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A High Gain & Wide Band Rectangular Microstrip Patch Antenna loaded with "Interconnected SRR" Metamaterial Structure

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Abstract

Communication applications require wide band and highly directive planner Antennas. For such requirement this work deals with the analysis and simulation of a Rectangular Microstrip Patch Antenna loaded with "INTERCONNECTED SRR" Metamaterial Structure at a height of 3.2mm from the ground plane. The work also investigates the potential properties of the proposed Metamaterial Structure. The proposed Antenna is designed at an operating frequency of 2.75GHz to meet S-Band (2-4GHz) applications. By loading "Interconnected SRR" Metamaterial Structure with the Rectangular Patch Antenna at a height of 3.2mm, the Antenna's bandwidth is found to be increased up to 378MHz and return loss is reduced to -42.2dB i.e. the potential properties like return loss, bandwidth, directivity, gain and total efficiency of the proposed Antenna increases to a great extent in comparison to the Rectangular Patch Antenna alone. Double Negative properties (permittivity & permeability) of the proposed Metamaterial Structure have also been verified by Nicolson-Ross-weir (NRW) method.

Keywords: *Metamaterial, Patch Antenna, Permeability, Permittivity, Gain*

1 Introduction

Patch Antennas are fabricated on a substrate with a high dielectric constant are strongly preferred for easy integration with *Monolithic Microwave Integrated Circuits Radio Frequency (*MMIC RF) front end circuitry. as this can lead to the poor efficiency and a narrow bandwidth. The losses can be reduced by increasing thickness of the dielectric substrate. By increasing the thickness, results the increasing factor of the power delivered by the source into a surface wave. Also in recent times, the function of various portable devices is increasing, so the Antenna designer's encountered difficulty in designing Antennas that could provide multiband operations with high gain & bandwidth. Therefore the proposed Antenna is designed in S-Band (2-4GHz) to provide communication applications with high gain & bandwidth.

The unusual properties of the Metamaterials [11][12] are utilized here in a Microstrip Patch Antenna at operating frequency in order to achieve an more efficient Antenna. Metamaterials were first introduced by Veselago [1][5][6][8] in 1967. Veselago first analyzed theoretically the wave propagation in a material with a negative electric permittivity and a negative magnetic permeability [4]. In such a left-handed (LH) material the electric field, the magnetic field, and the wave vector of an electromagnetic wave propagating obey the left-hand rule (instead of the right-hand rule for usual materials). Metamaterials permit Patch Antenna elements to cover a wider frequency range, thus making better use of available space for small platforms or spaces. Some applications for Metamaterial Antennas are wireless communication, space communications, GPS, satellites, space vehicle navigation, and airplanes.

2 Formulation, Designing and Simulation of RMPA & RMPA Loaded with Proposed Metamaterial Structure

Design parameters of Rectangular Microstrip Patch Antenna can be calculated from the formulas given below-

Formulation [2-3]
Width of Metallic Patch (W)

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Effective Dielectric Constant is calculated from:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \qquad (2)$$

Length of Metallic Patch (L)

$$L = L_{eff} - 2\Delta L \tag{3}$$

Where,

$$\text{Leff} = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}}$$

Calculation of Length Extension

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

Where,

ε_{reff} = Effective dielectric constant,

ε_r = Dielectric constant of substrate,

h = Height of dielectric substrate,

W = Width of the Patch,

L = Length of the Patch,

ΔL = Effective Length and

f_r = Resonating Frequency

Calculation of VSWR

$$\text{VSWR} = \text{S} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{5}$$

Where Γ = Reflection Coefficient

Calculation of Return Loss

$$\text{Return loss} = 20\log\ |\Gamma| \tag{6}$$

The design parameters of Rectangular Microstrip Patch Antenna calculated from the formulaes mentioned above are given in Table 1 below.

