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Design of Compact Sized Frequency Reconfigurable Spiral Antenna for 5G Applications

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Abstract
In this work, a frequency reconfigurable spiral antenna with square spilt ring resonator etched on ground plane was presented. The proposed design has a compact size of 28×28 mm^2 and was designed on FR4 substrate with a thickness of 1.6mm, ε_r= 4.4 and δ = 0.002 using HFSS v.15.0 simulation software. The antenna operates at four different states of two PIN diode switches which is being incorporated in the radiating area. The proposed frequency reconfigurable antenna operates with centre frequencies of1.7, 2.4, 2.5, 3.2, 4, 4.1, 7.4, 7.5, 8.5 and 8.7GHz band, with S11 less than -10 dB. The reflection coefficients, antenna's gain and radiation properties obtained makes the proposed antenna as a decent contender for current 5G wireless communication systems.

Keywords: Compact Sized Frequency, 5G Applications, Spiral Antenna

Introduction
The emergence of new technologies and the sharp increase in subscriber demands have been the driving forces behind extensive research in the field of wireless communication. The antenna sector has an important role to play in this regard, which has led to the advent of compact sized, low-profile and multifunctional antennas.
In recent years, the ability to reconfigure the operating frequency, radiation pattern, and polarizations of antennas is highly desirable, given the rapidevolution of wireless communications and the high demand for the integration of multiple wireless standards into a single platform [1]. The multibandreconfigurable antennas have emerged as an amazing remedy to these constraints and have received a lot of attention, due to its ability to modify the operating frequency, impedance bandwidth, polarization, and radiation pattern in accordance with the operating needs [2]. Frequency-reconfigurable antennas, akind of reconfigurable antenna, have the ability to alter their operating frequency band in real-time as needed, assuring the consistency of other performances, such as radiation pattern and gain [3]. The antenna can reconfigure its frequency by utilizing different switching techniques that alter the current flow distribution in the radiating structure [4]. Micro-electromechanical switches (MEMSs) [5], lumped elements [6], optical (photo conductive) switches [7], varactor diodes [8], PIN diodes [9], and electronic radio frequency (RF) switching devices [10] can all be used to achieve the reconfigurability feature.
Since PIN diode is considered as favourable candidate to many researchers as it has acceptable performance, low cost and ease of fabrication. In this work the PIN diode is used to alter the surface current flow in order to obtain frequency reconfigurability. Two PIN diodes are employed in the radiating patch of antenna and the on and off conditions of these diodes has an impact on the radiating patch's surface current distribution, which results in reconfiguration characteristics.

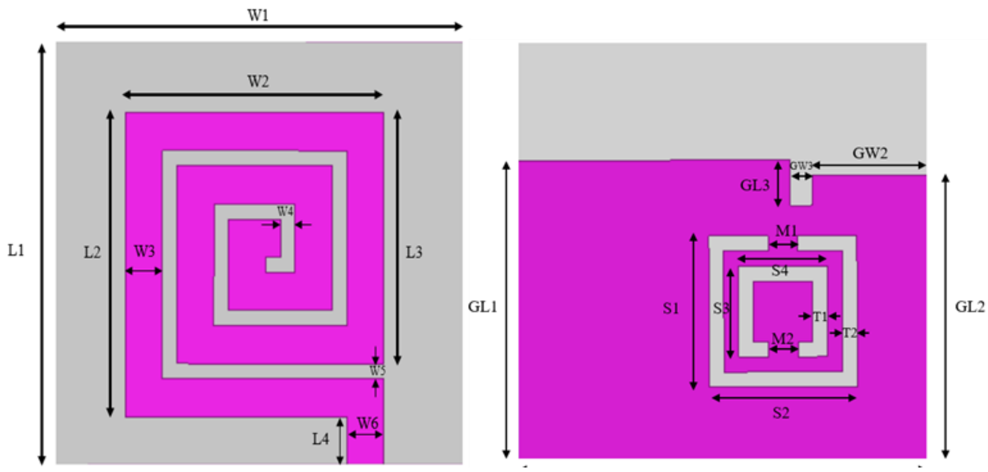
Related Work
Reconfigurable spiral antennas have drawn a lot of attention because of their appealing features, and a considerable amount of works have been presented in past years. In [11], a frequency reconfigurable spiral antenna suitable for mobile applications was proposed, 5 PIN diodes are inserted in various positions of spiral structure to achieve frequency

