

PERFORMANCE OF CIRCULAR SPLIT RING RESONATOR IN WIDEBAND FREQUENCY RECONFIGURABLE METAMATERIAL ANTENNA



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ABSTRACT

This paper presents the design of wideband frequency reconfigurable metamaterial antenna with circular split ring resonator (SRR). The design is based on SRR unit cell and series left-handed capacitance C_L . Bandwidth enhancement was achieved by utilizing effect of C_L , and gap capacitor of SRR unit cell. The wideband antenna was reconfigured by using Pin Diode switches. Computer Simulation Technology Software was used for simulation work. From the results obtained, antenna bandwidth covered (2.3-5.3) GHz, which is equivalent to 78% fractional bandwidth with gain of 2.5 dBi and 2.28 dBi for E and H plane respectively at center frequency 3.8 GHz. Two single bands which resonate at 2.4 GHz when only S_3 is ON, and 5.2 GHz when only S_2 is OFF. Then, dual band which resonates at 2.4 GHz and 5.2 GHz when all switches are OFF. From the result obtained, the antenna can be used for WLAN applications.

1. INTRODUCTION

Recent technological development in wireless communication attracts the attention of many researchers to design a compact, low cost and highly efficient antenna for multi frequency function to provide solutions of spectrum congestion and interference. This goal can be achieved by utilizing metamaterial behavior and frequency reconfiguration technique. Revealing information on metamaterial was initiated by Russian physicist Victor Veselago in 1968 [1]. Experimental finding was released by Smith in year 2000 [2]. Metamaterials are unnatural material with properties not available in nature depending on the negative permittivity ϵ and permeability μ , which satisfied homogeneity with cell size p much smaller than guided wavelength to achieve the desired goal [3].

Reconfigurable antennas are considered as class of antennas with the the ability to select its operating parameters like polarization, frequency, or radiation pattern to redirect its current distribution for frequency selectivity and reuse [4]. Reconfigurable antenna can be classified based on their operation parameters like frequency, radiation pattern, and polarization [5]. Split ring resonator is one of the famous resonant metamaterial structures used for antenna design. Nicolson-Ross-Weir (NRW) numerical method is considered for obtaining negative behavior of permeability or permittivity as expressed in equation (1) and (2) [6].

$$\mu_r = \frac{2}{jk_0 t} \frac{1-V_2}{1+V_2} \quad (1)$$

$$\epsilon_r = \frac{2}{jk_0 t} \frac{1-V_1}{1+V_1} \quad (2)$$

Where k_0 is the wave number, t is substrate thickness, V_1 and V_2 represent addition and subtraction of S-parameters as present in equation (3) and (4) [6].

$$V_1 = S_{21} + S_{11} \quad (3)$$

$$V_2 = S_{21} - S_{11} \quad (4)$$

By obtaining V_1 and V_2 , then sigma plot, MATLAB or any related software will be used to plot the negative dispersion curve of permeability or permittivity curves of the proposed metamaterial unit cell. Split ring resonator may be design in any shape as metamaterial structure, but the popular shapes are square and circular. Figure 1 shows the example of a square and circular split ring resonator [7].

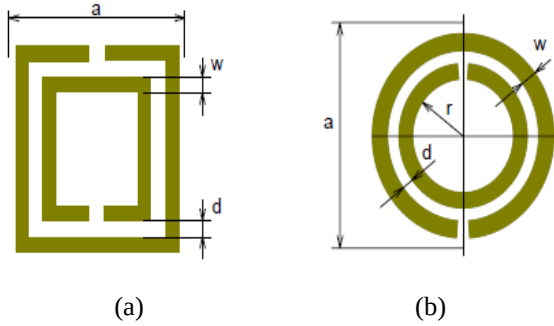


Fig. 1. Split Ring Resonator (a) Square (b) Circular [7]

