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A PLANAR RECONFIGURABLE MULTIFUNCTIONAL ANTENNA FOR WLAN/WIMAX/UWB/PCS-DCS/UMTS APPLICATIONS

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Abstract—A wideband slotted multifunctional reconfigurable antenna is proposed for WLAN/WiMAX/UWB/PCS-DCS/UMTS applications. The proposed antenna consists of monopole and spiral sections and microstrip feeding. A microstrip patch on FR4 substrate provides wideband return loss for each application. Total area of the antenna is $34 \times 45\,\mathrm{mm}^2$ that satisfies all the requirements for different applications in a low profile structure. Reconfigurable design is used in this antenna using RF MEMS switches. The proposed antenna has a nearly omnidirectional radiation patterns (doughnut shape) in different frequency bands. The notch is embedded in the ground plane to improve the impedance matching, and the dimensions of this notch are optimized. Moreover, the variation of group delay is about ± 2 ns in UWB application. Also a prototype of the proposed antenna is fabricated, and the results are compared with those obtained from simulations. Measured return losses are in good agreement with simulated ones. The proposed antenna has the advantages of multifunctional operation, low profile, low cost and omnidirectional pattern.

1. INTRODUCTION

The rapid increase of communication standards leads to a great demand in developing multiband internal antennas for mobile devices. For instance, dual band antennas satisfy the WLAN (Wireless Local area network) services which require both 2.4/5.8 GHz bands and Tri-band antennas covering three defined 2.5/3.5/5.8 GHz bands for WiMAX (Worldwide Interoperability for Microwave Access) application, or UWB (ultra wideband) antennas cover 3.1–10.6 GHz,

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Table 1. Wireless services frequency bands.

Services	Uplink (MHz)	Downlink (MHz)
DCS 1800	1710.0–1785.0	1805.0–1880.
PCS 1900	1850.0–1910.0	1930.0–1990.0
UMTS 2100	1920.0–1980	2110.0–2170.0
WLAN	802.11 (b and g)	2400–2484
WLAN	802.11a (indoor)	5150–5350
WLAN	802.11a (outdoor)	5725–5825

in addition antennas covering 1.8/2.1 GHz bands for PCS (Personal Communication System)-DCS (Digital Communication System) and UMTS (Universal Mobile telecommunication system) applications. Each of them has involved many researches and different configurations of microstrip planar antennas [1–4]. A list of some of these services is shown in Table 1. All the mentioned applications can be integrated in one reconfigurable antenna which can switch antenna function from one state to another by RF MEMS (Radio-Frequency Micro Electro Mechanical Systems) switches to reduce the cost of antenna for each application separately. Therefore, due to increasing importance of wireless communication applications, multifunctional reconfigurable antennas are becoming the key topic of researches in the field of antennas these days.

Also, in multifunctional antennas, besides covering different frequency bands, radiation patterns are important to satisfy distinctive application requirements. Here, quasi-omnidirectional radiation pattern is required for various applications, because this kind of antenna is designed for Laptop, PDA (Personal Digital assistant) or other portable devices and because the client side is not specified.

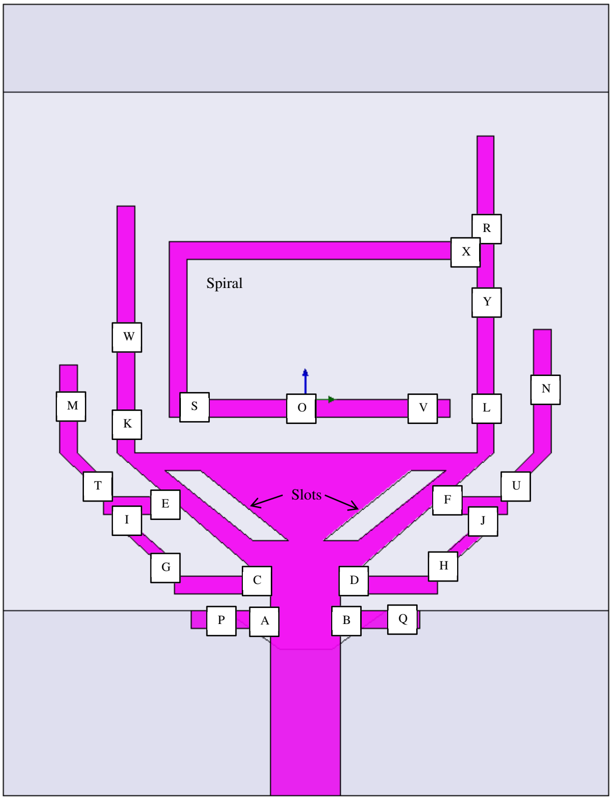
In addition, RF MEMS switches provide some advantages in parameters such as isolation, insertion loss, linearity, and energy consumption contrary to PIN diodes and FET transistors. Hence, RF MEMS switches are the best option for high frequency antennas [5], which are used in this reconfigurable antenna.

