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Technical Research

DESIGN OF NEW COMPOUND RECONFIGURABLE MICROSTRIP ANTENNA FOR C AND KU BANDS APPLICATIONS

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Abstract: A compound reconfigurable microstrip antenna has been analyzed and designed using switching a PIN diode to switch between different modes of operating frequencies as well as radiation pattern directions. In this paper, computer simulation technology (CST) software 2020 has been used. Due to the complex calculation of the circular microstrip patch antenna, the proposed design has reduced the complexity by using a structure that is compact, easy to fabricate, cheap to produce, and uses only one PIN diode, while maintaining peak antenna performance. The suggested design is appropriate to operate in two states conditional on biasing the PIN diode. The reconfigurable patch of 31.16 mm × 27.04 mm has a compact size with 1.6 mm of thickness. It functions in both the C band at 7.1 GHz with a shift of radiation pattern direction to 4 degrees, and in the Ku band at 12.5 GHz with a shift of radiation pattern direction to 28 degrees in state 2 where the PIN diode is on state. In addition, the ON and OFF state of the switching PIN diode has been extensively investigated via changing the resistance, inductance, and capacitance values for optimal antenna performance. The proposed reconfigurable circular patch can be implemented to operate in modern communication such as Radio navigation and earth exploration, space operation, earth-to-space satellite communication, 5G applications, and Wireless-Fidelity 7.

Keywords: *Compound reconfiguration; frequency reconfigurable antenna; pattern reconfigurable antenna; PIN diodes.*

1. Introduction

Any effective wireless communication system needs an antenna as a backbone. In a modern wireless communication network, an antenna is considered to be a very advanced field due to the evolving need for a small, directive, and reconfigurable design [1]. Nowadays, a significant requirement such as the reconfigurable capability has become essential. This vital ability reduces the need for multi-antennas implementation to support a precise task. The compound reconfigurable antenna is considered one of the preferred classifications of reconfigurable antenna, which is dynamically altering more than one of its properties in a particular frequency, polarization, and radiation pattern. To accomplish such a capability, different types of techniques can be applied.

On the other hand, the reconfigurable antenna proposal proposals deliberate in Jusoh et al. [1], Saeed Khan et al. [2], and Ma et al. [3] have showed that they have a sizeable geometry that could be inappropriate for modern systems. Furthermore, Liu et al. [4], Qin et al. [5], and Zhang et al. [6] are not ideal to work on Ku band applications. In addition, Han et al. [7] and Chiao et al. [8] have shown that their radiation pattern has a minor quantity of deflection within many diverse conditions of function. Also, in Li et al. [9] different feeding methods have been presented for MIMO applications. Moreover, in

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Yang et al. [10], and Wu et al. [11] RF switches have been used as an electrical technique to reconfigure the property of the proposed antennas. Mohanat et al. [12] have shown several techniques that have been used for designing a reconfigurable antenna with their supported applications. In Agarwal et al. [13] the proposed antenna design used PIN diodes as a switch circuit by biasing the PIN diodes to change the current distribution in the microstrip patch surface to support sub-5GHz bands as a frequency reconfigurable antenna. Rawal et al. [14] showed a frequency reconfigurable patch that has been used to support different operating frequencies depending on the several states of ON and OFF PIN diode that all frequencies work on C band applications. Md. A. Al-Mamun et al. [15] suggested a frequency reconfigurable U-shaped antenna and U-shaped inverted in the same patch. It used a PIN diode with a 4.4 relative permittivity (FR-4) substrate, which works in both bands S and C applications. In Bonthu et al. [16] an equilateral triangular (ET) shape was suggested, and it has been revised of C- shape niche with aid of PIN diodes. The proposed antenna supports L and S-band applications as pair 4G. But then, the proposed antenna delivered gain is low and it was around 2 dB. Devi et al. [17] have proposed a reconfigurable integrated microstrip antenna that works for the internet of things (IoT) application within the industrial scientific and medical band (ISM). But the proposed antenna has no RF switching as pairs only one operating frequency at 2.45GHz, which is clearly not an electrically reconfigurable (frequency). In Kumar et al. [18] the paper recommended a frequency reconfigurable rectangular patch shaped with a cutting laterally the radiation edge has an arc-shaped. Also, limiting the thickness of the substrate to 1mm only, for enhancing the bandwidth. The proposed design supports both X and C band applications with help of using two PIN diodes. Santamaria et al. [19] have presented an electronically pattern reconfigurable antenna with four wires patches. Pattern direction has been steered employing the SP4T switch. Moreover, it’s suited to the IoT application as it operates within the ISM band (2.24GHz-2.54Ghz).

