Dielectric Resonator Antenna Metallic Strip Integrated for Frequency Reconfigurable Applications

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Abstract

In this study, a frequency -reconfigurable dielectric resonator antenna (DRA) with a metallic strip coupling operating in the IEEE 802.11a band is presented. The resonating element consists of a single rectangular dielectric resonator (RDR) excited by three metallic strips attached to the front side of the RDR. To achieve frequency reconfigurability, the RDR can be excited by one, two, or three metallic strips. The exciting metallic strips are connected to a three -fork microstrip network integrated with two Positive-Intrinsic-Negative (PIN) diodes. Frequency reconfigurability is achieved by switching both PIN diodes from the OFF state to the ON state. The measured -10 dB return loss frequencies for the OFF-OFF state, ON-OFF state, and ON-ON state were 5.80 GHz, 5.60 GHz, and 5.58 GHz, respectively. The compact size of 30 × 25 mm2 makes it a suitable candidate for linearly polarized applications operating within the IEEE 802.11a band.

Keywords:

Dielectric resonator antenna, frequency reconfigurable antenna, IEEE 802.11a, PIN diodes.

Highlights:

- Dielectric resonator antenna
- Reconfigurable frequency

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1. Introduction

Reconfigurable antennas are good candidates for wireless systems as they are able to enhance channel capacity and support multifunctional devices, including Multiple-Input Multiple-Output (MIMO) systems [1]. However, the design complexity and compactness are major concerns that need to be considered [2].The dielectric resonator antenna (DRA) has gained much attention in recent years due to its appealing features compared to microstrip antennas: low cost, compact size, light weight and, ease of excitation [3].

Numerous procedures have been acknowledged in the literature for achieving frequency cognitive antennas. These approaches are essentially categorized into three main groups, namely: mechanical [4, 5], tunable materials [6, 7], and integrated electronics [8, 9]. Mechanical alteration requires a physical change, which necessitates precise time delays. However, tunable materials have major disadvantages such as temperature sensitivity and high bias voltages. Therefore, the electronic method has become the preferred choice for designing frequency reconfigurable antennas. Furthermore, electronic components provide the advantage of compact packaging, small size, and the availability of small commercially available components that can be incorporated with the antennas.

In the open literature, various methods have been introduced to achieve frequency–agile DRA antennas. Huang (2002) [10] presented a single—-element reconfigurable antenna. Frequency agility is achieved by embedding a pair of narrow slots in the antenna's ground plane, allowing the resonant frequency of the DRA antenna to be altered by modifying the embedded slot length. The 75 × 75 mm^2 antenna achieved dual resonance operation, with an operation frequency of 183 MHz for a slot length of 20 mm and 210 MHz for a slot length of 18 mm. Hao et al. (2011) [11] reported a single–-element frequency--agile DRA triggered by a differential port using either a chip capacitor or a chip Varactor. The 100 × 100 mm^2 antenna operates from 2.6 to 2.8 GHz with a gain of around 6 dBi for resonance frequency sweep. Yan et al. (2013) [12] presented a single DRA with a differential port for MIMO applications. Frequency agility is achieved by adding reconfigurable parasitic slot loadings. Danesh et al. (2016) [13] documented a single reconfigurable C-shaped DRA operating in the ISM and LTE bands. The 30 × 37 mm^2 antenna uses two PIN diodes as switches coupled to a Coplanar Waveguide (CPW) fed line. Previous reports have suffered from either bulky size or design complexity for frequency agility. In this study, an attempt to overcome these limitations is presented.

The objectives of the presented article are twofold. Firstly, to develop a simple feeding network to achieve a frequency reconfigurable DRA. Secondly, to ensure that the overall design size is compact compared to other designs presented in the literature.

The order of the presented manuscript is organized as follows: The proposed antenna design is elaborated in Section II. Then, the obtained results and related analysis are presented in Section III. Finally, the conclusions and future work are discussed in Section IV.

2. Antenna Configuration and Design

Fig 1. depicts the proposed antenna geometry. The antenna essentially consists of an RDR mounted on the top of a substrate. To achieve frequency reconfigurability, the RDR is excited by a three terminal microstrip network which is connected to metallic strips pasted on the RDR front side. The microstrip feeding network is integrated with two PIN diodes to achieve frequency agility as explained in Section 3. The metallic strip feeding topology is implemented due to its simplicity and compatibility to operate frequency reconfigurability compared to other coupling mechanisms such as slot coupling or direct microstrip coupling.

