Reconfigurable Dielectric Resonator Antenna for GSM, LTE, and 5G applications

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Abstract. For this research, a frequency reconfigurable dielectric resonator antenna (RDRA) is studied and designed, the reconfigurability is achieved by using two PIN diodes as switches. The designed antenna operates in the frequencies 3.6 GHz, 2.6 GHz, and 1.80 GHz. It is also operating on the lower band of 5G (3.4-3.8 GHz), which allows the antenna to be used in various mobile communication devices. The antenna is a compact one its dimensions are 20×36×4.8 mm3, The proposed antenna is made up of 3rectangular shaped Dielectric Resonatorsm (DR) 1, 2 and 3 (each with different permittivities and different dimensions) their respected permittivities are 12.85, 1.96 and 12.85 respectively. Two PIN diodes are used as switches and are positioned on the microstrip line between the DRs to guarantee the reconfigurability purpose. Finally, simulation results are presented and discussed, the results are related to the reference antenna from the literature for validation and performance measurement purposes. The designed antenna offers a suitable performance level and provides three modes of operation 20%, 12%, and 10%.

Keywords: Dielectric Resonator Antenna, Electromagnetics, measurements, Reconfigurable antennas

1 Introduction

Due to the attractive characteristics of Dielectric Resonator Antenna (DRA) to use p dielectric materials as radiating elements with the aim of building antennas, the approach has have gained considerable recognition in recent years. The major feature of this system is the number of feeding approaches used to stimulate a dielectric resonator's radiant modes [1, 2]. As mentioned in [3-5], in addition to other strengths such as substantial diminutive diameter, good radiation resistance, broad impedance bandwidth as well as high gain, an adequate microwave system model, various DRs numbers and shapes. Multiple techniques may be applied to excite Dielectric Resonator, some of them are; aperture coupling [10], coplanar wave guides (CPW) [9], microstrip feeds [7, 8], as they can be paired with lines of transmitting and wave guides [4][11],

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besides the evolutionary algorithms that include aperture and CPW and, probe and slot combinations, [2]. A systematic analysis of the various methods of feeding is stated in [2]. Because conductors are not used, Dielectric Resonator Antennas are distinguished by extremely low loss, occasioning higher performance when the low-loss dielectric radiation is used. With several design specifications such as scale, structure, dimensional ratios, electrical conductivity and seamless integration during the production processes, DRAs offer higher reliability in the design phases [12]. In comparison, DRAs give a relatively wider bandwidth as opposed to dipole antennas and microstrip. Miniaturization strategies must be added to create the size of the antenna ideal for realistic use within the appropriate operating frequency. Because of their use in contemporary communication networks reconfigurable antennas have gained a lot of interest. As multioperation antennas, they have numerous small and/or large bands concurrently to accommodate different frequency bands for multiservice networks. The reconfigurability concept has been embraced to obtain the selectivity of frequency bands, radiation pattern, and polarization of a given antenna so that the ultra-wide-band (UWB) and multi-band antennas can be replaced [13]. The reconfigurable antennas could provide several services in a comparably small structure. They are becoming serious contenders for the emerging and even existing wireless applications [14, 15].

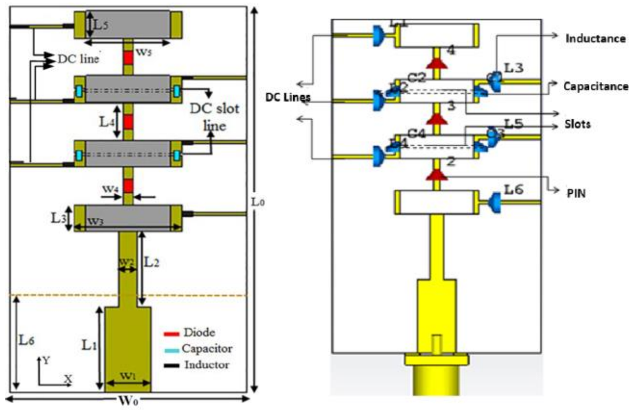
Owing to their potential application in contemporary mobile communications networks the reconfigurable antennas have gained a lot of interest. The literature has documented different frequency control methods [17]. Reconfigurability in an antenna structure could be achieved is mainly by connecting or disconnecting some of its parts using, optical switches, RF switches, Field Effect Transistors (FETs), varactor diodes, and PIN diodes [18]. The reconfigurability performances of DRAs have been investigated [20]. the Reconfigurarable DRAs offer tunability and adjustability in one of the antenna characteristics like Radiation pattern [22] [18], Polarization, operational frequency band [21], or a combination of them [25-27].

