High gain antenna with frequency and polarization diversities for C band

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Abstract

This paper proposes a high gain, frequency and polarization reconfigurable antenna with FR4 substrate. The antenna operates in the frequency range 5.044-5.511 GHz with gain ranging from 7.27-8.03 dB. The diversity in frequency and polarization occurs as a result of different switching conditions of a combination of three PIN diodes. The partial ground plays an important role in providing appreciably high gain.

Keywords: Reconfigurable antenna, PIN diodes, partial ground.

Introduction

Reconfigurable antennae are the need of the hour because of their ability to reflect more than one antenna characteristics with a single antenna. The characteristics that are altered may be the resonant frequency, the radiation pattern, the polarization or any combination of these characteristics resulting in frequency reconfigurable, pattern reconfigurable polarization reconfigurable antenna or a hybrid antenna respectively. A number of scientists and researchers have presented numerous ideas for the purpose. The reconfiguration is achieved by means of electrical, optical, physical or material change [1]. A varactor tuned printed inverted-F antennas (PIFA) has been suggested with single and dual band operation [2]. The antenna resonated from 1.6-2.3 GHz with bias voltage variation of 0-9.5 volts resulting in a gain from 2-3 dB and an efficiency of 70-75%. For dual band operation the antenna was tuned from 780-1020 MHz and 1700-2140 MHz with radiation efficiencies of 55% and 45% respectively. A compact, efficient and tunable slot antenna has been presented in [3] which exhibited four resonant frequencies from 540-890 MHz. Four PIN diodes have been used on 100 mil thick RT/Duroid substrate. [4] suggests a frequency reconfigurable antenna based on a PIFA designed with an L-shaped open slot with a MEMS. A frequency and polarization reconfigurable antenna has been proposed using 4 PIN diodes and varactor diodes [5], the operating frequency varies from 1.35-2.25 GHz for horizontal and/or vertical polarization and from 1.35-1.9 GHz for 45° linear polarization. A rectangular antenna with U slot and three PIN diodes has been suggested for L, S, C and X band applications [6]. The antenna worked in 8 different modes with different ON and OFF switching state of the PIN diodes resulting in operating frequencies ranging from 2.8-9.9 GHz. A pattern reconfigurable compact antenna has been proposed and investigated in paper [7]. It resonated at frequencies ranging from 3.91-4.05 GHz in 12 different states. The main radiation beam rotated by 30° from 0° to 330° in azimuth plane. Paper [8] proposed a polarization reconfigurable antenna at 4.3GHz (LHCP) and 4.19 GHz (RHCP) for communication.

Antenna Design Simulation and Analysis

The proposed antenna design has been shown in figure 1. Fig. 1(a) depicts the front view, fig. and 1(b) the bottom view. The geometry of the antenna has been shown in figure 2. Figure 2(a) shows the patch and 2(b) the ground of the antenna. The proposed has been designed on FR4 substrate of 1.6 mm with a permittivity ε_r =4.4 and loss tangent δ = 0.02. The dimensions of the antenna ground, patch and other parameters have been given in table I.

Table I: Antenna Dimensions

Patch		Ground	
Parameter	Dimensions (mm)	Parameter	Dimensions (mm)
L_1	20	L_{G1}	36
L_2	18	L_{G2}	23
L_3	13.89	L_{G3}	18
L_4	0.9	L_{SO}	2
W_1	18	L_{SI}	1.5
W_2	16	W_{G1}	20
W_3	0.72	W_{G2}	17

W_4	3	W_{SO}	4
Patch radius	15.5	W_{SI}	3.5

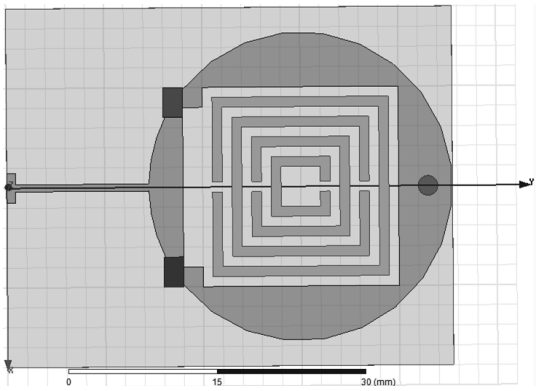

Fig. 1 (a)

