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A Multi-Band Frequency and Pattern Reconfigurable Antenna for Wi-Fi/WiMAX and WLAN Applications

Frequency and Pattern Reconfigurable Antenna

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Abstract—**This paper reports design and investigations on a planar multi-band frequency- and pattern- reconfigurable antenna by use of PIN diodes. The reconfiguration mechanism is achieved by changing the controlled activation of the slots placed on a circular disk which is fed by Coplanar Waveguide feed. The antenna is symmetrical along the longitudinal axis and consists of seven PIN diodes on each half of the circle cutting the longitudinal axis. A total of 15 PIN diodes are used to make the antenna operate in 7 different modes. A beam shape pattern reconfigurability is achieved by operating the antenna in all the modes. The basic antenna is a circular disk without slots and is designed to operate at 2.4GHz. Frequency reconfigurability is achieved by changing the electrical length of the slot by activating the switches in appropriate positions in different operating modes. Pattern reconfigurability is achieved by maintaining the same overall electrical length in each operating mode but changing the switch positions orient in a particular direction in each half of the circle. The investigative simulations were carried out using Ansys HFSS. The proposed antenna resonates is applicable to WiMAX, Wi-Fi, WLAN wireless services.**

Keywords-circular patch slot antenna; coplanar waveguide feed; multi-band antenna; frequency reconfigurable antenna; pattern reconfigurable antenna; PIN diodes; wireless communications

I. INTRODUCTION

Today's modern wireless and electronics communication systems require multifunctional, compact, smart antennas that can adapt to varying system requirements. These requirements are not met by fixed performance antennas whose fundamental properties like frequency, polarization and pattern characteristics are fixed. In this context there are two types of antennas (1) Reconfigurable antennas which have the ability to dynamically meet such adaptable service requirements [1]. Several antennas have been reported which have single reconfiguration capability i.e., either in frequency [2], polarization [3] or pattern [4]. (2) Multiband antennas that can meet the challenges like miniaturize circuit dimension while maintaining transmission performance, including multiple operation bands, low cost, high efficiency, wide bandwidth and acceptable gain are proved to be common solutions. Several multi-band antennas were reported. A folded slot monopole antenna [5], a meandered folded monopole antenna with extended staircase and F-shaped arms [6]. Moreover, pattern reconfiguration has received much attention because of their diversity functions in radiation patterns that enhances the performance of wireless communication systems. One of the techniques to achieve diversity in pattern is to reconfigure the beam shape which can be used to improve the system capacity and quality of the link [7]-[9].

The major contribution of this paper is to design an antenna combining multi-band functionality and two function reconfigurability in order to produce a very efficient and compact antenna satisfying all the requirements. Very less work is done in the area of multi-band reconfigurable antennas [10]-[12].

This paper starts by explaining the design analysis of the proposed antenna in Section II. Section III discusses the results followed by important conclusions specifying the antenna applications in Section IV.

II. ANTENNA DESIGN CONFIGURATION

A. Geometrical Construction

The geometrical configuration of the proposed multi-band frequency and pattern reconfigurable antenna is shown in Fig. 1. The antenna is designed on low cost FR4-Epoxy material with dielectric constant ε_r =4.4, loss tangent tan δ =

0.02 and thickness t=1.6mm. The dimensions of the antenna are 40mm X 60mm.

The main structure of the antenna consists of a circular disk which is designed to operate at 2.4GHz following the design guidelines given by (1), (2).

$$f_r = \frac{1.84118c}{2\pi a_e\sqrt{\varepsilon_r \mu_r}} \quad (1)$$

where $$a_e = a\left[1 + \frac{2h}{\pi a \varepsilon_r}\left\{\ln\left(\frac{\pi a}{2t}\right) + 1.7726\right\}\right]^{1/2} \quad (2)$$

where μ_r=1 in this case, 'c' is the velocity of the light and a_e is the effective radius, 'a' is the actual radius of the circular patch and 't' is the thickness of the substrate. The actual radius 'a' calculated from the above formula of the circular patch which resonates at 2.4GHz is 24mm but due to introduction of rectangular slots at the edges, the radius is reduced by 1.7 times (≈ 14mm). The other dimensions of the antenna are listed in Table I. A coplanar waveguide feeding is used to excite the antenna because of it's many advantages over the conventional microstrip line, such as simple fabrication, wide impedance bandwidth, easy surface mounting for series and shunt devices, and low radiation [13].