Various designs and techniques have been used to obtain multiband operation [6–9]. Also, RF MEMS switched antennas have been reported to achieve multiband function [8, 9].

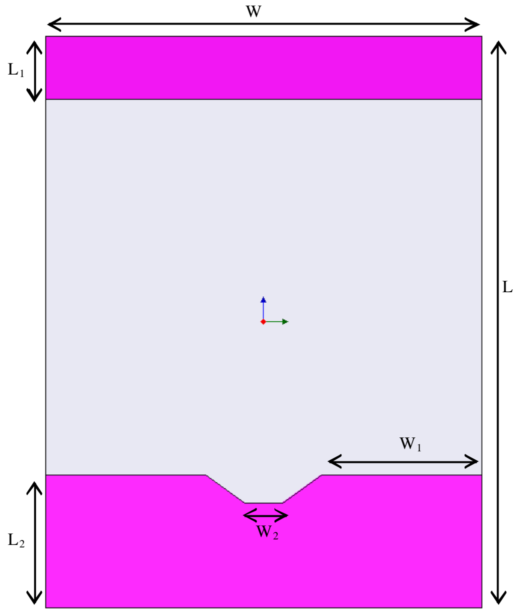
In this article, to realize the advantages of the reconfigurable antennas, a novel multiband reconfigurable antenna is presented. It consists of monopole and spiral sections fed by a microstrip line. The frequency reconfigurability is achieved by changing the length of these sections by connecting or disconnecting metallic branches using RF MEMS switches. Four prototypes, operating in the four frequency bands of the considered applications, have been fabricated with etched/ideal switches. The organization of this article is as follows. In Section 2, the antenna structure and design issues are given. The design parameters, simulated and experimental results are presented in Section 3.

2. ANTENNA DESCRIPTION

Planar monopole antenna design is a proper device to achieve UWB and multiband operating characteristics [10–15]. Another important feature of planar monopole antenna is monopole-like radiation pattern which is omnidirectional. Also meandered strip such as spiral part of antenna can produce resonant modes at lower frequencies. Therefore,



(a)



(b)

Figure 1. Geometry of the proposed antenna (a) upper layer, (b) bottom layer of antenna with $W = 34.50$, $L = 45.00$, $W_1 = 12.66$, $W_2 = 3.00$, $L_1 = 5.00$, $L_2 = 10.50\,\mathrm{mm}$.

joining triangular monopole antenna and spiral antenna could be useful to obtain multiband operation antenna. The geometry of the proposed antenna and determined places of RF MEMS switches is illustrated in Figure 1(a).

The antenna is printed on an inexpensive FR4 substrate with thickness (h) of 1.6 mm and has a relative permittivity of 4.4 and loss tangent of 0.02. The low profile of the proposed antenna makes it possible to be used in Laptop, PDA, or other small portable systems.

In addition to antenna resonating in desired frequencies, the radiation pattern of an antenna in these frequencies is also important. The radiation pattern of the antenna must be the same at various frequencies. The preliminary design of the antenna was dedicated to obtaining desired resonance frequencies for different applications. Some changes in antenna structure, such as adding slots [16] and parasitic elements [17], lead to desired radiation pattern.

At higher bands, resonant elements are monopole to which some branches are connected. But at lower bands, the spiral part of the antenna is the main resonant element. Also when the switches are 'off', multiple branches of the antenna couple capacitively to the main patch, which leads to impedance bandwidth improvement for UWB and other operations. In fact, the branches produce various resonant modes and widen the antenna bandwidth. When the switches are 'on', the additional branches are connected to the main patch via metallic paths which are provided by switches. Thus the effective length of the antenna is changed to cover the desired frequency band.

