A Compact Frequency Reconfigurable Split Ring Monopole Antenna for WLAN/WAVE Applications

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Abstract **─** A novel frequency reconfigurable dual band monopole antenna based on the triangular split ring element is proposed for wireless communications. The antenna with an overall compact size of 25×25×1.6 mm^3 is designed for the operating frequencies of wireless local area network (WLAN) 2.4/5.0 GHz standard and wireless access for vehicular environments (WAVE) 5.90 GHz standard. The parametric study is carried out for tuning the upper resonant frequency. The reconfigurability between the WLAN and WAVE frequency bands is achieved by using a pair of PIN diode. The design considerations for the proposed antenna are described and the experimental results are validated. The antenna exhibits almost uniform radiation characteristics and good gain at each frequency band with the -10 dB impedance bandwidth of 44.1%, 5.8% and 10.1% at 2.45/5.30/5.90 GHz WLAN and WAVE bands respectively.

Index Terms **─** Dual band, PIN diode, reconfigurable, split ring resonator, WAVE and WLAN.

I. INTRODUCTION

Rapid growth in the modern wireless communication systems leads to demand for multiband, low cost and compact antennas. In wireless communications, wireless local area network (WLAN) and wireless access for vehicular environment (WAVE) technologies are mainly used for its mobility and high-speed data accessing. Also, demand for compact and multiband antennas in modern wireless handheld devices are increased for passengers in vehicles to utilize the current wireless services such as entertainment applications, web browsing, emailing and data exchanging. As well as, the main applications of the WAVE technology includes intelligent transportation systems (ITS), high-speed communications and internet access, safety and security enhancements. The standard IEEE 802.11b/g covers the lower frequency band ranging from 2.40 GHz to 2.4835 GHz and the standard IEEE 802.11a covers the upper frequency band ranging from 5.15 GHz to 5.35 GHz and 5.725 GHz to 5.825 GHz for WLAN applications [1, 2]. The standard IEEE 802.11p covers the frequency band 5.85 to 5.925 GHz for WAVE applications [1].

The challenges in the design of dual band antennas are compact size, mechanically robust, wide bandwidth with good impedance matching, omnidirectional radiation patterns, high gain, low profile and low manufacturing cost [1, 3]. Due to the limited space availability in modern compact wireless devices, the design of multiband antennas requires much attention in terms of size along with aforementioned characteristics. Recently, different dual band antennas have been proposed for WLAN applications [1-5]. Although these antennas provide significant radiation characteristics, they lack on complex structure, bandwidth as well as large radiating area. In addition, the antennas reported in [6-9] are few notable multiband antennas operating in our frequency range of interest (WLAN). Although they provide wide band coverage and good radiation characteristics, they suffer from very poor compactness and tunability.

In recent years, split ring resonator (SRR) based monopole antennas are receiving a lot of interest towards the wireless applications, since it offers miniaturization due to its sub-wavelength

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resonant nature [2, 7-10]. Reconfigurable antennas play a significant role in telecommunication systems because they offer compact size by avoiding multiple antenna requirements to utilize more than one wireless standard in a single system, similar radiation characteristics, stable gain at each designed frequency band and low cost [9-11]. In order to allow the operating frequencies to be reconfigurable, switching components specifically varactor diodes [10] and PIN diodes [11], are often used in reconfigurable antenna applications compared to MEMS switches. Since the PIN diode has several advantages like good performance and low cost compared to other switching elements [11], we opted for PIN diode as a switch element in the proposed reconfigurable antenna design.

In this paper, a reconfigurable novel SRR based monopole antenna for dual band WLAN/WAVE applications is presented. The proposed SRR is a single ring structure; hence it is simple to design compared to the conventional double ring SRRs. This triangular SRR is a kind of metamaterial cell that has the advantage of versatility in controlling the resonant characteristics by altering its length. Thus, it alters the inductance and capacitance values of the resonant structure. It paved the way for frequency tuning. Hence, the frequency reconfigurability between the WLAN and WAVE standard is achieved by altering the electrical length of the proposed SRR by using a pair of PIN diode. Details of the antenna design are described in Section II. The parametric study and the proposed method of reconfigurability are explained in Section III along with its radiation characteristics. The concluding remarks are highlighted in Section IV.

