Reconfigurable meander line dipole antenna based on two rectangular defected ground structure

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ABSTRACT

In this study, a reconfigurable double-sided meander line dipole antenna (RMLA) incorporated with a tapered balun was developed to function at 0.9 GHz, 2.4 GHz, and 3.7 GHz. Furthermore, the suggests antenna functions at three modes at different frequency bands with pattern reconfiguration. Two positive-intrinsic-negative (PIN) diodes were embedded in the two rectangular defected ground structures to accomplish frequency and pattern reconfigurability. With excellent impedance matching, the return loss in each of these bands keeps beneath -10 dB. The suggested antenna was designed using computer simulation technology 2020 and constructed on a FR-4 substrate with a thickness of 1.6 mm, and dielectric constant of 4.3 mm respectively. Additionally, for antenna size reduction, meander line technique was embedded. The fundamental working mechanism of this reconfigurable antenna is accomplished by changing the status of a radio frequency (RF) switches, which is carried out in on or off mode. For the three resonant bands, the suggested antenna has a voltage standing waves ratio (VSWR) < 2. Up to 80%, the suggested structure radiation efficiency and gain (1−2.8) dBi are calculated. The suggested antenna is well suitable for global system mobile, wireless fidelity (WiFi) and C-band applications because of its notable features of high efficiency, good gain and frequency reconfigurability.

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1. INTRODUCTION

As of their inception, mobile communication and wireless technology development have advanced significantly. In the world of microwave technology, microstrip patch antennas have become increasingly popular recently. Patch antennas have drawn a lot of interest because of their durable, low-profile uses in satellite communications, airplanes, spacecraft as well as in other telecommunications networks [1]-[3]. A variety of feeding mechanisms are used to excite the antenna. Microstrip line feeding, co-axial feeding, proximity coupled feeding, and aperture coupled feeding are the most popular methods [4], [5]. The rapid advancement of contemporary wireless communication systems has increased the demand for multimode reconfigurable antennas, which may be employed in a variety of wireless services with a high data rate [6], [7]. Even farther, depending on the design and network needs, reconfigurable antennas are a possible solution to provide operation in several frequency bands or patterns [8].

Furthermore, instead of using several antennas operating at various frequencies for signal transmission or reception, a frequency reconfigurable antenna is likely the most practical choice for switching its operation to the necessary frequency [9], [10]. Consequently, three categories of reconfigurable antennas have been categorized: frequency reconfigurable, pattern reconfigurable, and polarization reconfigurable [11], [12]. This reconfigurable antenna's basic operating principle involves altering one or more of its operational characteristics, either electrically, mechanically, through switches, or structurally using smart materials, in order to adapt to changing operational requirements [13]. Various switching technologies have been employed. Numerous studies [4], [14], [15]; have documented the use of electrical switches like field-effect transistors (FETs), positive-intrinsic-negative (PIN) diodes, and varactor diodes. To improve isolation and lower losses, mechanical switches in the form of radio frequency micro electro mechanical system (MEMS) have been used. The frequency is adjusted by changing the surface current by toggling on and off the radiofrequency micro-electromechanical system (RFMEMS) switches [16]. PIN diodes offer reasonable performance and cost when compared to RFMEMS switches. A different approach uses photoconductive switching components and is known as optical reconfiguration. Due to their quick switching and quick dynamic reconfiguration capabilities, PIN diodes are preferred in reconfigurable antenna designs. Since PIN diodes are inexpensive, straightforward, and simple to manufacture, many researchers prefer them for their acceptable performance [17].

Additionally, the patch antenna's overall performance is enhanced and its size is reduced using the defected ground structure (DGS) approach [18]. Latterly, the DGS technique was created to improve the properties of numerous microwave devices. To achieve advantages such decreased mutual coupling, smaller antennas, and other advantages, DGS is used in microstrip antennas [19], [20]. Majid *et al.* [21] describes the design of an unique printed rectangular form, multi-band frequency reconfigurable antenna with defective ground structure (FRDGS) for several wireless communication standards. Sathikbasha and Nagarajan [22] provides a succinct explanation of the methods used to design a reconfigurable frequency on a microstrip antenna. Researchers have created a number of approaches that can be employed to offer as well as enhance a single terminal antenna's switching frequency technology.