The lengths of quasi-symmetrical branches of antenna are not the same, in order to widen the impedance bandwidth of antenna at various operating frequencies.

Furthermore, the distance between branches is selected twice the width of branches to avoid unwanted coupling in each application. Numerical simulations show that distances less than 1.7 times of the branches' width make unwanted coupling and have effect on antenna operation. The optimized distance between branches is 2 mm.

The main function of switches is to conduct the additional branches thus extending the effective length of the antenna for desired frequencies. In fact, the placement of switches controls the current on conductive parts of the antenna. Here, all the RF MEMS switches are considered as etched switches (ideal) in simulations to decrease complication of antenna structure. We used etched switches because the comparison between the results of etched switches and RF MEMS switches shows that there is a good agreement between their operations [18]. The switches have dimensions of $1 \times 1\,\text{mm}^2$ and are modeled as conductive metallic patches which connect/disconnect the adjacent branches and main patch.

The parasitic ground plane located at top part of the bottom plate (ground plate) is added to this structure to shape radiation patterns. This parasitic ground plate obstructs the shape of directional radiation patterns toward upper side of the patch and shapes radiation patterns toward both upper and bottom sides of the antenna patch. In addition, increasing the width of this parasitic plate, when it overlaps the upper radiating branches of spiral part, could influence the resonant frequencies in WiMAX, PCS-DCS and UMTS applications. Finally, the optimized width of parasitic ground plate, which in one way shapes the radiation pattern and in another way does not impact on resonance frequencies, is 5 mm.

Two symmetrical slots of size $2 \times 6.4\,\text{mm}^2$ are cut in antenna patch to shape the radiation pattern. Without these two slots, the radiation pattern of the antenna is limited to upper and bottom sides of the patch. Adding these symmetrical slots shapes radiation pattern at the sides and lateral angles. In fact, these two symmetrical slots act as slot array that shapes the antenna's radiation pattern. The placement of these two slots is based on the current distribution on triangular section concentrating at the edges of triangular section. Therefore, the slots disturb current distribution of the patch and change its radiation pattern without any changes in resonant frequencies.

Moreover, a notch is cut in the ground plane to improve the impedance matching. The sizes of slots and the notch and their exact places are optimized carefully by numerical simulations.

3. SIMULATIONS AND EXPERIMENTAL RESULTS

The structure of this antenna is simulated using HFSS software that is based on FEM method. To measure the return loss of this antenna, an edge-mount SMA connector was soldered to the edge of the board, and the return loss was measured on a network analyzer. The simulated results are verified by fabrication process and experimental results.

Besides parasitic ground plate, two symmetrical slots located at the center of the radiating patch play an important role in shaping the radiation patterns. Different arrangements of slots were analyzed during simulations to find the optimum configuration of slots satisfying the radiation pattern requirements.

RF MEMS switches bridge the small gaps which are created in the etched multifunctional antenna and change the physical dimensions of

Table 2. Application of antenna in various situations of switches.

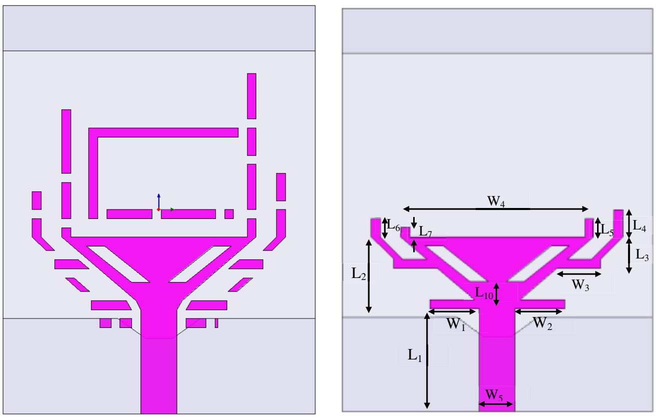
Application	On Switches
WLAN	C,D,E,F,T,U
WiMAX	C,D,E,F,K,L,R,W,Y
UWB	A,B,C,D,E,F,G,H,I,J,K,L,M,N,T,U
UMTS, PCS and DCS	A,B,E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U,V,W,X,Y

Table 3. Details of the length of different branches which are determined in Figures 2–5.