II. ANTENNA DESIGN

The geometry of the proposed split ring monopole antenna fed by a microstrip transmission line is shown in Fig. 1. The complete antenna is simulated using the EM simulator, Ansoft High Frequency Structure Simulator (HFSS) V.14.0, based on Finite Element Modeling (FEM) [12]. Also, it is fabricated on an FR4 substrate with dielectric constant $\varepsilon_r = 4.4$, thickness $h = 1.6$ mm and loss tangent $\tan\delta = 0.018$. The proposed antenna structure consists of a triangular SRR as the radiating element, a feed line, and a partial ground plane. The key antenna parameters of the antenna are optimized using optimetrics provided in the HFSS.

A pair of shunt arms of length L_3 in the triangular SRR plays an important role than the other parameters in the performance of the upper resonant frequency. Because it can create additional surface current paths in the antenna and therefore additional resonance is obtained. The overall length $2(L_2+T+L_3)$ contributes to split ring resonator's inductance and the split gap (s) contributes the capacitance, which determines the resonant frequency of the SRR. In addition, the presence of shunt arms completes the triangular split ring resonator; hence, the negative permeability can be created. Thus, the dimension of the shunt arm is varied for tuning of the upper resonant frequency. The feed length (f_L), width (W_1) and ground plane length (L_1) are optimized to 9 mm, 2.9 mm and 9 mm respectively, for good impedance matching. The various optimized design parameters of the antenna are given in Table 1.

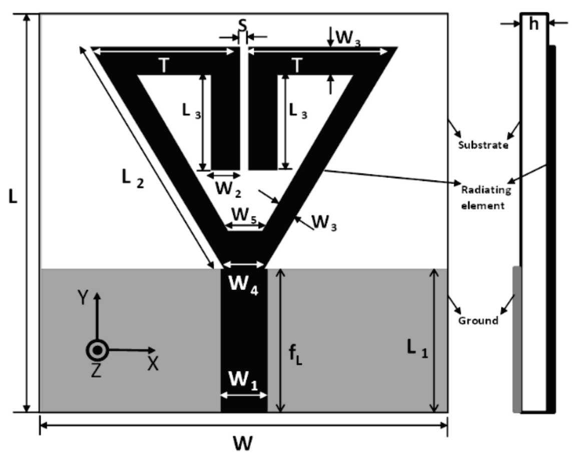


Fig. 1. Geometry of the proposed split ring monopole antenna.

Table 1: Design parameters of the optimized antenna

Parameter	Value (mm)	Parameter	Value (mm)
L	25	W_5	2.0
W	25	L_1	9.0
W_1	2.9	L_2	16.25
W_2	1.8	L_3	6.0
W_3	1.8	S	0.5
W_4	2.5	T	9.25

III. RESULTS AND DISCUSSIONS

In this section, the numerical and experimental results of the return loss and radiation characteristics are presented for the proposed split ring monopole antenna. The various design parameters are analyzed and based on that, the final prototype is fabricated and tested. The effect of feed width, shunt arm's length, possibility of reconfigurable antenna system and its radiation characteristics are discussed here.

A. Effect of feed width W_1 and shunt arm L_3

The split ring monopole antenna without the shunt arms (i.e., L_3= 0) is designed initially. It is observed that the SRR monopole without the shunt arm resonates at 2.45 GHz and 7.0 GHz. The lower frequency band is caused by the feed length (f_L), feed width (W_1), strip (L_2) and top edge (T) of the SRR; since it contributes to the longer electrical length of the structure. The parametric study of W_1 (1.7 mm to 3.5 mm) is shown in Fig. 2. The variation in W_1 has significant effect on antenna performance. For better impedance matching in both the frequency bands, the feed width is chosen to be 2.9 mm in the proposed antenna design. Due to the absence of L_3, the SRR characteristic is less effective, and hence, poor return loss is observed in the upper resonant frequency which is shown in Fig. 3. Therefore, the parametric study is carried out by varying L_3 and keeping all other antenna parameters as constants. While the length L_3 is increased from 1 mm to 6 mm, it is observed that the upper resonant frequency starts decreasing from 7.0 GHz to 5.30 GHz. Since the split ring's electrical length increases, it is attributed to high inductance value of the SRR; hence, the resonant frequency decreases. The proposed antenna without the shunt arm is also fabricated and the corresponding simulated and measured results are shown in Fig. 3. The measured impedance bandwidth of about 1040 MHz and 620 MHz is achieved at 2.45 GHz and 7 GHz bands, respectively. This can be used for downlink 7 GHz X-band satellite applications. However, since our aim is to design the antenna for WLAN and WAVE application, the shunt arm's length is parameterized accordingly for WLAN and WAVE applications. The numerical resonant characteristics of the upper frequency for the proposed split ring monopole antenna for various lengths L_3 are given in Table 2.

