

RESEARCH PAPER

Reconfigurable antennas with frequency, polarization, and pattern diversities for multi-radio wireless applications

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This paper presents different reconfigurable antennas with frequency, polarization, and pattern diversities. All the antennas have a very simple, novel, and compact structures, which are used for different wireless communication applications. These antennas employ switching for obtaining different reconfigurations. At first, an E-shaped antenna is designed for multi-band frequency reconfigurability. Second, circular and rectangular-shaped patch antennas are designed for achieving diversity in polarization. At last, a pattern reconfigurable antenna is designed with multiport excitation. These antenna performances are analyzed using various parameters such as return loss, radiation pattern, voltage standing wave ratio (VSWR), and gain. The prototypes of the antennas are fabricated and measured results along with simulated ones are presented. Both the results are in good agreement.

Keywords: Antennas and propagation for wireless systems, Antenna design, Modeling and measurements

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I. INTRODUCTION

Miniaturization of any device always reflects scientific progress. As there is an increase in demand of wireless services such as WiMAX, WLAN, Wi-Fi, Bluetooth, PCS, DCS, GPS, 3G, and 4G, the available radio spectrum is decreasing day by day. Hence there is a need of multifunctional antennas because it is not possible to dedicate single antenna for each of these services and also to reduce the complexity and size of the given wireless system. The purpose of multifunctionality is fulfilled by reconfigurable antennas. These antennas can change their operating frequency, impedance bandwidths (BWs), polarization, and patterns independently according to changing operating requirements of a given radio system. Accordingly, these are categorized into frequency diversity, polarization diversity, and pattern diversity reconfigurable antennas.

Due to their many advantages such as integration density, multiple functionality, reconfigurable capability, less cost, and miniaturized size, reconfigurable antennas attract military applications besides commercial ones. According to the design requirements and desired antenna performance, one among the different reconfiguration methods such as altering the physical structure of the antenna, changing feeding methods or implementing arrays, etc. can be chosen. This can be done through switching, material tuning, structural modifications, etc. The switching technology uses solid-state switches

field effect transistors (FETs), varactor or P-Intrinsic-N (PIN) diodes) or monolithic integrable surface micromachined radio frequency (RF)-micro-electro mechanical systems (MEMS) switches.

Lot of research has been made on reconfigurable antennas in the past, many latest researches use advanced reconfiguration mechanisms such as using metasurfaces (MS) [3–4], in which planar MS placed atop of and in direct contact with a planar slot antenna, both having a circular shape. By rotating the MS around the center with respect to the slot antenna, it can be reconfigured to different frequencies [3] and different polarizations linear polarization (LP), right hand circular polarization (RHCP), left hand circular polarization (LHCP) [4], using liquid metal (EGaIn) as switching mechanism enables the pressure-driven displacement of a low-loss dielectric fluid and the liquid metal from a reservoir atop the patch to switch between the different antenna states [5], a pattern reconfigurable antenna has parasitic elements that rotates around a fixed monopole element on a ground plane to attain rotated patterns for diversity. This rotation is based on electro active polymer [6], electronically beam steerable antenna system using active frequency-selective surfaces [7]. A frequency agile antenna is proposed for software defined radio application in [8] where in frequency reconfigurability is achieved by activating four groups of PIN diodes that connects central patch to four different peripheral patches that provides $2^4 = 16$ reconfiguring states. A symmetrical multipolarized circular patch antenna that generates six LPs at 30° interval using 12 p-i-n diodes placed across a circular ring slot on the patch is proposed in [9], an aperture-fed polarization reconfigurable antenna that switches between horizontal, vertical, and 45° linear polarizations in dual bands is proposed

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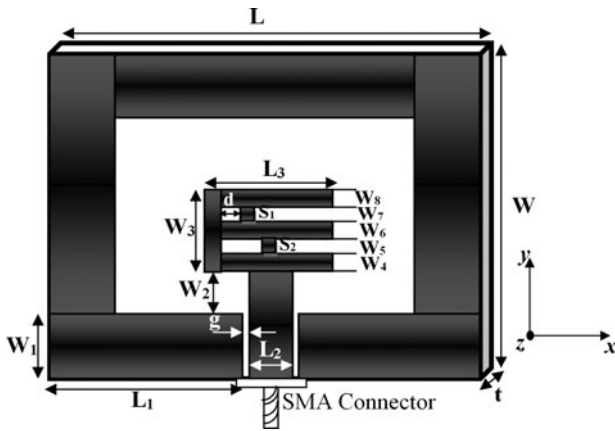


Fig. 1. Geometry of the proposed frequency reconfigurable antenna. The parameters of the antenna are $L_1 = 15.3$, $W_1 = 5.0$, $L_2 = 3.6$, $W_2 = 2.0$, $L_3 = 12.0$, $W_3 = 8.0$, $W_4 = W_6 = W_8 = 2.0$, $W_5 = W_7 = 1.0$, $L = 35.0$, $W = 30.0$, $g = 0.4$, and $t = 1.6$. All dimensions are in mm.

in [10]. A very high-gain beam switching antenna that can steer beam in five directions in both azimuth and elevation planes using four parasitic patches for WiMAX applications is proposed in [11].

More complex in terms of structure and number of switches, large dimensions, more than one layer and use of parasitic elements, less impedance BW ($<20\%$), feed radiation, and less efficiency due to conventional micro strip feeding mechanism are some limitations observed in the reconfigurable antennas mentioned above. In this work, simple, small, and thin wideband reconfigurable antennas are evaluated with independent control of operating frequency, polarization, and radiation patterns for improved performance of wireless systems.

In this paper, a study of different reconfigurable antenna designs for frequency, polarization, and pattern diversities is made. Switches are used to obtain reconfigurability. The prototypes of the respective antennas were fabricated and tested. Starting with frequency reconfigurability in Section II, a

Table 1. Measured versus simulated results of frequency reconfigurable antenna.

Antenna parameters	Antenna/mode 1 S_1, S_2 OFF	Antenna/mode 2 S_1 OFF, S_2 ON	Antenna/mode 3 S_1 ON, S_2 OFF	Antenna/mode 4 S_1, S_2 ON
Operating frequency (GHz)	5.8 (5.8)*	5.0 (5.2), 8.5 (9.2)	5.57 (5.6)	6.1 (5.8), 8.76 (8.8)
Operating band (GHz)	5.45–6.35 (5.4–6.12)	4.7–5.5 (4.83–5.73), 7.73–9.12 (7.6–9.6)	5.3–5.8 (5.3–5.6)	5.9–6.2 (5.55–6.25), 7.96–9.05 (8.55–9.15)
Bandwidth (BW) (%)	15.5 (12.4)	16 (17.3), 16.35 (21.7)	8.97 (5.5)	4.92 (12.06), 12.4 (6.8)
Return loss (dB)	28 (21.6)	17 (19.6), 28.2 (15.6)	15 (12.7)	25 (15.3), 38 (29.7)
Voltage standing wave ratio (VSWR)	1.09	1.33, 1.08	1.05	1.03, 1.02
Measured gain (dBi)	2.75	2.56, 4.66	2.9	5.15, 4.5
Application	WLAN	WLAN	WLAN	WLAN

*The values within braces indicate measured results.