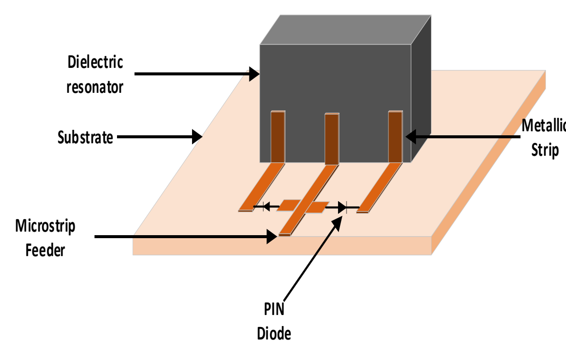


Fig. 1. The proposed reconfigurable DRA

The rectangular DRA shape was selected due to its attractive features such as; its design simplicity compared to other DR shapes like cylindrical and spherical geometries. Furthermore, two of the RDR dimensions shape can be selected independently. The dimensions of the RDR at the specified resonance frequency can be estimated using Eqs (1) – (3).

$$f_0 = \frac{15\left[a_1 + a_2(w/2h) + 0.16(w/2h)^2\right]}{w\pi\sqrt{\varepsilon_r}} \tag{1}$$

$$a_1 = 2.57 - 0.8\left(\frac{d}{2h}\right) + 0.42\left(\frac{d}{2h}\right)^2 - 0.05\left(\frac{d}{2h}\right)^3 \quad (2)$$

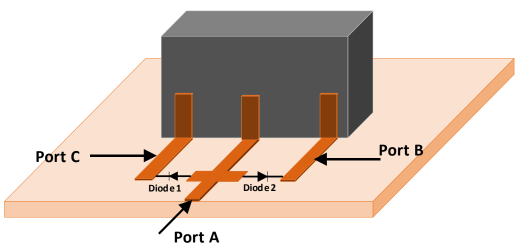
$$a_2 = 2.71\left(\frac{d}{2h}\right)^{-0.282} \quad (3)$$

Where d, w and h are the length, width, and height of the rectangular resonator respectively, ε_r is dielectric permittivity of the DR material.

The metallic strip was used in this design for various reasons. Firstly, their simplicity for fabrication compared to using a slot configuration. Secondly, the metallic strips can be easily integrated with the PIN diodes for frequency reconfigurability compared to other coupling schemes.

3. Reconfigurable Operation Principle

Three possible reconfigurable states are possible according to Fig 2. The frequency reconfigurability is achieved by switching the PIN diodes between ON and OFF state. By controlling the PIN diodes state, the number of metallic strips coupling the signal to the RDR is varied, resulting in different resonance states.



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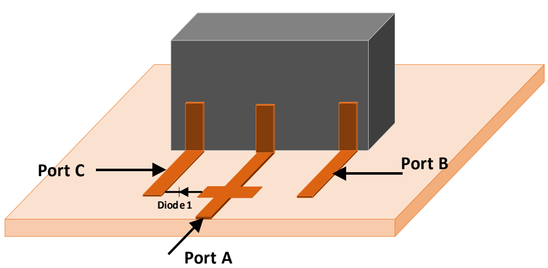

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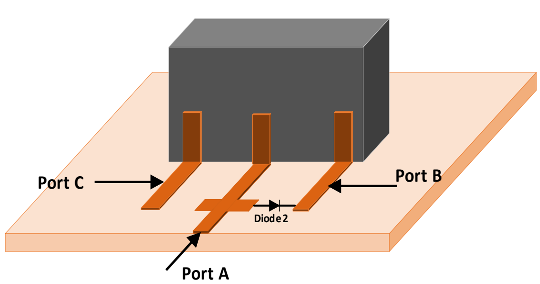

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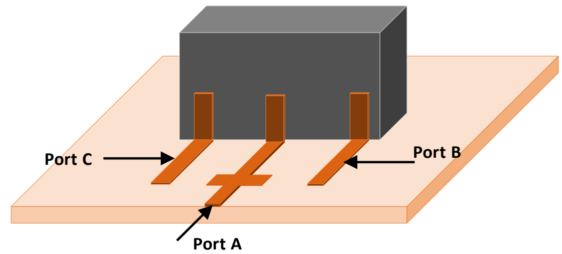


(d)

Fig. 2. Different coupling schemes for the RDR to achieve frequency agility

As can be seen from Fig. 2-a, when the two PIN diodes are in the ON state, ports A and B are connected, triggering the RDR and resulting in a unique resonance frequency. In Fig. 2-b, if PIN diode 1 is in the ON state, ports A and C couple to the RDR, leading to a different resonance frequency. Similarly, if only PIN diode 2 is in the ON state, the RDR will be triggered by ports A and B, causing a change in resonance frequency. Finally, if both diodes are in the OFF state, as shown in Fig. 2-d, the RDR will be triggered only by port 1, resulting in another resonance.