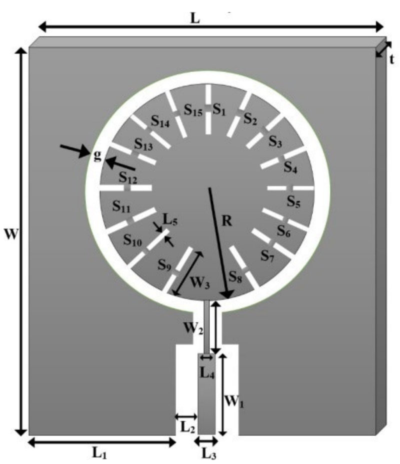

Figure 1. Geometrical layout of the proposed multi-band Frquency and Pattern Reconfigurable Antenna.

A strip of length W_2 and width L_4 is used as impedance matching stub between the feed and the circular patch to improve the radiation characteristics of the antenna. In order to have multi band operation slotting technique is employed in the design. Rectangular slots of equal length 7mm and width 1mm are placed at every 22.5^0 angle position starting from feed point on the circular disk as shown in Fig. 1. In order to achieve reconfigurability, 15 switches (S_1-S_{15}) as shown in Fig. 1 were placed at center position on each slot connecting them. The various operating modes are shown in Table II.

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TABLE I. GEOMETRICAL PARAMETERS OF THE PROPOSED RECONFIGURABLE ANTENNA

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L	40	L_3	3.0589
W	60	L_4	0.5345
t	1.6	L_5	1.0
R	14	W_1	15.80709
g	2.0	W_2	8.35536
L_1	16.47055	W_3	7.0
L_2	2.0	ε_r	4.4

TABLE II. OPERATING CONFIGURATIONS OF THE PROPOSED RECONFIGURABLE ANTENNA

Configuration	Switch Positions	Switch status	Type of Reconfigurability
C1	S_1-S_{15}	OFF	Frequency and Pattern
C2	S_1-S_{15}	ON	Frequency and Pattern
C3	S_7	ON	Pattern
	S_8	ON	
	S_{14}	ON	
	S_{15}	ON	
C4	S_2	ON	Pattern
	S_3	ON	
	S_9	ON	
	S_{10}	ON	
C5	S_1	OFF	Frequency and Pattern
	S_5	OFF	
	S_{12}	OFF	
C6	S_3	OFF	Frequency and Pattern
	S_7	OFF	
	S_{10}	OFF	
	S_{14}	OFF	
C7	S_1,S_3	OFF	Frequency and Pattern
	S_5,S_7	OFF	
	S_{10},S_{12},S_{14}	OFF	

At RF frequencies PIN diodes behave as a variable resistor, with equivalent circuit model for ON/OFF states, as shown in Fig. 2. Both the ON and OFF states have a package inductance L_S. The equivalent circuit for the ON state (forward biased) as shown in Fig. 2(a) has a low resistance R_S which contributes to insertion loss. The equivalent circuit for the OFF state (reverse biased) as shown in Fig. 2(b) has parallel combination of reverse bias resistance R_P and total capacitance C_T, which contributes to the isolation. In our design, the PIN diode is modeled in HFSS using two series lumped RLC boundary conditions, as shown in Fig. 3, where the first part of RLC boundary is L and second is either R_S for the ON state or a parallel combination of R_P and C_T for the OFF state. This way of modelling is used to achieve robustness in terms of reconfiguration between different frequency bands.

In this diode model, the ON state lumped parameter values are chosen to be R_S = 1Ω, L_S = 0.7nH and OFF state values are chosen as R_P= 2kΩ, C_T = 0.3pF are used according to the datasheet of the PIN diode SMP1340-079LF from Skyworks Solutions.

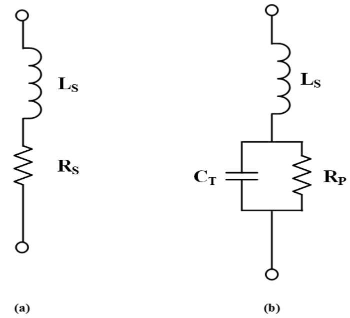


Figure 2. PIN diode equivalent circuit (a) ON state (b) OFF state.