This study is built on research conducted by Danesh et al.[3] addressing GSM, LTE, as well as 5 G technologies with a frequency reconfigurable antenna. A compact, reconfigurable DRA frequency is provided in this study. Dual-PIN diodes (BAR 50-02V), used as on-off switches are mounted on the power cable system and the dielectric resonator that follows is segregated. Through flipping the two PIN diodes, we identified 3 Narrowband operating modes. The recommended antenna may be used between 1.8 GHz and 3.8 GHz for GSM, LTE, and 5G devices.

2 Design and configuration

Fig. 1(a) displays the possible geometry of the reconfigurable antenna at [3]. It consists of rectangular Dielectric Resonators stimulated by a substrate of with $20\times36\times1.5748$ mm^3, $\varepsilon r=3.2$ and $\tan\delta=0.003$, PIN diode switches, metal sheet beneath the Dielectric Resonator Antenna and microstrip feed line. The DR dielectric constant has an $\varepsilon r=10$ and $\tan\delta=0.002$ and a thickness of h=4mm. Additionally, there are Direct Current lines as well as Direct Current slot lines within the framework. The black dots below the DRs indicate the slotted feed line. The substrate is mounted on a w1=3.8 mm width microstrip feed line with. Three PIN diodes are among each of the 2 rectangular DRS positioned on the feed lines.

A Direct Current bias circuit controls the three switching PIN diodes (BAR 50-02V). Within each Dielectric layer, 2 successive bias lines with a resistance of 100pH are attached to the antenna design. The DRA dimensions (mm) are: L6=9.0, L5=2.5, L4=3.5 mm, L3=2.5, L2=11.5, L1=8.0, W5=7.0, W4=0.7, W3=8.0 and W2=1.3.



(A) (B)

Fig. 1. Illustration. 1. (A) DRA schematics suggested in [3], (b) Re-simulation of the DRA relation using (CST) Microwave Studio.

2.1 Validating the re-simulated antenna

A re-simulation of this aforementioned has been instituted (Fig. 1(B)) to verify our present system based on the selected antenna addressed in [3]. For this project, the 4 narrow-band frequencies are moved approximately 210 MHz to the inferior frequency to accommodate the LTE band by the use of dielectric resonator. Furthermore, the usage of DR enhances radiation efficiency. 4 equivalent metal sheets of $8\times2.5mm^2$ are placed under the DRs. Using the DRs also affects the resonant frequencies to reach the optimum outcome for these narrow-band configurations.

The simulation outcomes of the same antenna indicate strong alignment with that of [3] (Fig. 2) for the last phase with a tiny adjustment. It can be explained by variations across simulation among the specifications of the inherently biased elements, the dwelling of the parasitic diode as well as the consistency. Subject to the circumstances of the PIN diodes this antenna may work at four separate ranges of frequency.

The proposed reconfigurable antenna is fed via a microstrip batch scribbled on the xz plane, as a result, the mode$TEx\delta11$ ($0<\delta<1$) has been excited. Dielectric Waveguide Model (DWM) [28] suggests that this mode's frequency response is usually determined by the y and z parameters, implying that available the x-axis variable may probably be described with a comparatively modest element.