Furthermore, in contemporary communication systems, small, high-performance antennas are crucial [23]. As a result, there is an urgent need to minimize the components of these devices. The use of high permittivity materials, the Sirpinski carpet fractal method, the meander line method, the shortening of pins between the patch and the ground plane, the introduction of slots into the patch method, the use of meta-materials, and reshaping the antenna are some of the most significant techniques that have recently been investigated for antenna size reduction [24], [25].

Reconfigurable meander line dipole antenna is designed and simulated in this research work. Utilizing the meander line method to minimize size and boost the patch antenna's overall effectiveness. Three resonance frequencies have been identified: 0.9 GHz, 2.4 GHz, and 3.7 GHz. These frequencies depend on the states of the switches. The return loss, voltage standing waves ratio (VSWR), current distribution, and radiation pattern reconfiguration are accomplished at every frequency from these ones. Through this work, the suggested antenna was simulated using computer simulation technology (CST) software.

2. ANTENNA CONFIGURATION

The suggested antenna's geometrical dimensions are illustrated in Figure 1. To illustrate, incorporated into the proposed antenna are two rectangular slots and a tapered balun. A 1.6 mm thick "FR4 free lossy" substrate with both a relative permittivity of 4.3 and a dielectric loss tangent of 0.019 is isolates it from the ground plane. Moreover, in order to minimize the antenna size, the meander curve is used as a radiating component. A microstrip line with an impedance of 50 ohms is used to feed the antenna. The antenna geometry is 126×76×1.6 mm^3 in size. For pattern reconfiguration and to redistribute the concentration of the surface current, two PIN diodes switches are integrated at the tapering balun in the slots at the optimized position. The bottom layer is a DGS. Figure 2, displays the analogous circuitry when pin diodes are used in on and off states. Table 1 summarizes the physical specifications and key characteristics of the optimized antenna. The general calculations following are used to figure out the overall size of the antenna structure.

$$L_T = \frac{c}{2\times f_r \times \sqrt{\varepsilon_r}} \quad (1)$$

$$W_{TB} = \frac{2\times c}{3\times f_r \times \sqrt{\varepsilon_r}} \quad (2)$$

$$L_{DGS} = \frac{c}{4 f_r \sqrt{\varepsilon_{reff}}} \quad (3)$$

Where:
- L_T is the length of radiating arms.
- L_{DGS} is the length of DGS.
- WTB is the width of tapered balun.
- c is the speed of light in free-space.
- f_r is resonant frequency.
- ε_r is the relative permittivity of substrate.
- ε_{reff} is the effective relative permittivity of substrate.

Table 1. Design parameters of the proposed antenna

Parameter	Dimension (mm)
Length (L_1) substrate	126
Width (W_1) substrate	76
Transmission line length (L_2)	75
Transmission line width (W_2)	4
Length (L_4) tapered balun	55
Width (W_4) tapered balun	64
Length (L_{s1}) rectangular slot-1	30
Length (L_{s2}) rectangular slot-2	20
Width (W_3) dipole arms	2