Table 1

	Dimensions	Unit
Dielectric Constant of FR-4 (Lossy) (єr)	4.3	-
Loss Tangent (tan ∂)	0.025	-
Thickness of FR-4 (Lossy) (h)	1.6	mm
Operating Frequency	2	GHz
Length (L)	27.1	mm
Width (W)	31.1	mm
Cut Width	5	mm
Cut Depth	10	mm
Path Length	29	mm
Width Of Feed	3	mm

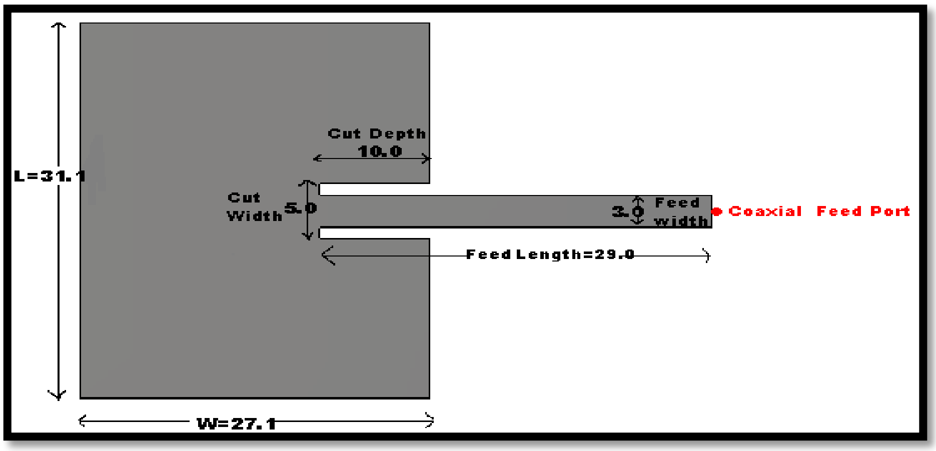


Figure 1: Rectangular Microstrip Patch Antenna designed at 2.75GHz (all dimensions in mm).

After designing the RMPA, CST-MWS software is used for the simulation in transient mode and results are shown in figure 2 and figure 3.

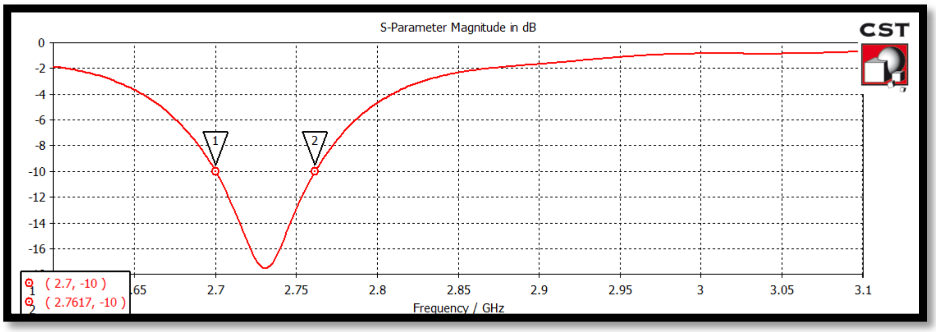
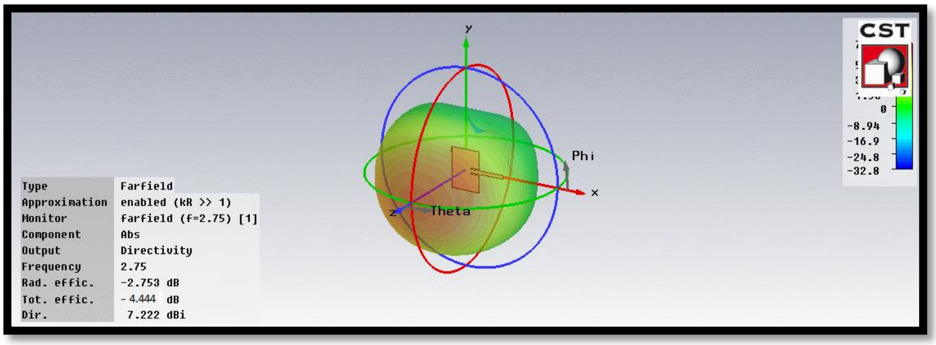