Several researches have been done to improve the performance operation of antennas by applying metamaterial characteristics. Among the research include enhancing bandwidth by generating large value of shunt left-handed inductance and shunt right-handed capacitance to merge fundamental mode as presented in [8]. Authors in [9] introduces IDC in order to reduce the value of Q-factor for bandwidth enhancement. Modifying series gaps G_1 and G_2 by [10] result to bandwidth enhancement based on the value left-handed capacitor C_L . Influence of substrate for bandwidth enhancement of metamaterial antenna was reported in [11]. Frequency reconfiguration by activating and deactivating two resonant structures using switch was achieved in [12]. Also, authors in [13] and [14] achieved frequency reconfiguration by activating and deactivating SRR. Similarly, author [15] modify SRR with a closed ring resonator to switch the antenna to multi bands. From the overview, there is a limited bandwidth of operation from the previous work to cover

many application bands. Also, chances of selecting unutilized bands, required more effort to actualize. Thus, design of compact wideband antenna with bandwidth that covers many application bands and reconfigure to select different bands is proposed in this research work.

2. ANTENNA DESIGN

This section presents the technique for enhancing antenna bandwidth to achieve wideband antenna. CRLH-TL parameter C_L contributed for bandwidth enhancement. Also, frequency reconfiguration technique to reconfigure the wideband antenna is presented and analyzed.

2.1 Design Process

Figure 2 shows the physical features of the proposed antenna in this paper. The antenna is designed based on the basic of the design reported in [16]. The antenna have the overall dimension of $30 \times 16.8 \text{ mm}^2$.

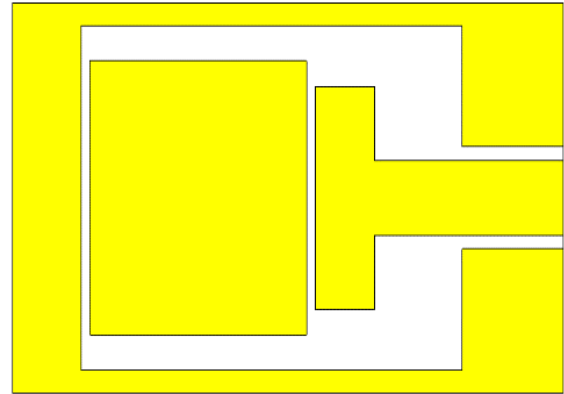


Fig. 2. Proposed Antenna

2.1.1 Bandwidth Enhancement

The design was started by taking the parametric studies at the top patch to adjust the position of the horizontal slot. The parametric result at the top patch for bandwidth enhancement at ten different positions are shown in figure 3 As observed from the results obtained, there is a slightly shift at the upper band while lower bands almost maintain their position throughout. These changes occur due different value of series left-handed capacitance C_L from the horizontal slot in the top patch. Finally, 1.3 mm was selected as the optimized value of the thickness of horizontal slot for bandwidth enhancement of short-ended strip antenna.

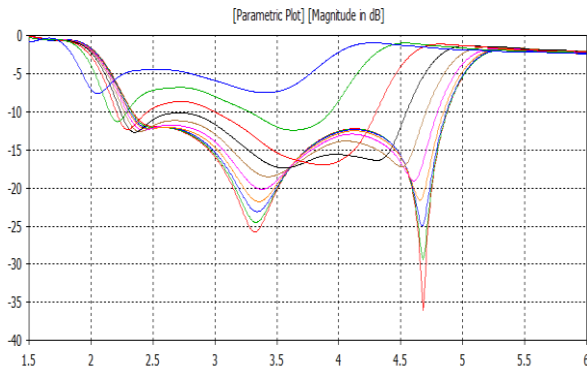


Fig. 3. Parametric Studies Results for Bandwidth Enhancement

After analyzing the results obtained from parametric studies, the proposed antenna was simulated to observe and analyze the behavior of current distribution at 5.2 GHz. Figure 4 shows the behavior of current distribution at 5.2 GHz. High concentration of current distribution was observed at the top patch and shorted strip line.



Fig. 4. Current Distribution at 5.2 GHz

After observing the result obtained based on the behavior of current distribution, the top patch was replaced with the circular patch with the same dimension. Figure 5 is the proposed antenna with circular patch.