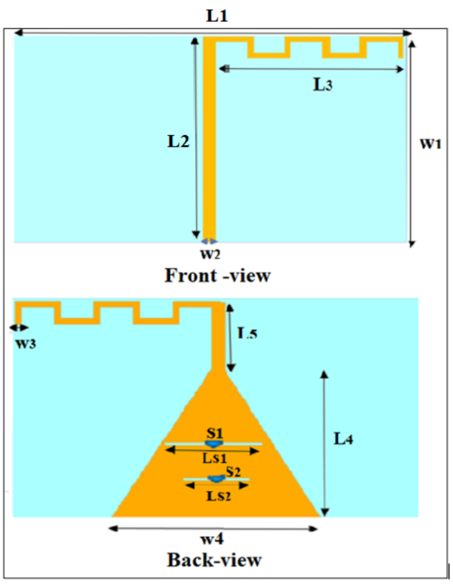


Figure 1. Reconfigurable dipole antenna structure configuration

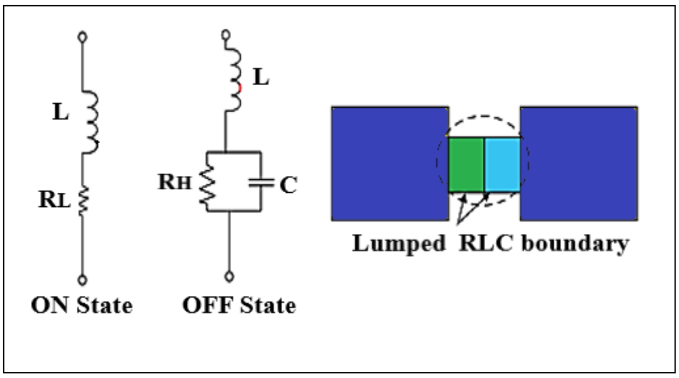


Figure 2. Equivalent circuit of PIN diode model [12]

3. OUTCOMES AND DISCUSSIONS

In this section, the results of the designed antenna will be illustrated. Radiation patterns, VSWR, gain, efficiency, and return loss plots are used to assess an antenna's performance. To verify that pin diodes were operating properly, the surface current distributions were studied.

3.1. Return loss of the reconfigurable antenna

In Figure 3, the combined S11 values with respect to frequency for all combinations of the three scenarios are shown. For an efficient antenna, the return loss should be less than -10 dB. The suggested antenna's resonance frequency is reached at 0.9 GHz with a return loss of -21.627 dB from the off state of both diodes (reverse biased) which is covering global system for mobiles (GSM) band. The proposed antenna may switch between up to three distinct frequency bands. The planned antenna operates at triple band frequencies of 900 MHz (GSM), 2.4 GHz (Wi-Fi), and 3.7 GHz for C-band applications with a return loss of -20.820 dB, -21.472, and -33.870, accordingly. This would be the on state of the two PIN diodes (forward biased) in scenario 2. Nevertheless, once diode D1 is turned on and diode D2 is reverse biased (case-3), the antenna resonates at dual band frequencies of 0.9 GHz and 2.4 GHz with return losses of S11 -28.261 dB and -23.460 dB, accordingly. Hence, at various reconfigurable frequencies, the simulated return loss outcomes are satisfactory.

3.2. Voltage standing wave ratio of the proposed antenna

To start with VSWR provides a numerical representation of the matching. Consequently, VSWR < 2 is chosen as the threshold by assuming that the antenna and transmission line are well-matched enough to prevent reflections of any kind. According to the Figure 4, it can be concluded that, the antenna will result in a single band frequency that is dropped at 0.9 GHz when both switches are in the off configuration at 0.9 GHz. On the other hand, the planned antenna operates on three bands when D1 and D2 are forward biased (on). Furthermore, the antenna utilizes dual band frequencies in scenario 3.

