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A Low Profile Frequency and Pattern Reconfigurable Antenna

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***Abstract*—This paper presents the design of a novel frequency and pattern reconfigurable antenna. The antenna consists of a simple rectangular patch with two longitudinal slits. The slits are connected to the patch through a pair of PIN diodes to enable frequency reconfiguration and pattern reconfiguration. The reconfigurable patch antenna operates at the frequency 4.5 GHz & 4.8 GHz / 5.2 GHz & 5.8 GHz and has a pattern tilt of -30°, 0°, +30°. The prototype antenna is fabricated and its performance is validated using measurements. Measured results agree well with the simulated results.**

***Index Terms*— Multi-band antennas, frequency reconfigurable, pattern reconfigurable**

I. Introduction

ANTENNAS with fixed frequency band and radiation pattern can be used for single service. This results in usage of more antennas for applications seeking multiple radios. More number of antennas result in large space consumption, interference between adjacent antenna elements, huge installation cost and complex hardware platform. For emerging wireless applications, antennas with small size, less interference, low cost and least complexity are required. To obtain these characteristics, reconfigurable antennas are used. A single reconfigurable antenna can perform the operation of multiple antennas [1-3]. In recent times, compound reconfiguration is explored in literature in which an antenna can reconfigure multiple performance metrics. This manuscript presents a simple antenna that can reconfigure its frequency and raditation pattern. The dynamic nature of the antenna has ability to overcome the drastic effects of the time varying channels. Also if more than one parameter is reconfigured at a given instant, the spectrum efficiency of the wireless link can be greatly enhanced.

In literature, several reconfigurable antennas are discussed. In most cases, the antenna is capable of reconfiguring anyone of the antenna performance parameters such as frequency, radiation pattern and polarization. In [4], MEMS switches are deployed in U shaped slot and L shaped stub to achieve frequency reconfiguration. Frequency agile antenna using stepper motor is designed and discussed in [5]. Reconfigurable filtering elements are used in the feedline of the antenna to tune to different frequencies in [6]. A polarisation reconfigurable antenna with Y shaped feed is reported in [7]. In [8], a circularly polarized antenna with frequency reconfiguration is analyzed. Adding to this, research is also conducted to investigate the reconfiguration in dual polarized antennas using MEMS switches [9]. A reconfigurable C shaped monopole antenna array is developed in [10]. An antenna with frequency reconfigurable characteristics for WiMAX and Bluetooth applications is reported in [11]. Furthermore, a pattern reconfigurable U slot antenna [12], antennas with complex actuation mechanism [13] and reconfiguration using optical pumping [14] are also designed and discussed. All these literature relate to the reconfiguration of a single parameter. A few literatures have proposed techniques to obtain compound reconfiguration. Frequency and pattern reconfigurable antenna is designed using FSS [15] and centre shorted strip in [16]. In [17] pixel antennas are used to achieve pattern and frequency reconfiguration. The limitation with such technique is the usage of more number of actuators and complex biasing network.

In this letter, a low profile planar frequency and pattern reconfigurable antenna is designed. The antenna has a footprint of 50 mm × 50 mm operating at 4.5 & 4.8 GHz / 5.2 & 5.8 GHz. Using simple actuation mechanism, the antenna is made frequency and pattern agile. The proposed antenna can be used for General Wireless Communication Service Band, Telemetry and WLAN applications. Section II presents the design of frequency and pattern reconfigurable antenna. Section III presents the results and discussions. Section IV presents the conclusion.

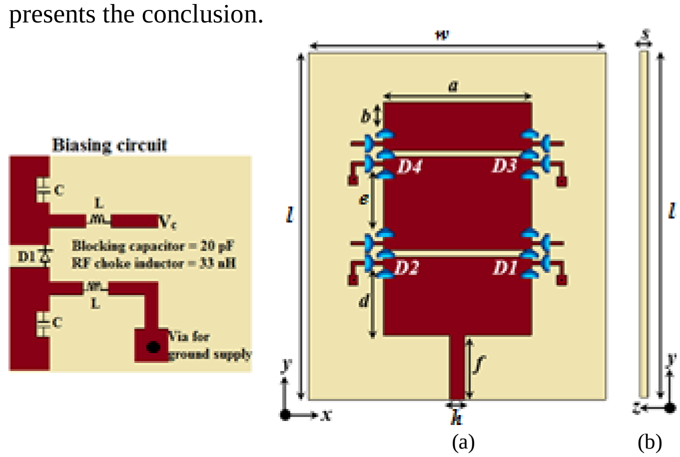

Fig.1:Proposed frequency and pattern reconfigurable antenna(a)Front view l=50mm,w=50mm,f=13mm,h=3mm,a=30mm,b=9mm,e=17mm,d=15mm,s=1.6mm (Black dot represents the via). (b) Side view.