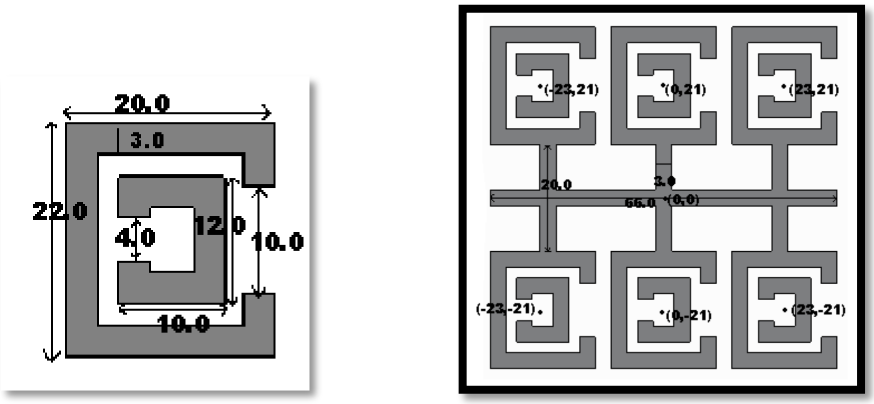
Figure 2: Simulated result of Rectangular Microstrip Patch Antenna showing bandwidth of 61.7MHz and return loss of -17dB.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.75) [1]
Component	Abs
Output	Directivity
Frequency	2.75
Rad. effic.	-2.753 dB
Tot. effic.	- 4.444 dB
Dir.	7.222 dBi

Figure **3**: Radiation Pattern of Rectangular Microstrip Patch Antenna showing directivity of 7.2dBi and total efficiency is 35.9%.

“INTERCONNECTED SRR” shaped Metamaterial Structure is proposed and dimensions of a single SRR are shown in figure 4(a).



(a) **(b)**

Figure 4: (a) Dimensional view of a single SRR (all dimensions in mm).
(b) Arrangement of Structure in XY Coordinate System

Two waveguide ports [16] were defined at the left and right of the X-Axis in order to calculate the S11 & S21 parameters and proposed Structure is placed at height 3.2 from the reference ground plane as shown in figure 5. The obtained S-parameters are exported to Microsoft Excel Software for calculating the value of the permittivity and permeability of the proposed Metamaterial Structure, by using the Nicolson-Ross-Weir (NRW) approach.

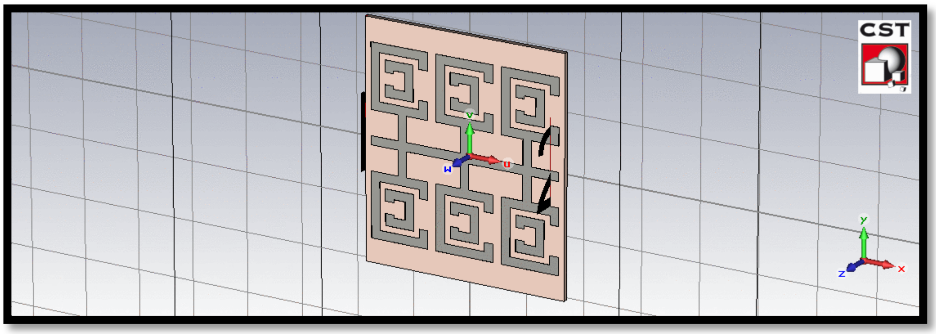


Figure 5: Proposed Metamaterial Structure placed between the two Waveguide Ports

Equations used for calculating permittivity & permeability using NRW approach [9] [10] [13]:-

$$\mu_r = \frac{2.c(1-v2)}{\omega.d(1+v2)i} \tag{7}$$

$$\varepsilon_r = \mu_r + \frac{(2.S11.c)i}{\omega.d} \tag{8}$$

Where,
V2 = S21 - S11
ω = Angular Frequency in Radian,
d = Thickness of the Substrate=1.6 mm,
c = Speed of Light =2.99x10^8,
V2 = Voltage Minima, and
i is the iota function

Where, V2 is calculated by using the simulated S11 & S21 parameters when the proposed metamaterial structure is placed between the two waveguide ports.

