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REGULAR ARTICLE

A Hepta-band Frequency Tunable Patch Antenna for Cognitive Radio Applications

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A novel and compact frequency tunable patch antenna for Cognitive radio applications (4-8 GHz) operating on seven different frequencies is presented in this article. Essential characteristics of this antenna are large tuning range and sufficient gain. Radiating patch of the antenna is a circular shaped structure and ground plane is modified with different slotted structure for reconfiguration purpose and capacitors are used to isolate the biasing terminals of the battery from RF power. The radiating patch divided into four parts by cutting slots in required manner and PIN diodes are placed at the appropriate position to reconfigure the antenna. These RF switches vary the length of the slots and also change the resonant frequencies. Frequencies generated by the antenna are 4.62 (4.55-4.68) and 6.68 (6.60-6.84) GHz, 5.33 (5.19-5.47), 5.59 (5.44-5.74), 5.81 (5.70-5.92), 6.12 (5.99-6.26) and 6.96 (6.85-7.15) GHz. Total substrate size of the antenna is 23×24 mm2 with thickness of 1.6 mm. Dielectric substrate material used is FR-4 having dielectric constant of 4.4 and loss tangent 0.002 for simulation and fabrication purpose. Parameters of the antenna are analyzed, and simulation and measured results shows an excellent agreement.

Keywords: Reconfigurable antenna, PIN diode, Cognitive radio, Tunable antenna, Multiband antenna.

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1. INTRODUCTION

For any wireless communication system, antenna plays a crucial role. Single band antennas are used for a specific wireless service and thus for multiple services more than one antenna required. Multiband antennas are also used if a wireless communication system supports more than service. But interference between different wireless standards is also a problem occurred in multiband antennas. To overcome these problems reconfigurable antennas can be implemented as the reconfigurable antennas are able to change the parameters according to requirement. Reconfigurable antenna can improve the system capacity, hardware complexity and number of antennas used in a communication system can also be reduced. Reconfigurable antennas can be reconfigured to operate at different frequencies to provide various functions [9]. For any antenna designer it is a challenge to operate the antenna for a desired function [10]. There are various techniques to convert an antenna into a reconfigurable antenna. Basically the reconfiguration techniques of the antenna can be categorized into four types: electrical, mechanical, material change and optical. Researches preferred electrical reconfiguration method because this method is inexpensive and easy to implement. PIN diodes, varactor diodes and RF-MEMS switches are used in this reconfiguration technique. These switches change the current path and thus also the parameters like frequency, polarization and pattern etc. frequency reconfigurable antennas are designed using PIN diode and varactor diode in [11] and [12]. Switching tuning and continuous tuning type are main approaches to reconfigurable the antennas. MEMS switches, Varactor diode, PIN diodes and stepper motors etc. can be used as a switching device in reconfigurable antenna. PIN diode has a numerous advantages over all these switching devices. It has a small size, low cost and easy to operate. A triple band antenna for WiMAX and WLAN applications with compact size 18×18 mm^2 has tuning ranges 2.5 GHz, 3.47 GHz and 5.75 GHz proposed by Ali et al. in [5]. its gain range is very low.

A lowprofile frequency-reconfigurable slot antenna which can be tuned from 2.14 to 3.33 GHz with 43.51% efficiency and gains varying from 1.10 to 2.42 dBi is described in [2]. To obtain the continuous tuning two varactor diodes are used as a switching device. Design simulated in CST software. This antenna can be used for only low frequency applications. In [8] A more compressed unidirectional reconfigurable rectangular patch antenna using coaxial feed with size 25.34×25.33 mm^2, which is tunable from 2.901 to 5.321 GHz for S band and C band for wireless communications achieved maximum gain 2.59 to 4.79 dB, designed using F shaped and E shaped slots technique and two varactor diodes used as a switching device for achieved continuous frequency. Poor linearity is major drawback of Varactor diode.