Recently, the compound reconfigurable antenna is extensively preferred due to its excellent instantaneous tuning of more than one antenna property such as frequency, pattern, and polarization. A frequency reconfigurable antenna can support more than one operating frequency (different applications) without the need of using another antenna system to operate. This can be designed by using a switching component which is called the electrically reconfigurable antenna technique [20]. In addition, a pattern reconfigurable antenna is the ability to alter the direction of the radiation pattern main-lobe toward an intended direction where the receiver is mounted. The dimension of the proposed antenna is been designated optimally using (1) [20] to compute the width of the microstrip transmission line that excited the patch, (2) [20] is used to calculate the radius of the circular patch along with (3) [20] to make a perfect match between the feedline and patch:

$$w = \frac{7.48 \times h}{e^{\left(z_0 \frac{\sqrt{\varepsilon_r + 1.41}}{87}\right) - 1.25 \times t}} \quad (1)$$

$$R = \frac{F}{\{1 + \frac{2h}{\pi \varepsilon_r F}[ln\left(\frac{\pi F}{2h}\right) + 1.7726]\}^{1/2}} \quad (2)$$

Where F is calculated by:

$$F = 8.791 \times \frac{10^9}{f\sqrt{\varepsilon_r}} \quad (3)$$

Where:

w is the width of the transmission feed line h is the thickness of the substrate, $z_0$is the reference impedance, $\varepsilon_r$is the relative dielectric, t is the thickness of the patch and the ground plane, R is the radius of the patch, F is constant and f is the center frequency.

In this paper, two operating frequencies with an excellent S11 and a very good deflection of the radiation pattern using only one PIN diode has been accomplished. The PIN diode has a very compact size (1mm) which is implemented easily into the proposed compact fabricated antenna structure. Substantial considerations have been abstracted to acquire an acceptable balance among the performance of the antenna parameters and the antenna dimensions.

The paper layout consists of four sections. The first section has presented the introduction and related work survey. The second section has offered the complete design structure and parameters of the proposed antenna design. The third section has involved the results of the antenna parameters. The last section has described the conclusion and the significance of the suggested antenna.

2. The Proposed Reconfigurable Antenna

Fig.1 shows the proposed reconfigured antenna. The back side of the proposed antenna is covered by copper (lossy) to offer a full ground plane. The fully ground plane has been selected over a partial or a half grounded for electrical fields because the performance of the antenna was considerably better.

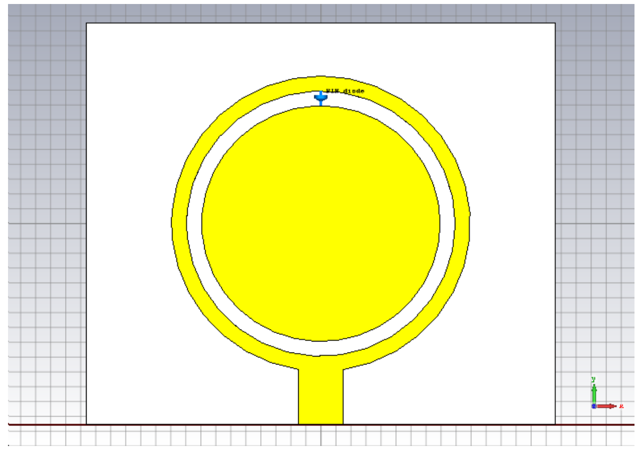

Figure 1. The proposed antenna design

The ground plane dimension was chosen optimally at 31.16mm × 27.04mm to maintain the compact size of the antenna. Furthermore, the structure consists of a circular shape patch with a radius of 7.93mm chosen optimally. Then 1mm gap between the circle and the outer circular ring to fit perfectly with a 1mm PIN diode size. The outer ring has been selected optimally and found to be 1mm in thickness after the gab. The outer circular ring is connected with the feed line from the bottom which has been calculated optimally the width of the feedline from (1) with a dimension of 3 mm and length of 3.57 mm to offer a good matching impedance equal to 50 ohms. In this proposed circular patch design, the complexity of circular patch calculation has been reduced significantly and also provides an easy fabricated structure.