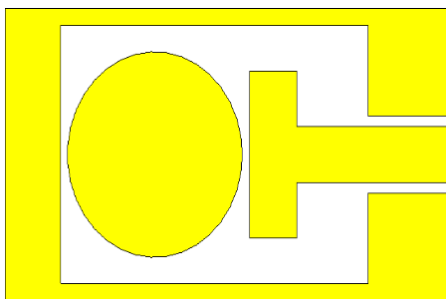
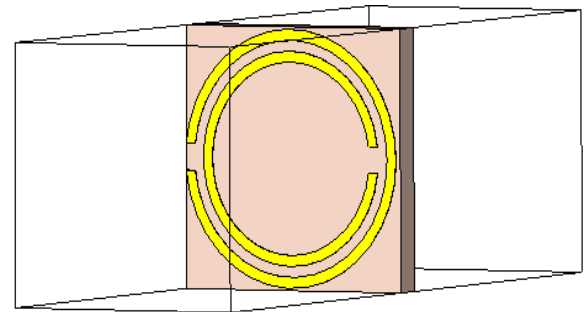
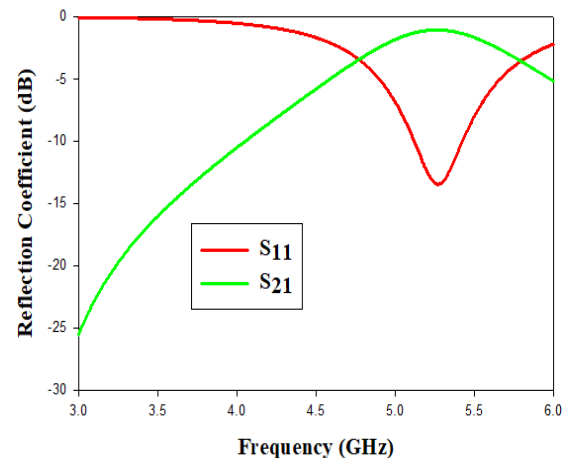


Fig. 5. Proposed Antenna with Circular Patch

The circular SRR metamaterial unit cell structure with the same overall radius with the circular patch was modified and designed at 5.2 GHz. Figure 6 (a) shows the SRR unit cell, while (b) represents the S-parameters S_{11} and S_{21} for proposed SRR unit cell. The red color represents S_{11} and green color represents S_{21} . From the results obtained, both S_{11} and S_{22} resonate at 5.2 GHz with cross at resonating band.



(a)



(b)

Fig. 6. (a) SRR Unit Cell (b) S_{11} and S_{21} for SRR

The circular patch was replaced with the SRR unit cell. SRR unit cause adjustment at the high band to extend and cover 5.2 GHz band. Low-cost FR4 substrate with 1.6 mm thickness and dielectric constant of 4.4 was used. The simulation work was done by using Computer Simulation Technology (CST) Software. Figure 7 represents the optimized figure of proposed antenna in this work. The structure has the overall dimensions of $16.8 \times 30 \times 1.6 \text{ mm}^3$. The remaining dimension in millimeter are $G_1 = 0.6$, $G_2 = G_3 = 1.2$, $L_F = 10.3$, $L_1 = 9.6$, $L_2 = 3.5$, $W_F = W_1 = 3.2$, $R_1 = 5.9$, $R_2 = 4.9$ and $T = 1.0$.