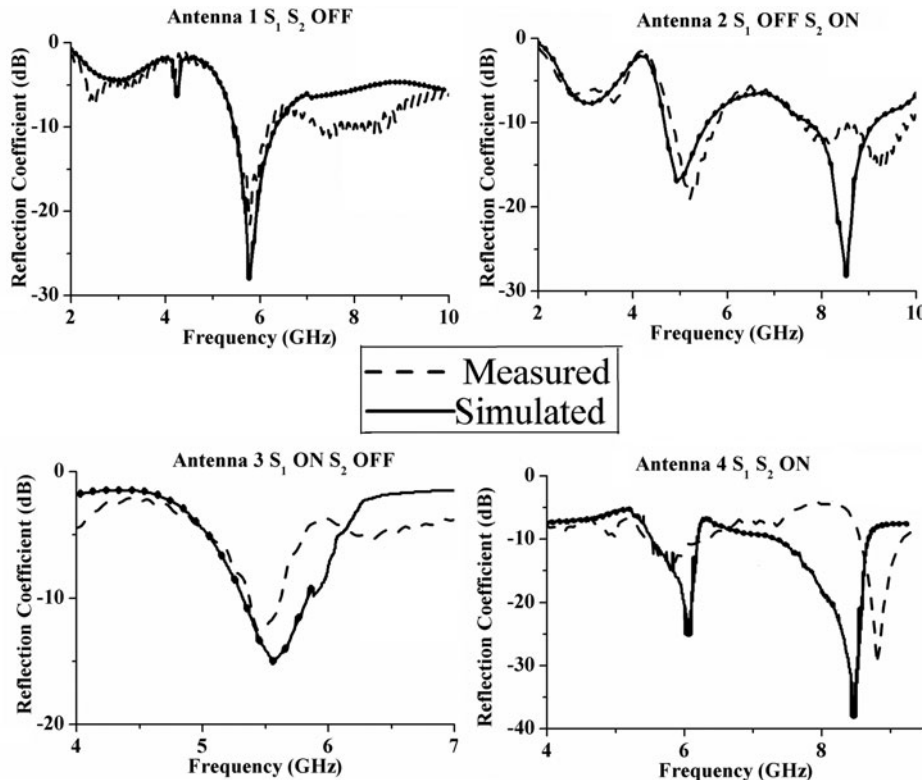


Fig. 2. Measured and simulated reflection coefficients curves of the frequency reconfigurable antenna.

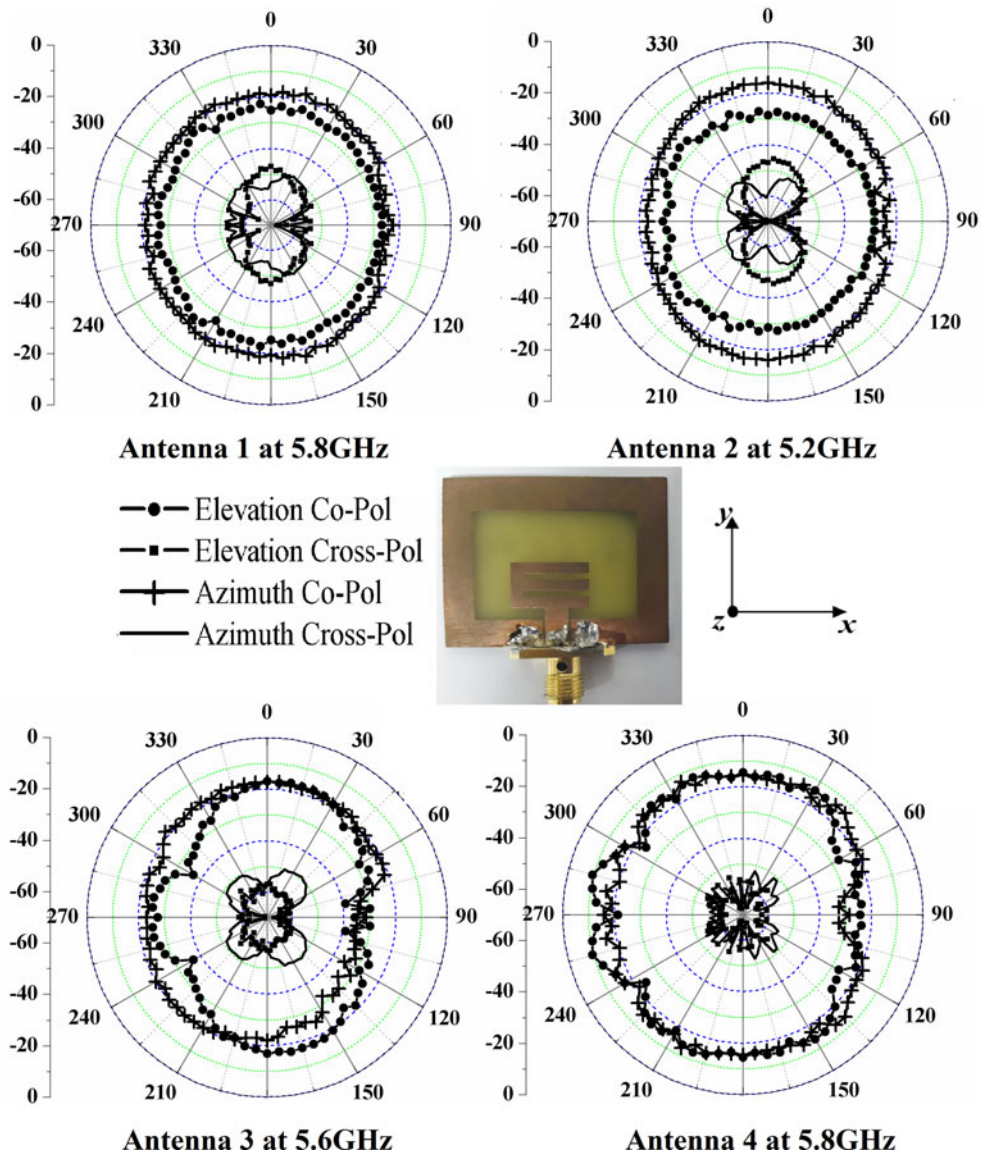


Fig. 3. Measured radiation patterns in azimuth and elevation planes with co and cross-polarizations of frequency reconfigurable antenna.

simple and compact E-shaped antenna with two switches was designed to operate at four frequencies serving four different applications. In Section III, rectangular- and circular-shaped patch antenna designs and their principle of operation for polarization selectivity are discussed. Section IV presents, a pattern reconfigurable antenna with multiport excitation without using any switches. In all the cases, the coplanar

waveguide (CPW) feeding technique is used to get enhanced operating BW and the experimental results are compared with simulated ones in [12–14]. Finally, conclusions and possible applications were discussed in the last section.

II. FREQUENCY RECONFIGURABLE E-SHAPED ANTENNA

The geometry of the proposed E-shaped reconfigurable antenna is shown in Fig. 1. The antenna is etched on a single layer of low-cost FR4 ($\epsilon_r = 4.3$) dielectric substrate which is $35 \times 30 \text{ mm}^2$ in dimension. Two switches S_1 and S_2 are incorporated in the main structure to redirect the current in certain directions so as to change the effective electrical length of the antenna which in turn is responsible for changing operating frequencies. These switches are used to connect two rectangular patch lines in the E-structure to operate the antenna in four different operating modes as given in Table 1.