The patch was positioned on a roger (RT5880) substrate via a relative dielectric constant of 2.2 which has uniform electrical properties over an extensive frequency range. The dimensions of the substrate are exactly the same as the ground plane dimensions and the thickness of the substrate is selected to be 1.6 mm optimally for better results and easier fabrication .

The proposed design can operate in two diverse modes of functionality depending on using a switching circuit PIN diode. Biasing the PIN diode can make the antenna reconfigure its functionality to meet a certain requirement. In this design, only one PIN diode has been selected and connected between the outer ring and circular patch as shown in Fig.1. The place was extensively searched and found that the best place is to put furth away from the feedline where are more current flow freely on the top part of the gab. PIN diode (DSG6405) is adapted carefully in the suggested design. Table 1 shows the forward and reverse biased mode (ON and OFF) RLC optimized component offers. Resistance, inductance, and capacitance values have been adjusted broadly using the lumped elements section within the CST suite. The RLC has been selected wisely and then compared with various types of PIN diodes datasheet to match our ultimate antenna performance.

Table.1 RLC component Values of the PIN diode

PIN Diode	R	L	C
Forward (ON)	4.5 Ohms	2.6e-13H	0
Reverse (OFF)	20K Ohms	0	0.5pF

The first mode is when the PIN diode is OFF (reverse) and the second mode is when the PIN diode is ON (forward) as it shown in Table 2 below.

Table.2 Mode of operation

Mode of operation	PIN Diode
Mode 1	OFF
Mode 2	ON

In operation of mode 1, the PIN diode is reverse the biased (OFF State) hence it will not permit the current to stream beginning the outer ring toward the circular patch. While Mode 2 of operation where the PIN diode is ON State (Forward biased) will allow the current to stream beginning the outer ring toward the circular patch. Also, the current density will transfer towards the center of the patch.

3. Results

3.1. Reflection Coefficient (Return Loss)

In operation of mode 1, the reconfigurable microstrip resonates within the Ku band at a center frequency of 12.85 GHz. Whereas in the operation of mode 2, the resonant frequency change to a minor center frequency of 7.1 GHz within the C band and 12.5 GHz within the Ku band.

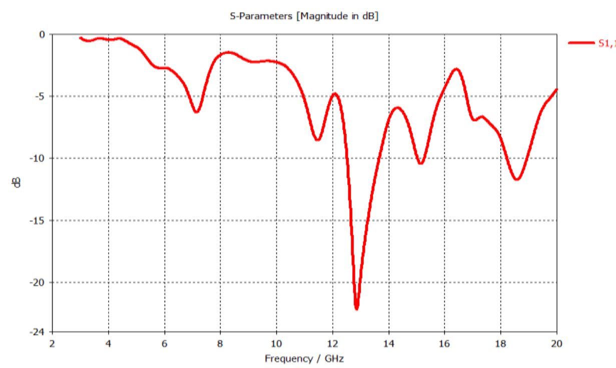

Figure 2. Reflection Coefficient (S11) of mode 1

Fig.2 shows the functioning frequency has been calculated to be 12.85GHz, appropriate to function for Ku-band applications. The reflection coefficient (S11) of this operating frequency is -23 dB which considers the proposed design extremely beneficial.

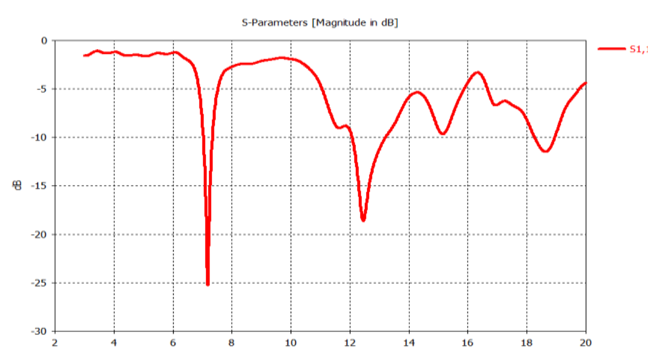

Figure 3. Reflection coefficient (S11) of mode 2

In the same way, fig.3 shows the operation of mode 2, the resonating frequency is found at 7.1 GHz and 12.5 GHz by an acceptable return loss (S11) of -25 dB and -18 dB respectively. Note that, this proposed design can easily shift its operation beginning Ku band toward the C band in this mode where these frequencies come under the IEEE suggested band.

3.2. Radiation Pattern

The reconfigurable antenna has successfully directed the radiation pattern major lobe to 29 degrees as it is shown in Fig.4 below.