reconfiguration. Tingting Zhanget al proposes a frequency and polarization reconfigurable spiral antenna which exhibits wider reconfigurable bandwidth in [12]. The reconfiguration is achieved by adding an extended dual-layer microfluidic to the spiral antenna and tuning the channels with liquid metal EGaIn. A reconfigurable 4-arm Archimedean spiral antenna was presented in [13]. The antenna operates at 3 different bands at different operating states of two RF switches. In [14], a frequency and pattern reconfigurable spiral antenna,based on graphene, designed for terahertz specific band applications was presented. The antenna can operate at 1-2 THz, and the obtained maximum impedance bandwidth can be up to 26.68 %. A reconfigurable square spiral antenna operating between 0.4–3 GHz and 4.4–5.9 GHz was presented in [15]. Two PIN diode is implanted after the third and fifth turn of spiral in order to achieve reconfigurability.

In this paper, a frequency reconfigurable spiral antenna loaded with square spilt ring resonator in the ground plane was presented. The antenna is designed on FR4 substrate with thickness of 1.6 mm and has a compact dimension of 28×28 mm^2. Two PIN diodes are employed in radiating patch to achieve frequency reconfigurability and thus antenna radiates at 1.7, 2.4, 2.5, 3.2, 4, 4.1, 7.4, 7.5, 8.5 and 8.7GHz band,with S11 less than -10 dB in different switching states of diode. All the simulations in this work are carried out in HFSS version 15.0.

Antenna Design Methodology.

The proposed design of spiral antenna is shown in the Figure 1 and detail dimensions was listed in Table 1. The proposed structure is outlined on FR4 substrates with thickness h = 1.6 mm, relative permittivity ε_r= 4.4 and loss tangent δ = 0.002, and has a compact dimension of 28×28 mm^2. Along with the three turns of spirals, as radiating patch, the antenna has a Defective Ground Structure with a Square Slit Ring Resonator (SSRR) structure etched into the ground plane. The Three turn spirals has equal width of 2.5 mm(W3), and 1mm(W4) spacing between them which is printed on top of the FR4 dielectric material with ground plane in bottom. With square slit resonator structure in ground plane along with slots, the near field boundary conditions are changed, resulting in additional resonating band with better radiation performance.



(a)(b)

Fig. 1: The Proposed Structure of Microstrip Spiral Antenna

Table 1: Dimensions of Proposed Design.

• Parameters	• Dimensions(mm)	• Parameters	• Dimensions(mm)
• L1	• 28	• GL3	• 3
• W1	• 28	• GW2	• 8
• L2	• 20	• GW3	• 1.5
• L3	• 16.5	• S1	• 10
• L4	• 3.25	• S2	• 10
• W2	• 17.5	• S3	• 6
• W3	• 2.5	• S4	• 6
• W4	• 1	• M1	• 2
• W5	• 1	• M2	• 2
• W6	• 2.5	• T1	• 1
• GL1	• 20	• T2	• 1
• GL2	• 19	•	•

Results and Discussion

The antenna shown in Figure2 operates at four band with S11 less than -10 dB which is shown in Figure 6.7. The operates at 2.4, 3.2, 4.1 and 7.5 GHz, with -27 dB, -15dB, -16.6 dB, and -14 dB respectively, satisfying the current demand for 5G applications. In particular the antenna exhibits -10 dB impedance bandwidth ranging from 2.3 to 2.52 GHz with 2.4 GHz as centre frequency, 3.13 to 3.3 GHz at 3.2 GHz frequency band, 3.97 to 4.24 GHz with 4.1 GHz as centre frequency, and lastly 7.38 to 7.82 GHz with 7.5 GHz as centre frequency.