Graph in figures 6 & 7 are obtained from the equation 7 and 8, shows that the proposed Metamaterial Structure possesses negative values of permittivity (ε) and permeability (μ) at the operating frequency, that proves the proposed Structure is metamateial.

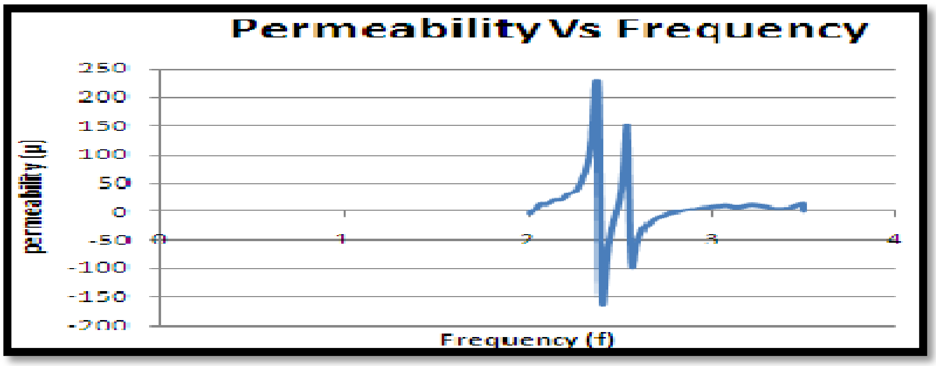


Figure 6: Permeability versus Frequency (in GHz) Graph of the proposed "STRR".

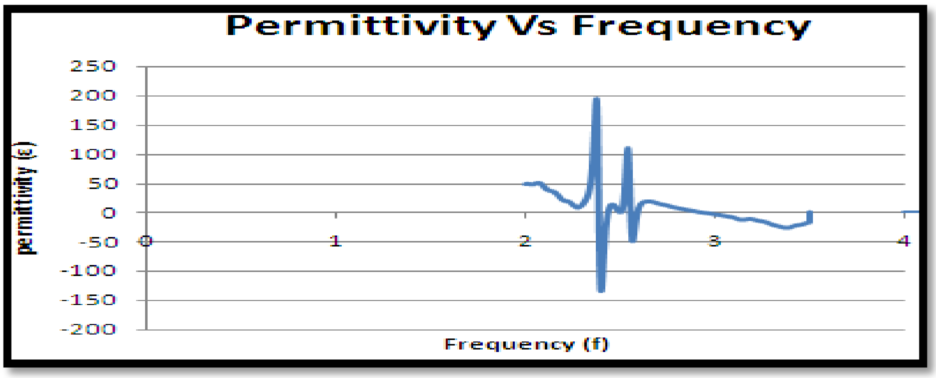


Figure 7: Permittivity versus Frequency (in GHz) Graph of the proposed "STRR"

The figure 8 (a) below shows the ground plane and figure 8 (b) shows the RMPA loaded with the "INTERCONNECTED SRR" Metamaterial Structure at a height of the 3.2mm from the ground plane.