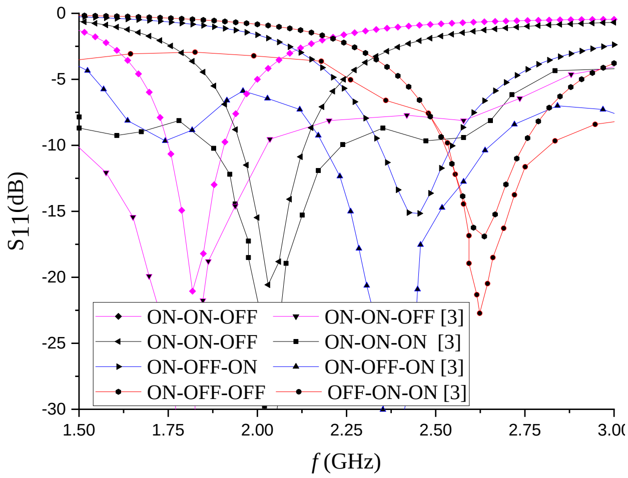
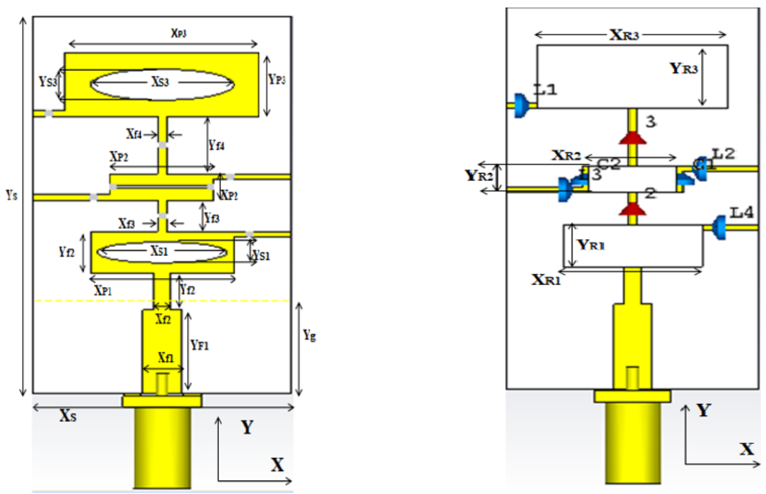


Fig. 2. Comparative analysis of S11 simulation responses with [3] for various switching phases of the PIN diodes.

2.2 Illustration of proposed Reconfigurable Dielectric Resonator Antenna diagram

The next aspect of this research is the optimization of the new Reconfigurable Dielectric Resonator Antenna. Fig. 3 illustrates the desired configuration of the antenna using the CST program interface with the dimensions in table.1.



(a) (b)

Fig. 3 Proposed design in the CST interface (a) top view without DRs, (b) top view with DRs

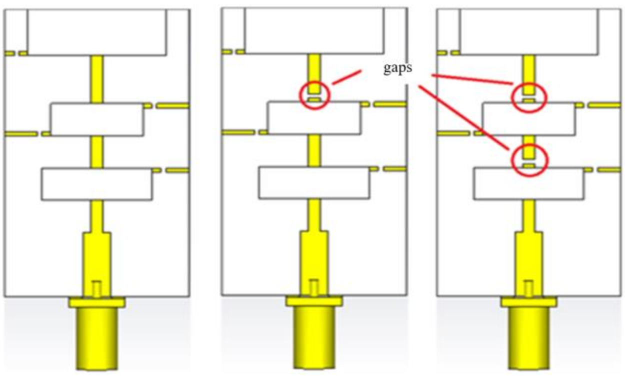
The distinction among our configuration with that of [3] exists in the quantity of resonators as well as DRs in which we have three rather than Four in [3], and the depth of the substrate in our research is 0.8 mm whereas in [3] it is double, which significantly reduces the surface waves thus increases the performance of the antenna.

Table 1 Dimensions for Geometrical parameter of the proposed antenna.