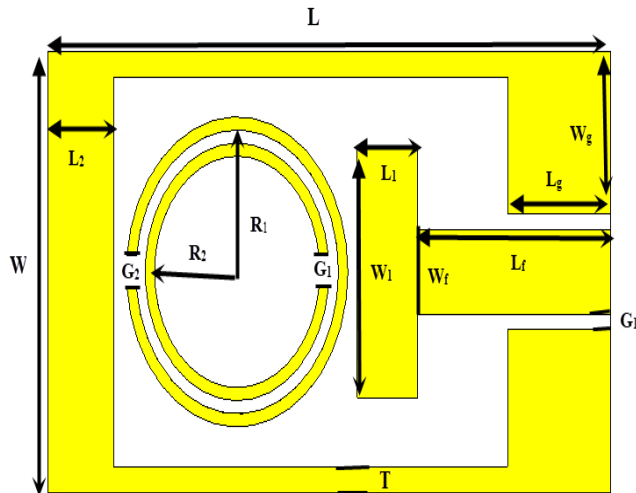


Fig. 7. Optimized Proposed Antenna

2.1.2 Frequency Reconfiguration

The frequency reconfiguration technique was applied to reconfigure the wideband antenna to single band and dual band. The optimized antenna was simulated to analyze the behavior of current distribution at 2.4 GHz. figure 8 shows the behavior of the current distribution at 2.4 GHz for the optimized antenna. The result shows the domination of high current distribution in the shorted strip in both sides.

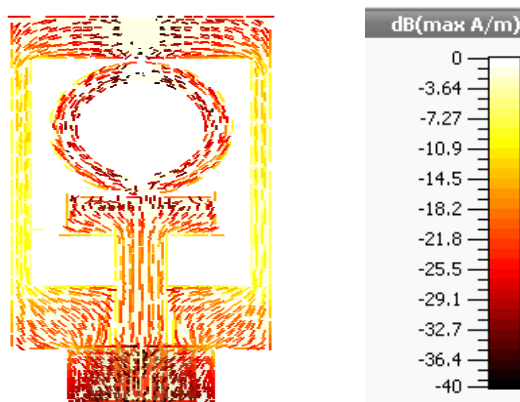


Fig. 8. Current Distribution at 2.4 GHz

Reconfiguration process is continuing by taking parametric studies at the shorted strip in both side by creating two slots. to identify the proper position of the switches. Figure 9 shows the parametric results for four different configurations. The results obtained were analyzed and identify the position of two switches for single band operation which resonate at 2.4 GHz.

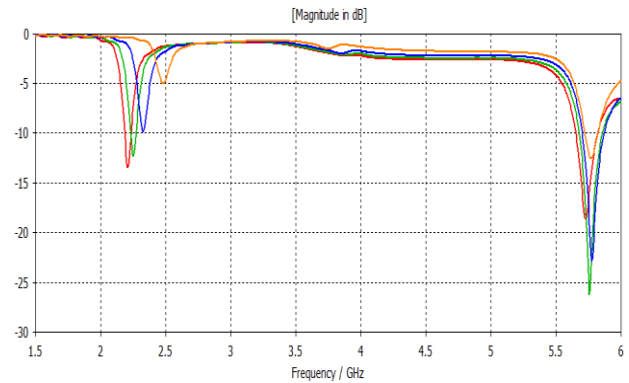
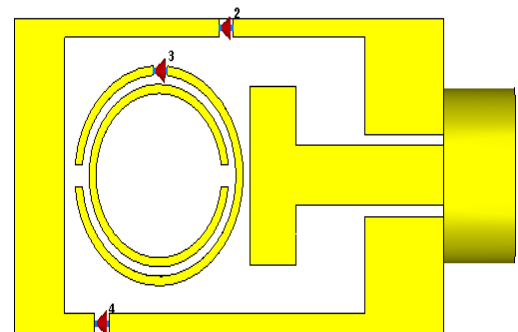
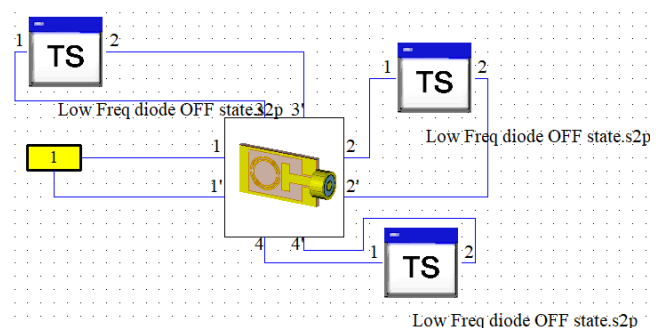


Fig. 9. Parametric Result for Reconfiguration

To obtain resonant at 5.2 GHz, additional slot was created at outer ring of SRR. Figure 10 (a) represents the antenna geometry with three Pin Diode switches, and figure 10 (b) is the switching diagram which can be used to switch the antenna to achieve different configuration. Pin diode switch in right-hand side strip is leveled as S_2 , the one in SRR is S_3 while the one in left-hand strip is leveled as S_4 . Since all the switch are operated as open and closing of the slot, ON state means the slot is deactivated, while OFF state means the effect of slot is activated.