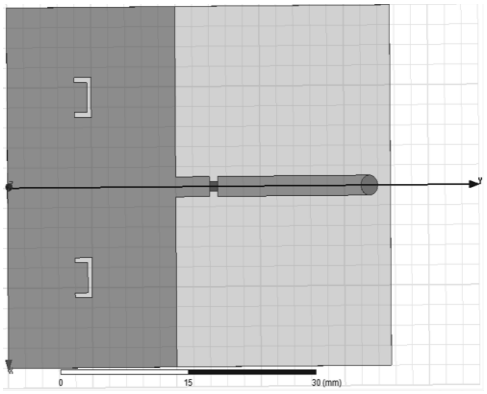

Fig. 1 (b)

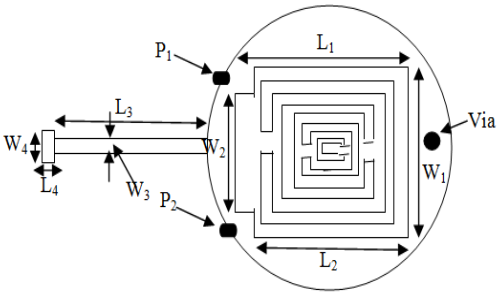

Fig. 2 (a)

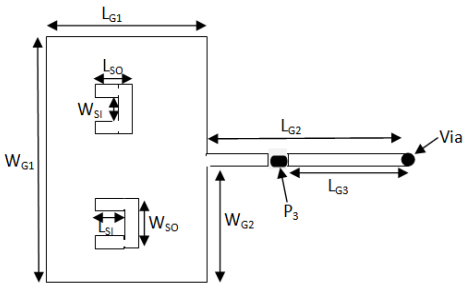

Fig. 2 (b)

Figure 3 depicts the steps of antenna design. Fig.3 (a) shows the antenna patch with the partial ground plane which resonates at a frequency (f_r =) 5.667 GHz and provides a gain of 7.54 dB at f_r, figure 3(b) shows the next step of introducing two slots in the ground plane which result in improving the gain to 7.586 dB. Fig. 3(c) shows the next step in designing where a "via" has been used with an extension to the partial ground, this resulted in a shift in the resonant frequency to f_r= 5.5889 GHz with a gain of 7.688 dB. Further fig. 3 (d) shows the changes in the patch where a square complementary split ring has been introduced which made the antenna resonant at two frequencies, f_{r1}= 5.044 GHz with a gain of 8.697 dB and f_{r2}= 5.667 GHz with a gain of 7.205 dB. Step 5 in designing has been shown in fig. 3 (e) where another square complementary split ring has been introduced which made the antenna resonate at two frequencies, f_{r1}= 5.122 GHz with a gain of 8.362 dB and f_{r2}= 5.822 GHz with a gain of 6.91 dB. For the purpose of achieving diversity in radiation characteristics two PIN diodes P_1 and P_2 have to be inserted in the periphery and before that a rectangular segment has been removed to detach any connection between the patch segments in step 6 shown in fig. 3 (f) which resulted in a resonant frequency of 4.9667 GHz with a gain of 8.10dB.

