International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-3, February 2020

Miniaturized MPA with Asymmetric Z-Shaped CSRR Loading

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***Abstract:** The work in the paper demonstrates a rectangular microstrip patch antenna with a Z-shaped CSRR loading in the ground plane. A Z-shaped CSRR created in the ground plane, shown a 63.3% miniaturization in the radiating patch size compared to conventional rectangular patch antenna, resonating at 6.5GHz frequency in C-band. The simulation results find a significant increase in the fractional bandwidth (5.54%, with the centre frequency of 6.5GHz). Furthermore, the antenna has simulated gain of 2.83dB and return loss of -26.33dB at 6.5GHz. The electrical size of proposed antenna is 0.325λo × 0.260λo × 0.034λo (i.e., 15mm×12mm×1.6mm). The proposed antenna may find application in satellite communication systems in C-band and Wireless local area network (WLAN).*

***Keywords-** Microstrip patch antenna (MPA), Complementary Split Ring Resonator (CSRR), Miniaturization, Fractional bandwidth.*

I. INTRODUCTION

A most important application of microstrip patch antenna is in the field of satellite communication systems. Most of the satellite communication systems operate in the C-band of the electromagnetic spectrum. The antenna designed specifically for satellite communication systems is required to have large value of antenna fractional bandwidth and must have small dimensions. This paper presents an antenna having miniaturized dimensions and large bandwidth at 6.5GHz in comparison to the conventional patch antenna at same resonant frequency. Use of slotted ground structure or making defects in the ground plane of the patch antenna is a method, initially applied to get a reduction in the size of patch antenna [1]. Adding a defect in the ground plane couples a reactive circuit with the patch antenna which may subsequently results an increase in the electrical path length [2,3]. An increase in the electrical path length results in a decrease in the antenna physical dimensions. But this method of antenna miniaturization may also decrease the efficiency of the patch antenna. One new approach of miniaturization of patch antenna is the use of Complementary Split Ring Resonator (CSRR). These CSRRs reduce the size of the patch antenna without affecting the radiation characteristics. Number of research papers are available showing patch antenna design with CSRR in ground plane or in the patch [4-7]. Inclusion of split ring resonator in the patch antenna results in a decrease in the guide wavelength and subsequently the antenna physical dimensions [8].

Revised Manuscript Received on February 05, 2020.
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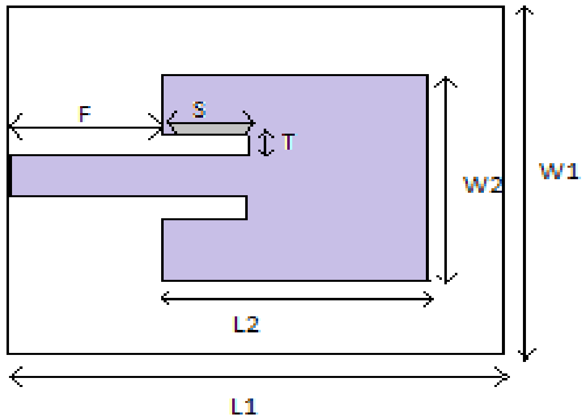
In this research paper, a rectangular microstrip patch antenna fed with a inset microstrip line and having a Z-shaped CSRR in the ground plane is designed. The designed antenna is simulated with hfss v15 software and all radiation characteristics are drawn and attached with the paper. The CSRR used in the antenna is of asymmetric shape. The equivalent circuit of the CSRR is also explained in the paper. The results obtained by the simulation are discussed.

II. ANTENNA GEOMETRY

The geometric configuration of the proposed microstrip patch antenna with Z- shaped CSRR loading in the ground plane is shown in the figure 1. The antenna is designed using an inexpensive FR4 epoxy glass substrate of thickness 1.6mm having relative permittivity εr =4.4 and loss tangent tanδ=0.02. A Z- shaped CSRR is created by etching a Z-shape of fixed dimension in the ground plane and a rectangular radiating patch with inset feed is used as a radiating element. The dimensions of the proposed antenna are mentioned in table 1.