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In [3] A Microstrip Patch antenna, which operates on three frequencies, 5.40 GHz, 6.76 GHz and 8.82 GHz proposed. This hexagonal shaped antenna is of compact size of 17 × 15 mm². It is mainly used for WLAN, 5G license band (5.2 to 5.7 GHz), TV satellite broadcasting and also for radar applications. In this antenna design gain increased with frequency. For eg.: If frequency range increases from 5.38 GHz to 8.82 GHz, the gain simultaneously increases from 2.42 dBi to 4.28 dBi. This microstrip patch antenna can be reconfigured and further there is an option to control the notch bands also. PIN diode is used as a switching device and further changing the configurations of PIN diode over C band (4-8 GHz) for long distance radio telecommunications and X bands (7.5-8.5 GHz) for Satellite communication. Designer can utilize it as a dual band or triple band. HFSS Software has been used here for simulation.

In [7] Frequency reconfigurable antenna, which can be tuned to different frequencies 4.9 GHz ,6.0 GHz, 6.6 GHz and 7.4 GHz for cognitive radio applications introduced. Simulation is done in HFSS software.

In [4] For Wi-Fi, WiMAX and WLAN applications, a defected ground plane antenna with size 83 × 56 mm2 using split Ring Resonators technique proposed. It resonates on three different frequencies 2.45 GHz, 3.55 GHz and 5.55 GHz with gain 3.88 dB, 3.87 dB and 3.83 dB respectively. it gives almost uniform gain on these different frequencies. For wireless sensors applications, a triband flexible single antenna with two F shaped resonators planar patch which operates at three frequency bands, i.e., 1.8 GHz, 3.5 GHz, and 5.4 GHz proposed in [6]. At 1.8 GHz, 3.5 GHz and 5.4 GHz Frequencies the simulated peak gains of this antenna obtained 2.34 dB, 5.2 dB, and 1.42 dB respectively. But has a backdrop as the frequency range increases from 1.8 GHz to 5.4 GHz, its radiation efficiency degraded from 73% to 59% simultaneously. A small size 22 × 26 mm² reconfigurable patch antenna for wireless communication applications designed and can be tuned in four different frequencies 3.6 GHz, 4.1 GHz, 6.6 GHz and 8.8 GHz with 1.14 dBi, 0.58 dBi, 2.46 dBi, 2.95 dBi gains respectively in [1].

2. ANTENNA DESIGN METHODOLOGY

2.1 Geometry of the Antenna

The presented antenna has two-layer geometry. Top layer is a patch consists of a circular shaped radiator with slotted structure fed with a microstrip line of resistance 50 *Ω*. Antenna simulated and fabricated over FR-4 substrate material having dimensions of 23 × 24 mm² with dielectric constant of 4.4 because it

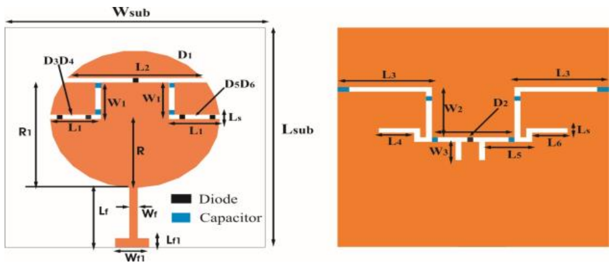


Fig. 1 – Geometry of the Antenna

provide better insulating properties and can enhance the effectiveness of antenna. Ground plane also modified to regulate the bandwidth. Total six PIN diodes are integrated for the reconfiguration purpose. During the simulation of the design lumped elements are used to design PIN Diodes.

Dimensions of final design summarized in Table 1.