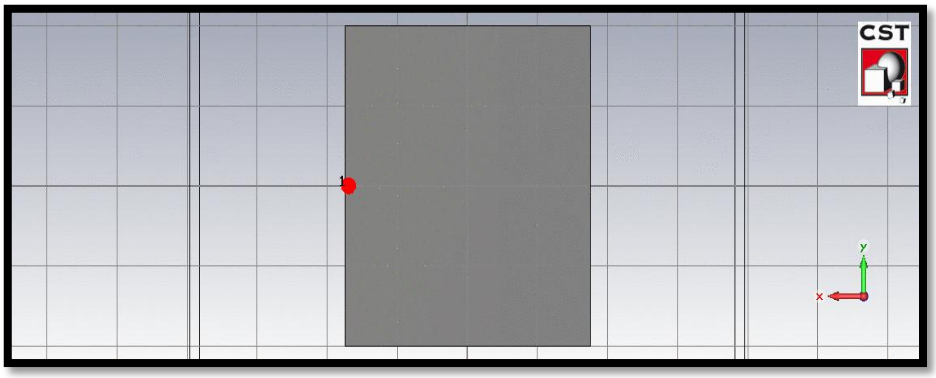


Figure 8 (a): Ground Pane

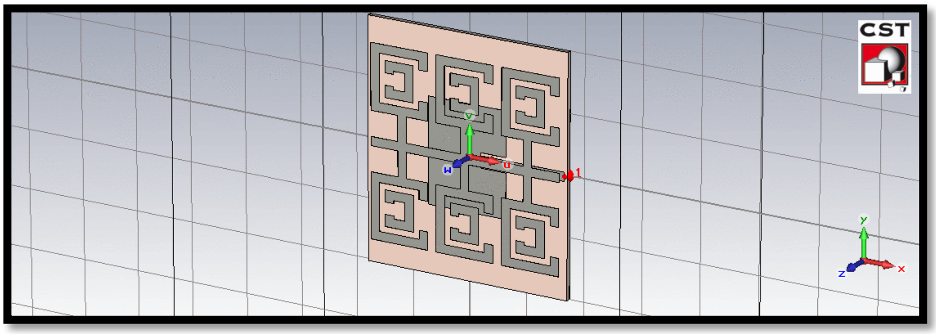


Figure 8 (b): Rectangular Microstrip Patch Antenna loaded with “INTERCONNECTED SRR” Metamaterial Structure at a height of 3.2mm from the ground plane.

Figure 10 & 12 shows the simulated and experimently tested results of the reduced size RMPA along with proposed Metamaterial Structure respectively , it is clear from figure that the bandwidth of the proposed Antenna is remarkably improved[17] in operating frequency range and return loss is significantly reduced in comparison to the conventinal RMPA.

Figure 9 shows the simulated result of the RMPA along with proposed Metamaterial Structure , it is clear from the figure that the bandwidth of the proposed Antenna is remarkably improved[14-15] in operating frequency range and return loss is significantly reduced in comparison to the RMPA alone.

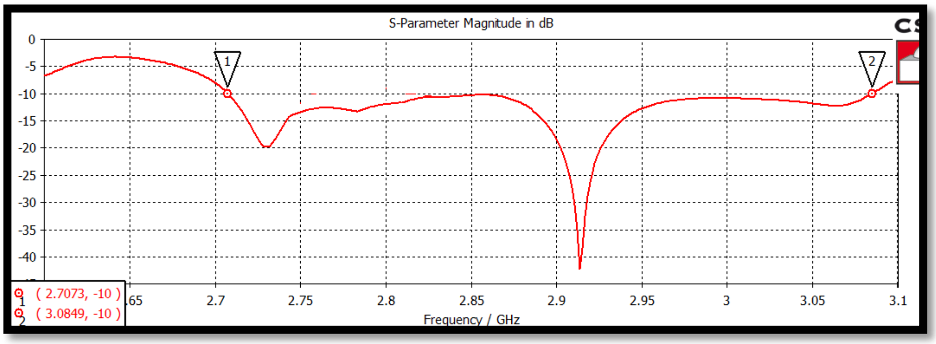
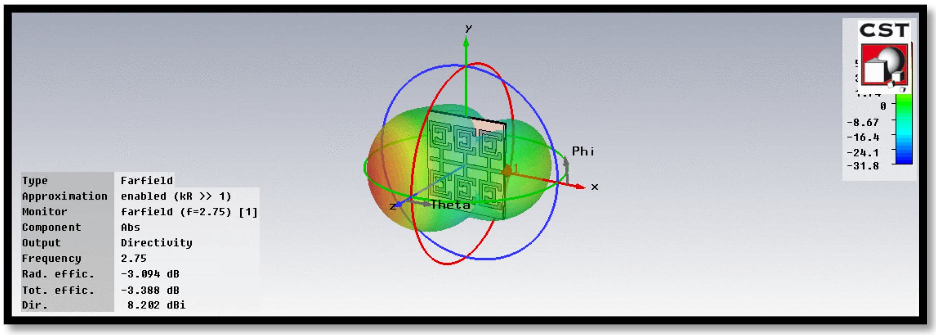