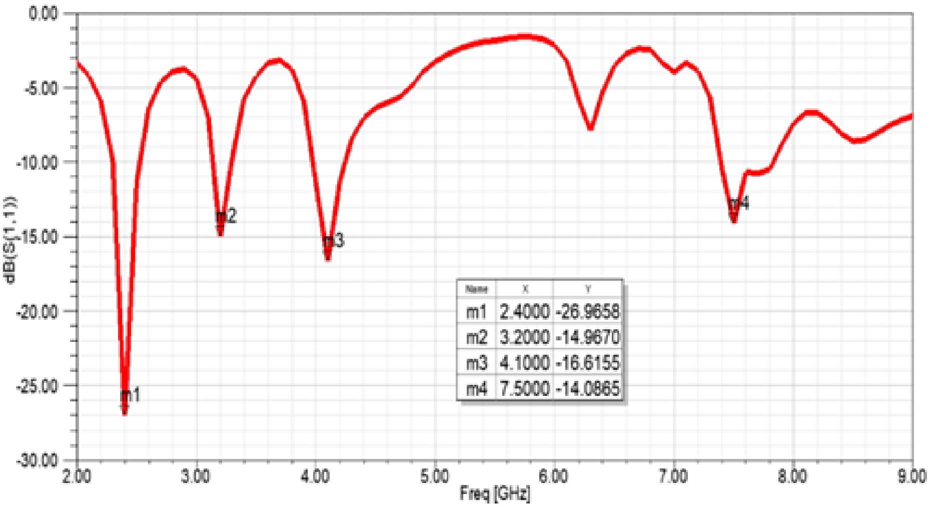


Fig. 2: S11 Plot of Proposed Spiral Antenna.

The Voltage Standing Wave Ratio (VSWR) for center frequenices is shown in Figure 3. VSWR at 2.4, 3.2, 4.1, and 7.5 GHz are 1.09, 1.43, 1.34 and 1.49 GHz respectively and also the antenna exhibits the peak gain of 0.9, 4.14, 4.04 and 1.60 dB at 2.4, 3.2, 4.1 and 7.5 GHz respectively and the directivity obtained is 2.49, 3.456, 5.011 and 4.03dB.

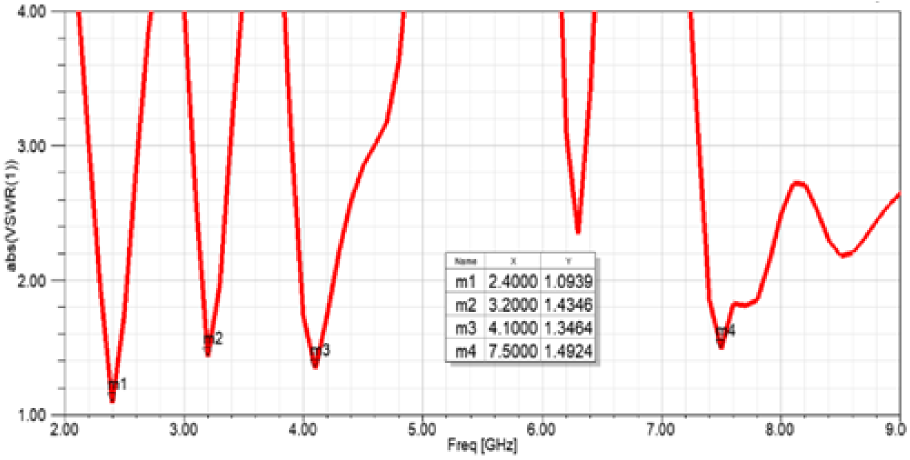
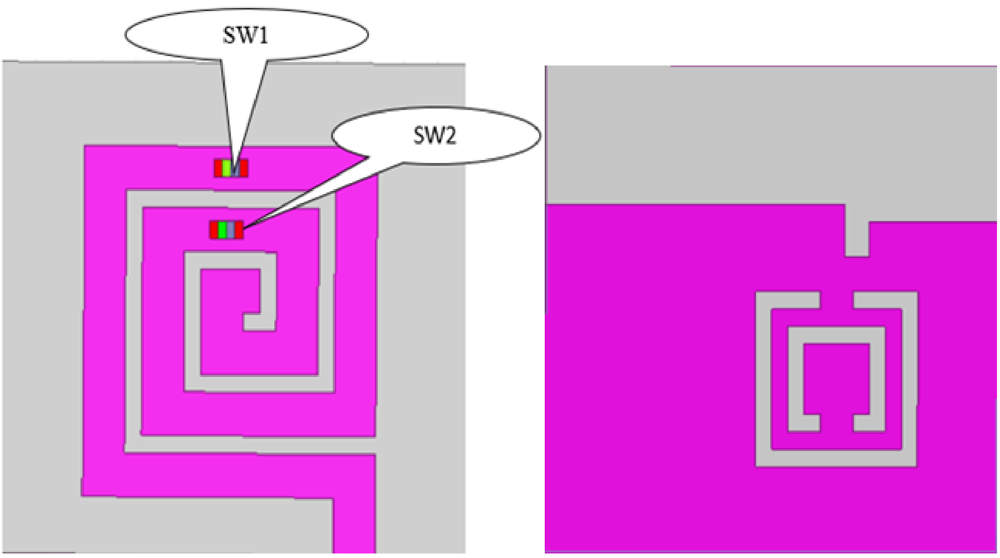