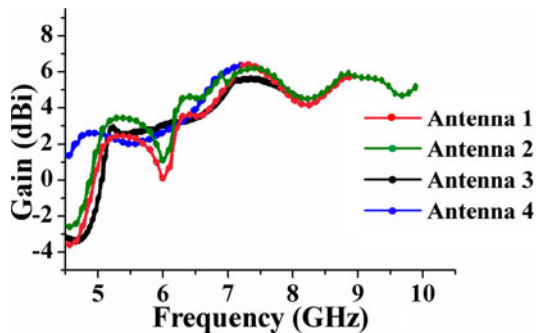


Fig. 4. Measured gain of the proposed frequency reconfigurable antenna.

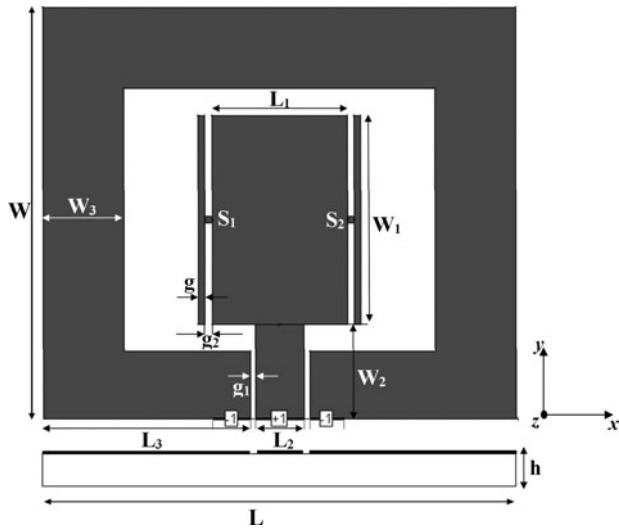


Fig. 5. Geometry of the rectangular polarization reconfigurable antenna. The parameters of the antenna are $L_1 = 10$, $W_1 = 15$, $L_2 = 3.6$, $W_2 = 7.0$, $L_3 = 15.3$, $W_3 = 6.0$, $g_1 = 0.4$, $g_2 = 0.5$, $g = 0.5$, $L = 35.0$, $W = 30.0$, and $t = 3.0$. All dimensions are in mm.

The ON and OFF conditions of switches are realized by forward and reverse biasing of PIN diodes. Ideally, when a forward bias is applied to make the switch ON, the switch would have low impedance characteristic, acts as short and the current can flow through the diode. On the other hand, when a reverse bias is applied to make the switch OFF, the switch exhibits high impedance characteristic and acts as open circuit which implies that there is no connection. These two switches in the simulation are realized as short copper paths. Presence of the path is treated as ON and absence as OFF. The measured and simulated S-parameters of all the switch configurations are shown in Fig. 2. When both the switches are OFF, the antenna resonates at a single resonant frequency of 5.8 GHz which suits for IEEE 802.11a WLAN (5.725–5.875 GHz) applications. When either of the switches is ON, it is observed that the antenna resonates at two operating bands, among them one is in C-band and another one is in X-band. The simulations were carried out on commercially available electromagnetic simulator Integral Equation 3-Dimension (IE3D) by Mentor Graphics. The detailed simulated and measured parameters are listed in Table 1.

The measured radiation patterns in the azimuth ($x-y$) plane and elevation ($x-z$ & $y-z$) planes for all the switch

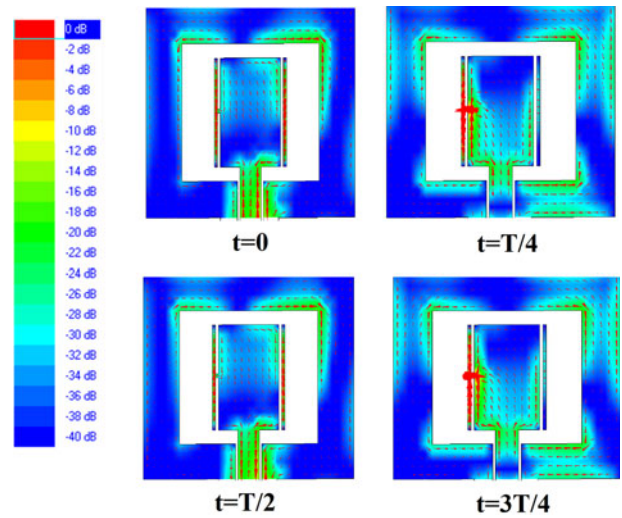


Fig. 6. Surface electric current distribution of the proposed antenna in Case 3 at each quarter interval.

combinations are shown in Fig. 3. The measured gain of all the operating modes of the antenna are shown in Fig. 4. The antenna has a gain of above 2 dBi for all the operating modes and VSWR close to the value one.

III. POLARIZATION RECONFIGURABLE ANTENNAS

A) Rectangular antenna for polarization diversity

The first structure of the polarization reconfigurable antenna is shown in Fig. 5. The antenna is designed and prototype of the same is fabricated on the FR4 substrate of thickness 3.2 mm whose dielectric constant is $\epsilon_r = 4.4$. The basic structure consists of a rectangular patch of length 10 mm and width 15 mm. The structure of the basic patch is modified by introducing two rectangular strips of 0.5 mm \times 15 mm dimension on both sides of the main radiating patch, in order to achieve circular polarization (CP). These strips are connected through two switches namely S_1 and S_2 to the main patch. By making two switches ON/OFF, the

Table 2. Simulated versus measured results of rectangular polarization reconfigurable antenna.

Antenna parameters	Mode/antenna 1 S_1, S_2 OFF	Mode/antenna 2 S_1 OFF, S_2 ON	Mode/antenna 3 S_1 ON, S_2 OFF	Mode/antenna 4 S_1, S_2 ON
Operating frequency (GHz)	4.62 (4.99)*	4.47, 5.76 (4.67, 5.68)	4.47, 5.76 (4.73, 5.75)	4.23 (4.42)
BW (GHz)	4.24–5.06 (4.6–5.2)	4.05–4.78, 5.54–5.79 (4.09–5.01), (5.52–5.75)	4.04–4.78, 5.54–5.79 (4.16–5.28), (5.69–5.8)	3.86–4.44 (4.09–4.6)
BW (%)	17.7 (12.02)	16.33, 4.34 (19.7), (4.04)	16.55, 4.34 (23.67), (1.91)	13.71 (11.5)
Return loss (dB)	15.37 (29.35)	28.2 (37.8), 21.6 (30.9)	29.15 (28.6), 22.1 (15.0)	28.44 (15.9)
VSWR	1.41	1.08, 1.18	1.07, 1.17	1.11
Gain (dBi)	(2.076)	(3.01, 5.04)	(2.99, 5.21)	(2.65)
Axial ratio (dB)	–	(0.904, 0.621)	(0.973, 0.756)	–
Polarization	LP	RHCP	LHCP	LP
Application	Wi-Fi	WLAN/(HIPERLAN 2)	WLAN/(HIPERLAN 2)	–

*The values within braces indicate measured results.