4. Results and Discussions

Fig 3. shows the simulation carried out using Computer Simulation Technology (CST) microwave studio. The DR was made of Alumina material with a dielectric constant of 9.8. The laminate form Rogers 4003C with a dielectric constant of 3.38 is used to model the substrate. The width of the metallic strips was kept the same as of the three microstrips etched on the substrate front plane to maintain the same impedance of 50 Ω.

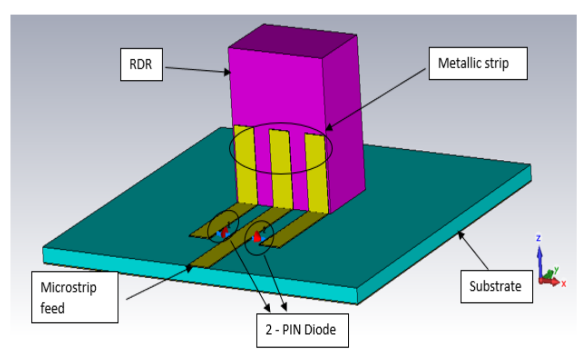
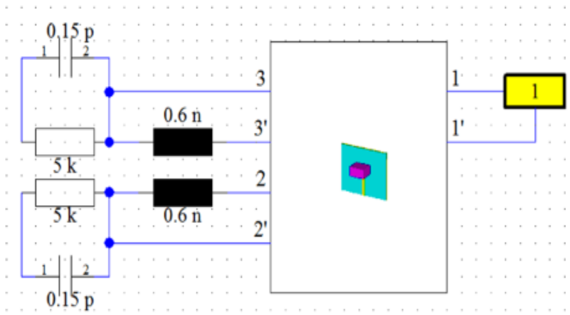


Fig. 3. The modeled antenna using CST software

Fig.4 depicts the proposed antenna's circuitry with the PIN diodes integrated. This design makes use of Infineon company PIN diodes BAR63-02V. According to the datasheet of the PIN diodes, in the ON state, the PIN diode acts as a parallel tank of capacitor and inductor in series with resistance, as shown in Fig 4-a. The diode equivalent circuit consists of a resistor in series with a reverse-biased inductor. The values of the lumped elements are provided by the manufacturer datasheet. To obtain accurate results, the simulation of the proposed resonator with the integration of the PIN diodes requires many details. Fig 4-b depicts the integration of the PIN diodes when both diodes are turned OFF. The datasheet specifies the values of the lumped elements.



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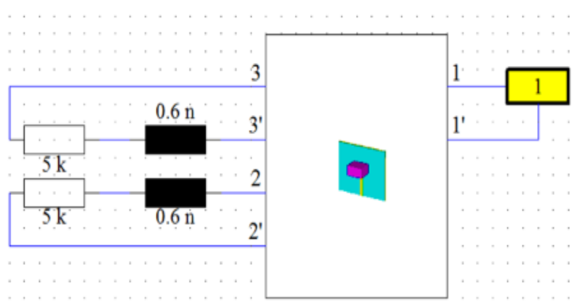
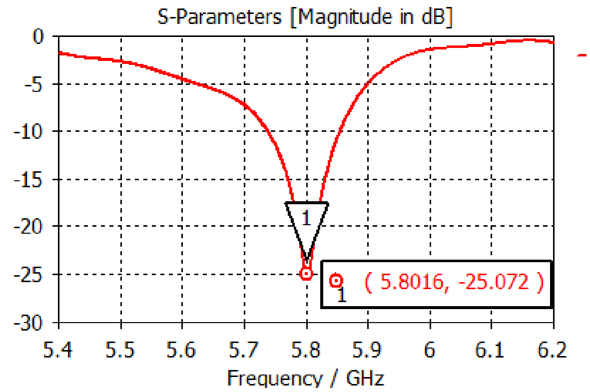


(b)

Fig. 4. Modeled antenna with integrating the PIN diodes; (b) both diodes are ON; (a) both diodes are OFF