Fig. 3: VSWR values of obtained operating bands

6.3.3. Frequency Reconfiguration

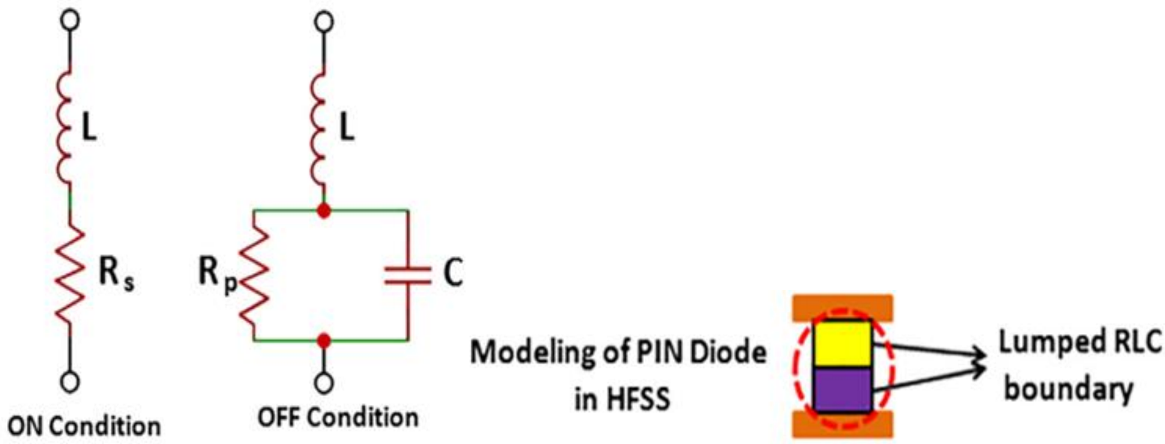
Two PIN diode switches are used in the proposed configuration to achieve frequency reconfiguration, which are placed after the first and second turn of spirals in radiating patch respectively as shown in Figure 4.



(a) (b)

Fig. 4: Proposed Frequency Reconfigurable Spiral Antenna Structure: (a) Radiating Patch and (b) Ground Plane

In the proposed design, asmall rectangular strip has been positioned to accommodate as PIN diode during HFSS simulation. After selecting lumped RLC, the resistance (R) value, which denotes the ON state, is declared and then the capacitance(C) value is declared for the OFF state. PIN diode exhibit some capacitance when it is inOFF and some resistance when it is ON.Fig 5(a) shows the equivalent circuit modelling of a PIN diode in both ON and OFF circumstances, while Fig5(b) shows its equivalent HFSS model. The value of resistance used is, R_s = 1 KΩ with inductor L = 0.6 nH for ON condition and R_p = 15 KΩ with capacitor of capacitance C = 0.5pF for OFF condition. Two 0.5 µF capacitors is placed before and after the diode to function as a biasing circuit.



(a) (b)

Fig.5: (a) PIN diode Equivalent Circuit under ON and OFF Condition (b) HFSS equivalent model for PIN diode.

The antenna operates at six different bands (1.7, 2.5, 3.2, 4.1, 7.5 & 8.6 GHz) with S11 less than -10 dB at different states of two PIN diode switches and its plot is shown in Figure 6. The detailed parameters at different switch states are shown in Table 2.