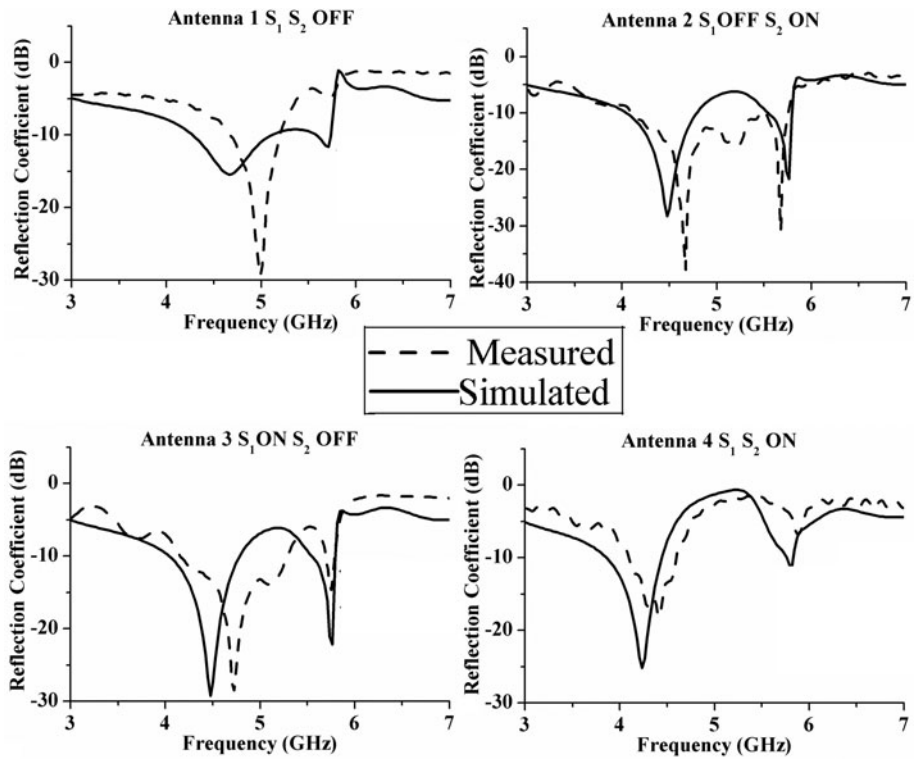


Fig. 7. Reflection coefficient (S_{11}) curves of the proposed rectangular polarization reconfigurable antenna in different operating modes.

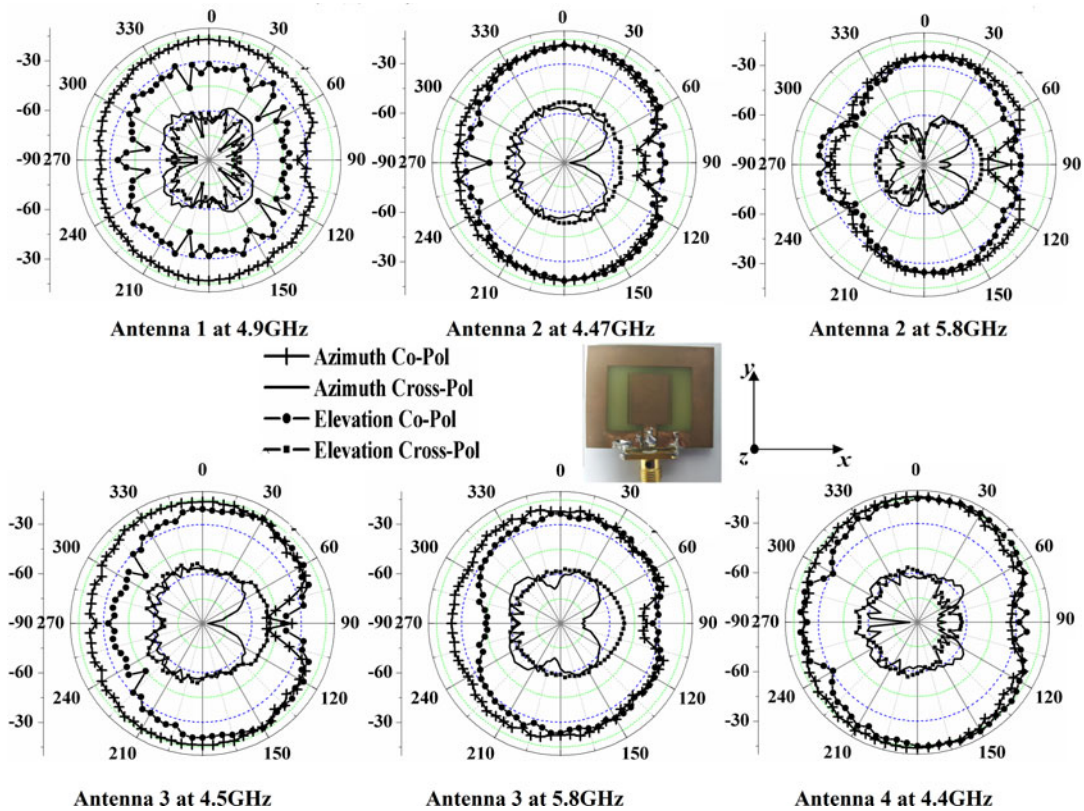


Fig. 8. Measured radiation patterns in azimuth and elevation planes with co and cross-polarizations of rectangular polarization reconfigurable antenna.

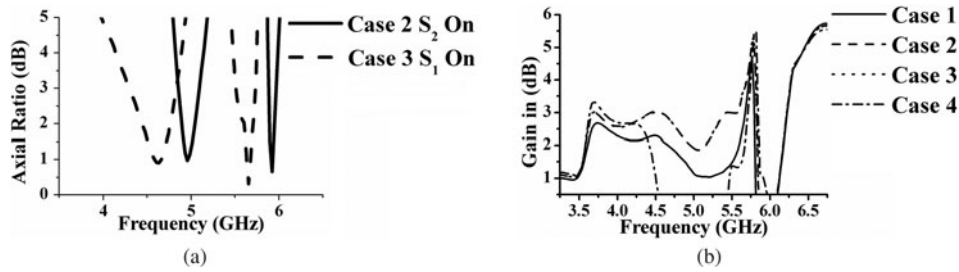


Fig. 9. (a) Measured axial ratio and (b) measured gain of rectangular polarization reconfigurable antenna.

polarization of the antenna can be changed from vertical linear to circular (RHCP, LHCP). Different reconfiguring cases of the antenna are given in Table 2.

The antenna is designed and simulations were carried out on popular Mentor Graphics electromagnetic simulator IE3D that employs Method of Moments (MoM) technique. For reconfigurable operation, in Case 1, when both the switches are in OFF state, the antenna exhibits linear polarization because of the symmetry in the antenna structure. In Case 2, when S_1 is OFF and S_2 is ON, due to the quasi-symmetric structural configuration, two orthogonal degenerate modes are generated which makes the antenna to excite in CP. Thus when the antenna is reconfigured from Cases 1 to 2, the polarization switches from linear to circular. The current distributions of the reconfigurable antenna in case 3 when S_1 is ON and S_2 is OFF are shown in Fig. 6.