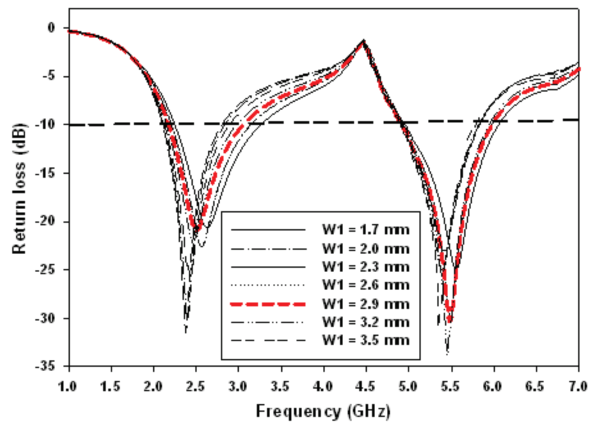


Fig. 2. Simulated return loss characteristics of the proposed antenna for various feed width.

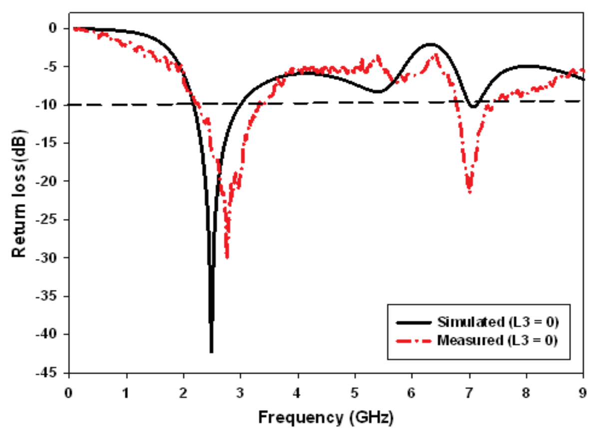


Fig. 3. Simulated and measured return loss characteristics of the proposed antenna when L_3= 0.

Table 2: Effect of length L_3

L_3 (in mm)	f_r (in GHz)
0	7.0
1	6.77
2	6.67
3	6.13
4	5.90
5	5.80
6	5.30

B. Dual band antenna for WAVE/WLAN application

From the above parametric study it is noted that for the shunt arm length 4 mm and 6 mm, the proposed antenna has an upper resonant frequency of 5.90 GHz and 5.30 GHz, respectively. These are the operating frequencies of WAVE and WLAN bands correspondingly. The incremental length L_3 and its effect on the upper resonant frequency have paved the way for reconfigurability. It is decided to access WAVE and WLAN bands alternatively by using a switching element.

As shown in Fig. 4, the spaces left in the antenna configuration (#1) is used for the switches. Where 0.5 mm space is left for the switch and 1.5 mm length stub is placed successively. When the switches are in OFF state, the length L_3 is 4 mm, which contributes to the 5.90 GHz WAVE band. Similarly, when the switches are in ON state, the 1.5 mm stub gets added to L_3, which increases its electrical length to 6 mm contributing to the 5.30 GHz WLAN band. In the simulation, the presence and absence of a metal strip represent ON state and OFF state, respectively [9].

The switching can be practically achieved by introducing a pair of PIN diodes as switch element in the spaces left in configuration #1. The PIN diodes can go from the OFF state to the ON state by controlling the applied DC bias currents. In our practical realization, the PIN diode (BAP 6503, SOD323V) is used as a switch element in the spaces provided. Initially, the switches are kept in OFF state and the corresponding measurement is carried out.