Table 1 – Optimized parameters of the suggested antenna

Parameter	Value (mm)	Parameter	Value (mm)
L_{Sub}	24	W_{Sub}	23
R	7.5	L_s	0.5
L_1	4.5	R_1	12.5
W_1	3.5	W_f	0.75
L_2	12.5	L_f	5.75
W_{f1}	3	L_4	3
L_{f1}	1	W_2	5
L_3	8	W_3	2
L_5	3.5	L_6	3

2.2 Design Process of the Antenna

Several modifications were made in the patch and ground before obtaining the final antenna design and different results obtained summarized in Table 2. Four step design procedure is followed to obtain the final antenna design and optimized the antenna to find the appropriate position of the RF switches. Many elements are generally required to design the reconfigurable antenna such as cutting slots, creating sections and placing parasitic strips. The major effect of these all is either creation of new frequencies or the filtering of some undesired frequencies i.e. introduction of notch. These elements are connected to antenna using switches such as PIN diodes, metallic strips or RF-MEMS switch. As mentioned in previous section that modifications were made in the patch and ground. These modification results different operating frequencies and then antenna tuned for several frequencies. Reconfigurability achieved by introducing slots and integrating PIN diodes in both ground and patch. BAR50-02V PIN diode from Infineon technologies are used for reconfiguration purpose. Antenna continuously reconfigured from 4.46 GHz to 7.94 GHz so a wide range of reconfigurability achieved.

Table 2 – Operating frequency ranges for all design steps

Iteration No.	Operating Frequency (GHz)
Iteration 1	5.44
Iteration 2	6.36
Iteration 3	7.78
Iteration 4	4.57

Equivalent circuit of the used PIN diode and parameter values BAR50-02V is shown in Fig. 2 and Table 3 respectively.

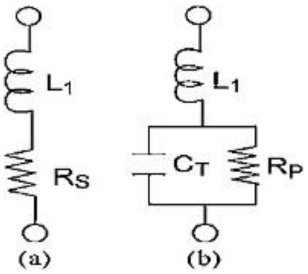


Fig. 2 – PIN diode equivalent diagrams (a) ON state (b) OFF state

Table 3 – Element values of BAR50-02V

PIN Diode Model	State	L_1	C_T	R_P	R_S
BAR50-02V	OFF		0.15 pF	3 KΩ	
	ON	0.6 nH			3Ω

As DC supply is used to operate the PIN diodes so it affects the RF current and provide and additional path to flow the RF current. To stop the flow of RF current to back to DC supply, RF inductors are used between DC supply and PIN diodes. To stop AC current and to pass the DC is the well-known property of inductor. Impedance value of the inductor must be larger to stop the flow of AC through the DC line. So XL is chosen to be greater than 1.5 KΩ. Inductor value is to be calculated using minimum operating frequency i.e. 4.6 GHz. Inductive impedance of 3 KΩ is used here to calculate the inductor value.

$$XL \geq 1.5\ K\Omega$$

$$XL = 2\ \pi f L$$

$$L = XL/2\ \pi f$$

$$L = 3000/2 \times 3.14 \times 4.6 \times 109\ H$$

$$L = 103\ nH$$

The calculated value of inductor is 103 nH. Thus an inductor of 100 nH is used in the biasing circuit. Also a resistor has been inserted to limit the DC voltage across the PIN diode. This biasing circuit also maintains the energy of main device. This effect sustains the antenna key parameters during switching from one state to another.

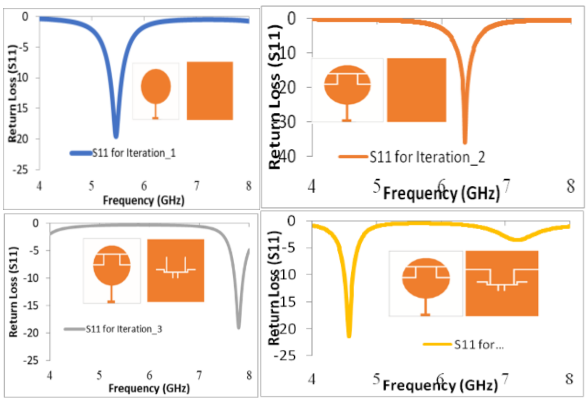


Fig. 3 – Simulated Return Loss for different design steps

3. RESULTS AND DISCUSSION.

3.1 Reflection Coefficient Results

To validate the antenna presented concept and simulated results, a prototype of the antenna fabricated and measured the reflection coefficient and radiation parameters.