Figure 9: Simulated result of the RMPA along with “INTERCONNECTED SRR” Metamaterial Structure showing Bandwidth of 378MHz & Return Loss of -42.2dB

The radiation pattern is a graphical representation of the relative field strength transmitted from or received by the Antenna, Simply it can be said that the power radiated or received by the Antenna is the function of angular position and radial distribution from the Antenna. In figure 10 radiation pattern of the proposed Antenna is shown. It is clear from the figure 10, that directivity has been improved by 0.9dBi and total efficiency of Antenna increased from 35.9% to 45.9%.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.75) [1]
Component	Abs
Output	Directivity
Frequency	2.75
Rad. effic.	-3.094 dB
Tot. effic.	-3.388 dB
Dir.	8.202 dBi

Figure 10: Radiation Pattern of the RMPA loaded with “INTERCONNECTED SRR” Metamaterial Structure showing directivity of 8.2dBi & total efficiency is 45.9 %.

Figure 11 shows the smith chart [7] of the RMPA along with “INTERCONNECTED SRR” Metamaterial Structure, it has been found that impedance curve passes through the center (normalized match impedance = 50Ω) of the smith chart i.e. impedance of the Antenna is matched with the co-axial cable at 2.9GHz.

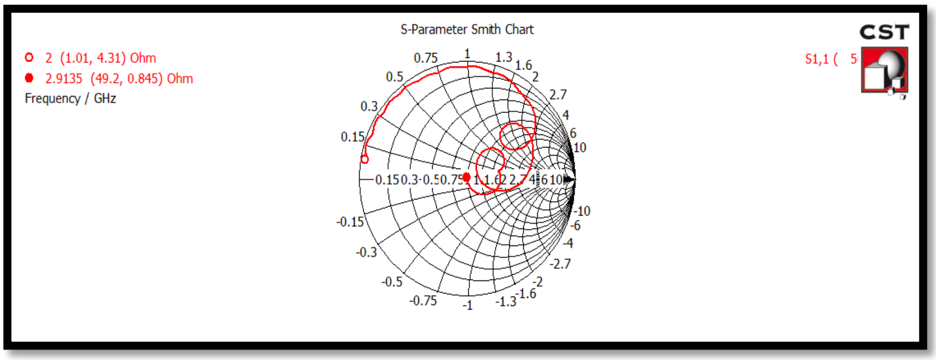


Figure 11: Smith chart of the RMPA loaded with “INTERCONNECTED SRR” Metamaterial Structure at 2.75GHz.

In Figure 12(a) and 12(b) shows E field and H field broadband radiation pattern of the proposed antenna respectively.

