*I.J. Wireless and Microwave Technologies*, **2016, 4, 1-11**
Published Online July 2016 in MECS(http://www.mecs-press.net)
DOI: 10.5815/ijwmt.2016.04.01

***Available online at*** http://www.mecs-press.net/ijwmt

# Dual Band High Directivity Microstrip Patch Antenna Rotated-Stepped-Impedance Array Loaded with CSRRs for WLAN Applications

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**Abstract**

A suspended dual band planar antenna based on a stepped-impedance structure modified to an array, loaded with Complementary Split-Ring Resonators (CSRRs), possessing good directivity pertaining point to point backhaul communication is acquainted. The presented antenna radiates at 2.4-2.5 GHz (4.4%) and 5.3-5.9 GHz (12%) with $|S_{11}| < -10$ dB, accompanying directivity of 11.6 dBi and 11.3 dBi respectively. The antenna is loaded with CSRRs which works as a L-C tank resonator, to obtain better coupling, and to lower the frequency of radiation in 2.4 GHz band along with decreasing the return loss for both the bands of WLAN. The Suspended antenna, symmetrical across vertical axis, has four branches, each of which are obtained from Maximally Stepped-Impedance filter. A stable radiation pattern with high directivity in both the WLAN bands is achieved.

**Index Terms:** Antennas, array, CSRR, dual-band, filter, metamaterial, microstrip antennas, miniaturized antennas, multi-frequency antennas, patch antennas, planar, resonators, SRR, Stepped-Impedance, WiFi, WLAN.



## 1. Introduction

PLAIN profile antennas have been exploited for point to point backhaul communication links for a long time. They exhibit a profile lower than that of horn, cavity backed, and reflector antennas. Reduced Q-value, loss tangent, and lower cost have been observed with suspended patch antennas, where the substrate's material is replaced by air. As a result, lower dielectric, surface wave losses with better bandwidth has been achieved, at the cost of increased height .01$\lambda$-.1$\lambda$, where $\lambda$ is the free space wavelength.

Industrial, Scientific, and Medical (ISM) bands, unlicensed bands, are very popular for the obvious reason,

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no need to get license or pay for the same. IEEE 802.11 a/b/g/n [1] WLAN standards, operate in this band, namely 2.4 GHz band with frequency range 2.4-2.485 GHz, and 5 GHz bands with frequency range 5.150-5.350 GHz, 5.470-5.725 GHz, and 5.725-5.850 GHz. Bandwidth of channels varying from 5 MHz to 20 MHz within each band. Usually, for point-to-point communications, 2.4 and 5 GHz antennas are mounted separately, excited through discrete ports, whereas, Broadband Planar antennas, usually, does have a stable directional pattern, for this complete range. Therefore, a dual band Patch [2][3][4] can be used for its simple configuration, low profile, and configurable directional patterns. This paper exhibits a Dual Band Microstrip Patch antenna loaded with Complementary Split-Ring Resonators (CSRRs) [5] for WLAN applications.

## 2. Design Methodology

While designing this microstrip patch antenna, following problems have been taken into consideration:

1) Overlapping of radiation of individually placed antennas for 2.4 GHz and 5.5 GHz, the presence of coupling between them results in reduction in radiation efficiency.
2) Electrical length of antennas (for 2.4 GHz & 5.5 GHz) are different, this 2.4 GHz radiator has large electrical length at 5.5 GHz, higher order modes from 5.5 GHz resonances with 2.4 GHz radiation, giving out unwanted radiation patterns.
3) Separate single port feeding is required for each radiating antenna.
4) Directivity of the antenna should be high.
5) Material costs should be low, so that the antenna can be easily used commercially.