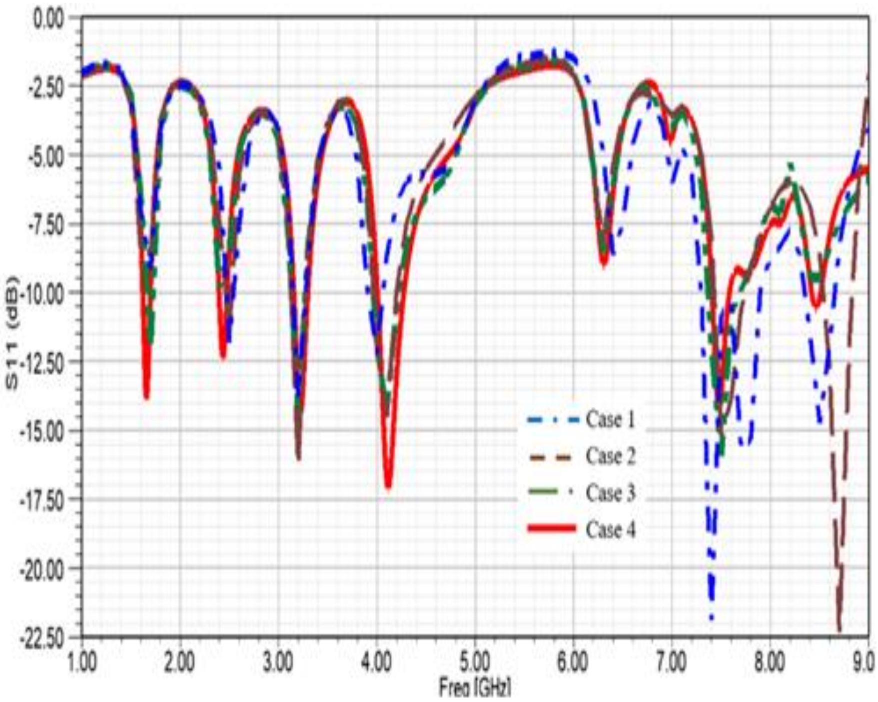


Fig. 6: S11 Comparison of Proposed Reconfigurable Spiral Antenna for different switch states.

Table 2: Results of Reconfigurable Spiral Antenna at different switch states.

Cases	SW1	SW2	Operating Bands (GHz)	Bandwidth (MHz)	Peak Gain (dB)
1	OFF	OFF	2.5, 3.2, 4, 7.4, 8.5	70, 130, 160, 60, 310	0.9, 6.5, 6.3, 11.0, 7.9
2	ON	OFF	2.5, 3.2, 4.1, 7.5, 8.7	60, 150, 240, 320, 300	0.4, -0.9, 6.6, 19.3, 23.9
3	OFF	ON	1.7, 3.2, 4.1, 7.5	60, 140, 260, 330	0.3, 10.2, 17.7, 10.04
4	ON	ON	1.7, 2.4, 3.2, 4.1, 7.5, 8.5	80, 90, 150, 280, 180, 40	0.9, 1.49, 19.3, 17.3, 14.6, 11.5

A comparative analysis has been done to know the significance of the proposed design and it is given in Table 3.

Table 3: Comparative analysis of the proposed Antenna configuration.

Sl No.	Ref	Size (mm^3)	Antenna Designed	Centre Frequencies	Freq Reconfig
1.	[15]	95.5 x 95.5 x 20	Reconfigurable Square Spiral Antenna	Single (UWB)	Yes
2.	[16]	33 × 16 × 1.6	L shaped Freq Reconfigurable MSPA	Six	Yes
3.	[17]	34 × 34 × 3.2	A new polarization reconfigurable antenna	Single	Yes
4.	[18]	28 x 28 x 1.6	spiral shaped of circular microstrip patch antenna	Four	No
5.	[19]	24 x 22 x 0.6	Octagonal Spiral Antenna	Eight	No
6.	[20]	45 × 40 ×0.254	Spiral Antenna Array	Single (UWB)	No
7.	Prop.	$28 \times 28 \times 1.6$	Reconfigurable Rectangular Spiral Antenna	Ten	Yes

Conclusion

A novel planar frequency reconfigurable spiral antenna which consists of three spiral turns as radiating area is presented in this work. Since the antenna has a compact size of $28 \times 28 \times 1.6$ mm^3 it can easily be integrated into modern wireless devices.The antenna consist of three turns of spiral structure as a radiating area and has a Defective Ground Structure with a Square Slit Ring Resonator(SSRR) etched into the ground plane.Two PIN diodes are employed in radiating patch to achieve frequency reconfigurability.The frequency reconfigurability implementation led to the performance improvement. The reconfigurable antenna designed operates at ten different centre frequencies (1.7/2.4/2.5/3.2/4/4.1/7.4/7.5/8.5/8.7) at four different switching states of PIN diodes with better gain, wider bandwidth, and exhibits stable radiation properties throughout the entire band of operation.For applications specific to WLAN, WiMAX, and C-band standards, the design is promising because to its small size and frequency reconfigurability phenomenon.

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