Application	Dimensions (mm)													
WLAN	W_1	W_2	W_3	W_4	W_5	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_{10}	
	5.50	5.50	4.84	21.50	4.00	11.50	8.00	3.50	3.00	2.00	2.00	1.00	3.00	
WiMAX	W_1	W_2	W_3	W_4	W_5	L_1	L_2	L_3	L_4	L_5	L_6			
	5.50	5.50	4.84	21.50	4.00	11.50	8.00	3.50	14.00	18.00	3.00			
UWB	W_1	W_2	W_3	W_4	W_5	W_6	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_{10}
	2.30	3.20	5.50	4.84	20.5	4.00	10.5	8.00	3.50	7.00	8.00	5.00	6.00	3.00
UMTS, PCS and DCS	W_1	W_2	W_3	W_4	W_5	W_6	L_1	L_2	L_3	L_4	L_5			
	4.50	4.50	19.50	15.00	17.50	4.00	5.00	7.00	18.00	10.00	14.00			

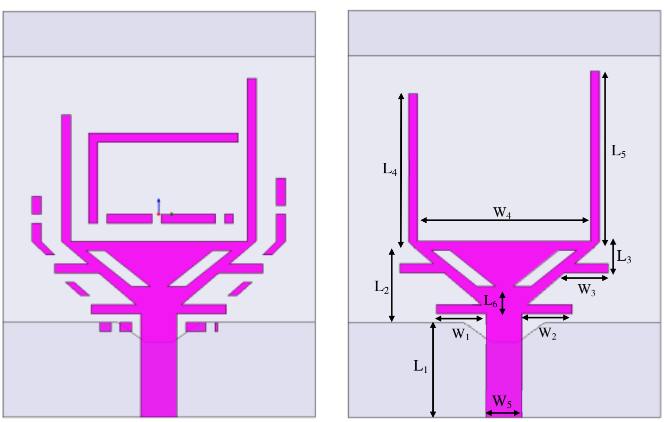
the antenna for various frequencies.

The parameters of the antenna's circuit layout for different applications are shown in Figures 2–5 and summarized in Table 2. The length of different branches which are determined in Figures 2–5 are listed in Table 3. The value of width of the branches is 1 mm.



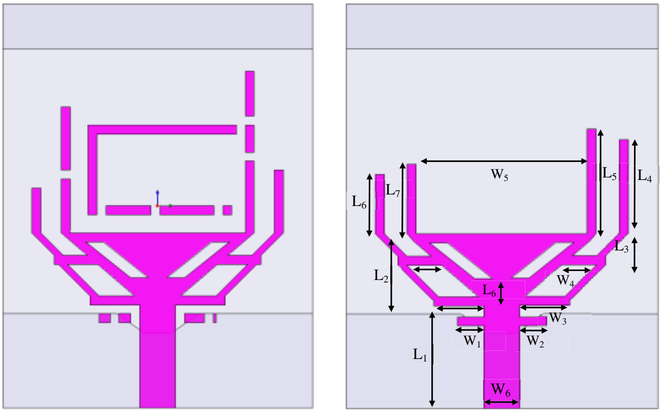
(a) (b)

Figure 2. Antenna structure for use in WLAN systems. (a) Antenna geometry with all the ON and OFF switches. (b) Upper layer of antenna geometry with all the ON switches.



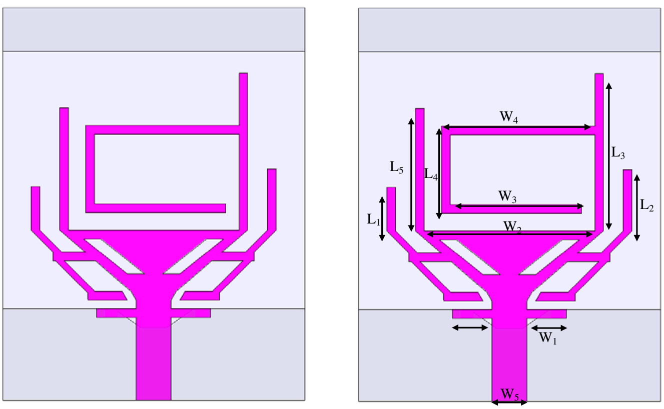
(a) (b)

Figure 3. Antenna structure for use in WiMAX systems. (a) Antenna geometry with all the ON and OFF switches. (b) Upper layer of antenna geometry with all the ON switches.