The proposed solutions are as follows:

1) Series fed network is used, reducing the count of microstrip lines, minimizing the unwanted mutual coupling between various feeding networks and radiators. Also Split Ring Resonators (SRRs) are employed to manipulate the coupling further.
2) Microstrip Stepped-Impedance low pass filter is used such that it has a passband over 2.4 GHz and stopband over 5.5 GHz, to excite the 2.4 GHz radiator. This avoids 2.4 GHz radiations from showing resonance in 5.5 GHz band. This hi-Z low-Z low pass filter is easy to design and occupy less space than that used with stubs, but this does not produce a sharp attenuation, which is not needed here as both the bands are not consecutive but far apart.

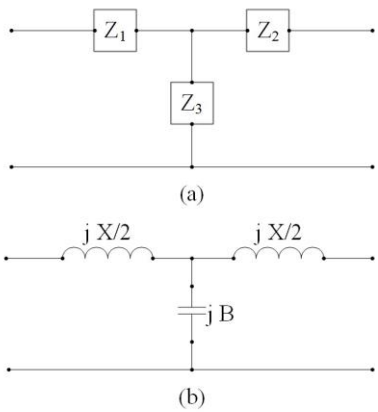



Fig.1.(a) General Two-Port T-Network. (b) Equivalent circuit for short Transmission-Line

3) Signals are reflected through resonators, and then radiated again. Better impedance matching is employed, adding more control over parameters through Split Ring Resonators.
4) For better directivity, design is a modification over an array [6], where arrays are always known to enhance the directivity.
5) This design is a suspended patch antenna design, thus air is used as a substitute for substrate material, So that the material cost for substrate is very less, which can play a big role in commercial use.

## 3. Design of Feeding Network, Filter, and Split Ring Resonators

Here, distributed elements have been used for designing the filters, with significant distances between them. Lumped Circuit Models can not predict accurately the filter response of the Distributed circuit. Hence, a full-wave simulator, specialized in Electromagnetic simulations at high frequency, CST Microwave Studio® 2014 [7] has been used for all simulation work in this paper. This simulation software work on a numerical method called Finite Integration Technique (FIT) [8], which discretizes the below mentioned Maxwell's equations [9] in integral form instead of differential ones,

$$\oint \mathrm{E}.d\mathrm{L} = -\int_s \frac{\partial B}{\partial t}.d\mathrm{S} \tag{1}$$

$$\oint \mathrm{H}.d\mathrm{L} = -\int_s \left( \mathrm{J} + \frac{\partial \mathrm{D}}{\partial t} \right).d\mathrm{S} \tag{2}$$

$$\oint_s \mathrm{D}.d\mathrm{S} = \int_{vol} \rho_v.dv \tag{3}$$

$$\oint_s \mathrm{B}.d\mathrm{S} = 0 \tag{4}$$

where **D** is Electric flux density, **E** is Electric Field Intensity, **B** is Magnetic Flux Density, **H** is Magnetic Field Intensity, **J** is conduction current density, $\rho_v$ is volume charge density and dL, dS, d$v$ are differential length, surface area, volume respectively. This software breaks the calculation domain in small cuboidal cells, and solves the maxwell equations on all of its facets (boundaries).

A general Two-Port T network is shown in figure 1, with ABCD parameters as:

$$A = 1 + \frac{Z_1}{Z_3} \tag{5}$$

$$B = Z_{1+}Z_2 + \frac{Z_1 Z_2}{Z_3} \tag{6}$$

$$C = \frac{1}{Z_3} \tag{7}$$

$$D = 1 + \frac{Z_2}{Z_3} \tag{8}$$

Table 1.Maximally flat low pass filter prototype element values

| N | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ |
|---|---|---|---|---|---|
| 1 | 2.00001 | .0000 | | | |
| 2 | 1.41421 | .41421 | .0000 | | |
| 3 | 1.00002 | .00001 | .00001 | .0000 | |
| 4 | 0.76541 | .84781 | .84780 | .76541 | .0000 |

where Z is the impedance at or between the respective ports, and $Z_0$ is the line's characteristic impedance. This gives the impedance parameters as:

$$Z_{11} = Z_{22} = \frac{A}{C} = -jZ_0 \cot \beta l \tag{9}$$

$$Z_{12} = Z_{21} = \frac{1}{C} = -jZ_0 \csc \beta l \tag{10}$$

where $\beta$ is the imaginary part of propagation constant, furthermore $l$ is length of the line. So, the series element comes out to be:

$$Z_{11} - Z_{12} = -jZ_0 \frac{\cos \beta l - 1}{\sin \beta l} = jZ_0 \tan \frac{\beta l}{2} \tag{11}$$

whereas shunt element for T network is $Z_{12}$. When $l < \frac{\pi}{2}$, the series impedance is mainly positive reactance (Inductive) and shunt impedance is mainly negative reactance (Capacitive), giving out the equivalent circuit of figure 1(b) where,

$$\frac{X}{2} = Z_0 \tan \frac{\beta l}{2} \tag{12}$$

$$B = \frac{1}{Z_0} \sin \beta l \tag{13}$$

where $X$ is reactance, and $B$ is susceptance. So, the series Inductance may be replaced by high-impedance ($Z_h$) line section, and shunt capacitance may be replaced by low-impedance ($Z_l$) line section. Using scaling equations,

$$L' = \frac{R_0 L}{w_c} \tag{14}$$

$$C' = \frac{C}{R_0 w_c} \tag{15}$$

Electrical lengths of Inductance and Capacitance can be calculated as:

$$\beta l = \frac{CR_0}{Z_h} \quad \text{(Inductor)} \tag{16}$$

$$\beta l = \frac{CZ_l}{R_0} \quad \text{(Capacitor)} \tag{17}$$

where L is inductance, and C is capacitance. Using table I [10], taking 2nd order filter with $N = 2$, $C_1 = 1.4142$, $L_2 = 1.4142$, $C_3 = 1.0000$, Step-Impedance [11] Microstrip Low-pass filter with pass-band in the 2.4 GHz band along with stop-band in 5 GHz band, possessing a low return loss around 2.5 GHz is depicted in figure 2. A high high-low impedance ratio is used, for better approximations. Half of the filter, shown in Figure 2 is $180^{\circ}$ rotated, and the dimensions of lower and higher impedance lines are changed, and configured as an array structure as shown in figure 3 to obtain radiation in 2.4, 5 GHz bands. Figure 3 shows the planar antenna array obtained from modifications in stepped-impedance structure, it shows three possible bands of radiations, around 2.69 GHz, 3.85 GHz, and 5.5 GHz. The first band needs to be shifted towards lower frequency, and the middle one is unwanted as it will reduce the radiation aperture for the two bands of WLAN network. These two problems, as well as lower return loss at required frequency bands will be obtained by incorporating this design with CSRRs, which are discussed in following sections.

CSRRs exhibit negative permittivity [5]. Here it works mainly as a resonator instead of a radiator, providing more control over the coupling. It acts like a tank L-C Resonator circuit [12] as shown in figure 4. The Capacitive coupling is mainly obtained from ring slots, while the outer ring’s split provides magnetic coupling.