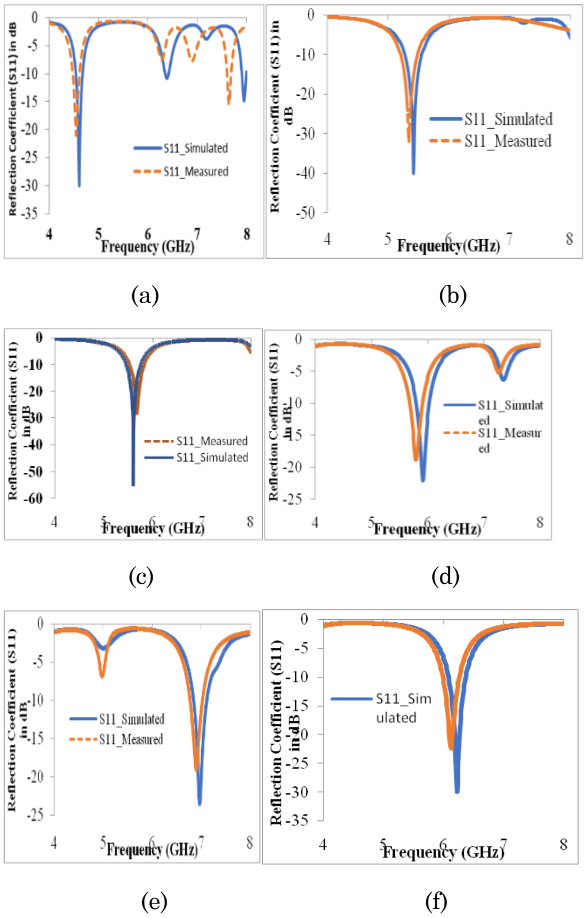


Fig. 4 – Reflection Coefficients of Proposed Antenna for Diodes configuration (a) 000000, (b) 001111, (c) 011111, (d) 101111, (e) 110000, (f) 111111

The solid line indicates simulated and dashed line shows the measured reflection coefficient. There is some mismatch between simulated and measured results which is due to some mechanical inaccuracies and non-ideal conditions after fabrication. From Fig. 6 it is evident that the antenna provides a tuning of frequency from 5.20 GHz to 6.26 GHz. so it is useful in cognitive radio applications.

The fabricated prototype of the antenna is shown in Fig. 5.

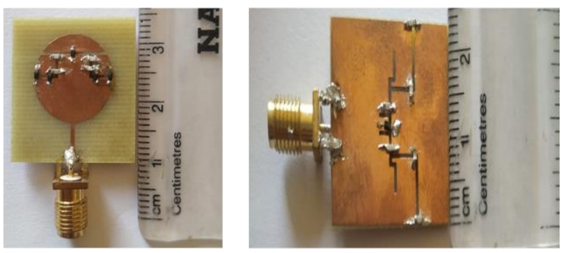
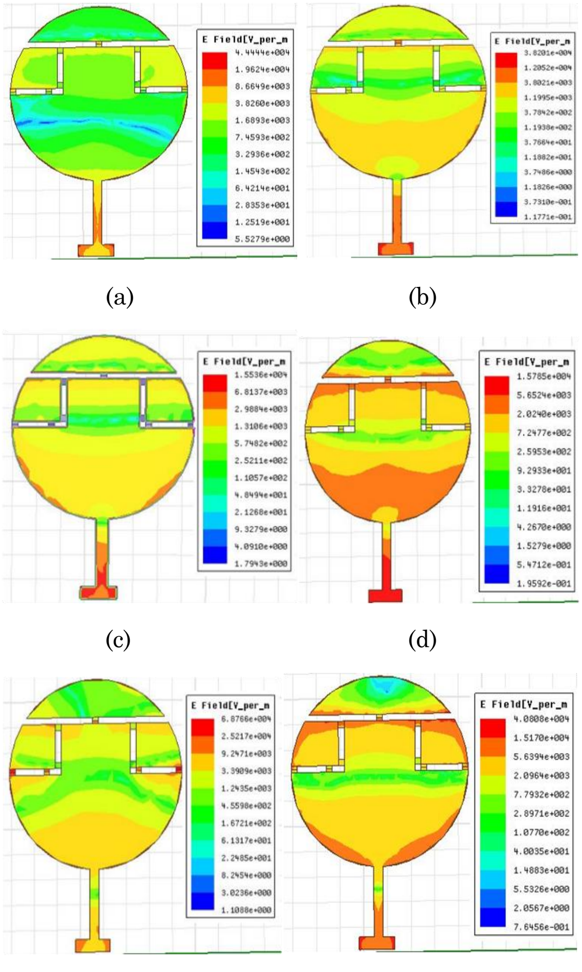