Initially, the antenna was fine-tuned to operate at 5.8016 GHz once both diodes are set to the OFF state as can be seen in Figure 5-a with a bandwidth ranging from 5.75-5.85 GHz. In Fig 5-b if one of the diodes is set to the ON state, the resonance frequency is shifted to 5.603 GHz with a bandwidth range from 5.58-5.65 GHz. Lastly, in Fig 5-c, with both diodes set to the ON state, the resonance frequency is shifted to 5.588 GHz with a bandwidth from 5.75-5.605 GHz. From these results, it can be observed that the objective of attaining a frequency-reconfigurable antenna using the proposed configuration is achieved. The impedance matching was approximately 49 Ω matching the antenna feed impedance for the first resonating state. A 47 Ω impedance was obtained for the second resonating state and 46 Ω for the third resonating state. The impedance matching is optimal when no PIN diode is activated due to the losses associated with the PIN diode integration and circuitry.



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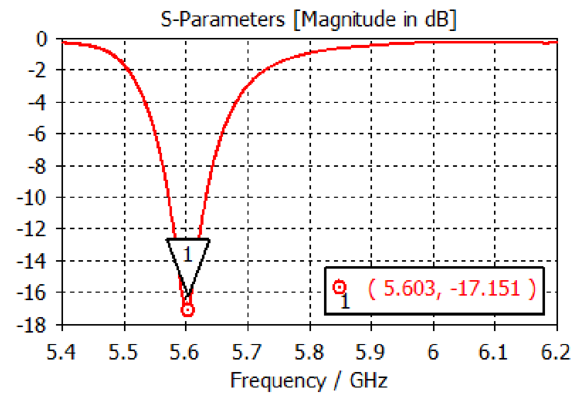

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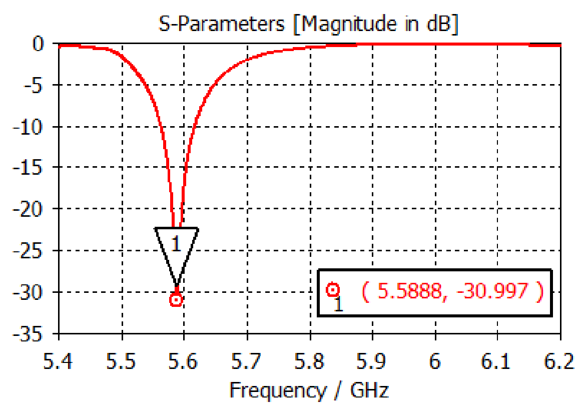
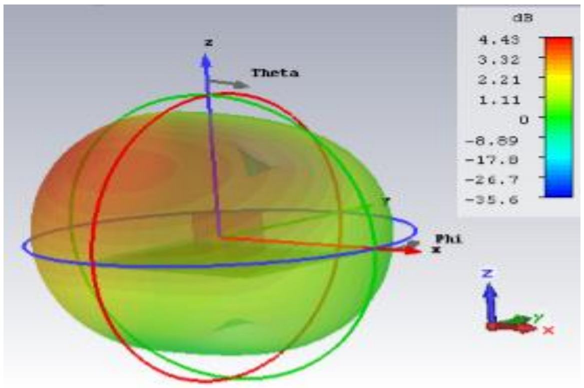


(c)

Fig. 5. Different resonance states for proposed antenna (a) both diodes are OFF state; (b) one diodes is ON state; (c) both diodes are ON state

Fig 6. depicts the 3D radiation pattern. Fig 6.a shows the radiation pattern when both of the PIN diodes are in the OFF state, with a gain of the antenna at 4.43 dBi at 5.8 GHz. Meanwhile, Fig 6.b shows that the obtained gain is about 2.62 dBi. Finally, when both diodes are in the ON state, the obtained gain is around 2.18 dBi. Three main things can be noticed from Fig 6. Firstly, a directive radiation pattern is obtained for the three resonance frequencies. Also, the gain amount is reduced as the number of excitation ports is reduced.

However, the gain range for the three cases is still acceptable. The radiation efficiency when no PIN diodes are in the ON state was 75%. When one PIN diode is set to the ON state, the efficiency was approximately 70%. Finally, when two PIN diodes are set to ON state the efficiency was 68%.