(a) (b)

Figure 4. Antenna structure for use in UWB systems. (a) Antenna geometry with all the ON and OFF switches. (b) Upper layer of antenna geometry with all the ON switches.



(a) (b)

Figure 5. Antenna structure for use in PCS-DCS/UMTS applications. (a) Antenna geometry with all the ON and OFF switches (b) Upper layer of antenna geometry with all the ON switches.

According to simulated results, a prototype of the proposed multifunctional antenna is fabricated as shown in Figure 6. A 50-microstrip line is etched on the FR4 substrate to feed the antenna.

The simulated and measured return losses for these states versus frequency are presented and compared in Figures 7(a)–(d), and there is a good agreement between the simulated and experimental results.

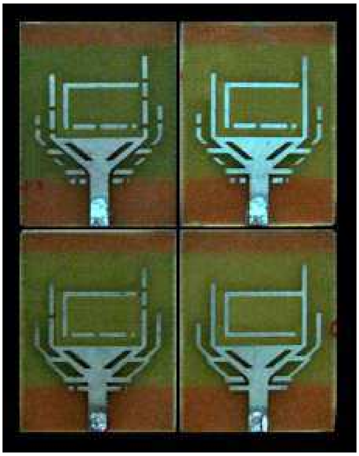


Figure 6. Fabricated prototype of proposed multifunctional antenna.

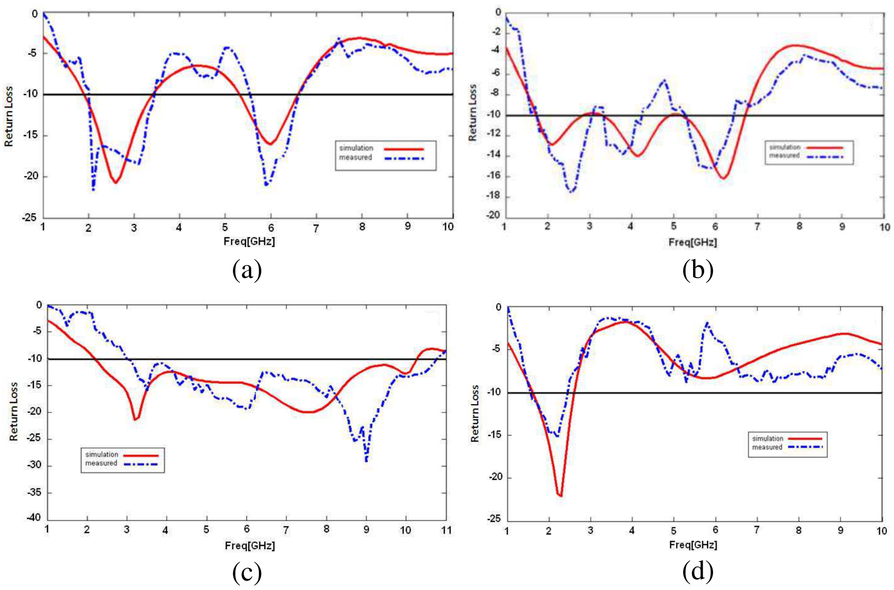


Figure 7. Measured and simulated return loss versus frequency for (a) WLAN, (b) WiMAX, (c) UWB, (d) PCS-DCS/UMTS application.

The radiation patterns in both E and H planes are shown in Figures 8–11, which are almost constant in different operating frequency bands.