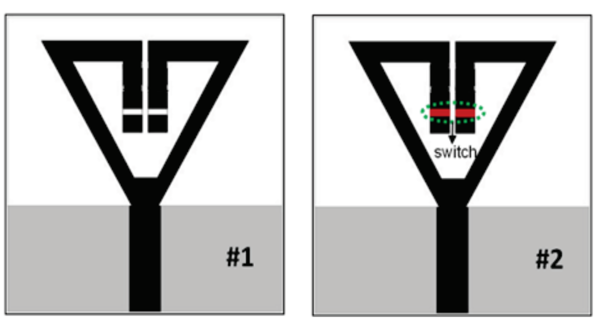


Fig. 4. Configurations of the reconfigurable split ring monopole antenna.

Figure 5 illustrates the simulated and measured return loss characteristics of the configuration #1 when the switches are in OFF state. In the dual band system, the measured first resonant frequency occurs at 2.45 GHz with the wide impedance bandwidth of 1080 MHz (2.01–3.09 GHz), and the second resonant frequency occurs at 5.90 GHz with an impedance bandwidth of about 600 MHz (5.76–6.36 GHz). It covers the lower band of WLAN as well as the WAVE frequency band (5.85–5.925 GHz). This makes the proposed antenna highly suitable for IEEE 802.11P WAVE standard.

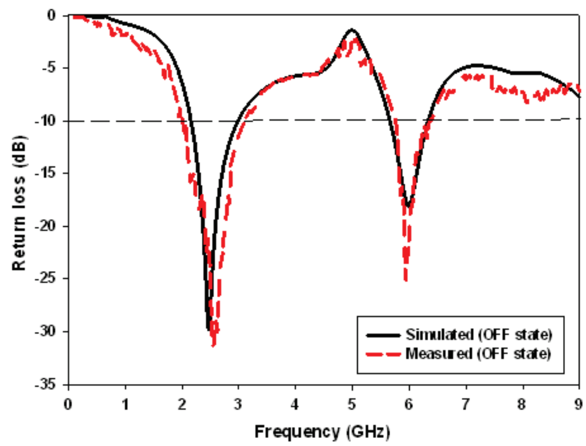


Fig. 5. Simulated and measured return loss characteristics when switches are in OFF state.

Then, by enabling the switches to ON state, the electrical length of shunt arms L_3 increases and reaches 6 mm, where the conductor stub is connected to the triangular split ring monopole antenna as shown in the configuration #2. The corresponding return loss characteristics are shown in Fig. 6, which shows the resonant frequencies at 2.45 GHz and 5.30 GHz bands, which are the desired WLAN bands. Figure 6 illustrates that similar results are obtained for both the proposed triangular SRR monopole antenna (without switches) and the reconfigurable antenna (#2). The measured impedance bandwidth of about 700 MHz (2.17–2.87 GHz) and 840 MHz (5.05–5.89 GHz) is achieved with good impedance matching at 2.45 GHz and 5.30 GHz bands respectively, which meet the specifications (2.4–2.4835 GHz & 5.15–5.825 GHz) of WLAN standard. The fabricated prototype of the proposed antenna is shown in Fig. 7 (a). Figure 7 (b) illustrates the antenna configuration (#2) with the PIN diodes.

The Figs. 8 (a) and (b) shows the simulated surface current distributions in 2.45 GHz and 5.30 GHz for the proposed antenna. While focusing the current distribution at 2.45 GHz, the maximum radiation can be observed in the feed line, strip L_2 and top edge T. As mentioned earlier, the shunt arm L_3 contributes to the upper resonant frequency of the antenna, and hence, a maximum current is distributed around L_3 for the upper resonant frequency 5.30/5.90 GHz.

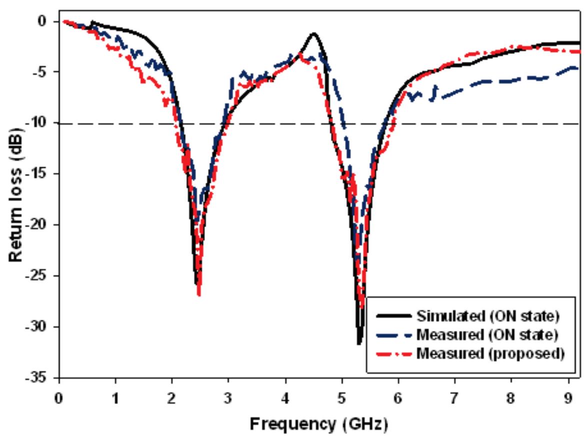


Fig. 6. Simulated and measured return loss characteristics when switches are in ON state.