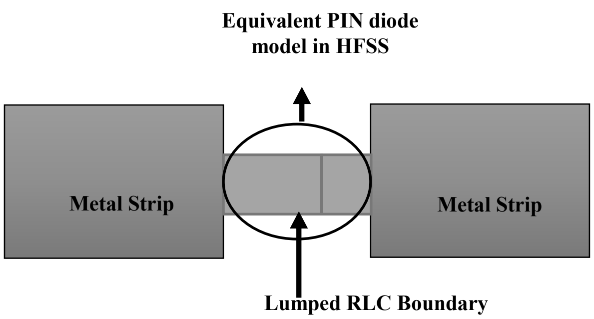
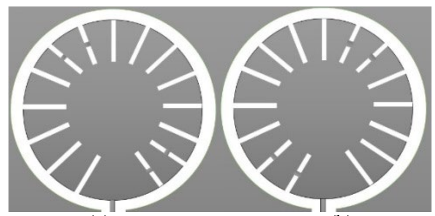


Figure 3. Modelling of OIN diode in HFSS.

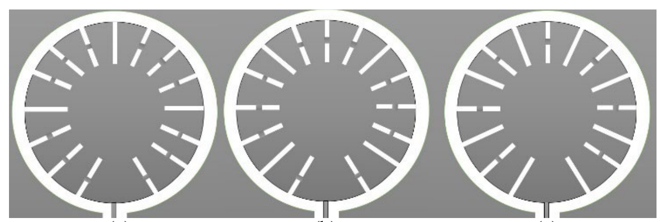
B. Working

When all the switches are OFF, the antenna is set to operate in C1, the antenna resonates at four fundamental frequencies namely 2.3GHz, 4.9GHz, 5.28GHz and 5.55GHz and when all the switches were made ON in configuration C2, the antenna resonates at 2.4GHz, 4.6GHz, 6.2GHz, 8.2GHz and 9.0GHz. It is observed that there is change in the radiation pattern in elevation plane by 30^0 at first fundamental frequency. Hence the antenna is said to have simultaneous frequency and pattern reconfiguration when operated in C1 and C2. In C3, when the switches at 22.5^0 and 45^0 position of the bottom right half of circular disk (S_7, S_8) and top left half of circular disk (S_{14}, S_{15}) are activated as shown in Fig. 4 (a), the antenna exhibits triple band resonating at 2.3GHz, 4.29GHz and 5.5GHz. In C4, when the switches in opposite direction to that of C3 i.e., (S_2, S_3) and (S_9, S_{10}) are activated as shown in Fig. 4 (b), the antenna resonates at the similar frequencies but there is a change in radiation pattern direction in elevation plane. Hence the antenna is said to exhibit multi-band pattern reconfigurability when it is reconfigured from C3 to C4. Likewise, in C5, when the switches at 22.5^0 and 45^0 positions are turned to ON state as shown in Fig. 5(a), it operates at 5 bands and in C6, the switches at 22.5^0 and 90^0 positions are activated to make the antenna change its radiation pattern when operated from C5 to C6. This is shown in Fig. 5(b). In this configuration, the antenna operates at two bands centred at 2.34GHz and 7.11GHz. Hence the antenna can able to switch between frequency and pattern when it is reconfigured from C5 to C6. Finally, when it is reconfigured to C7 i.e., when switches at 45^0 and 90^0 positions were made ON as shown in Fig. 5(c), it is observed that there is a change in number of bands and the frequencies with change in radiation pattern. It operates at 2.3GHz, 4.2GHz and 5.05GHz with good return loss at 2.3GHz compared to other frequencies. Hence it shows simultaneous frequency and pattern reconfiguration when it is reconfigured from any of the above configurations. However, C7 configuration is not used for practical applications because of poor performance at other bands.



(a) (b)

Figure 4. Antenna operating in C3 and C4 configurations.