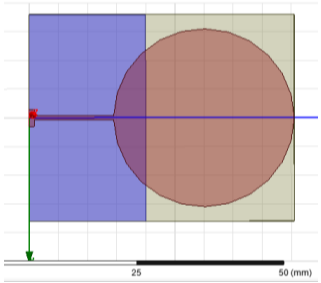

Fig. 3(a)

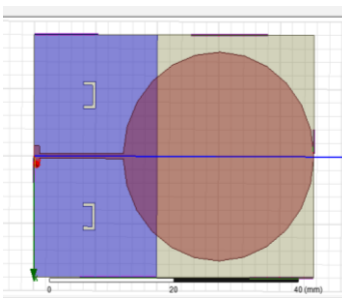

Fig. 3(b)

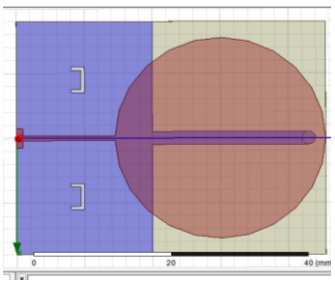

Fig. 3(c)

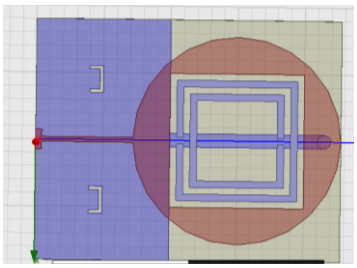

Fig. 3(d)

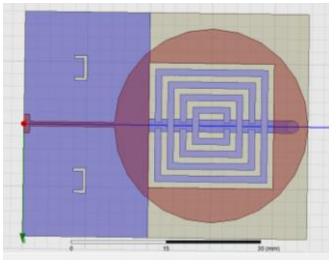

Fig. 3(e)

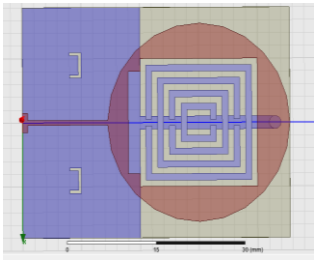

Fig. 3(f)

A PIN diode P_3 has been inserted in the path of partial ground and via. The three diodes P1, P2 and P3 made the antenna work in eight different states/modes as per their switching conditions as mentioned in table II.

Table II: Antenna modes with PIN diodes' switching conditions

Mode	P_1	P_2	P_3
000	OFF	OFF	OFF
001	OFF	OFF	ON
010	OFF	ON	OFF
011	OFF	ON	ON
100	ON	OFF	OFF
101	ON	OFF	ON
110	ON	ON	OFF
111	ON	ON	ON

Figure 4 shows the reflection coefficients and gain of the antenna in subsequent steps. Fig. 4 (a) shows the reflection coefficients of the antenna in steps 1, 2 and 3. Fig. 4 (b) shows S_{11} in steps 4, 5 and 6. In a similar way fig. 4 (c) depicts the antenna gain in steps 1, 2 and 3, whereas fig. 4 (d) shows the antenna gain in steps 4, 5 and 6.

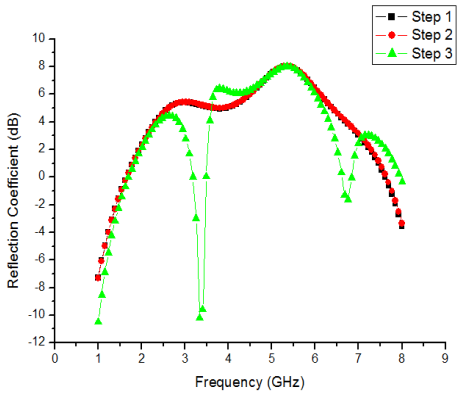

Fig. 4 (a)

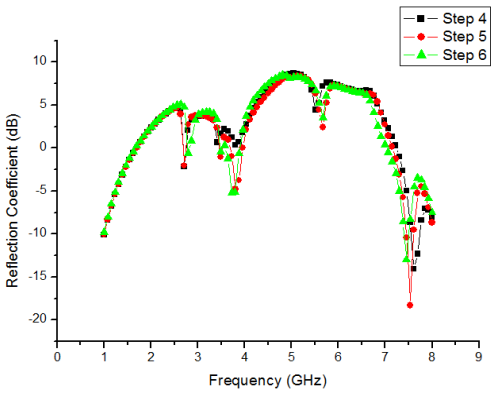

Fig. 4 (b)