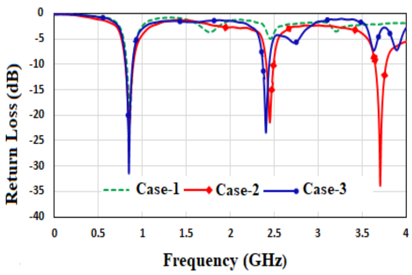


Figure 3. Simulated S11 for the proposed antenna

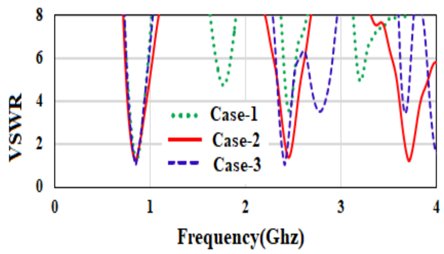


Figure 4. VSWR simulation for the suggested antenna

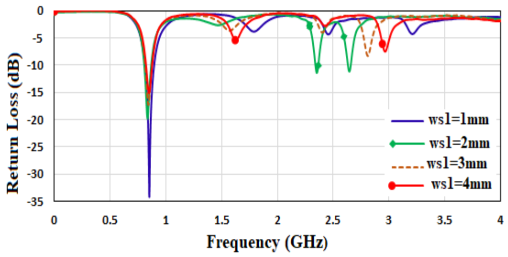
3.3. Parametric study and analysis

On the basis of the return loss data obtained from different DGS widths and locations, parametric experiments were carried out. In Figure 5, the effect of the rectangular DGS1's etched slot width is depicted. For all scenarios, the excavated slot width, w, was altered while the slot length, L, was maintained constant at 30 mm as it was determined by (1). Table 2 illustrates how the breadth and placement of DGS1 effect the return losses of both acceptable and unwanted frequencies. When Ws1 is 1 mm, Vmin is 25 mm, and Vmax is 26 mm, the optimal outcome is obtained. Hence, DGS1's ability to filter out unwanted frequencies is improved.

Likewise, in Table 3, the effects of DGS2's width and position on return losses were compiled. Figure 6, demonstrates the impact of the rectangular DGS2's carved slot width on the reflection losses of the unacceptable frequencies. While varying the etched slot width (Ws2), the DGS2 length (Ls2) was kept constant at 20 mm throughout all cases investigated. When W5 is 3 mm, Vmin is 13 mm, and Vmax is 14 mm, the optimal outcome is attained. As a result, DGS2's ability to get rid of unwanted frequencies is enhanced.

Table 2. Different widths and locations of DGS1's influence on (S11)

DGS1 dimensions (mm)		DGS1 location (mm)		Return loss (dB)		
Length	Width	V_{min}	V_{max}	$f1$	$f2$	$f3$
30	4	18	22	-14.96	-2.5	-7.47
30	3	15	18	-19.77	-11.1	-1.15
30	2	10	12	-19.4	-20.2	-2.77
30	1	25	26	-32	-2.50	-1.42



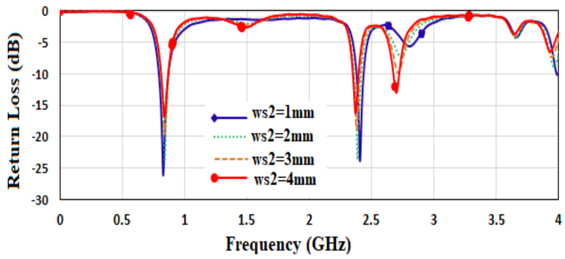


Figure 5. S11 with a variety of DGS1 slot widths

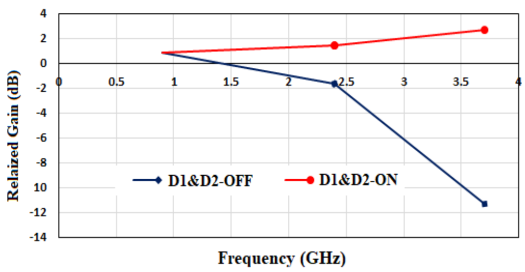
Figure 6. S11 with employing DGS2 slot widths vary

Table 3. DGS2's various widths and locations' impacts on (S11)

DGS2 dimensions (mm)		DGS2 location (mm)		Return loss (dB)		
Length	Width	V_{min}	V_{max}	f1	f2	f3
20	4	18	22	-14.96	-2.5	-7.47
20	3	15	18	-19.77	-11.1	-1.15
20	2	8	10	-19.4	-20.2	-2.77
20	1	13	14	-32	-2.5	-1.42

3.4. Realized gain, bandwidth and radiation efficiency

As seen in Figure 7, the simulated realized gain is greater than 1 dB when two diodes are on at all frequencies being examined. The use of the DGSs, nevertheless, influences the undesirable frequency gain when D1 and D2 are reverse biased (off). A single band frequency is used by the designed antenna as a result. Figure 8, illustrate the maximum efficiency of the proposed antenna with respect to frequency is 80% at 0.9 GHz. Much farther, for each of the three diode cases, the computed bandwidths of the resonant frequencies are listed in Table 4. It is evident that the application of DGSs has a significant impact on the operating frequencies' bandwidth.