(a)



(b)

Fig. 10.(a) Antenna with Switches (b) Switching Diagram

2.2 Results and Discussion

Since the antenna is short ended at both side, bandwidth enhancement in this paper was achieved by utilizing series parameter left-handed capacitance C_L . Bandwidth of the wideband metamaterial antenna in this paper covered (2.3-5.3) GHz which is equivalent 78% fractional bandwidth. Figure 11 shows S_{11} response which describe the wideband nature of the proposed antenna.

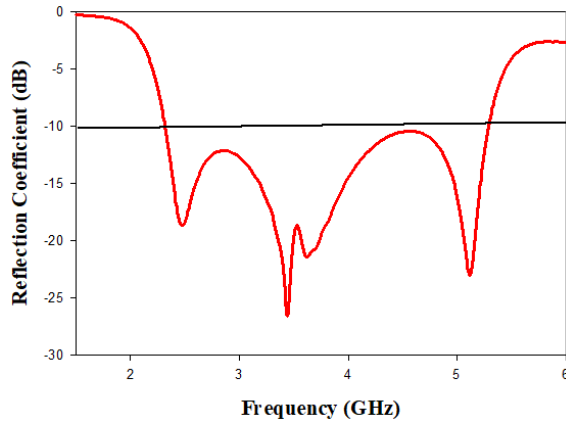


Fig. 11. Wideband Antenna Result

Figures 12 (a) and (b) represent E and H-plane radiation pattern at center frequency 3.8 GHz for the wideband antenna. As observed, better omnidirectional pattern is obtained in E-plane as compared with H plane. Realized peak gain in E-plane is 2.5 dBi, and 2.28 dBi in H-plane.

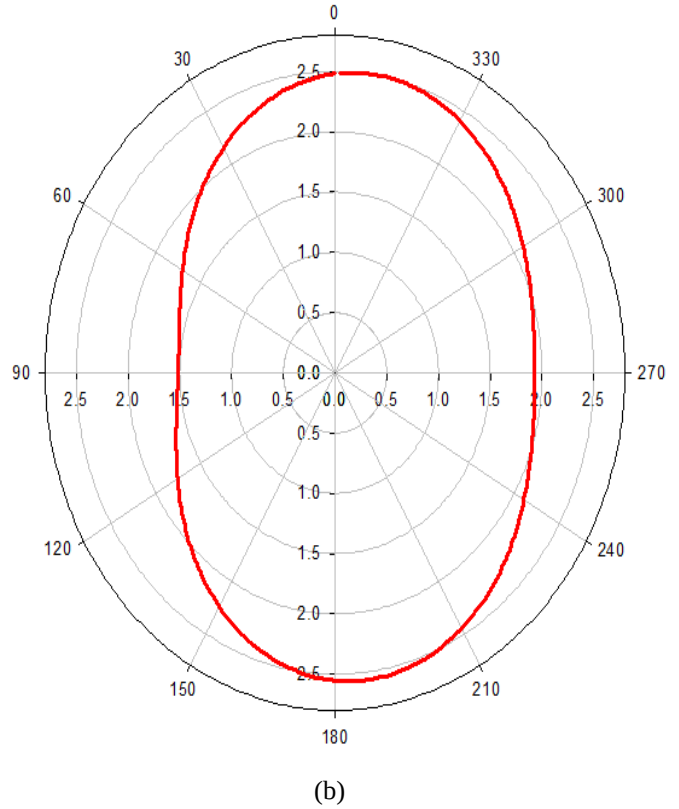
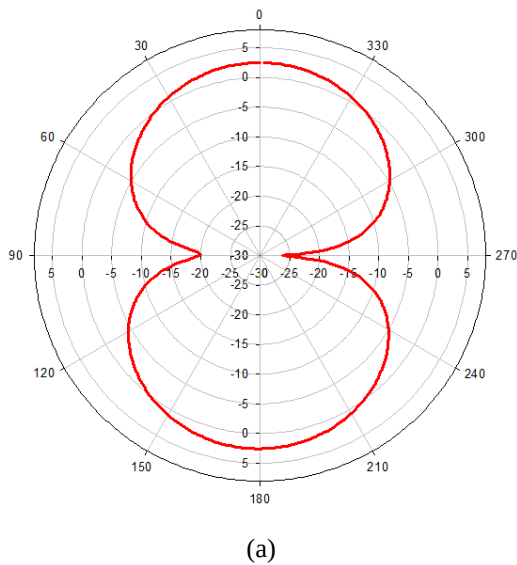