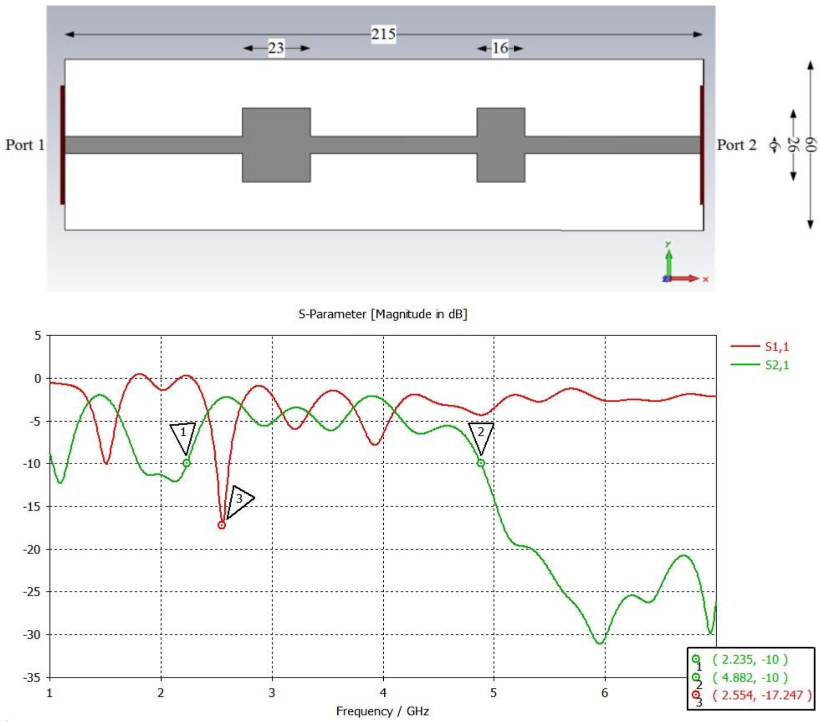



Fig.2.(a) Stepped-Impedance Low Pass Filter design. (b) S-Parameters

## 4. Antenna Design

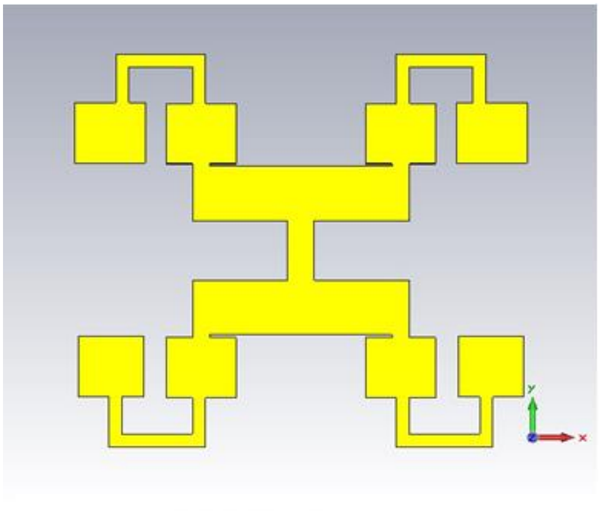
Figure 5 shows the planar antenna array loaded with Complementary Split Ring Resonators. This design is symmetrical across y-axis, giving symmetrical radiation in H-plane. The structure is suspended above the ground plane at the height of 1 mm. All the measurements and angles have been depicted in the figure itself. Stepped-Impedance structure is used and modified as an array, for better directivity; which radiated in 2.5 GHz, 5 GHz bands, in addition to an unwanted band. This shortcoming was removed by using CSRRs, which act as a resonator providing more maneuverability over mutual coupling, it also results in better reflection coefficients in both the required bands, and left shifting the lower band to radiate in the exact 2.4 GHz band.

## 5. Results and Discussions

Figure 6 (a) depicts the Scattering parameter $S_{11}$, this reflections coefficient shows that very less power is reflected back from 2.423 GHz to 2.5283 GHz, with the minimum going to −19.11 dB at 2.472 GHz, giving a potential bandwidth of 105.3 MHz for the first band of WLAN i.e. 2.4 GHz band. For the second band of WLAN, this antenna again shows very low return loss from 5.2701 GHz to 5.8879 GHz, likewise the minimum going to −24.378 dB at 5.568 GHz, giving a potential bandwidth of 617.8 MHz for 5 GHz band. Using equation 18 [13], most of the power feed to antenna, in these two bands will be utilized by the antenna, and a very less power will be reflected back, giving out very low Standing Wave Ratio of 1.02485 and 1.007325 at 2.472 GHz and 5.568 GHz respectively.

$$SWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{18}$$

where SWR is Standing Wave Ratio for the wave with the reflection coefficient Γ. Figure 6 (b) and (c) shows the absolute farfield directivity, at a fixed azimuthal angle of 90° in both the bands at 2.472 GHz as well as 5.568 GHz. The antenna has a good directivity because of array type structure, the first band shows a directivity of 11.6 dBi at polar angle of 22° with a 3 dB angular width of 25.2°. The second band shows a directivity of 11.3 dBi at polar angle of 25° with a 3 dB angular width of 27.1°. Since, the design is symmetrical