II. ANTENNA DESIGN

This section presents the design of frequency and pattern reconfigurable antenna. The antenna consists of a rectangular patch antenna with two horizontal slits (one at the top and the other at the bottom). Thus the antenna could be visualized as three rectangular strips with the feed connecting the bottom strip. These three rectangular strips are capcitively coupled. Furthermore, the three strips can be connected/disconnected using a pair of PIN diodes, viz. D1, D2, D3 and D4 deployed at the edges of the slit which inturn alters the electrical length

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of the patch antenna. Certain combinations of the PIN diode state also provide beam tilting upto 30° in the left and the right hand side. The proposed antenna is shown in Fig. 1. The antenna is developed on a 1.6 mm thick FR4 substrate with dielectric constant 4.3 and loss tangent 0.025. The volume of the antenna is 50 × 50× 1.6 mm^3. All the simulations are carried out using CST Microwave Studio 2015 and measurements are done using Keysight's E5071C ENA series Vector Network Analyzer. The proposed antenna has 7 operating states with 3 states corresponding to frequency reconfiguration with radiation pattern directed along 0°. The remaining 4 states provide beam tilting in 2 directions for two fixed frequencies.

A. *Frequency Reconfiguration:*

To obtain frequency reconfiguration the following switch states are maintained. When all the diodes are in ON state, the ends of the slit are electrically shorted. Thus a single rectangular patch with two slits provide quad band resonance at 4.5/ 4.8/ 5.2 and 5.8 GHz (State I). The operation of the reconfigurable antenna is explained by assuming an initial condition with diodes in OFF state. When D1 and D2 are alone turned ON (State II), the lower slit is shorted with the middle strip. The shorted strip whose electrical length is 32 mm corresponding to the wavelength of 4.5 GHz gets excited to create resonance at 4.5 GHz. Further, the band at 4.8 GHz is resonated due to the capacitive coupling between the strips above and below the upper slit. Similarly when the diodes D3 and D4 are turned ON while maintaining the other diodes in OFF state (State V), the upper slit is short circuited with the middle strip along the edges. The shorted strip above the lower slit has the electrical length of 15 mm correspondging to half the wavelength of 5.2 GHz is excited to create resonance at 5.2 GHz. The band at 5.8 GHz is resonated because of the capacitive coupling between the strips above and below the lower slit.Thus a multi-band reconfiguration is achieved using a simple rectangular patch antenna.

B. *Pattern Reconfiguration:*

The pattern reconfiguration is achieved by changing the current direction in the patch radiator. In conventional antenna system, the change in the phase of the excitation current results in pattern tilting. However in this case the excitation source is kept constant and the path which the current travels has been altered. Thus in the pattern reconfiguration states, the current travels additional distance leading to path difference which further produces a phase difference.

The pattern reconfiguration is derived as a subclass of State II and State V. In State II, D3 and D4 are maintained in OFF state. If anyone of these diodes is turned ON, the antenna radiation pattern can be tilted upto 30 degree. The direction of tilting depends on the diode being turned ON. With D3 ON and D4 OFF, the main beam of the radiation pattern shifts to +30 degree (State III). Similarly with D4 ON and D3 OFF, the main beam of the radiation pattern shifts to -30 degree (State IV). During both these cases, the antenna provides dual frequency response 4.5 and 4.8 GHz. A similar characteristics is also derived under State V. With D1 ON, D2 OFF, the main beam of the radiation pattern shifts to + 30 degree (State VI) while with D1 OFF, D2 ON the direction of the main beam shifts to – 30 degree (State VII). Thus during State VI and VII, the pattern reconfiguration is achieved at 5.2 and 5.8 GHz. Thus in State III, the current travels from left to right resulting in beam formation along +30° and in State IV, the direction of the current flow is reversed leading to beam formation along -30°. The same reasoning is attributed to State VI and VII operating at 5.2 and 5.8 GHz respectively.