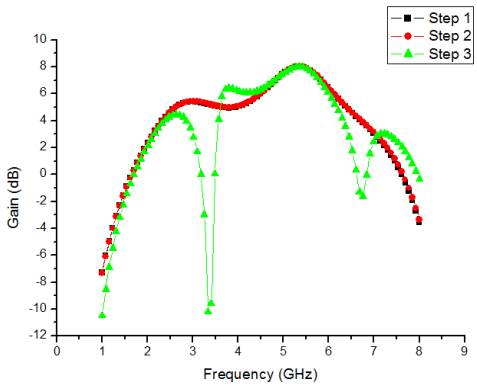

Fig. 4 (c)

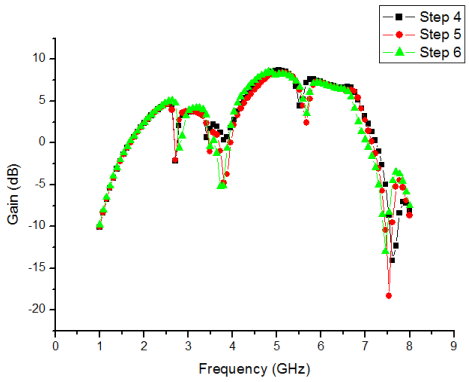

Fig. 4 (d)

The resonant frequencies with their reflection coefficients, gain, axial ratio and efficiency have been listed in table III.

Table III: Antenna modes with radiation characteristics

Mode	Resonant Frequency F_r (GHz)	Reflection Coefficient S_{11} (dB)	Gain (dB)	Axial Ratio (dB)	Radiation efficiency (%)
000	5.511	-19.48	8.03	47.36	59.34
001	5.433	-24.35	8.07	29.09	77.28
010	5.356	-20.13	7.88	39.62	73.36
011	5.278	-18.61	7.69	31.26	70.30
100	5.278	-24.14	7.28	26.42	71.15
101	5.278	-18.07	7.71	27.86	70.14
110	5.122	-16.38	7.27	49.45	63.77
111	5.044	-15.48	6.93	35.89	59.58

The reflection coefficients of the proposed antenna in different modes have been shown in figures 5 (a) to 5 (d). The reflection coefficient varies from -15.48 dB (in mode 111) to -24.35 (in mode 001).

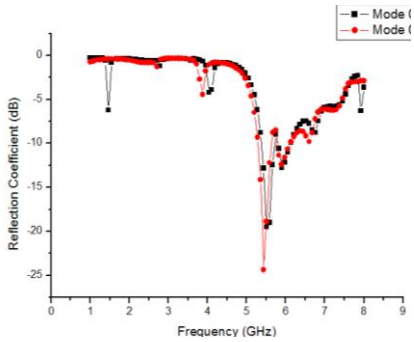

Fig. 5 (a)

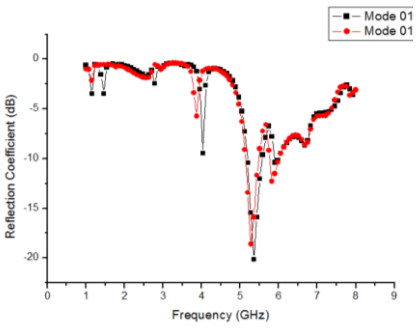

Fig. 5 (b)

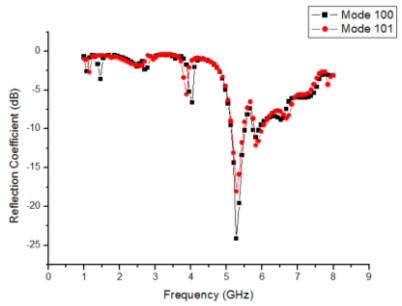

Fig. 5 (c)