Fig. 5 – Fabricated Antenna

The surface current distribution describes the operating phenomenon of the antenna for different modes indicates that the effective electric length is reduced for lower band of frequencies and increases for upper band of frequency. Changes in electric field distribution with changing in diode states for the radiating patch can be seen clearly in the figure below.

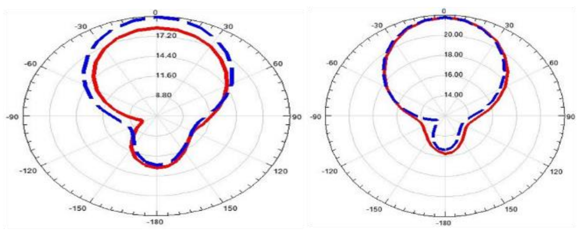
3.2 Radiation and Gain Pattern

For all biasing arrangements and operating frequencies, the simulated and measured radiation patterns are shown in Fig. 7. The entire pattern observed to be stable for all operating frequencies.

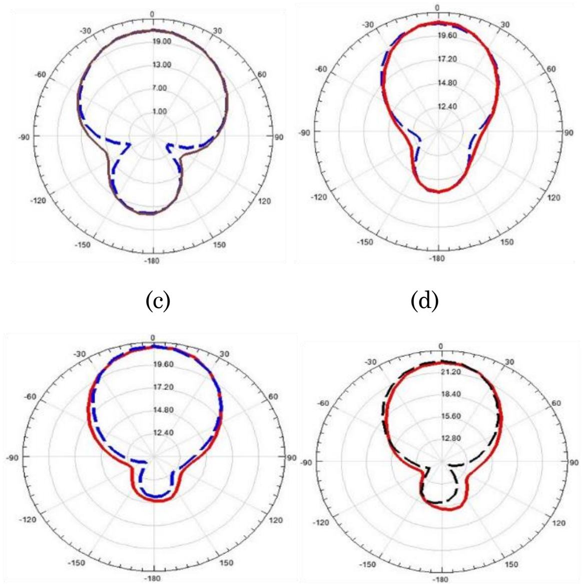


(a) (b) (c) (d) (e) (f)

Fig. 6 – Electric field distribution of Proposed Antenna for Diodes configuration (a) 000000, (b) 001111, (c) 011111, (d) 101111, (e) 110000, (f) 111111