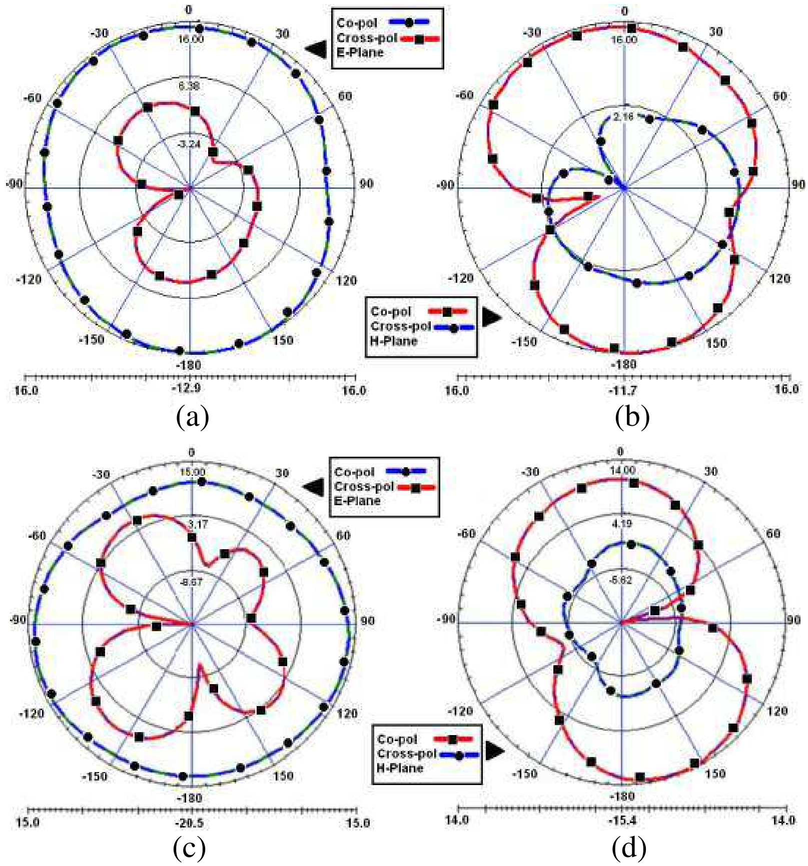


Figure 8. Radiation patterns for WLAN application at 2.40 GHz for (a) E-plane, (b) H-plane, and at 5.80 GHz for (c) E-plane, (d) H-plane.

In addition, impulse response of the antenna in UWB application is important, because any transfiguration of received and transmitted pulses and also timing errors are related to it. Therefore, the amplitude and group delay distortion should be limited to have a reliable system. In other words, group delay is expected to be constant and stable over the entire frequency band [19]. The simulated group delay of the proposed antenna is illustrated in Figure 12; the amplitude of the group delay is almost constant (within a range of ± 2.5 ns).

Finally, the measured peak gains for some of the operating frequencies are presented in Table 4.