Fig. 12.(a) Radiation Pattern (a) E-Plane (b) H-Plane

2.2.1 Frequency Reconfiguration

The wideband antenna was reconfigured by using three Pin diode switches. Four different configuration which consist of wideband, two single band and one dual band are obtained. The first configuration represents the initial wideband result when all switches are in ON state. When S_3 and S_4 are in ON condition, but only S_2 is OFF, the antenna is reconfigured to a single band which resonates at 5.2 GHz. For the case when only S_3 is in ON state while S_2 and S_4 are OFF, another single band which resonates at 2.4 GHz was obtained. Finally, when all switches are switched OFF, the antenna reconfigured to a dual band which resonates at 2.4 GHz and 5.2 GHz. Figure 13 (a), (b), (c), and (d) represents the reconfiguration results obtained based on each switch configuration. Table I summarizes the results and status for each configuration.

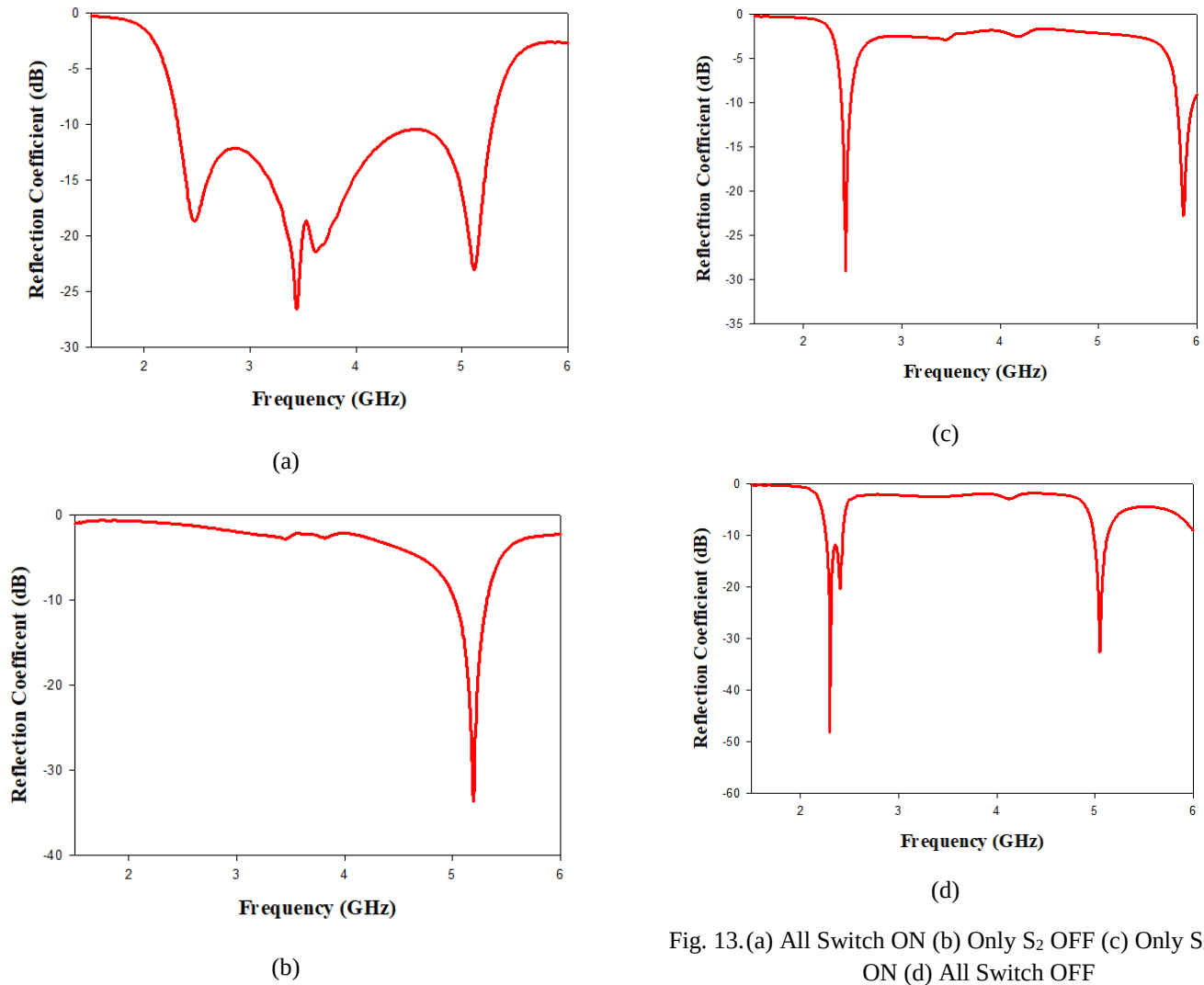