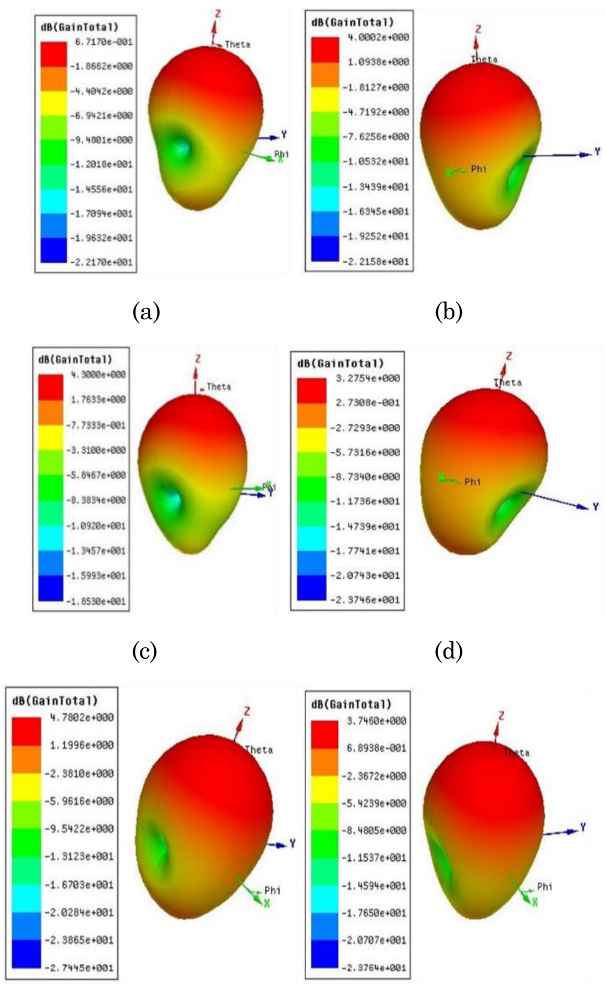


(a) (b)



(c) (d) (e) (f)

Fig. 7 – Radiation Pattern of Proposed Antenna for Diodes configuration (a) 000000, (b) 001111, (c) 011111, (d) 101111, (e) 110000, (f) 111111



(a) (b) (c) (d) (e) (f)

Fig. 8 – Gain plot of Antenna for Diodes configuration (a) 000000, (b) 001111, (c) 011111, (d) 101111, (e) 110000, (f) 111111

Table 4 – Operating modes of the diodes

Diode Configuration ($D_1D_2D_3D_4D_5D_6$)	O.F-Simulated (Measured) in GHz	S11 (Measured)	Maximum Gain (in dBi)
000000	4.61 (4.54)	-20.99	0.67
001111	5.41 (5.34)	-31.86	4.0
011111	5.60 (5.62)	-30.05	4.3
101111	5.9 (5.78)	-18.01	3.2
110000	6.97 (6.88)	-22.01	4.7
111111	6.22 (6.11)	-20.23	3.7

Table 5 – Validation of proposed design with designs studied in the literature.

Ref.	Technique	Size (mm²)	Switch Device	Frequencies (GHz)	Gain (dBi)	Efficiency
5	F-shaped and E-shaped slots	18 × 18	Multi-band Antenna	2.55, 3.47, 5.75	0.2, 0.16, 0.62	NA
6	Ring slotted and T-shaped feed line	24 × 40	Varactor	2.14, 2.38, 2.73, 3.33	1.10 to 1.38, 2.04, 2.42	43.51%
7	F-shaped and E shaped slots	25.34 × 25.33	Varactor	2.90 - 5.32	2.59 -4.79	NA
8	Hexagonal shaped with two inclined strips	17 × 15	PIN	5.4,6.76,8.82	2.42, 2.46, 4.28	89.57%
10	Split ring resonant(SRR)	83 × 56	NA	2.47, 3.55, 5.55	3.88, 3.87, 3.83	NA
11	F-shaped Planar patch	60 × 50	Multi-band Antenna	1.8, 3.5, 5.4	2.22, 5.18, 1.38	73%
12	Inset feed and slotted ground	22 × 26	PIN	3.6,4.1, 6.6, 8.8	1.14, 0.58, 2.46, 2.95	NA
13	Defected Ground Structure (DGS)	35 × 35	PIN	2.4,3.5, 4.7,5.8	2.3-4.81	79%
This Work	DGS slotted patch	23 × 24	PIN	4.62, 6.68,5.33, 5.59, 5.81, 6.12, 6.96	3.27 - 6.72	85%