The summary of the antenna operating states is given in Table I. The simulated reflection co-effieicnt characteristics are shown in Fig. 2. Thus from the results, it is evident that the antenna operates either in quad or dual band mode depending upon the ON/OFF state of the diodes.

TABLE I
OPERATING STATES OF THE ANTENNA

STATE	PIN DIODES				FREQUENCY (GHz)	MAIN BEAM DIRECTION (°)
	D1	D2	D3	D4		
I	ON	ON	ON	ON	4.5, 4.8, 5.2, 5.8	0
II	ON	ON	OFF	OFF	4.5, 4.8	0
III	ON	ON	ON	OFF	4.5,4.8	+30
IV	ON	ON	OFF	ON	4.5, 4.8	-30
V	OFF	OFF	ON	ON	5.2, 5.8	0
VI	ON	OFF	ON	ON	5.2, 5.8	+30
VII	OFF	ON	ON	ON	5.2, 5.8	-30

(Grey box - frequency reconfiguration. Yellow box - ±30° pattern tilt in the frequency reconfigured states. Orange box –0°pattern tilt in the frequency reconfigured state)

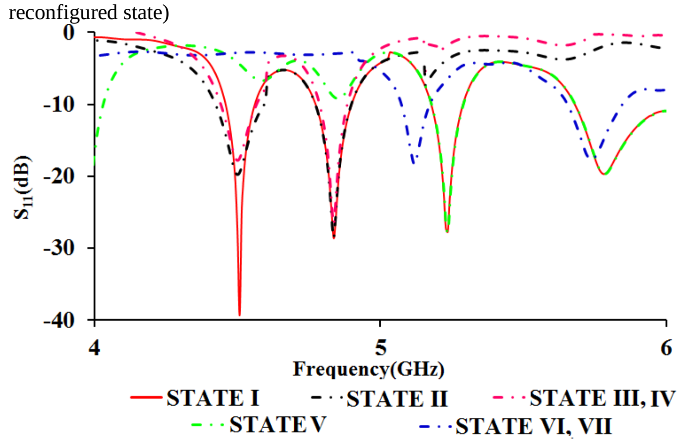

Fig 2: Reflection coefficient characteristics of the proposed antenna

III. RESULTS AND DISCUSSION

The prototype antenna is fabricated and tested for impedance and radiation characteristics. BAR64-03W PIN Diode is utilized to reconfigure the antenna charateristics. The ON state series resistance and inductance are 2.1 Ω and 1.8 nH respectively. The OFF state shunt capacitance is 0.2pF with a reverse resistance 300 kΩ.The bias lines and the feed lines are isolated using appropriate L and C components. Futhermore, the biasing lines are designed with smaller dimensions, so that the antenna's radiation characteristics are left undisturbed. In the proposed design, the thickness of the bias lines is 0.25 mm and length is 1 mm. To separate the RF and DC components,

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a DC blocking capacitor of 20 pF and a RF choke inductor of 33 nH are used. L and C values are chosen such that the characteristic impedance of the RF lines and the biasing circuitry match.

A. Impedance Characteristics

The measured reflection coefficient characteristics are shown in Fig.3. The electrical length of the radiator is varied using the diodes to obtain frequency reconfiguration. The measured 10dB impedance bandwidth at 4.5 GHz, 4.8 GHz, 5.2 GHz and 5.8 GHz are 2.2 %, 2.3 %, 2.38 % and 3.5 % respectively.

