resonating frequency of 3.584 GHz.

E-Plane Radiation Patterns

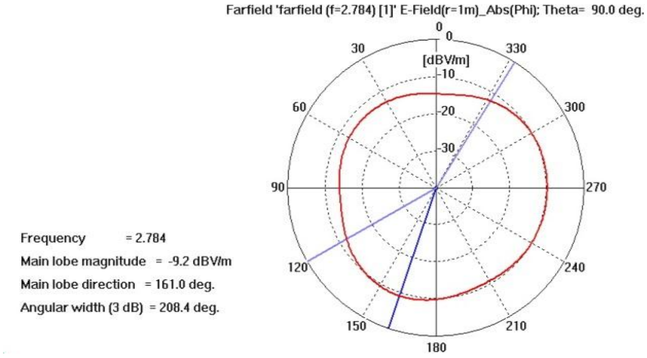
The E- field radiation pattern of multiband microstrip patch antenna for different frequency bands is shown below:



Frequency = 2.312
Main lobe magnitude = 2.3 dBV/m
Main lobe direction = 46.0 deg.
Angular width (3 dB) = 109.7 deg.

Fig.11 (a) E-plane radiation pattern for frequency 2.312 GHz.

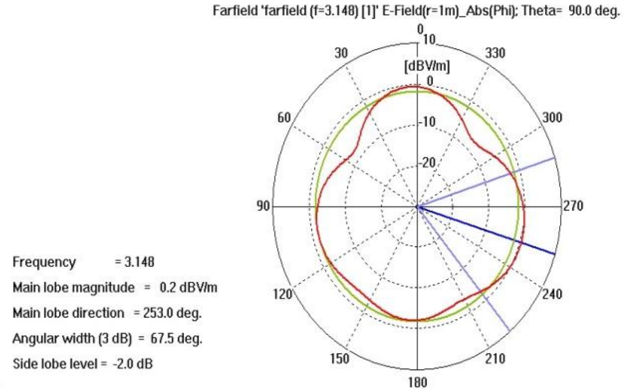
Figure 11(a) show E-plane (theta= varying, phi=90º) radiation patterns for proposed antenna configuration at the resonating frequency of 2.132 GHz.



Frequency = 2.784
Main lobe magnitude = -9.2 dBV/m
Main lobe direction = 161.0 deg.
Angular width (3 dB) = 208.4 deg.

Fig.11(b) E-Plane radiation pattern for frequency 2.784 GHz.

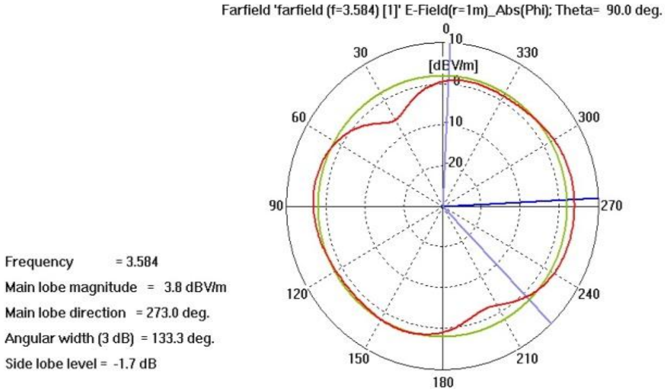
Figure 11(b) show E-plane (theta= varying, phi=90º) radiation patterns for proposed antenna configuration at the resonating frequency of 2.784 GHz.



Frequency = 3.148
Main lobe magnitude = 0.2 dBV/m
Main lobe direction = 253.0 deg.
Angular width (3 dB) = 67.5 deg.
Side lobe level = -2.0 dB

Fig.11 (c) E-Plane radiation pattern for frequency 3.148 GHz.

Figure 11(c) show E-plane (theta= varying, phi=90º) radiation patterns for proposed antenna configuration at the resonating frequency of 3.148 GHz.



Frequency = 3.584
Main lobe magnitude = 3.8 dBV/m
Main lobe direction = 273.0 deg.
Angular width (3 dB) = 133.3 deg.
Side lobe level = -1.7 dB

Fig.10(d) E-Plane radiation pattern for frequency 3.584 GHz.

Figure 11(d) show E-plane (theta= varying, phi=90º) radiation patterns for proposed antenna configuration at the resonating frequency of 3.584 GHz.

IX. CONCLUSION

In this paper a multiband microstrip patch antenna using metamaterial has been presented investigating the return losses, VSWR, radiation patterns for wireless applications. The proposed design in comparison to microstrip patch antenna alone, found that the potential parameters of the proposed antenna is increased. The measured results of microstrip patch antenna with metamaterials shows the return losses -37.41dB, -15.8dB,-11.17dB,-28.96dB at frequency 2.312GHz , 2.784GHz, 3.148GHz ,3.584GHz respectively.

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