Fig. 13.(a) All Switch ON (b) Only S_2 OFF (c) Only S_3 ON (d) All Switch OFF

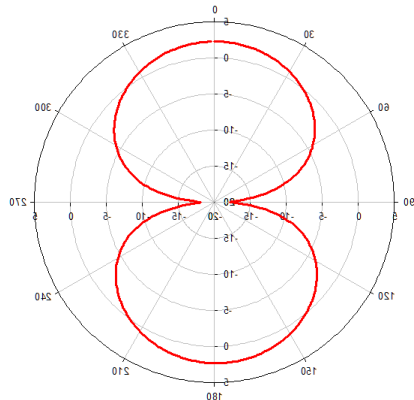
Table 1. Summary of Switch Configuration

S/NO	Table Column Head				
	S_2	S_3	S_4	Resonating Band (GHz)	Status
1	ON	ON	ON	2.3-5.3	Wideband
2	OFF	ON	ON	5.2	Single Band
3	OFF	ON	OFF	2.4	Single Band
4	OFF	OFF	OFF	2.4 and 5.2	Dual Band

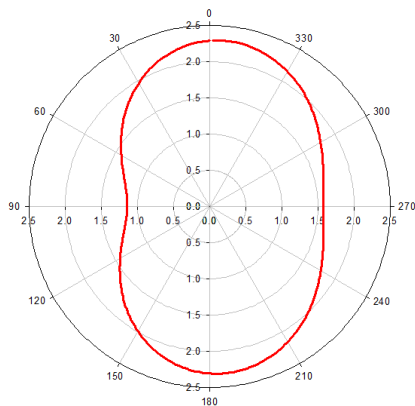
Figure 14 (a) and (b) shows the E and H plane radiation when all switches are in ON state. Both E and H plane shows omnidirectional pattern. The realized peak gain for E and H plane at this condition are 2.5 dBi, and 2.28dBi respectively. Figure 14 (c) and (d) are the E and H plane radiation when only S_2 is OFF. Also, both

pattern looks omnidirectional. The realized peak gain in this configuration for both E and H plane are 2.4 dBi and 2.1 dBi, respectively. Figure (e) and (f) represent third configuration when only S_3 is ON. The E plane looks directional while H plane partially looks like omnidirectional. The realized peak gain in this