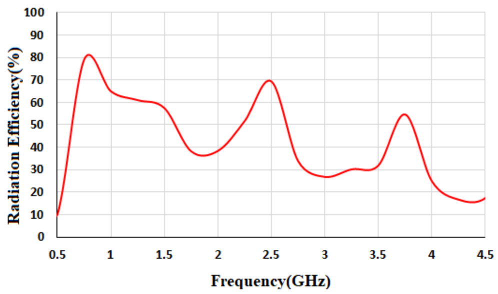


Figure 7. Simulated antenna gain performance with and without DGSs

Figure 8. Efficiency vs frequency of the proposed antenna

Table 4. Simulated bandwidth at (0.9,2.4, and 3.7 GHz) for all cases

Frequency	Bandwidth % (MHz)		
GHz	Case-I	Case-II	Case-III
0.9	79.67	106.22	75.16
2.4	–	92.7	75.2
3.7	–	128.7	–

3.5. Distributions of surface current on the radiating arms of the proposed antenna

Surface current distributions on the whole proposed antenna at various resonant frequencies (0.9 GHz, 2.4 GHz, and 3.7 GHz) are displayed in Figure 9, in intended to even further illustrate the reconfigurable antenna operation mechanism. To illustrate, these plots reveal how the antenna functions in various modes of operation by highlighting resonant regions that contribute to radiation. Distinct colors clearly depicted different distributions of surface current magnitude. As observed, changing the current distribution of the antenna involves turning diodes on and off, which modifies the current flowing over the antenna's surface and alters the resonating frequency. As could be noticed, when both PIN diodes are off, the current is primarily focused on the radiating meander arms at 0.9 GHz, in contrast to the two other frequencies, which exhibit substantial variations (2.4, 3.7 GHz). Given that the current distribution passes via the radiating elements for the three frequencies, the second column of Table 4 demonstrates how the antenna operates in triple bands. The distributions of surface currents in all cases, concern the ability of all operating frequencies to be reconfigured.

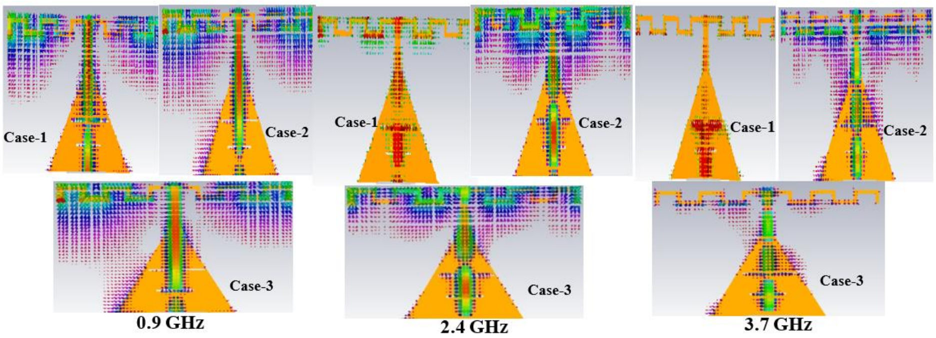


Figure 9. Surface currents distribution of all cases at (0.9, 2.4, 3.7 GHz)

3.6. Radiation patterns of the 3-scenarios

Further, the linearly polarized radiation patterns of the constructed reconfigurable antenna are shown in Figure 10, at various resonant frequencies. Blue and red lines indicate the H and E planes, respectively. One can see that, in all scenarios, the suggested antenna exhibits an omnidirectional radiation pattern in the E-plane at 0.9 GHz, on the other token, a bi-directional radiation pattern in the H-plane ($\theta = 90^0$) which is suitable for GSM applications. For the other two frequencies (2.4 and 3.7 GHz), it has been reported that the antenna embodies omnidirectional radiation in the E-plane ($\theta = 0^0$) while nearly bi-directional radiation in the opposite plane. Because of how the two PIN diodes are switched in this instance, the radiation pattern is reconfigurable.