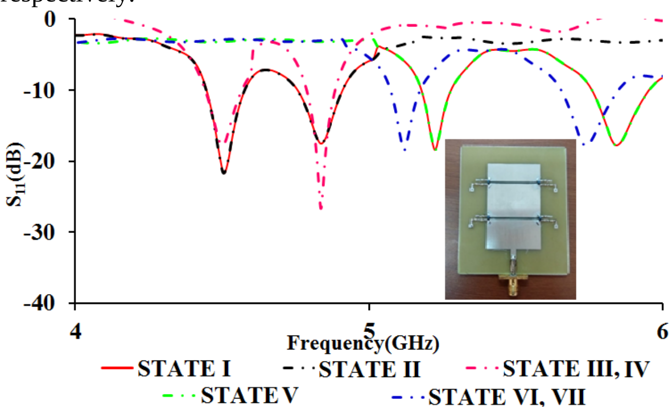

Fig 3: Measured reflection coefficient characteristics of the proposed antenna (Photograph of the fabricated prototype is shown as an inset)

B. Radiation Characteristics

The performance of the proposed antenna is tabulated in TABLE II. The pattern tilt at the four operating frequencies are shown in Fig. 4. The direction of tilting depends on the diode being turned ON. Whereas the magnitude of the degree of the tilt (30°) is proportional to the width of the radiator. In state I, II, III, IV, V, VI and VII, the peak gain & percentage efficiency are 4 dBi & 84%, 3.4 dBi & 83%, 3.8 dBi & 78%, 3.2 dBi & 82%, 3.2 dBi & 82%, 3.7 dBi & 77% and 3.7 dBi & 77% respectively. The variation of average gain and average efficiency as a function of frequency is shown in Fig.5.

TABLE II

PERFORMANCE OF THE ANTENNA

Parameter/Frequency		4.5 GHz	4.8 GHz	5.2 GHz	5.8 GHz
% BW	STATE I	2.2%	2.3%	2.38%	3.5%
	STATE II	2.3%	2.3%	-	-
	STATE III	-	-	2.38%	3.5%
	STATE IV	2.2%	2.3%	-	-
	STATE V	2.2%	2.3%	-	-
	STATE VI	-	-	2.38%	3.5%
	STATE VII	-	-	2.38%	3.5%
Gain(dBi)	STATE I	3	3.5	3.7	4
	STATE II	2.8	3.4	-	-
	STATE III	-	-	3.6	3.8
	STATE IV	2.7	3.2	-	-
	STATE V	2.7	3.2	-	-
	STATE VI	-	-	3.4	3.7
	STATE VII	-	-	3.4	3.7
Efficiency(%)	STATE I	84	78	79	79
	STATE II	83	76	-	-
	STATE III	-	-	78	76
	STATE IV	82	75	-	-
	STATE V	82	75	-	-
	STATE VI	-	-	77	75
	STATE VII	-	-	77	75