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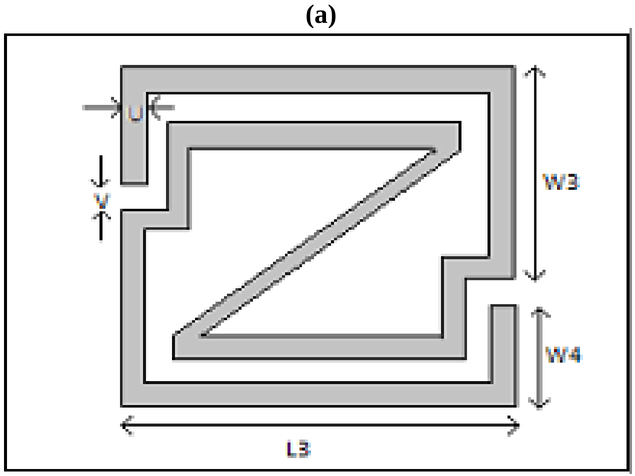

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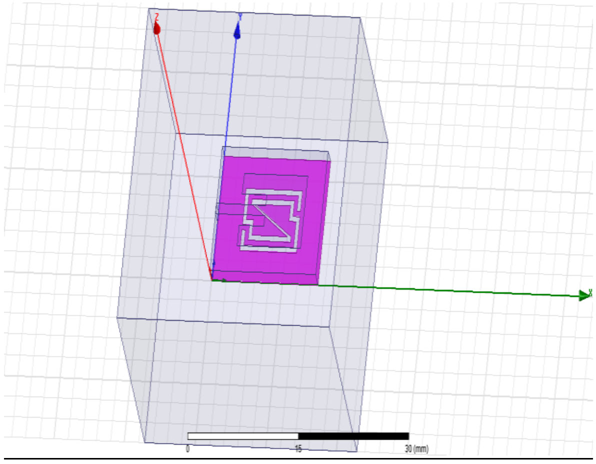

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Figure 1. (a) top, (b) bottom and (c) hfss view of the proposed antenna

TABLE I. Physical dimensions of the patch antenna

Parameter	Unit (mm)	Parameter	Unit (mm)
L1	15	F	3.5
W1	12	L3	8
L2	9	W3	4
W2	7	W4	1.5
S	3.5	U	0.5
T	1	V	0.5

S and F that defines the inset feed connection are chosen in such a way that the feed and the radiating patch have impedance matching. Other dimension of the patch antenna are the dimensions after miniaturization.

III. EQUIVALENT CIRCUIT OF THE PROPOSED Z-SHAPED CSRR UNIT CELL

Figure 2 shows the equivalent circuit model of Z-shaped CSRR [9]. The proposed Z-shaped structure consists of a inductive-capacitive resonance circuit.

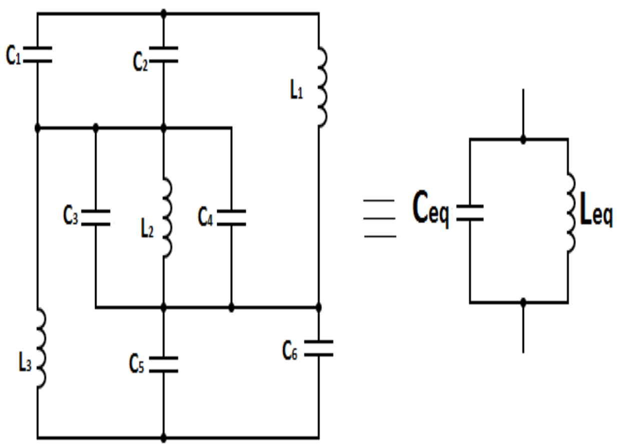


Figure 2. Equivalent circuit of proposed Z-shaped CSRR

The resonant frequency (fr) can be written as,

$$f = \frac{1}{2\pi\sqrt{L_{eq}.C_{eq}}}$$

where L and C represents the equivalent inductance and capacitance of the proposed Z-shaped CSRR equivalent circuit.

The structure etched in the ground plane is equivalent to a metal strip folded in Z shape and placed on a dielectric substrate. This circuit behaves like a inductive capacitive circuit. Fringes that reach the ground plane from dielectric in the form of surface waves result in electric and magnetic resonance condition.