This figure clearly shows the rotation of current vector in the clockwise direction at the position of switch S_1 at time instances $t = 0, t = T/4, t = T/2,$ and $t = 3T/4,$ where T is the time period of the RF excitation signal. This implies antenna operates in LHCP. Similarly in Case 2, it exhibits RHCP. In Case 4, the antenna radiates through center rectangular patch in linear polarization. The measured and simulated return loss curves of all the operating modes of the antenna are shown in Fig. 7. When the switches S_1 and S_2 are OFF, the electrical length of the antenna is small and hence the antenna resonates at high frequency (f_h) (5.0 GHz). When both switches are ON, the effective electrical length is large and the antenna resonates at low frequency (f_l) (4.4 GHz) and when one of the switches is ON and the other is OFF, the relation between the frequency of operation is $f_l < f < f_h$ (4.7 GHz) $< f_h$. The given antenna has same frequency characteristics when operating in two polarization diversity modes. The measured and calculated antenna parameters of the proposed antenna are summarized in Table 2. The measured radiation characteristics of the antenna are shown

in Fig. 8, and measured gain, axial ratio curves are shown in Fig. 9.

B) Circular-shaped antenna for polarization diversity

A circular-shaped antenna is proposed for polarization reconfiguration, which is designed on a very thin Rogers RT/Duroid 5880 substrate with a thickness of 0.254 mm and having dielectric constant of 2.2 as shown in Fig. 10. The radius of the circular patch is 6 mm which is fed by CPW feed. The CP effect in the basic patch is introduced by cutting the original circular patch at 2.0 mm distance from two sides of horizontal diametric edges. These left out patches are connected to the main patch through switches S_1 and S_2 . The four fundamental modes of operations of the proposed antenna are given in Table 3. For the case of basic circular patch without switches, the fundamental mode TM_{11} is excited. By introducing switches in the antenna to accommodate the CP effect,

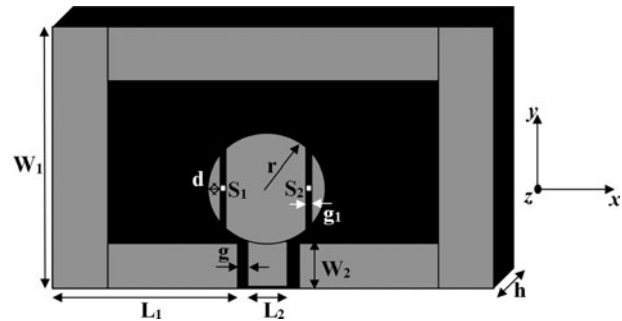


Fig. 10. Geometry of the circular polarization reconfigurable antenna. The parameters of the antenna are $L_1 = 15.3, L_2 = 3.6, W_1 = 30, W_2 = 7, h = 0.254, g_1 = 0.5, d = 2.0, g = 0.4,$ and $r = 6.0$. All dimensions are in mm.

Table 3. Simulated versus measured results of circular polarization reconfigurable antenna.

Antenna parameters	Mode 1 S_1, S_2 OFF	Mode 2 S_1 ON, S_2 OFF	Mode 3 S_1 OFF, S_2 ON	Mode 4 S_1, S_2 ON
Operating frequency (GHz)	2.65 (2.78)	2.45 (2.5)	2.47 (2.44)	2.47 (2.3)
BW (GHz)	2.15–4.22 (2.22–3.95)*	1.96–4.1 (1.8–3.6)	1.96–4.22 (2.03–3.84)	1.96–3.97 (1.99–3.72)
BW (%)	78.1 (62.2)	87.3 (72.0)	91.5 (74.2)	81.4 (75.2)
Return loss (dB)	17.54 (17.76)	24.69 (21.66)	24.45 (23.17)	28.44 (15.9)
VSWR	1.31 (1.35)	1.12 (1.45)	1.13 (1.34)	1.09 (1.41)
Gain (dBi)	(3.96)	(3.32)	(2.86)	(3.56)
Axial ratio (dB)	–	(1.48)	(1.85)	–
Application	–	Bluetooth	Bluetooth	Bluetooth

*The values within braces indicate measured results.

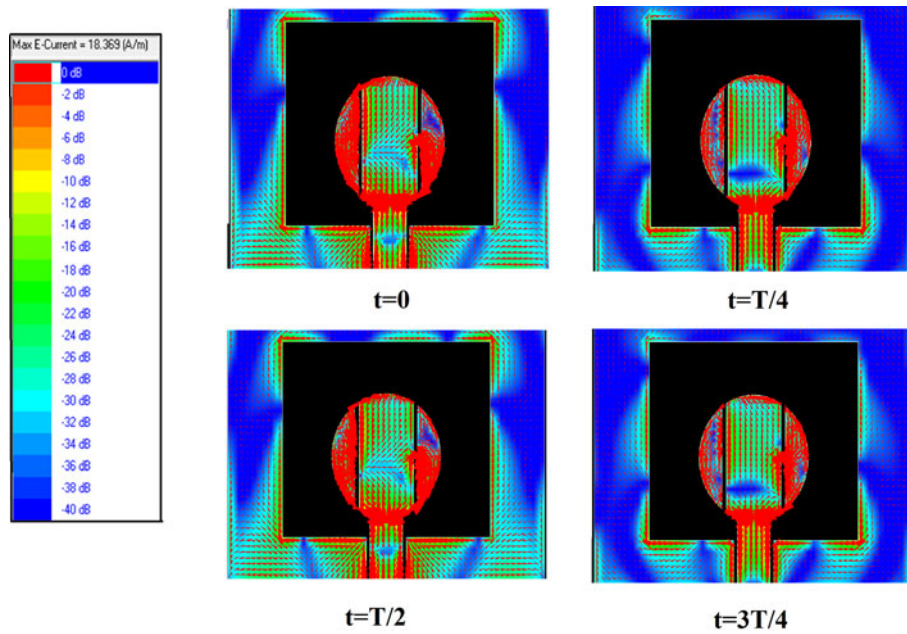


Fig. 11. Surface electric current distribution of the proposed antenna in Case 3.

the surface current path gets modified and the fundamental mode TM_{11} splits into two near degenerate resonant modes.

The antenna in mode 1, when both switches are OFF, generates vertical LP and resonates at 2.9 GHz. In mode 2, when S_1 is ON and S_2 is OFF, due to the quasi-symmetrical structure, the slot near the left edge of the circular patch perturbs the current by changing the length of the surface current vector in the x -direction without affecting current vector directed along the y -direction. This makes the fundamental

mode TM_{11} split into two orthogonal degenerate modes with equal amplitude and 90° phase shift and the instantaneous surface current vector on the circular patch rotates and thus the radiated field is circularly polarized. The direction of the current vector is counter clockwise hence the antenna has the RHCP pattern. Similarly, when the antenna operates in mode 3, i.e. when S_1 is OFF and S_2 is ON, the slot near the right edge of the patch changes the current perturbation and the two degenerated orthogonal modes have equal