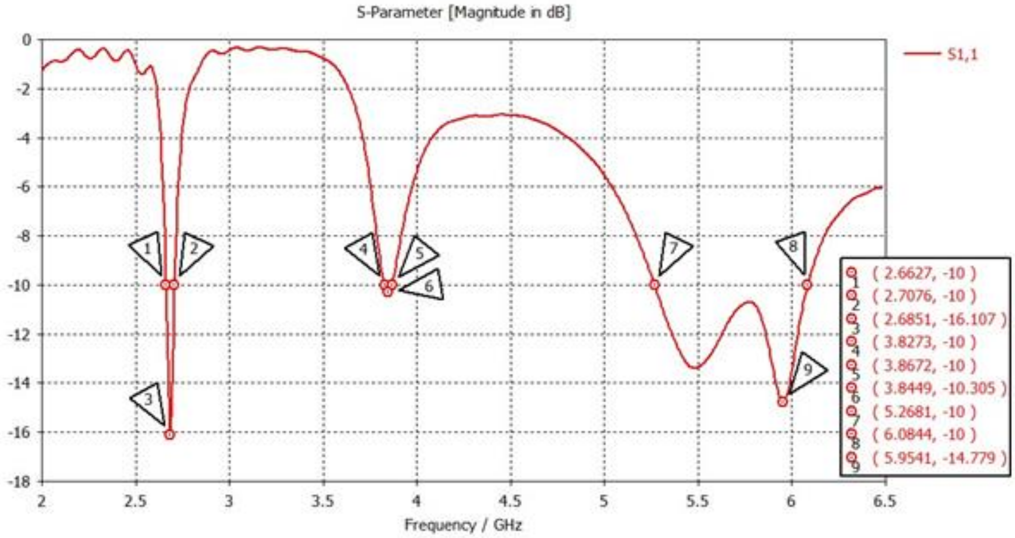



Fig.3.(a) Planar array design without CSRRs. (b) Reflection Coefficient.

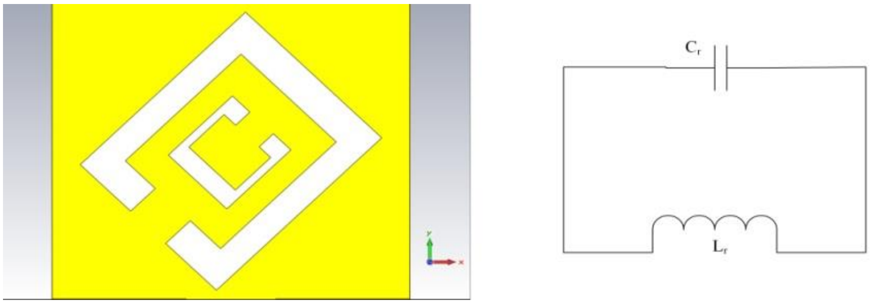



Fig.4.CSRR and its equivalent circuit

across y-axis, this gives a symmetrical radiation pattern in H-plane, in both the bands. Usage of Complementary Split Ring Resonators in array structure, has improved mainly four result aspects of the design, one is further reduction of return loss in first WLAN band 2.4 GHz, likewise second is also further reduction of return loss in second WLAN band 5 GHz, third is removal of unwanted radiation at 3.845 GHz giving forth a better radiation efficiency in both the radiating bands of WLAN, fourth is left shifting the 2.4 GHz band to radiate suitably in proper band. As the antenna is also covering the band for Bluetooth 2.4 GHz to 2.5 GHz, this configuration can be used for Bluetooth applications as well.