C1, C2, C3 ,C4 and C5 are the capacitance values due the splits and L1, L2 and L3 are the inductances due to the metal strip as shown in the equivalent circuit.

IV. RESULTS, DISCUSSIONS AND ANALYSIS

4.1 Return loss- The plot of parameter s11 which is also called as Return loss is depicted in the figure 3. This plot demonstrate the impedance matching condition for the designed patch antenna. The C-band resonant frequency of the miniaturized antenna is 6.5GHz and the return loss is -26.33dB at this resonant frequency. The fractional bandwidth of the proposed antenna is 5.54% (with centre frequency of 6.5GHz).

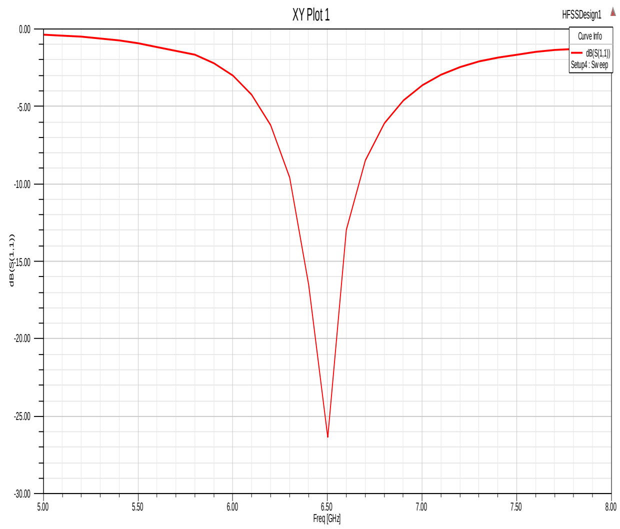


Figure 3. Return loss plot of the proposed antenna

4.2 Gain and Directivity- The antenna proposed in the paper gives a positive gain value at its resonant frequency. The peak value of gain for the miniaturized antenna is 2.83dB and its directivity at same resonant frequency is 3.96dB.

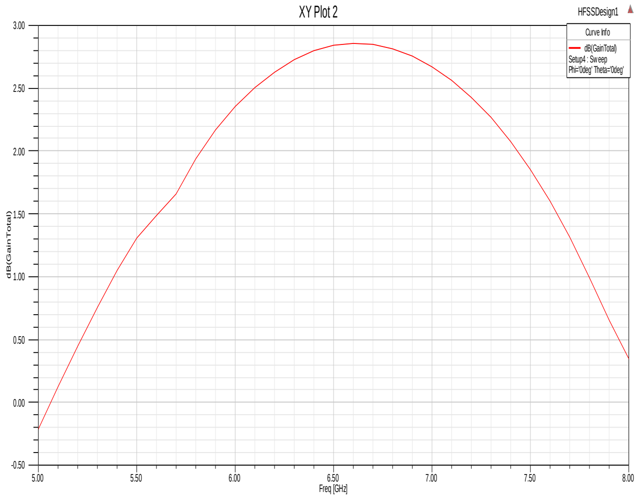
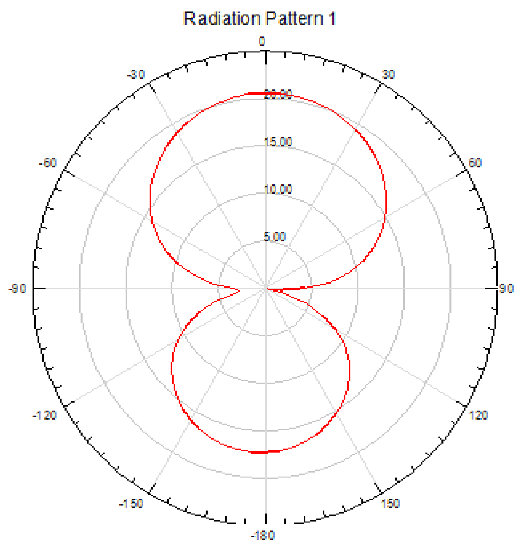


Figure 4. Gain vs frequency plot of the proposed antenna

4.3 Radiation Pattern- Radiation pattern of an antenna can be drawn as a 2D radiation plot or as a 3D polar plot. Both of these plot shows the radiation direction and direction of maximum radiation for a designed antenna. The plot in the figure 5 shows the semi-omnidirectional pattern which is good for satellite communication systems.