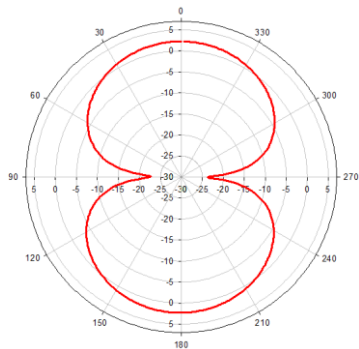
configuration for both E and H plane are 2.1 dBi and 2.0 dBi, respectively. Finally, figure 14 (g) and (h) represent E and H plane when all switches are in OFF state. E plane look directional in pattern, while H plane looks like omnidirectional pattern. The realized peak gain in this configuration for both E and H plane are 2.5 dBi and 221 dBi, respectively.



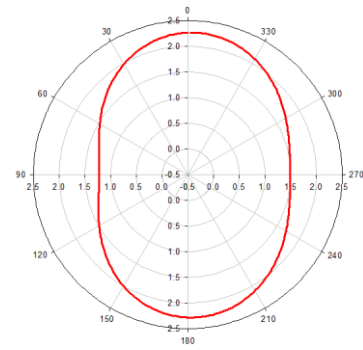
(a)



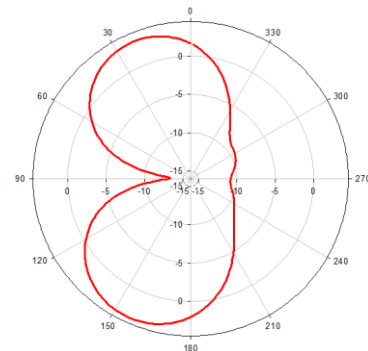
(b)



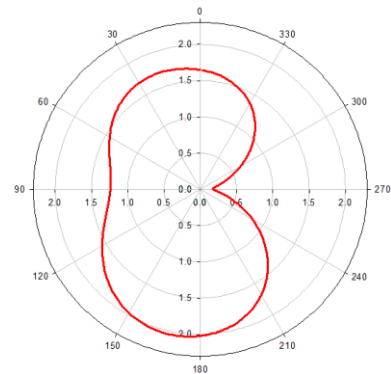
(c)



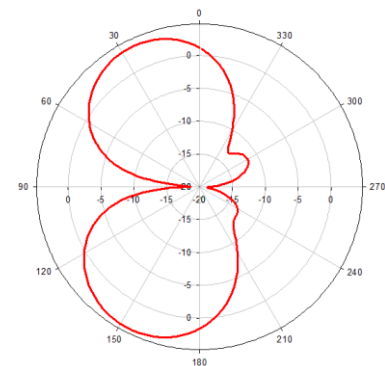
(d)



(e)



(f)



(g)

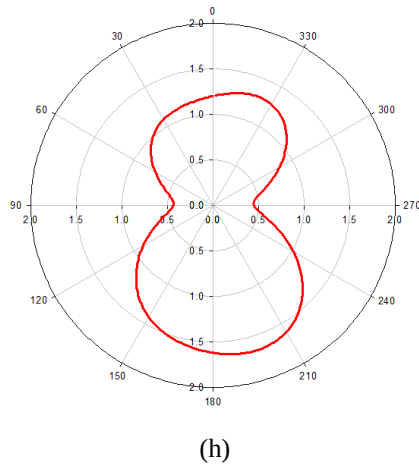


Fig. 14. (a) All Switch ON (b) Only S_2 OFF (c) Only S_3 ON (d) All Switch OFF

3. CONCLUSION

The Wideband reconfigurable metamaterial antenna was designed by utilizing a circular split-ring resonator and series left-handed capacitor C_L . The design, analysis, and results obtained show and proved the effect of metamaterial structure in bandwidth enhancement. Also, frequency reconfiguration technique was utilized and reconfigure the wideband antenna to single band and dual band. Further work needs to be done to fabricate the antenna and compare simulated and measured results.

4. ACKNOWLEDGEMENT

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