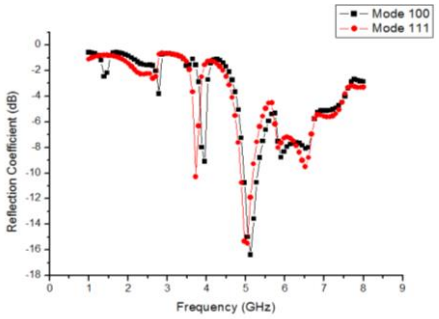

Fig. 5 (d)

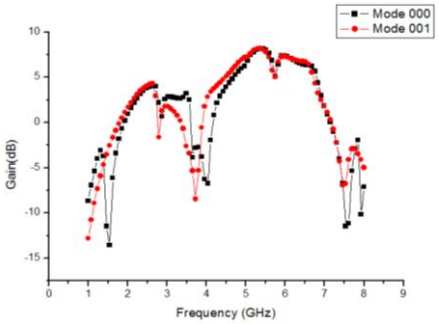

Fig. 6 (a)

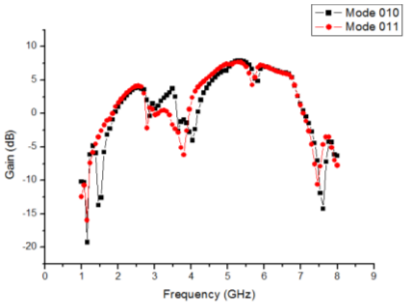

Fig. 6 (b)

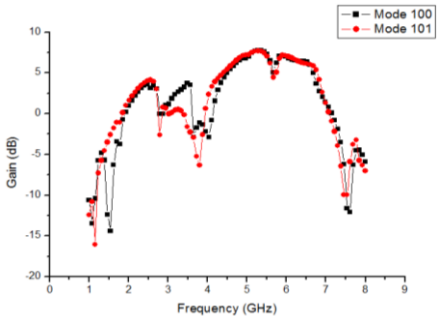

Fig. 6 (c)

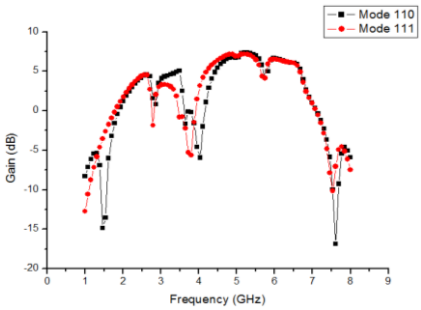

Fig. 6 (d)

Frequency diversity

The antenna resonates at frequencies ranging from 5.044 GHz (in mode 111) up to 5.511 GHz (in mode 000) with gain ranging from 6.93 dB (at 5.044 GHz in mode 111) up to a maximum value of 8.07 dB (at 5.433 GHz in mode 001). The reflection coefficients and gains of the antenna with respect to the frequencies have been plotted in figures 5 and 6 respectively.

Polarization diversity

The proposed antenna exhibited elliptical polarization in mode 001 (at 5.433 GHz), in modes 100 and 101 at 5.2778 GHz. The polarization is determined by means of the axial ration which is defined as the ratio of minor to major axis of the polarization ellipse. For equal major and minor axis it transforms into a circle. Thus for circular polarization the axial ratio is 1 or 0 dB (ideally), practically axial ratio less than or equal to 3dB (sometimes 6 dB) is considered the case of circular polarization. For linear polarization this ratio i.e the ratio of major axis to minor axis is infinite ideally (practically a value greater than 30 db is considered as the case of linear polarization). Fig. 7 (a) shows axial ratio (in dB) for modes 000 which shows linear polarization (axial ratio = 47.36 which is > 30 dB) and 001 (axial ratio = 29.09 which is < 30 dB) which shows elliptical polarization, whereas fig. 7 (b) shows the value of axial ratio in dB for modes 100 and 101, both modes as the ratio lies between 3 dB and 30 dB. In all other modes it exhibited linear polarization. The axial ratio of the antenna in modes 000, 001 and 100, 101 have been shown in figure7.