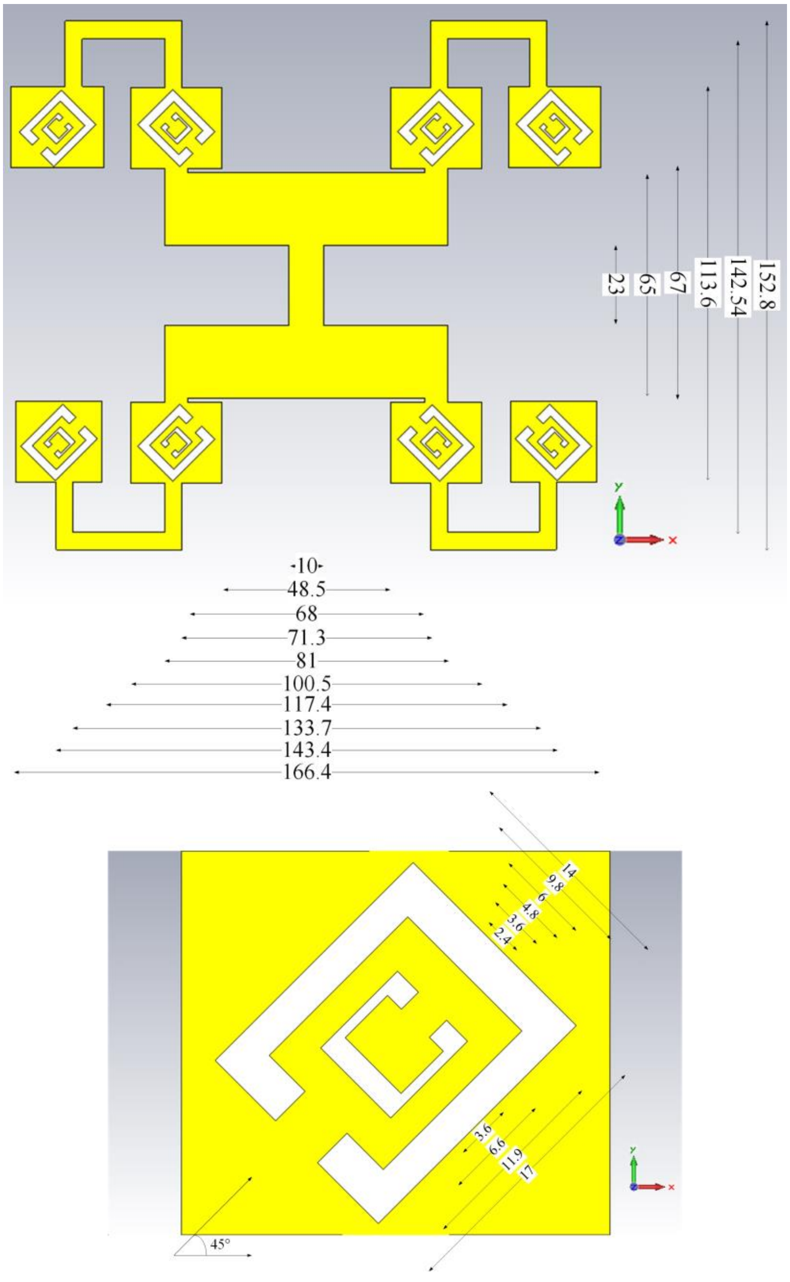


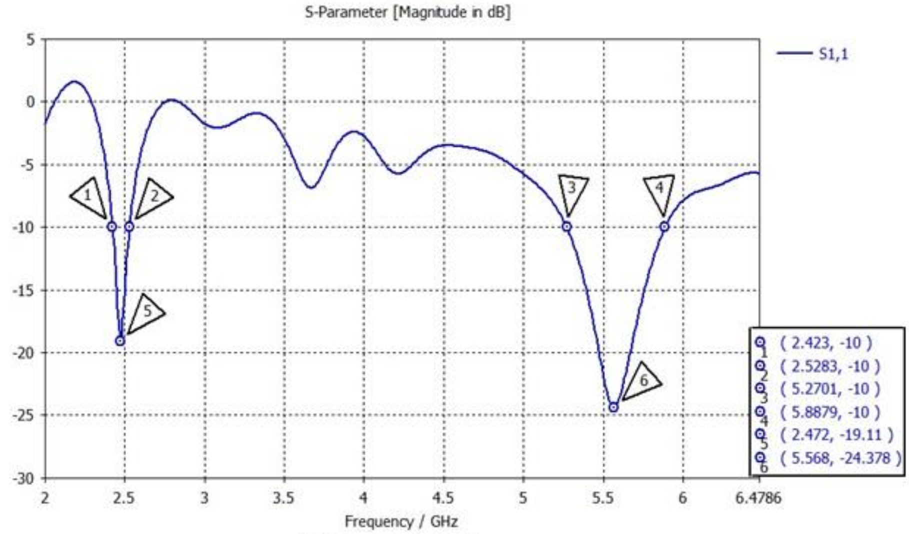

Fig.5.(a) Schematic diagram of Rotated-Stepped-Impedance array loaded with CSRRs (b) Schematic diagram of loaded CSRR.

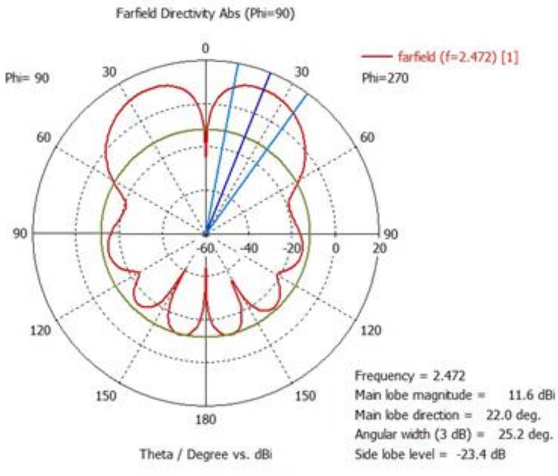
## 6. Conclusions

The antenna is the planar dual band microstrip patch antenna for WLAN (WiFi) applications. It is based on a array structure, having stepped impedance filter, loaded with Complementary Split Ring Resonators, thus giving a good directivity and low return losses. It can be used commercially as its giving good result and the structure is robust, have a good mechanical tolerance, compact, and cost effective.