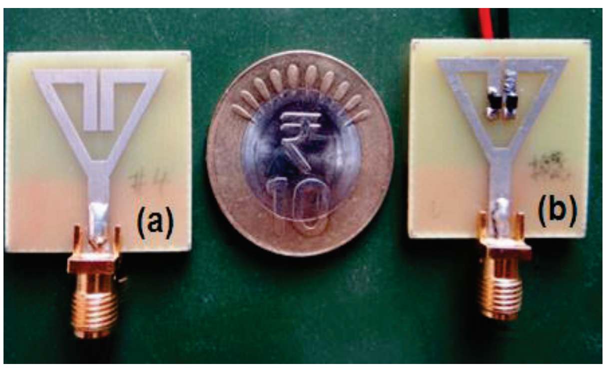
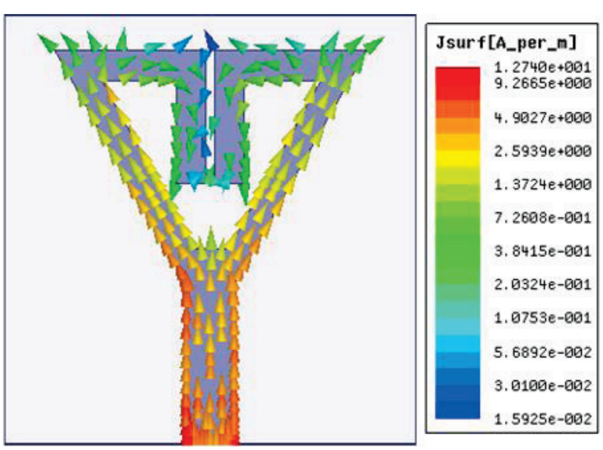
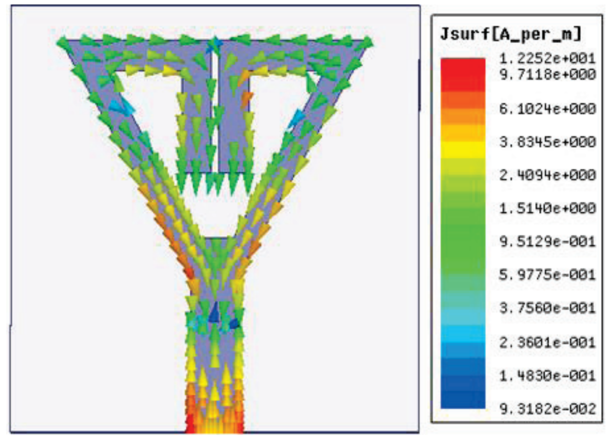


Fig. 7. Photographs of: (a) the proposed antenna, and (b) with switches.



(a)



(b)

Fig. 8. The simulated surface current distributions at: (a) 2.45 GHz, and (b) 5.30 GHz.

C. Radiation patterns and gain

The radiation patterns of the proposed reconfigurable antenna have also been measured in an anechoic chamber using double ridge horn as transmitting antenna, and the proposed split ring monopole antenna as the receiving antenna. Figures 9 (a), (b) and (c) show the normalized co-polarization and cross-polarization radiation patterns in E-plane (yz–plane) and H-plane (xz–plane) at three different frequencies of 2.45 GHz, 5.30 GHz, and 5.90 GHz respectively. From these radiation patterns, it is observed that the proposed antenna displays omnidirectional radiation characteristics in the H-plane and dipole-like radiation in E-plane at all the desired frequencies. A low cross-polarization level of less than -20 dB is observed at all frequencies of interest.