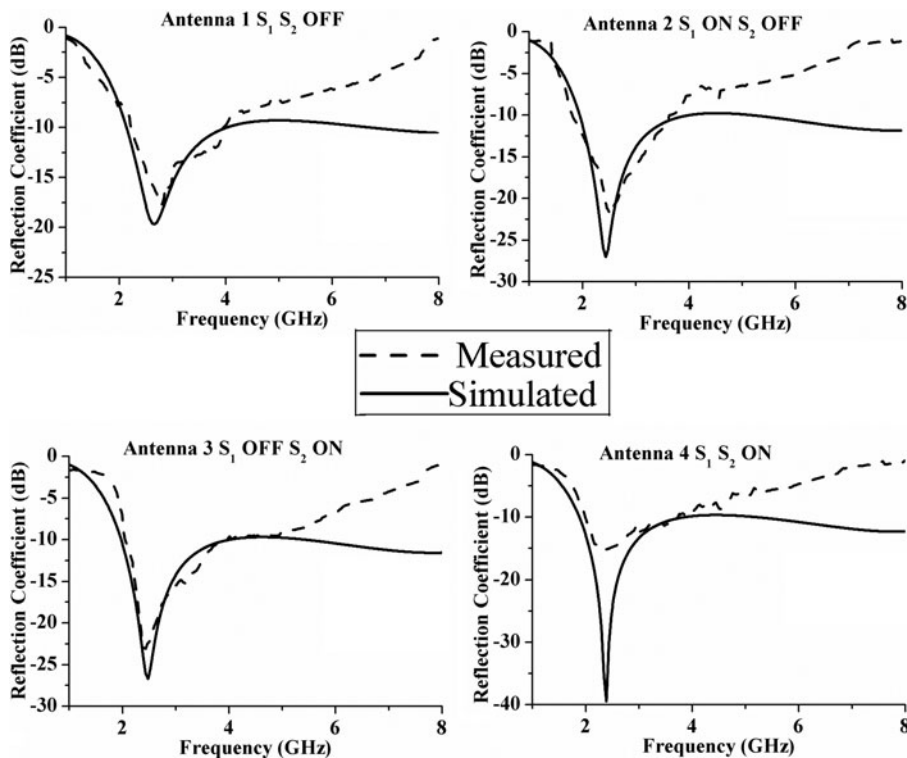


Fig. 12. Reflection coefficient (S_{11}) of the circular shaped reconfigurable antenna.

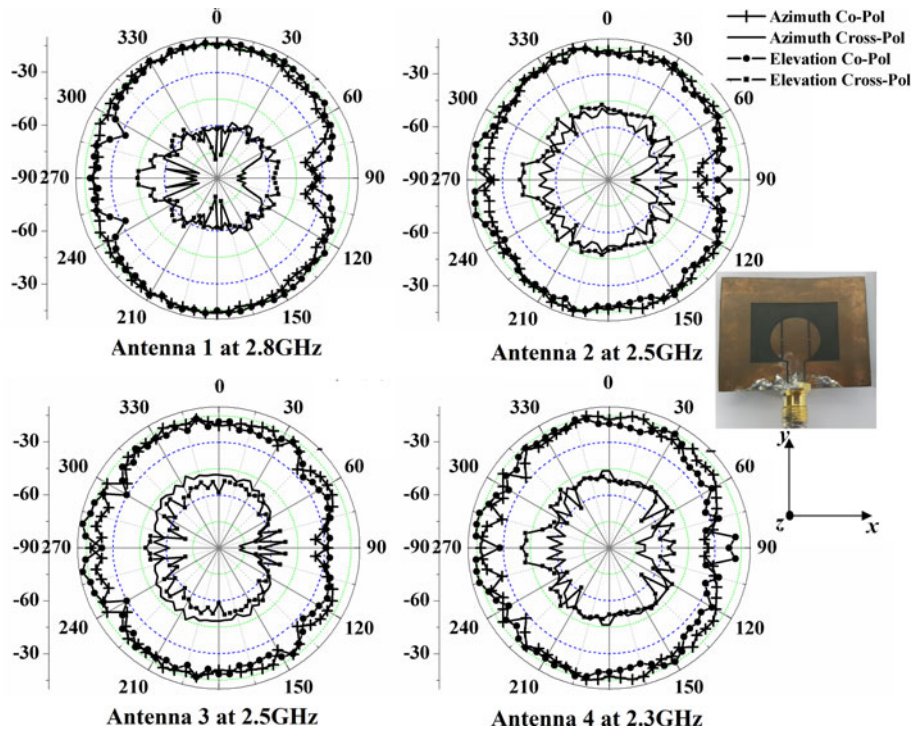


Fig. 13. Radiation patterns of the antenna in E_θ and E_ϕ planes with co- and cross-polarization.

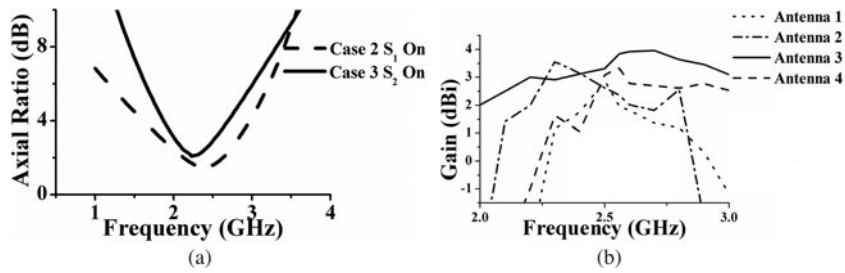


Fig. 14. (a) Measured axial ratio and (b) measured gain of CP reconfigurable antenna.

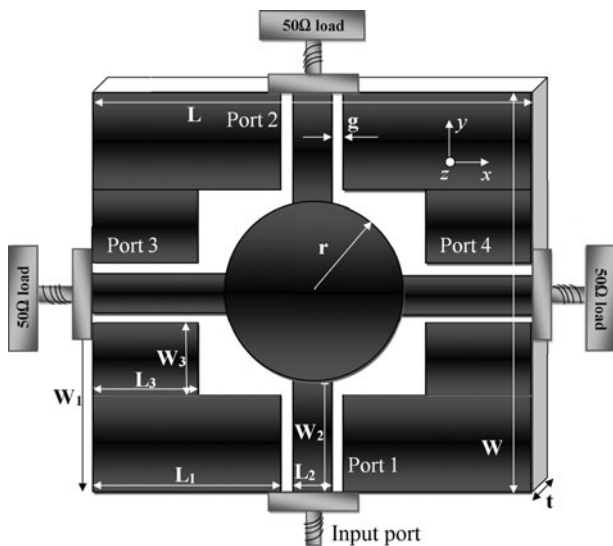


Fig. 15. Geometry of the proposed pattern reconfigurable antenna $L = 14$ mm, $W = 13.8$ mm, $t = 1.6$ mm, $g = 0.3$ mm, $L_1 = 6.05$ mm, $W_1 = 5.95$ mm, $L_2 = 1.3$ mm, $W_2 = 4.5$ mm, $L_3 = 4$ mm, $W_3 = 1.95$ mm, and $r = 2.5$ mm.

amplitude and -90° phase shift, which make the surface current vector rotate in the clockwise direction producing the LHCP pattern. Figure 11 shows the surface current distributions on the circular patch in mode 3, at the switch S_2 at time instances $t = 0, T/4, T/2,$ and $3T/4$.

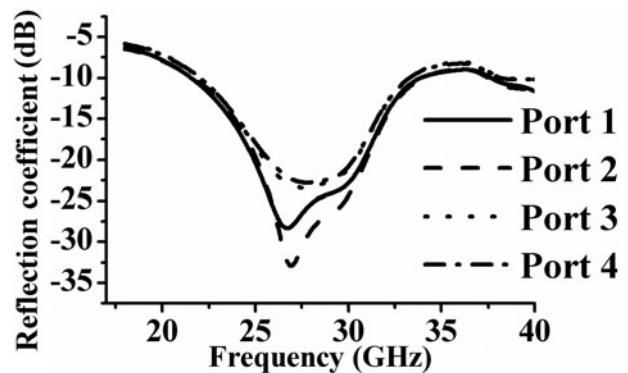


Fig. 16. Reflection coefficient (S_{11}) curves of the pattern reconfigurable antenna operating in four different modes.