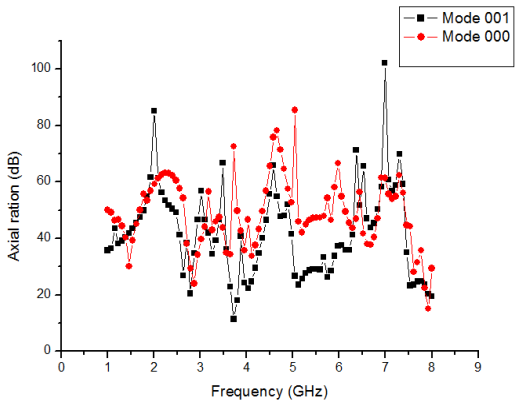

Fig. 7 (a)

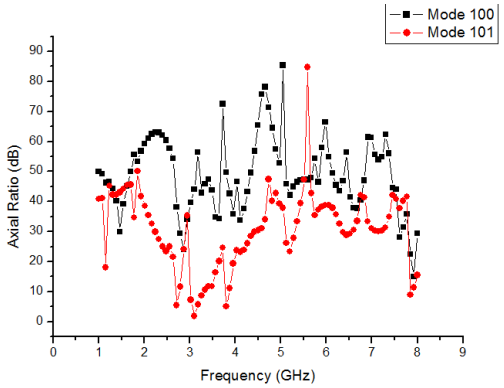

Fig. 7 (b)

For switching purpose PIN diodes BAP65-03 have been used, datasheet of NXP USA Inc. [9]. The PIN diodes have been simulated as a resistance of 5Ω in ON condition and as a parallel combination of a high resistance of 999GΩ and a 0.15 pF capacitor as shown in figure 8. These values have been evaluated by practically using the diodes.

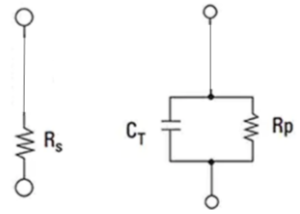

Fig. 8: Equivalent model of PIN diode in ON condition R_s = 5 Ω and in OFF condition R_P = 999GΩ and C_T = 0.15 pF

Table IV shows the characteristics of the proposed antenna in contrast with those of reference antennas. The proposed antenna finds its advantages in terms of compactness, diversity in frequency as well polarization with less number of switching elements. However the characteristics this antenna excels is its gain.

The gain of microstrip patch antenna has always been a matter of concern which usually lies within 5 dB. This antenna offers a gain from 6.93 dB (in mode 111) up to a maximum value of 8.07 dB (in mode 001). The radiation efficiency ranges from 59.34% (in mode 000) up to a maximum value of 77.28% (in mode 001).

Table IV: Comparison of proposed Antenna with antennas designed in the reference papers

Reference Paper	Operating Frequency (GHz)	Antenna Size (mm)	Number of states /modes	Maximum gain (dB)	Maximum Efficiency	Switching element(s)	Reconfigurable Characteristic(s)
2	1.6-2.3	80X50X1.575	4	2.92	96	2 varactor diodes	Frequency
3	540-890 MHz	127X127X2.54	4	< 2	47	4 PIN diodes	Frequency
4	0.8-2.5	75X30X8	2	N.A	N.A	MEM switches	Frequency
5	1.35-2.25	70X66.5X3.175	3	6.4	N.A	4 PIN diode and 8 Varactor diodes	Frequency and Polarization
6	4.5-9.9	60.43X36.7X1.5	8	N.A	N.A	3 PIN diodes	Frequency
7	3.91-4.05	62X62X3	12	5.75	87.1%	6 MEMS	Pattern
8	4.19-4.3	60X30X1.6	2	4.9	N.A	Copper areas	Polarization
*	5.044-5.511	45.4X36X1.6	8	8.07		3 PIN diodes	Frequency and Polarization

* : Proposed Antenna

N.A: Not available

Conclusion

The antenna finds its application in Wi Fi, WLAN and other C band applications. In future this antenna can be further investigated and modified to achieve pattern and bandwidth diversity and bandwidth enhancement.

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