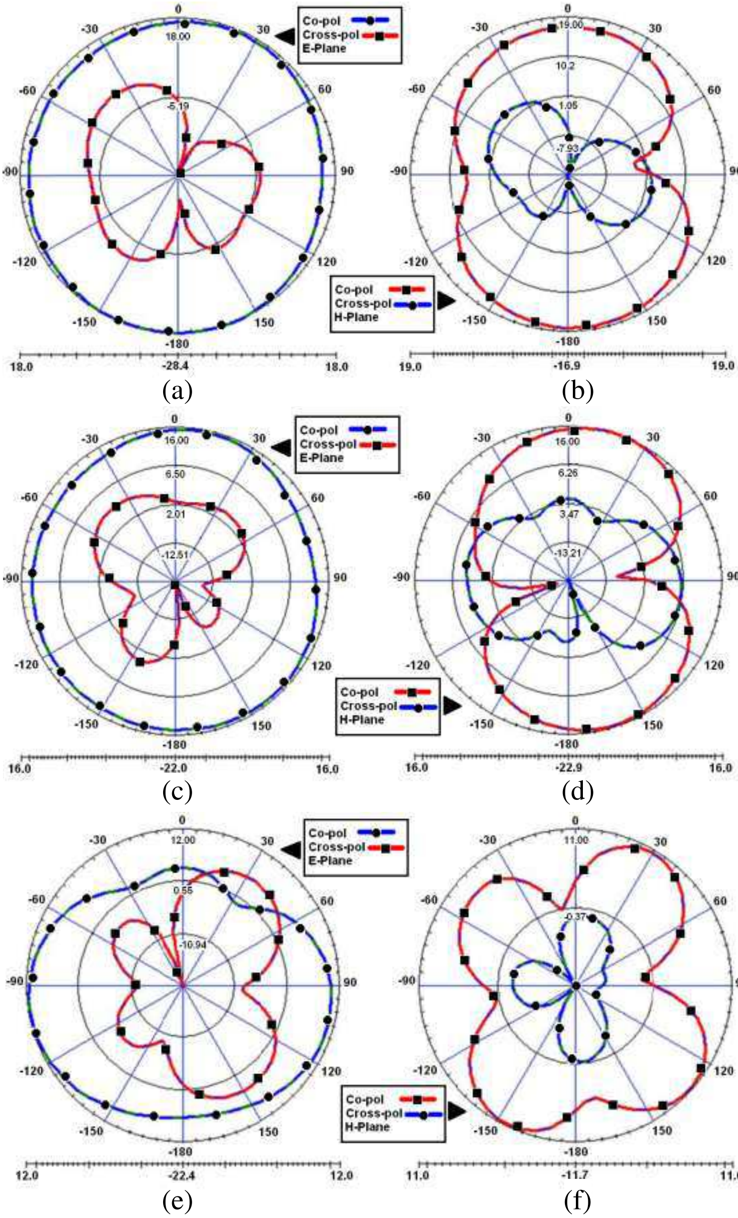


Figure 9. Radiation patterns for WiMAX application at 2.50 GHz for (a) E-plane, (b) H-plane, and at 3.50 GHz for (c) E-plane, (d) H-plane, and at 5.80 GHz for (e) E-plane, (f) H-plane.

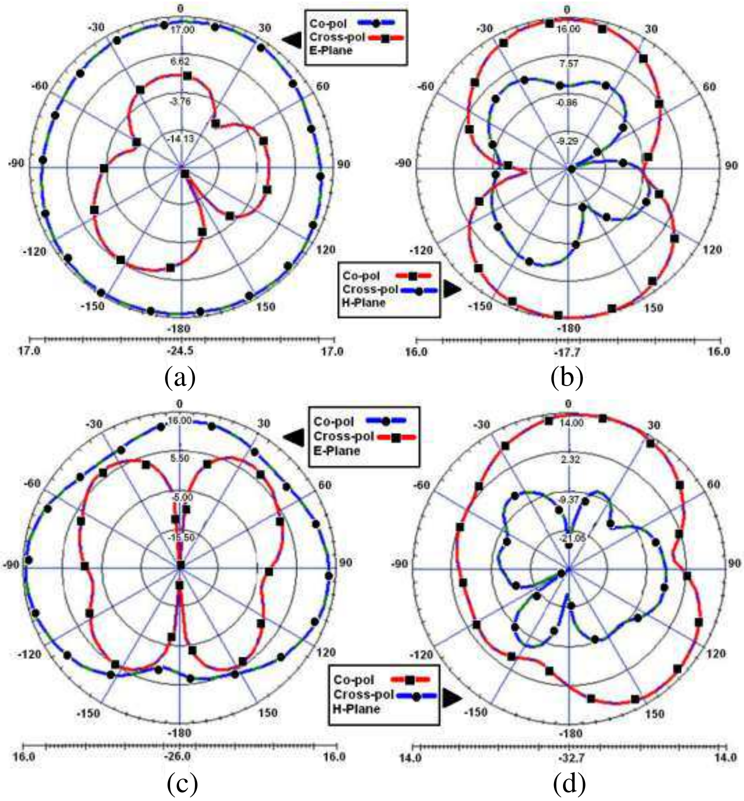
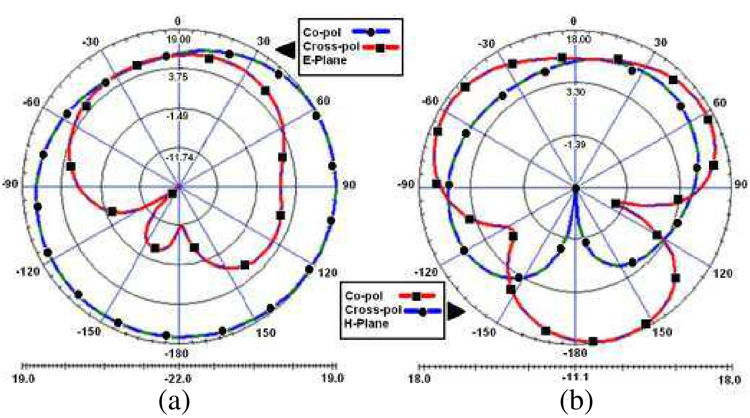
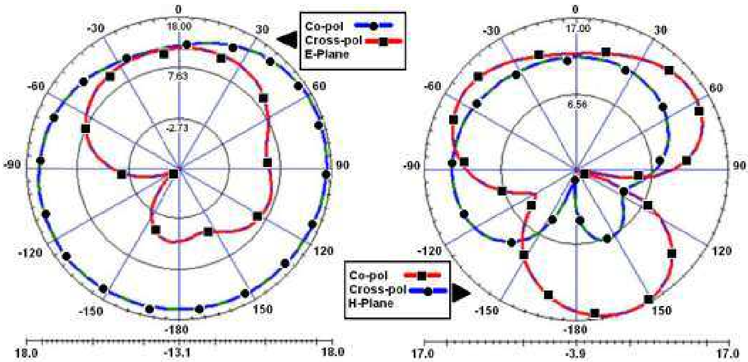