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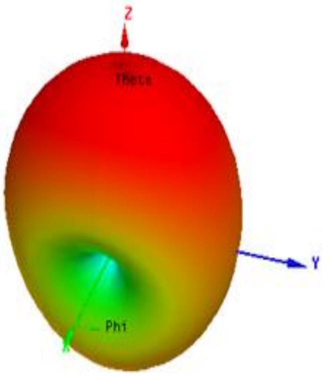

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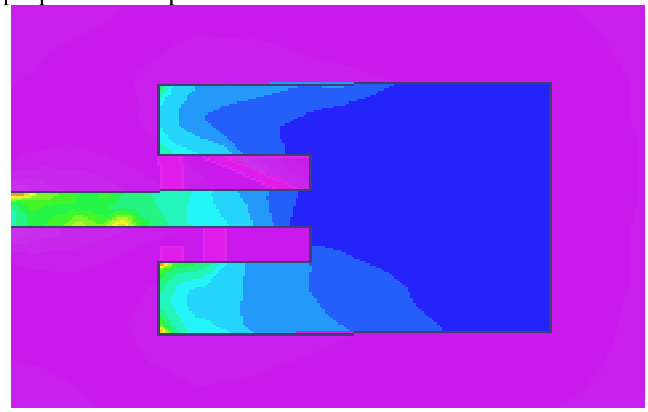
Figure 5 (a) 2D Radiation Pattern, (b) 3D Polar plot of the proposed antenna at 6.5GHz

4.4 Antenna Efficiency- Efficiency of an antenna defines the ability of antenna to radiate. Proposed antenna results a good radiation efficiency of 77%.

4.5 Field distributions- Figure draws the E-field distributions and the H-field distributions for the patch and proposed Z-shaped CSRR.



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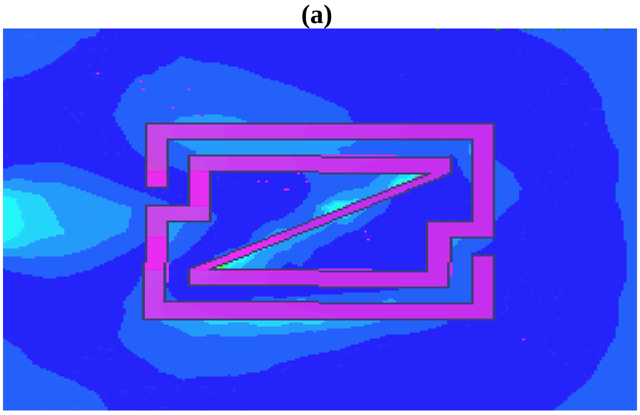
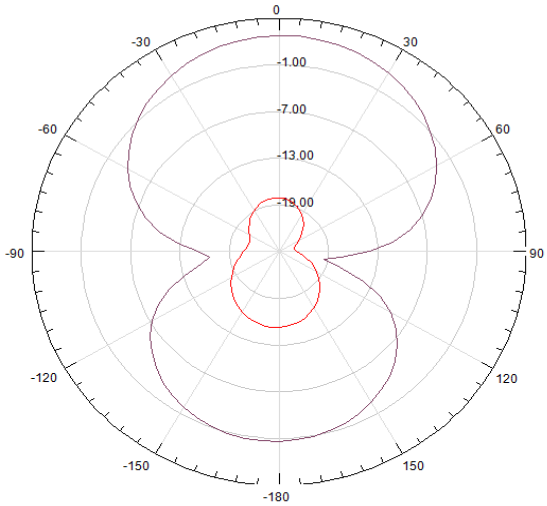


(b)

Figure 6. E-field distribution of (a) rectangular patch, (b) Z-shaped CSRR in ground plane.