## Acknowledgement

The authors sincerely thank Dr. Rajesh Khanna, Professor at Thapar University Patiala, India, for the support he has provided by establishing Antenna Research Lab, and giving his valuable guidance during the course of research. The authors also thank $\mathrm{L^AT_EX}$ community for its typesetting support.



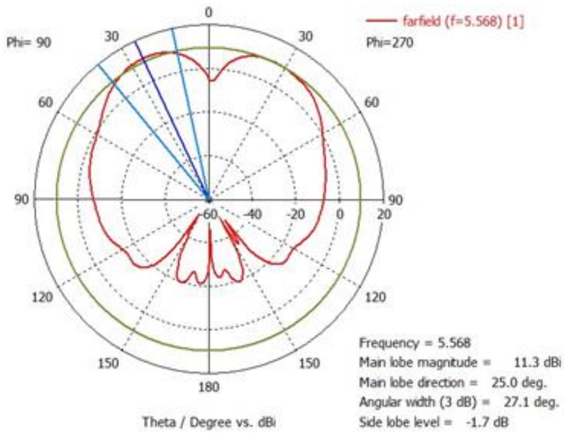



Fig.6.(a) Reflection Coefficient. (b) Farfield at first frequency band-2.4 GHz. (c) Farfield at second frequency band-5 GHz

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**How to cite this paper:** Deepak, Jaswinder Kaur,"Dual Band High Directivity Microstrip Patch Antenna Rotated-Stepped-Impedance Array Loaded with CSRRs for WLAN Applications", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.6, No.4, pp.1-11, 2016.DOI: 10.5815/ijwmt.2016.04.01