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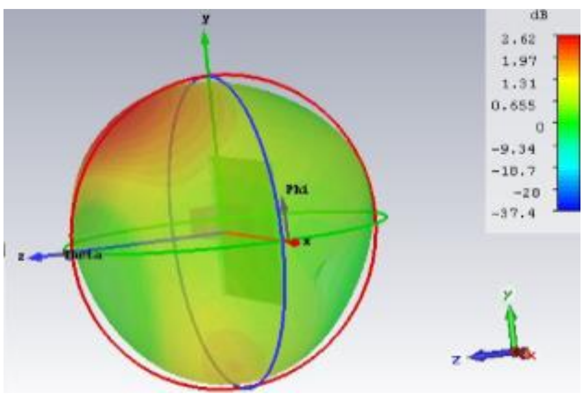

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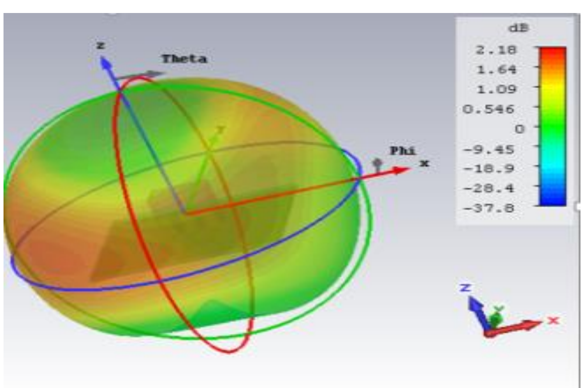

(c)

Fig. 6. The 3D radiation pattren for (a) both diodes are OFF; (b) one diodes is ON; (a) both diodes are ON

5. Limitations and Future Work

The limitations of the proposed antenna are related to the number of metallic strips that can be pasted on the RDR front side. For future work, the proposed resonating element can be implemented to create an array to enhance the gain performance and expand the resonance frequency. The tradeoff between the compactness and the gain and bandwidth performance can be compensated for if an array design is considered

6. Conclusions and Future Work

In this article, a novel frequency reconfigurable DRA operating in the IEEE 802.11a band is presented. The frequency agility is achieved by controlling the resonant frequency using three metallic strips driven by two PIN diodes. Initially, the antenna is fine-tuned to operate at 5.8 GHz. If one of the PIN diodes is set to the ON state, the resonance shifts to 5.60 GHz. If both PIN diodes are set to the ON state the resonance frequency becomes 5.58 GHz. The compact size of the 30 × 25 mm^2 antenna makes it a suitable candidate for linearly polarized applications within the IEEE 802.11a band such as WIFI systems. Table 1 compares the proposed design with other single DRA reported in the literature.

Table 1: Compression between proposed antenna and other frequency reconfigurable single DRA presented in the literature

Reference	size [mm^2]	Gain [dBi]	Operating frequencies	Efficiency%	practical considerations
Huang 2002 [10]	75 × 75	6	Three resonating states 1832 MHz 2010 MHz 2033 MHz	Not mentioned	The DR is coupled by two slots carved at the bottom plane. The resonance frequency is obtained by varying the slot length. To vary the slot length, the proposed antenna model was fabricated with different slot lengths to obtain frequency agility
Hao et al (2011) [11]	100 × 100	6	Four resonating states 2.74 GHz 2.52 GHz 2.33 GHz 2.12 GHz	Not mentioned	The antenna model consists of dual port excitation. The frequency agility is obtained by loading the DR sides with Varactor diodes which capacity depends on the applied voltage.
Yan et al (2013) [12]	80 × 84	Not mentioned	Three resonating states 622 MHz 700 MHz 780 MHz	Not mentioned	The design is complex as it utilize a two port feeding topology and frequency agility is achieved by exciting different resonance modes within the DR boundaries
Danesh et al (2016) [13]	30 × 37	Not mentioned	Three resonating states 210 MHz 260 MHz 410 MHz	71	The antenna consists of a C-shaped DR. The frequency agility is obtained by loading the DR with two PIN diodes.
Proposed work	30 × 25	4.42	Three resonating states 5.8 GHz 5.6 GHz 5.58 GHz	75	The DR excited by three metallic strips pasted on the DR sides. The frequency reconfigurability is obtained by controlling the metallic strips number exciting the DR with the use of PIN diodes.

Conflict of Interest

The authors state that they have no recognized competing financial interests or personal relationships that could appear to have influenced the work described in this paper.

Data Availability

The data used to support the findings of this study are included in the article. Further data or information is available from the corresponding author upon request.

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