In Table 5, the performance of the suggested antenna is contrasted with several related works. Analyzing the outcomes shown in this table, it can be deduced that, compared to the research published in [26]-[28], the recommended antenna has a better gain and has better radiation efficiency than the work reported in [28]. The proposed antenna can operate over three separate frequency bands, which is more bands than any other antenna except [28].

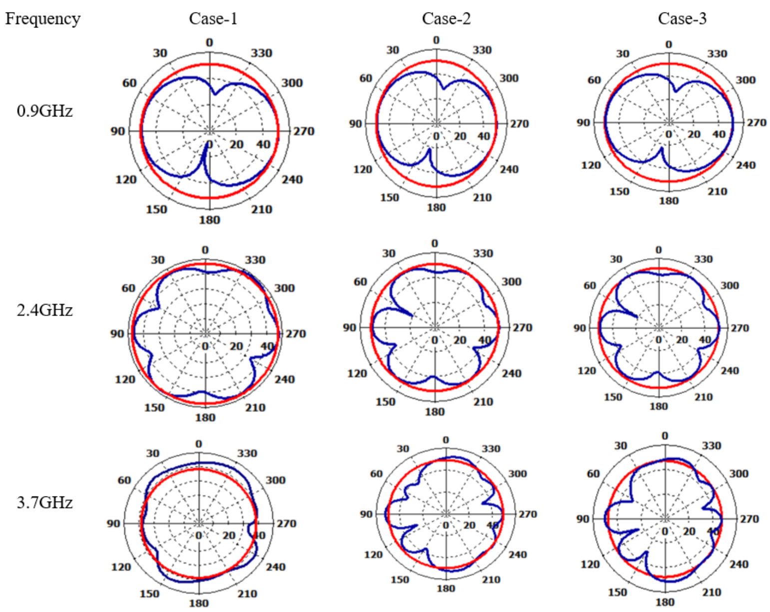


Figure 10. Far-field radiation pattern (E- and H-planes) of the proposed antenna for all 3-senarios

Table 5. Comparison between proposed and some reported reconfigurable antennas

Ref	Number of operating bands	BW (MHz)	S11 (dB)	Gain (dBi)	No. of RF switches used	Size (mm^2)	Radiation efficiency %
[26]	2	400	-17, -36	2.24–2.76	Four diodes	40×30	nil
[27]	3	57.6, 38.7, 22.2	< -10	nil	Four diodes	45×45	nil
[28]	3	4000–1610	< -10	2	Two diodes	30×40	50
This work	3	106.22, 92.7, 128.7	-20.82, -21.47, -33.87	1–2.8	Two diodes	126×76	80.1, 70, 55

4. CONCLUSION

Ultimately, in this investigation, a reconfigurable meander line dipole antenna with tapered balun was constructed. Meander line technology was also integrated for antenna size reduction. Two PIN diodes (S1 and S2) switches are integrated at the tapering balun in the two rectangular DGSs at the optimal position for pattern reconfiguration and to redistribute the concentration of the surface current. Based on the three D1 and D2 scenarios (off, off), (on, on), and (on, off), respectively, the developed antenna operates in single (0.9 GHz) for GSM, dual (0.9, 2.4 GHz) for GSM and WiFi, and triple bands (0.9, 2.4, and 3.7 GHz) for GSM, WiFi, and C-band applications. The outcomes show that, acceptable peak gain, good efficiency, current distribution, and radiation patterns, which qualifies it for use in wireless applications.

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