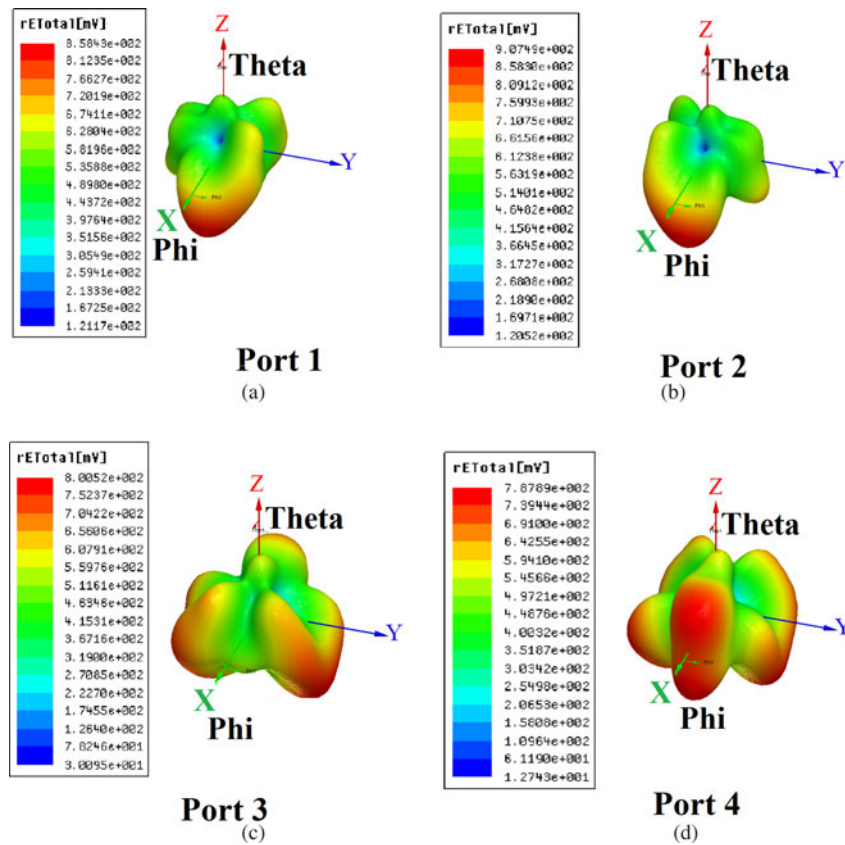


Fig. 17. 3D radiation patterns of the proposed pattern reconfigurable antenna.

The prototype of the proposed reconfigurable antenna is fabricated and tested in anechoic chamber. The simulated and measured return loss, radiation patterns in the E_θ elevation and E_ϕ azimuth planes for each operating mode are shown in Figs 12 and 13, respectively. It shows that the antenna when operated in mode 1, resonates at 2.7 GHz. Since both the switches are OFF, its electrical length is small compared with other three cases and hence it resonates at higher frequency. In mode 4, the electrical length of the antenna is large compared with other cases; hence it resonates at lower frequency of 2.38 GHz. When the antenna operates in modes 2 and 3, i.e. when one of the switches is ON, asymmetry is created in structure and this creates little perturbation of the fundamental mode TM_{11} and hence the resonant frequency is slightly increased to 2.45 GHz. The measured gain and axial ratio curves are shown in Fig. 14, respectively. Table 3 summarizes all the measured and simulated results.

IV. PATTERN RECONFIGURABLE ANTENNA

A very simple, compact, and wideband pattern diversity antenna with multipoint excitation is designed and analyzed. Instead of using switches for reconfiguration, four ports are used to excite the basic patch one at a time, where the pattern changes its direction to 90° with each individual port exciting the main radiating patch. The geometry of the proposed antenna is shown in Fig. 15. The antenna is simulated on a 1.6 mm thick low-cost FR4 substrate whose

dielectric constant is 4.4 with loss tangent 0.02. The radius of basic circular patch is 2.5 mm. The size of the antenna is 14 mm \times 13 mm \times 1.6 mm which is very compact. The simulator tool used here is Ansoft High-Frequency Structure Simulator which employs finite element method numerical technique for solving three-dimensional (3D) electromagnetic (Em) problems. The signal is fed through the four ports, independently, which are placed at the four sides of the basic rectangular patch. When the patch is fed by one port, all the remaining ports are terminated by a 50Ω load for proper impedance match. The signal fed through each individual port changes the spatial current distribution on the radiating patch and thus changes the radiation pattern.

The simulated S_{11} (in dB) curves are shown in Fig. 16 for all the operating modes when the antenna is fed through four ports individually. The operating frequency of the antenna when it is fed through port 1 is 26.7 GHz with -10 dB impedance BW of 12.2 GHz (46.8%), through port 2 it has same frequency characteristics as the antenna fed through port 1. Through port 3 it is 27.5 GHz with a BW of 11.15 GHz (40.64%) and through port 4 it has same frequency characteristics as the antenna fed through port 3. The radiation characteristics of the basic circular patch are determined by the electric or magnetic current distribution on the radiating structure which in turn are responsible for changing frequency characteristics. Because of this relationship between the source currents and the resulting radiation, it is difficult to achieve pattern reconfigurability without having many changes in frequency characteristics. Hence there is a slight change in frequency in each operating mode.