Simulated 3D plot of gain is also shown in figure 8. Vertical and azimuth plane radiation pattern at 4.62 GHz, 6.68 GHz, 5.33 GHz, 5.59 GHz, 5.81 GHz, 6.12 GHz and 6.96 GHz are shown in Fig. 8 for simulation and measurement values and this designed antenna yields maximum gain of 4 dB, 4.3 dB, 3.3 dB, 3.7 dB and 4.7 dB. This antenna offers maximum gain of 4.8 dB at 4.96 GHz. We can also conclude that the return loss is less than –10 dB and VSWR value is less than 1.2 in all the resonating frequencies. Due to good impedance matching it provides better return loss of -31.98 dB at 5.34 GHz. Good radiation efficiency is also achieved for all the resonating frequency bands.

The proposed fabricated hepta band antenna is compared with all mentioned previous designed antennas and shown in Table 5. The comparison of all these antennas are based on techniques of fabrication, overall size, switches, resonant frequencies, bandwidth, gain and efficiency. Proposed antenna in this paper has compact size and sufficient bandwidth as compared to other antennas.

4. CONCLUSION

Compact seven-band frequency reconfigurable patch antenna fractal shaped geometry of area 23mmx24mm is presented in this paper. The presented antenna covers the 4.62(4.55-4.68) and 6.68 (6.60-6.84) GHz, 5.33 (5.19-5.47), 5.59 (5.44-5.74), 5.81 (5.70-5.92), 6.12 (5.99-6.26) and 6.96 (6.85-7.15) GHz bands. The bandwidth of 130 MHz, 240 MHz, 280 MHz, 300 MHz, 220 MHz, 270 MHz and 300 MHz respectively is provided by the antenna. Six PIN diodes are inserted at the selected locations to switch the antenna from one frequency to another desired frequency. Thus, by changing the states of PIN diodes, frequency reconfigurability can be achieved. Acceptable gain and VSWR value have been achieved for desired frequencies. A comparison of the proposed antenna with some earlier designed structures validated the design. Due to its compact size, this antenna can be easily integrated with communication and various portable electronic devices. Thus, the antenna is suitable to be used in Vehicle-to-Everything communications, WLAN, C-band for satellite communication system, weather radar systems and multiband communication systems.

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Семидіапазонна регульована патч-антена для додатків когнітивного радіо

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У статті представлено нову та компактну патч-антену з регульованою частотою для додатків когнітивного радіо (4-8 ГГц), що працює на семи різних частотах. Основними характеристиками антени є великий діапазон перебудови і достатній коефіцієнт посилення. Випромінювальна ділянка антени являє собою круглу структуру, а площина заземлення модифікована іншою щілинною структурою з метою реконфігурації. Конденсатори використовуються для ізоляції клем зміщення батареї від радіочастотного живлення. Випромінювальна ділянка розділена на чотири частини прорізами необхідним чином, а PIN-діоди розміщені у відповідному положенні для зміни конфігурації антени. Дані радіочастотні перемикачі змінюють довжину слотів, а також змінюють резонансні частоти. Антеною генеруються частоти 4,62 (4,55-4,68) і 6,68 (6,60-6,84) ГГц, 5,33 (5,19-5,47), 5,59 (5,44-5,74), 5,81 (5,70-5,92), 6,12 (5,99-6,26) і 6,96 (6,85-7,15) ГГц. Загальний розмір підкладки антени становить (23×24) мм^2 при товщині 1,6 мм. Для моделювання та виготовлення використовувався матеріал підкладки FR-4 з діелектричною проникністю 4,4 і тангенсом втрат 0,002. Параметри антени і результати моделювання та вимірювання показали високу узгодженість.

Ключові слова: Реконфігурована антена, PIN-діод, Когнітивне радіо, Регульована антена, Багатодіапазонна антена