Figure 10. Radiation patterns for UWB application at 4 GHz for (a) E-plane, (b) H-plane, and at 7 GHz for (c) E-plane, (d) H-plane.





(c) (d)

Figure 11. Radiation patterns for PCS-DCS/UMTS application at 1.80 GHz for (a) E-plane, (b) H-plane, and at 2.10 GHz for (c) E-plane, (d) H-plane.

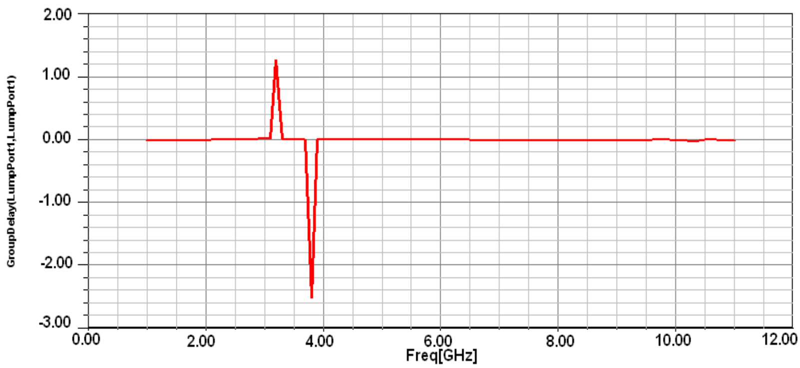


Figure 12. The group delay characteristic of the proposed antenna.

Table 4. Measured peak gain for operating frequencies.

<table>
<tr><td>Application</td><td colspan="6">Gain</td></tr>
<tr><td rowspan="2">WLAN</td><td colspan="3">At 2.4 GHz</td><td colspan="3">At 5.8 GHz</td></tr>
<tr><td colspan="3">0.22 dB</td><td colspan="3">0.36 dB</td></tr>
<tr><td rowspan="2">WiMAX</td><td colspan="2">At 2.5 GHz</td><td colspan="2">At 3.5 GHz</td><td colspan="2">At 5.8 GHz</td></tr>
<tr><td colspan="2">0.45 dB</td><td colspan="2">0.33 dB</td><td colspan="2">0.18 dB</td></tr>
<tr><td rowspan="2">UMTS, PCS and DCS</td><td colspan="3">At 2.1 GHz</td><td colspan="3">At 1.8 GHz</td></tr>
<tr><td colspan="3">1.45 dB</td><td colspan="3">0.80 dB</td></tr>
</table>

4. CONCLUSION

By combining a monopole and spiral antenna and RF MEMS switches, a broadband multifunctional reconfigurable antenna is designed and implemented. The proposed antenna covers the required frequency bands for WLAN/WiMAX/UWB/PCS-DCS/UMTS applications. This antenna can resonate in two or three frequencies simultaneously for WLANand WiMAX applications. The proposed antenna supports UWB application which is not supported in [8, 9]. Besides, by RF MEMS switches its operation can change from one state to another to cover different applications. This design satisfies the bandwidth, radiation pattern, and return loss requirements for mentioned applications. Low profile and lower cost of the fabrication of this antenna are some of the important advantages of the proposed design.

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