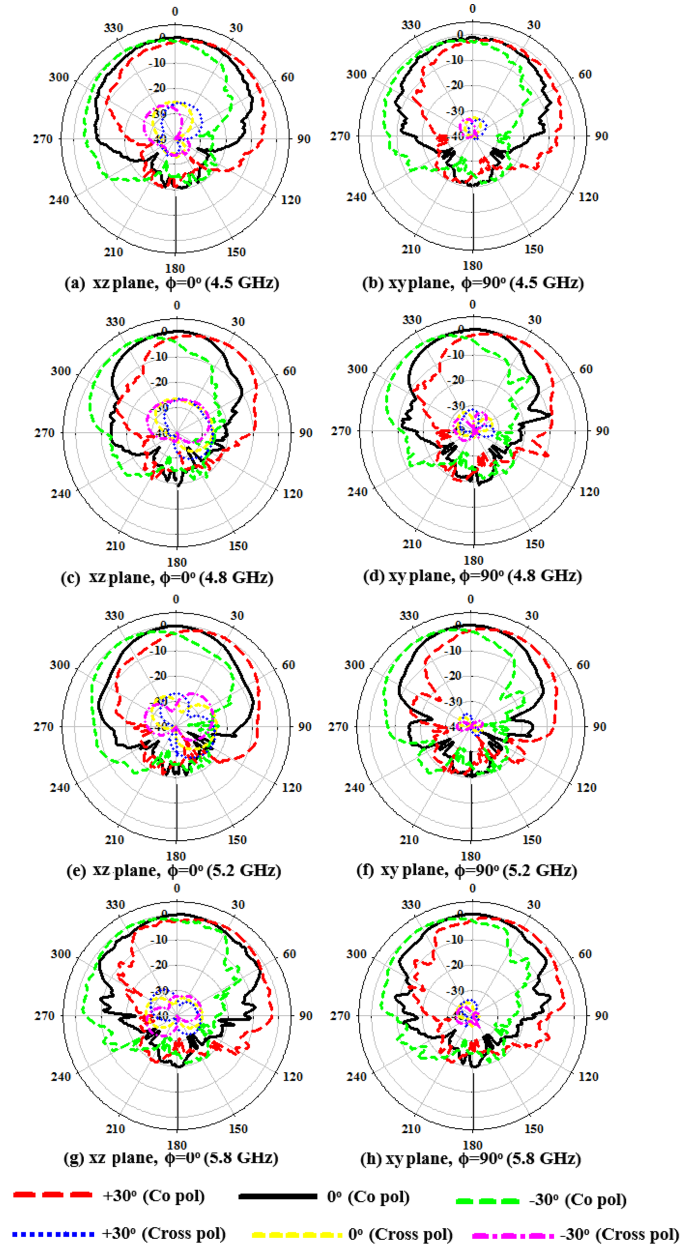

Fig.4:Measured radiation pattern

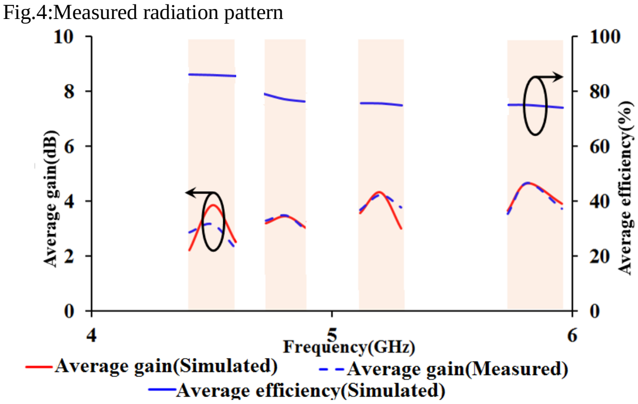

Fig 5: Simulated and measured Average gain and Average efficiency

The features of the proposed antenna are the following:

1. The proposed antenna reconfigures both frequency and pattern and helps in efficient utilization of the spectrum;
2. This letter presents solution for low profile actuator fabrication with less complexity compared to [18];
3. The antenna does not require fabrication of actuators in

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between the antenna layers to offer agile performance [21] and [22]. Also this antenna uses less number of actuators compared to [20 – 22];

4. The proposed antenna does not require matching network for impedance matching of the antenna[24].

TABLE III
COMPARISON WITH EXISTING STATE OF ART

Work	Antenna size (mm)	Reconfigu raion	Actuato rs	Features		
				BW (MHz)	Gain (dBi)	η (%)
[18]	46×20	Frequency	4 MEMS	90/ 125/ 100	-0.15/ 3.14/ 2.57	55/ 90/ 75
[19]	58×30	Pattern	2 PIN Diodes 1 FSS	150	9.1	NR
[20]	130×160	Frequency and Pattern	11 Switches	200/ 150/ 150	5.6/ 4.6/ 3.3	88.7/ 87.7/ 89.5
[21]	80×45.8	Frequency and Pattern	5 PIN Diodes	580/ 290	1.9/ 2.1	71/ 51
[22]	120×120	Frequency and Pattern	12 PIN Diodes	63.4/ 88.3	9.15/ 10.52	94.9/ 94.8
[23]	34×36	Frequency and Pattern	2 Switches	100/ 70	4/ 5.6	NR
[24]	50×50	Frequency and Pattern	2 PIN Diodes	120/ 100/ 100	NR	NR
This work	50×50	Frequency and Pattern	4 PIN Diodes	180/ 200/ 180/ 200	4/ 3.8/ 4.4/ 5	90/ 82/ 78/ 77

IV. CONCLUSION

In this work, a low profile frequency and pattern reconfigurable antenna is presented. The antenna operating at 4.5 GHz & 4.8 GHz / 5.2 GHz & 5.8 GHz is designed. Therefore the antenna can be used to serve General Wireless Communication Service band, Telemetry and WLAN applications. This authenticates that the antenna is a suitable choice for wireless data transfer. The radiation pattern has a tilt of -30º/ 0º/ +30º. Since the antenna reconfigures frequency and pattern, the allocated bands are utilized efficiently. The prototype is fabricated and it is validated using measurements.

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