(a) (b) (c)

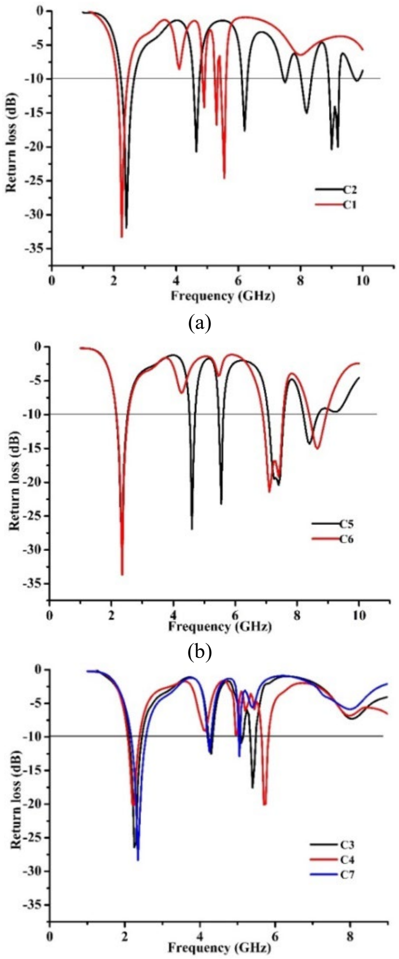
Figure 5. Antenna opearating in C5, C6 and C7.

III. RESULTS AND DISCUSSIONS

The numerical optimizations have been performed to achieve the desired resonant frequencies using commercial EM simulator HFSS V 17.0 which is based on finite element method numerical technique.

It has been observed that frequency and pattern switching of the proposed multi band reconfigurable antenna is obtained by positioning PIN diodes as switch on the slot. The proposed antenna is reconfiguring simultaneously in frequency and pattern when operated in C1, C2 and C5, C6 configurations. The frequency is reconfigured in S, C and X frequency bands with resonant frequencies from 2.3 to 9.6 GHz respectively. Figs. 6(a)–(b) show the return loss graphs for switching configurations C1, C2, C5, C6 and C7. The pattern reconfiguration is observed when the proposed antenna is reconfigured in C3, C4 configuration modes. Fig. 6(c) shows the return loss graph for the pattern reconfiguration and the return loss graph of the antenna operating in configuration C7 is also included in Fig. 6(c).

Table III summarize the corresponding frequency band of resonant frequency at all switching configurations. The simulated returns loss for all the switching configurations are below −10 dB. The obtained maximum gain at these resonant frequencies is also tabulated for each antenna configuration.



(a)

(b)

(c)

Figure 6. Return Loss of the proposed multi band reconfigurable Antenna operating in all configurations.

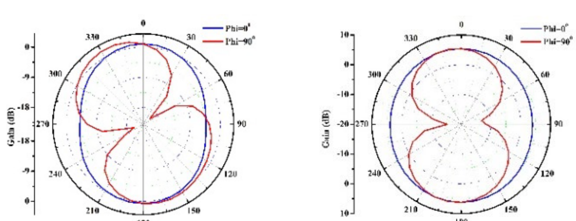
TABLE III. OPERATING FREQUENCIES AND BANDS OF THE PROPOSED ANTENNA IN EACH CONFIGURATION

Configuration	Operating Frequency (GHz)	Operating band (MHz)	Gain (dB) (xz-plane)	Applications
C1	2.3	340	2.15	S-band WiMAX
	4.89	70	-1.07	-
	5.28	70	-6.11	-
	5.55	160	-7.00	-
C2	2.41	420	6.29	S-band Wi-Fi
	4.65	200	3.80	C-band
	6.2	170	3.17	C-band
	8.2	320	5.81	X-band
	9.01	330	1.41	X-band
C3	2.27	350	4.22	WiMAX
	4.29	120	-2.22	-
	5.42	140	3.24	WLAN
C4	2.22	310	2.3	S-band
	4.98	50	-1.59	-
	5.72	180	2.26	C-band Wi-Fi
C5	2.33	350	5.64	S-band WiMAX
	4.61	180	3.28	C-band
	5.54	140	1.8	-
	7.4	500	4.99	C-band
	8.4	490	5.38	X-band
C6	2.34	380	5.25	S-band WiMAX
	7.11	660	3.4	C-band
C7	2.36	390	12.87	S-band WiMAX

A highest bandwidth of 660MHz is obtained with resonant frequency of 7.1GHz when the antenna is operated with PIN diode configuration C6. Further it is observed that the proposed frequency reconfigurable antenna can be used for S- & C-band based Wi-Fi and WiMAX applications. It is observed that the narrowband functionality of the proposed antenna offers virtual antenna size reduction.