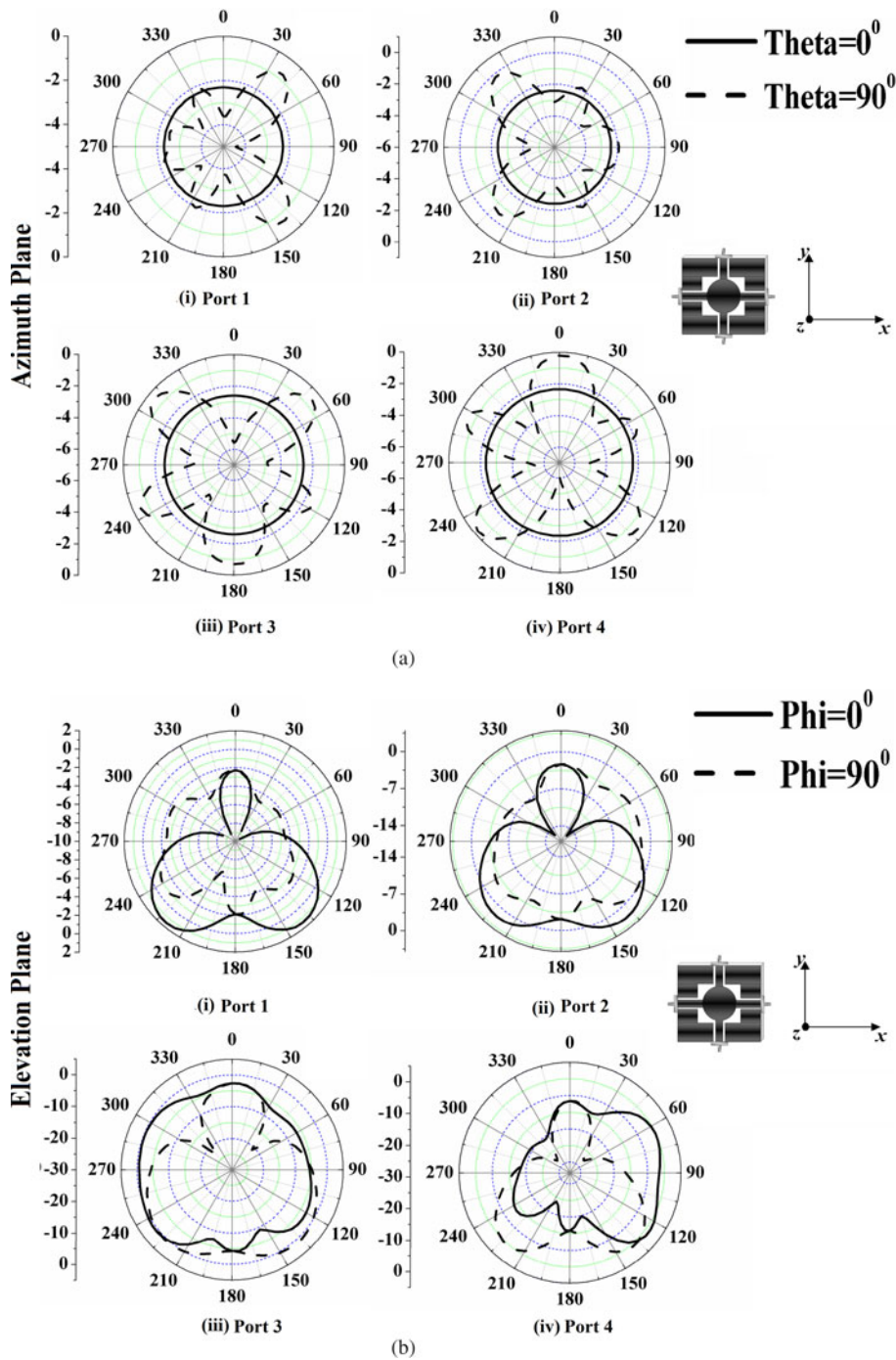


Fig. 18. (a) 2D radiation patterns of the pattern reconfigurable antenna in azimuth plane with different ports of excitation. (b) 2D radiation patterns of the pattern reconfigurable antenna in elevation plane with different ports of excitation.

The 3D and two-dimensional (2D) plots of the radiation patterns of the antenna operating in four different modes are shown in Figs 17 and 18. It is observed that when the antenna feed is changed from ports 1 to 3, ports 3 to 2, ports 2 to 4, and again to port 1, the radiation pattern changes by 90° each time.

It is observed from the above figures that frequency characteristics are maintained, while changing the radiating characteristics when the antenna is fed through different ports individually which satisfies the principle of pattern reconfigurability. The transmission coefficients of the

antenna when fed through port 1 are shown in Fig. 19. It is known that $S_{ij} = S_{ji}$ and here in this case $S_{12} = S_{34}$. Also, $S_{31} = S_{41} = S_{32} = S_{42}$. We can say that, when the antenna is fed through any one port there is more chance of the signal getting leaked in the adjacent ports.

The average correlation between the total power radiated by antenna when fed through different ports within the 3D space, called envelope correlation coefficient envelope correlation coefficient (ECC) is calculated to evaluate the diversity performance [15]. This is calculated from S-parameters obtained in the simulations using the formula (1). A good

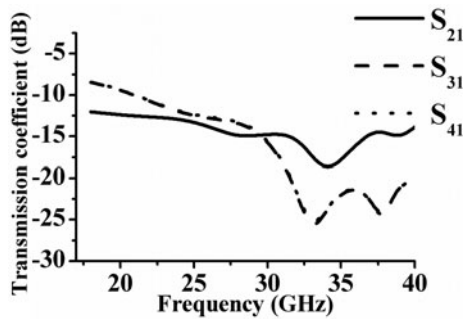


Fig. 19. Transmission coefficients of the proposed antenna when fed through port 1.

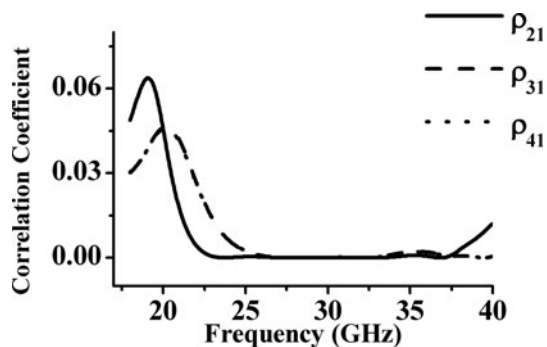


Fig. 20. Simulated envelope correlations (ECs) of the proposed antenna.

diversity performing antenna has the correlation factor < 0.5 . The correlation between the ports 1 and 2 is given by equation (1). It is known that, $\rho_{ij} = \rho_{ji}$, and also in our case $\rho_{31} = \rho_{41}$, because of the equal length of the two vertical sides of the rectangle. Figure 20 shows the ECCs obtained from the simulated S-parameters:

$$\rho_{12} = \frac{|S_{11} \times S_{12} + S_{21} \times S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))(1 - (|S_{22}|^2 + |S_{12}|^2))}. \quad (1)$$

The ECC for ρ_{21} is < 0.07 and for ρ_{31} is < 0.06 which satisfies the low correlation criteria of $\text{ECC} < 0.5$. Hence the designed antenna has a very good diversity performance.

V. CONCLUSION

A study on frequency, polarization, and pattern diversity reconfigurable antennas is presented in this paper. The antennas are implemented on very simple and compact structures in order to satisfy several wireless applications. The CPW feeding technique is used for all the antennas to attain wide BWs. A frequency reconfigurable antenna is designed with two switches which operate at four different operating bands. This antenna can be used in WLAN (5.15–5.35) GHz, HIPERLAN 2 (5.47–5.725) GHz, and WLAN (5.725–5.875) GHz applications. Two polarization selective antennas are designed operating at 5.8 and 2.4 GHz with polarization reconfigurations from vertical LP to RHCP and LHCP. The first polarization selective antenna can be used in Wi-Fi 802.11a (5.0 GHz), WLAN (5.47–5.75) GHz applications

and the second one can be used in Bluetooth 2.45 GHz applications. The prototypes of all the three antennas are fabricated and tested and the measured results are found in good agreement with simulated ones. In all the above three cases, the measured results are slightly deviated from simulated ones. The reasons for the difference between simulated and measured results are due to minor fabrication inaccuracies, dielectric imperfections, and SubMiniature Version A (SMA) connector solder losses (i.e. while testing, SMA connector can be treated as the extension of the ground which creates some impedance mismatch at the CPW feed). Finally, a pattern reconfigurable antenna with multiport excitation is proposed which operated in K-band. The antenna is capable of rotating its radiation pattern by 90° with each port excitation without having major changes in frequency characteristics. A very low ECC is obtained between four ports which can be used in different multiple input multiple output (MIMO) applications. Due to its compact dimension and high isolation between the different ports and wide BW, the proposed antenna is suitable for mobile satellite communication applications operated under K-band.

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