The measured gain plot of the proposed reconfigurable antenna is shown in Fig. 10; maximum gain of 2.52 and 2.65 dBi is obtained at the WLAN frequencies 2.45 and 5.30 GHz respectively. Also, for the maximum gain of 2.75 dBi is observed for the 5.90 GHz WAVE frequency band. It is obvious that the antenna gain decreases drastically at the frequency where the SRR exhibits stop band characteristics due to its negative permeability characteristics. It is useful in antenna design for providing a very good out of band rejection between the operating bands. In the future, the proposed SRR can be used in filter applications and UWB communications for creating notches at the desired frequencies by using its negative permeability feature. It can be achieved by varying the inductance and capacitance values of the proposed SRR by altering its length and split gap.

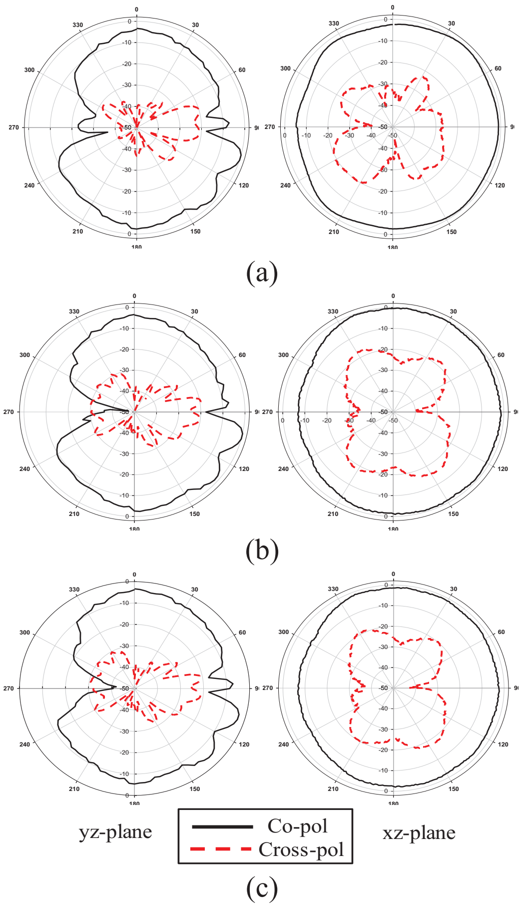


Fig. 9. Measured radiation patterns at: (a) 2.45 GHz, (b) 5.30 GHz, and (c) 5.90 GHz.

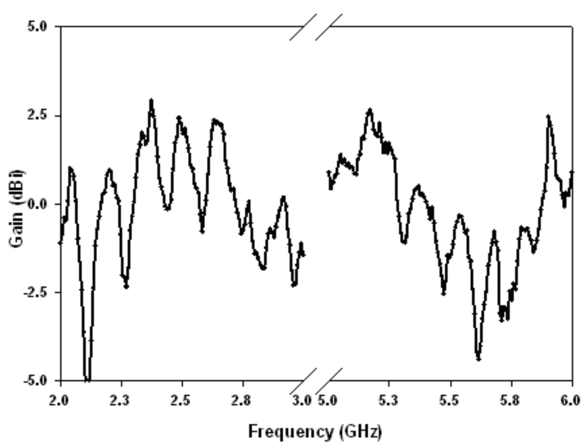


Fig. 10. Measured gain of the proposed antenna.

IV. CONCLUSION

A compact frequency reconfigurable dual band monopole antenna based on the split ring element is discussed. The operating frequencies of the proposed antenna are 2.45/5.0/5.9 GHz, which meet the specifications of WLAN/WAVE standards. A prototype with a very compact dimension, with respect to recently reported antennas, is fabricated and measured. By placing PIN diodes in the tuning stub (L_3), reconfigurability is demonstrated. The wireless devices in the fast moving vehicles can switch over from WLAN to WAVE mode, which is specifically designed for wireless access in a vehicular environment. Also, the proposed antenna finds most useful application in intelligent transportation systems. Measured results validate the reconfigurability of the proposed antenna. The experimental result shows good agreement with the simulation results. The compactness in size, consistency in gain and reconfigurable system approach makes the designed antenna suitable for practical application in the WLAN/WAVE communications.

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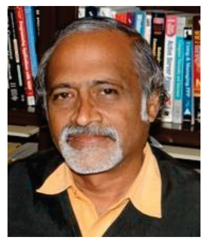

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