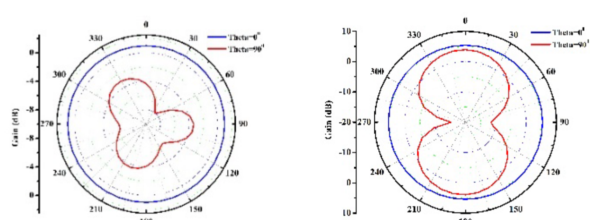
The pattern reconfiguration of the proposed reconfigurable antenna in various operating modes at the most useful frequency in a configuration of PIN diodes is shown in Fig. 7-8. Fig. 7 depicts the Elevation (E-plane) pattern in *xz*-plane ($\varphi=0^0$) and *yz*-plane ($\varphi=90^0$) and Fig. 8 depicts Azimuth (H-Plane) pattern in *xy*-plane ($\theta=0^0$ and $\theta=90^0$) when operated in (C1, C2), (C3, C5).

Each band of the proposed antenna when operated in different configurations with acceptable gain (gain>2dB) can be used in several wireless applications like IEEE 802.16 WiMAX 2.3GHz (2.3-2.4GHz), IEEE 802.11b/g Wi-Fi 2.4GHz (2.4-2.485GHz) in S-band, WLAN (5.1-5.8GHz), IEEE 802.11a Wi-Fi (5.72-5.87GHz) in C-band. Such applications for each configuration are listed in Table III.



(a) at 2.3GHz in C1

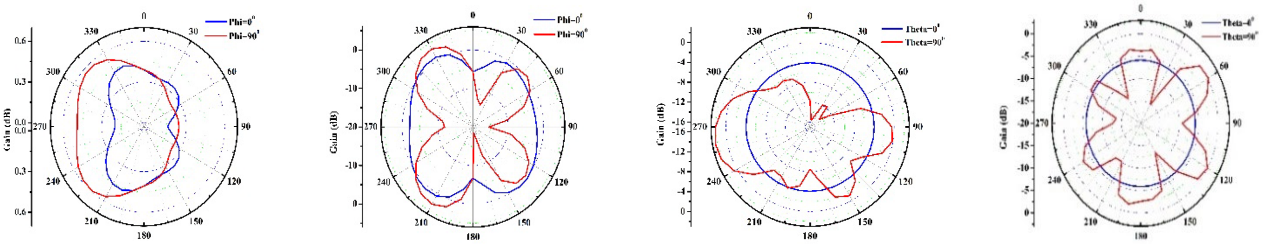
(b) at 2.4GHz in C2



(a) at 2.3GHz in C1

(b) at 2.4GHz in C2

Figure 7. Radiation Pattern in E-Plane (*xz*- plane and *yz*-plane).



(c) at 5.7GHz in C3 (d) at 7.4GHz in C5 (c) at 5.7GHz in C3 (d) at 7.4GHz in C5

Figure 8. Radiation pattern in H-Plane (xy- plane).

IV. Conclusion

This paper presents a multi-band frequency- and pattern-reconfigurable circular patch antenna using coplanar waveguide feeding. The multi-band operation is achieved by using rectangular slots at edges of the circular patch at an interval of 22.5^0 each. The reconfigurability in frequency can be obtained by suitably changing the electrical lengths of the patch using 15 RF PIN diode switches that are placed between the slots and operate in various configuration modes. The direction of the pattern is changed by changing the current distribution of the patch which is achieved by carefully selecting the appropriate switches. The antenna operates at different resonant modes in different configurations. Mostly it is operated at 2.3GHz, 4.9GHz, 5.3GHz, 5.55GHz, 6.2GHz, 7.2GHz, 8.2GHz frequencies in various operating modes. Simulation results demonstrate that the obtained S_{11} parameter value less than −10 dB at all the frequencies of operation. An acceptable gain is achieved in all operating modes except at few bands. The proposed antenna finds application in S-band WiMAX, Wi-Fi and C-band Wi-Fi, WLAN applications.

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