Par.	*Dim. (mm)*	*Par.*	*Dim. (mm)*	*Par.*	*Dim. (mm)*
X_{P3}	15	Y_{P3}	6	Y_{R3}	6
X_g	20	Y_g	9	X_{s3}	5.5
X_{p2}	7.0	Y_{P2}	2.5	Y_{R1}	3
X_{f2}	1.3	Y_f2	3.5	X_{R2}	7
X_{f4}	0.7	Y_{f4}	5.5	Y_{R2}	2.5
X_{f3}	0.7	Y_{f3}	3	Y_{s3}	1.5
X_s	20	Y_s	36	X_{s1}	5
X_{f1}	3	Y_{f1}	8	X_{R1}	11
X_{P1}	11	Y_{P1}	4	X_{R3}	15

2.3 Design and configuration of the proposed antenna with real switches

Figures 3.b, as well as 4, show the layout of our suggested reconfigurable antenna consisting of three different sizes rectangular DR, all of them have the same thicknesses which are 4 mm, with tanδ=0.0019 and εr3=1.96 for DR2 and, tanδ=0.0019, εr=12.85 for DR3 as well as DR1. The 3 DRs are paired with a 3.8 mm long microstrip patch antenna projected on a 20×36×0.8mm3 substrate with a permittivity of εrs=3.2 and tanδ=0.002. Within the conductor patch positioned under the DRs are mounted 3 slots of various shapes and designs. Two Direct Current-like PIN diodes on the feed line are separated by the central rectangular DR, as well as 4 inductors.



(a) (b) (c)

Fig. 4. Antenna with ideal switches: (a) state ON-ON, (b) state ON-OFF, and (c) state OFF-OFF.

To prevent short circuits a 0.2mm notch is introduced to isolate the metal reinforcement below DR2. At the ends of the tube, 2 22 pF capacitors are positioned to offer the RF signal via the feed, and thus the Direct Current signal isolated. To build higher isolating impedance, Bias Direct current-lines that appear to be wired to the Direct Current supply of power through cables that are fitted inductors.

2.4 Reconfigurable antenna's optimization steps

The reproduction aftereffect of the first improved design (Figure 4) with no RF parts or genuine controller has appeared in the 5th figure. Basic hole is scratched on line (Feed line) between the various pieces of radio wire in order to fill in as levers.

Figure 6 shows how RF parts were stacked on the antenna. Expansion RF segments (inductances and capacitors) have indicated a little impact on the input impedance of the antenna, bringing about a balance on the S11 for frequencies under 4 GHz (Figure 7), anyway for frequencies above 4.0 GHz, the impact gets noteworthy.

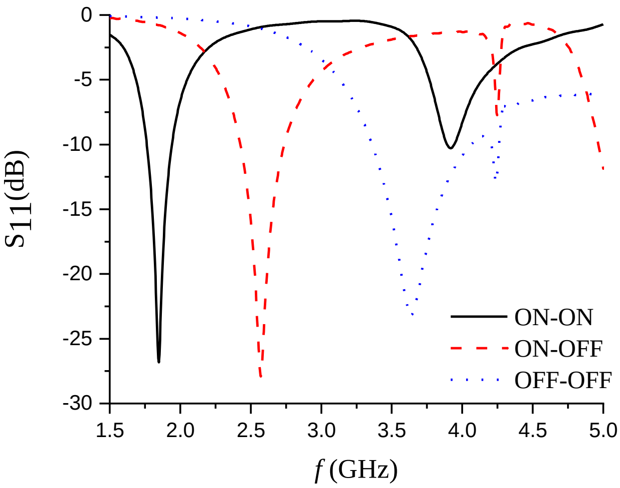


Fig. 5. Results for S11 demonstrating different states of controllers

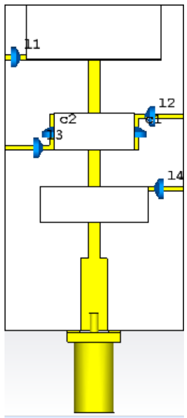


Fig. 6. Demonstration of antenna with ideal controllers and illustrating positions of RF components.

3 Simulation Results

In the following section, a parametric report is mainly propelled to optimize and enhance the dimensions and other parameters of the designed antenna structure to ensure coverage of 1.8 GHz

(GSM) groups, reasonable to be used in LTE systems and supports other 5G applications. After the addition of diodes, the designed antenna structure experienced a noteworthy change in its properties. A streamlining of the distinctive considered boundaries, for example, the elements of the patches under the DRs, the spaces embedded inside these patches and the variety of the DRs Permittivity permitted us to get the last setup of our proposed design.