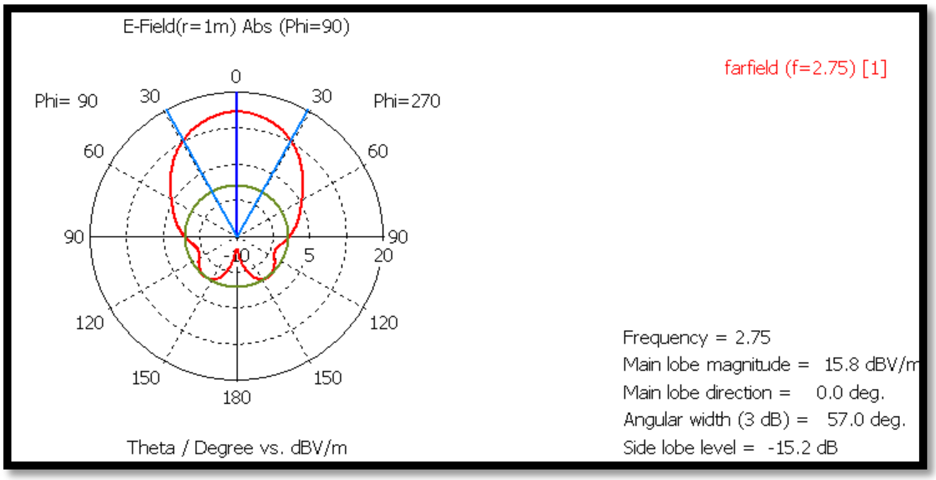


Figure 12 (a): E Field of the reduced size RMPA loaded with “STRR” metamaterial structure at 2.75GHz.

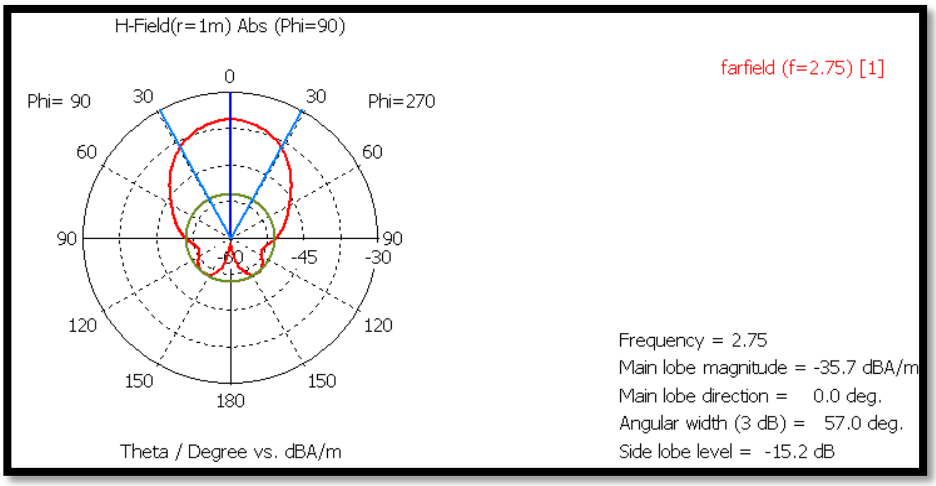


Figure 12 (b): H Field of the reduced size RMPA loaded with “STRR” metamaterial structure at 2.75GHz.

3 Conclusion

In this work, the behavior of a Rectangular Microstrip Patch Antenna loaded with “INTERCONNECTED SRR” Metamaterial Structure at a height of 3.2mm from the ground plane is examined. It is revealed that placing the proposed structure on the patch antenna significantly improves the potential characteristics of the antenna. The proposed “INTERCONNECTED SRR” Metamaterial Structure antenna is electrically small and suitable to handle easily. The proposed antenna could be used in several microwave applications that requires improved bandwidth & reduced return loss at the operating frequency. The proposed structure could be considered as a novel approach for improving antenna’s potential characteristics. From the results it is observed that the minimum return loss obtained at design frequency of the proposed antenna is -42.2dB and the bandwidth is 378MHz i.e., remarkable improvement in S-band (2-4GHz) frequency range. It is clearly observed that the total efficiency and directivity is improved significantly by employing proposed “INTERCONNECTED SRR” Metamaterial Structure. In case of single element it has been observed that the antenna gain, bandwidth, directivity and total efficiency is quite low. But, while deploying it with the Metamaterial structure, all the potential parameters increases significantly. The purpose of the work is to design a minimal, low cost Antenna that can be used for wideband communication applications.

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