4.6 Co-Polarisation and Cross-**Polarisation-** Plots of both the polarizations are drawn in terms of a rectangular graph. A table is also drawn showing the maximum and minimum values of both the polarization components.



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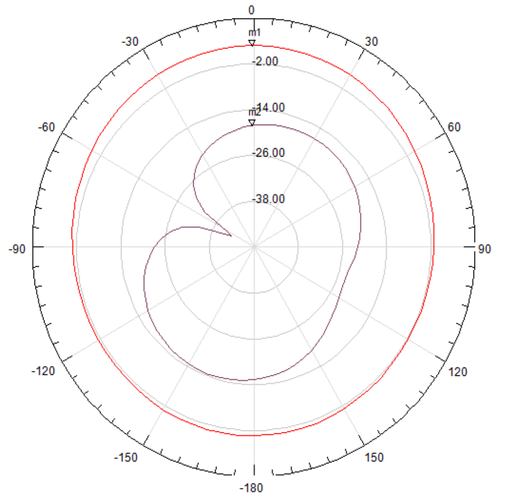

(b)

Figure 8. (a) E-Plane Co-polarisation and Cross-polarisation, (b) H-Plane Co-polarisation and Cross-polarisation

TABLE II. Co-Polarisation and Cross-Polarisation

Plane	Max. Co-pol.(dB)	Max. Cross-pol.(dB)
E-Plane	2.80	-18.05
H-plane	2.80	-18.05

4.7 Voltage Standing Wave Ratio (VSWR)- Antenna's impedance matching characteristic is measured using the parameter VSWR. The simulation result gives the VSWR to be 1.10. So, it can be said that the proposed antenna is matched with the feed source.

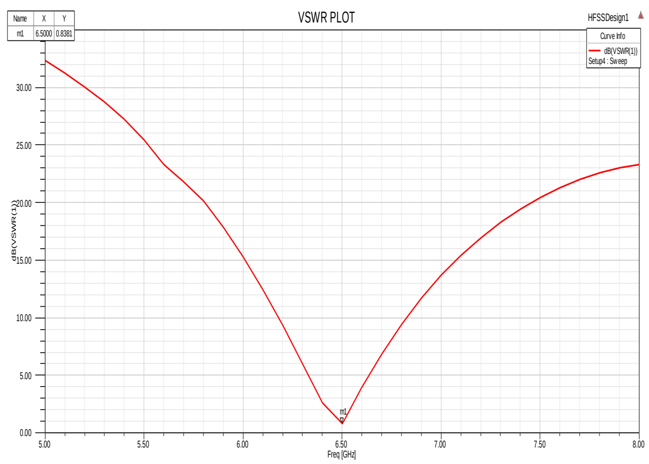

Figure 9. VSWR vs Frequency plot of the proposed antenna at 6.5GHz

4.8 Miniaturization- The effective area of the conventional patch antenna at resonant frequency of 6.5GHz is about 518 mm² whereas the effective area of the proposed antenna for the same resonant frequency is 180 mm². The proposed antenna results in 63.30% reduction in radiating patch size whereas 65.25% reduction in overall antenna size. Table 3 gives a comparison between the dimensions of patch for conventional patch antenna and that of the proposed antenna.

TABLE III. Comparison between the conventional patch dimensions and proposed antenna patch dimensions

Antenna	Freq. (GHz)	Patch length ,L (mm)	Patch Width,W(mm)	Patch Area, (mm²)	Electrical size of whole antenna
Patch without CSRR	6.5	11.3	15.2	172	0.244λo×0.329λo× 0.034λo
Patch with CSRR (Z-shaped)	6.5	9	7	63	0.325λo×0.260λo× 0.034λo

V. CONCLUSION

A microstrip patch antenna with Z-shaped CSRR loading in the ground plane is designed and simulated using hfss v15 software. The results and figures obtained by simulating this antenna are attached in the paper and discussed as well. The antenna results in very good radiation characteristics and designed in compact size. The fractional bandwidth of the antenna is 5.54% which is quite good in case of a patch antenna. This antenna find its application in the C-band which is reserved for satellite and wireless communication applications. This antenna can be further improved by using CSRR arrays in the ground plane.

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