Figure 5 shows the reflection coefficient (S_{11}) of the proposed antenna with actual switches. Three groups of frequency are gotten relating to the accompanying three states OFF-OFF, ON-OFF, and ON-ON. These groups are: 2.6GHz (LTE), 1.8GHz (GSM), 3.4-3.7, 3.6, and 3.4-3.8GHz, and 4.99GHZ for 5G as appeared in Table 2. As plainly, our structure contrasted with that in [3] presents the above frequency groups by three potential cases (of two switches) though in [3] just 1.8, 2.14, 2.53, and 2.77GHz are acquired by four potential cases (of three switches).

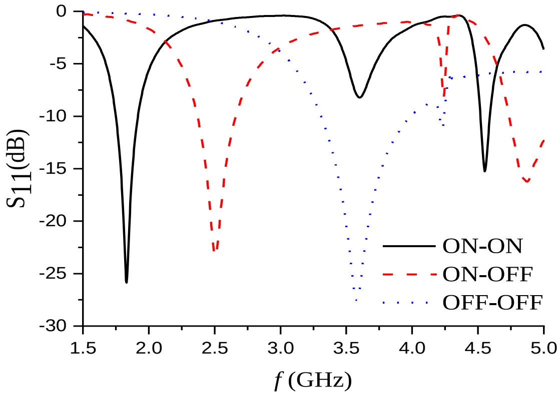


Fig. 7. S11 results after simulation of antenna that comprise of RF components

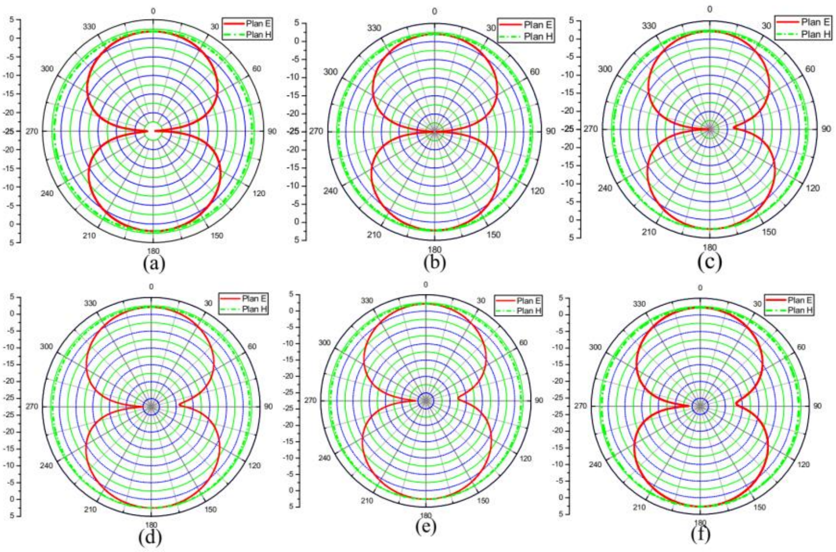


Fig. 8. Simulated radiation patterns of the proposed antenna. H (xz) and E (yz) planes at (a) 1.8 GHz, (b) 2.6 GHz, (c) 3.6 GHz, (d) 3.5 GHz, (e) 3.7 GHz and (f) 3.8 GHz.

Figure 7 shows different operating fervency bands related to different states of the switches (Pin Diodes), A narrow band in the range of1.9 GHz and 1.72, this is corresponding to the ON-ON state of the switches, it covers the 1.8 GHz GSM where 9% bandwidth impedance was obtained. The second band is obtained by the ON-OFF state, this band coffers frequencies between 2.47 to 2.76 GHz with a middle frequency 2.6GHz, the bandwidth of 11% was achieved which is appropriate for LTE systems. The final band achieved by the third state of the switches, OFF-OFF, this band 3.4-4.2 GHz with a middle frequency of 3.6GHz and 19% bandwidth impedance, which suitable for 5G networks.

Table 2 Frequency bands for different switches states.

State	***Frequency bands (GHz)***	***State [3]***	***Frequency bands (GHz) [3]***
1- ON-ON	1.8	1- ON-ON-ON	1.8
2-ON-OFF	2.6	2- OFF-ON-ON	2.14
2-ON-OFF	4.4-4.5 and 4.8-4.99		
2-ON-OFF	4.5-4.9	3- ON-OFF-ON	2.53
3-OFF-OFF	3.6		
3-OFF-OFF	3.4-3.7	4- ON-ON-OFF	2.77
3-OFF-OFF	3.4-3.8		

Fig. 8. shows the simulated radiation pattern of the proposed antenna for six different frequencies. It is noted that the antenna is omnidirectional

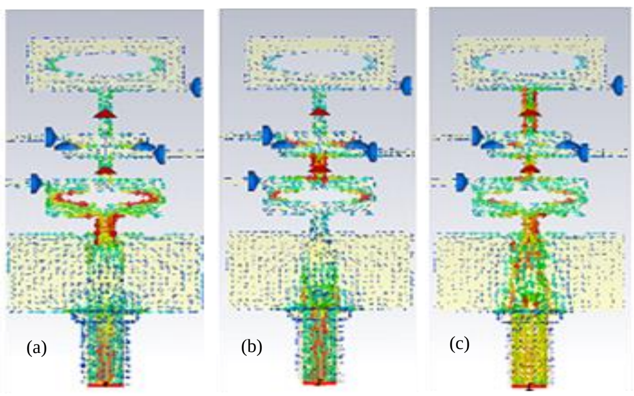


Fig. 8. Illustration of current distribution (a) 3.6GHz, (b) 2.6GHz and (c) 1.8GHz.

Figure 9 presents the simulation of the current distributed on the surface of the antenna structure. In the first OFF-OFF mode, just the first patch is resonating, while in the second mode ON-OFF, both first and second patches are resonating as shown in figure 9(b), while in the last mode ON-ON, the current is concentrated around the second and the third patches.

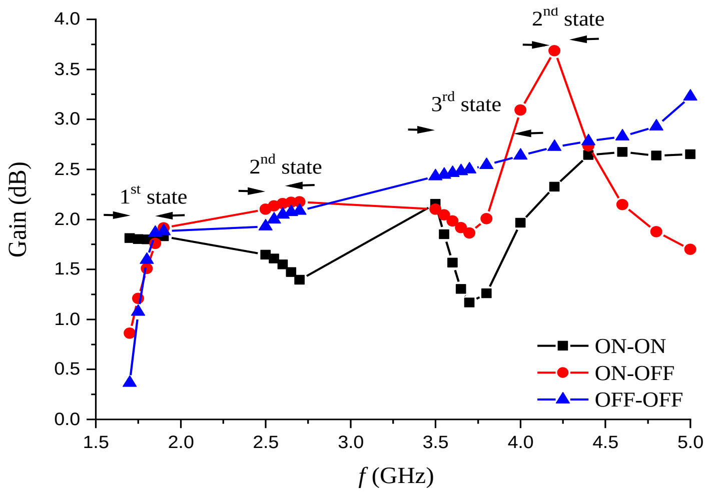


Fig. 9. Antenna gain for different switching states.

The antenna gain is varying massively through the different modes of operations. In OFF-OFF mode, the gain is higher than the other states as shown in Figure 10.

3 Conclusion

A minimized Reconfigurable Dielectric Resonator Antenna, RDRA, has been introduced; it is working at three distinctive frequency groups: 3.6 GHz, 1.8 GHz, 2.6 GHz. In this structure, is reconfigurable DRA fed through microstrip, the physical dimensions are 20×0.8×36mm^3.
There different operation modes for the antenna were generated using two Pin Diodes, which were used as switches with three different combinations (OFF-OFF, ON-OFF, and ON-ON), these modes of operations of the antenna have 19%, 11%, and 9% bandwidth efficiency reciprocally. All 5G, LTE, and GSM applications and services are supported by the antenna structure proposed.

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