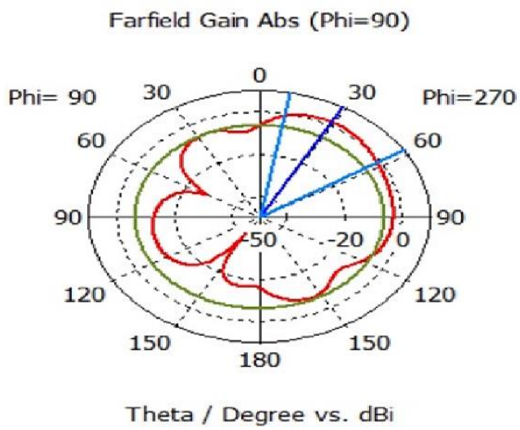

Figure 4. Radiation pattern in mode 1

The proposed reconfigurable antenna design can achieve more deflection. As it is shown in Fig.5 the radiation pattern can direct its major lobe in the direction of 4 degrees only when it functions around the 12.4GHz to 12.9 GHz beside the new operating frequency of 7.1 GHz.

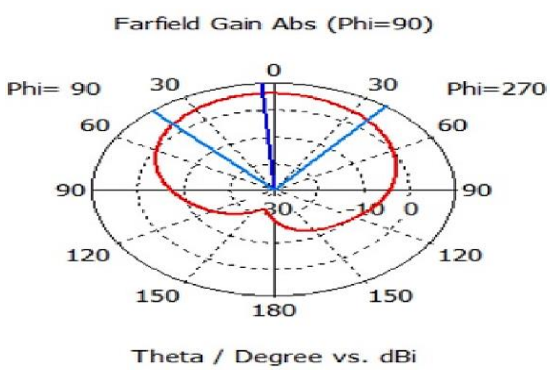

Figure 5. Radiation pattern in mode 2

3.3. Gain, VSWR and Group Delay

The antenna gain can describe by how strong the signal can be sent in an intended direction for receiving and sending. In another word, the ability of the proposed antenna to radiate more or less signal. The designed antenna operates on 12.85 GHz at the state of operation mode 1 with an IEEE gain 5.8 dB as shown in Fig.6. While in mode 2 operation of state ON the resonant frequency is 7.1 GHz with a gain of 6.15 dB and 12.5 GHz with a gain of 4.13 dB as illustrated in Fig.7.

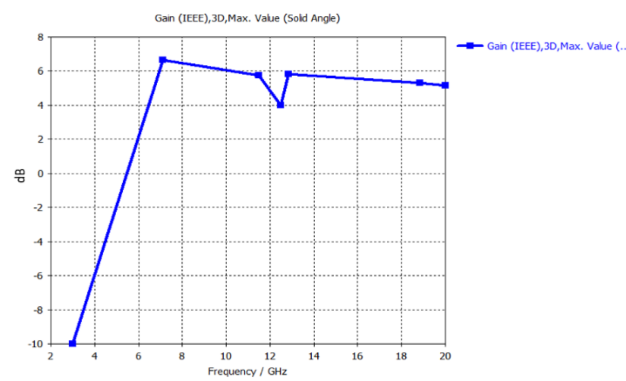

Figure 6. IEEE Gain of mode 1

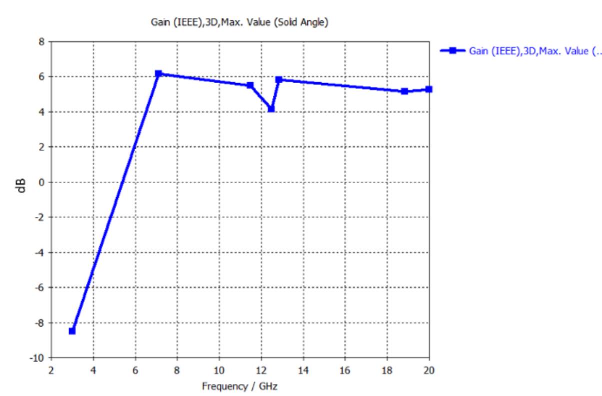

Figure 7. IEEE Gain of mode 2

Voltage standing wave ratio (VSWR) is another important aspect that shows how efficient RF power is transmitted through the transmission line (antenna). The proposed antenna in mode 1 has a VSWR of around 1.1 as shown in Fig.8 which is considered very efficient.

Also, the VSWR of mode 2 is founded to be around 1.1 as demonstrated in Fig.9.

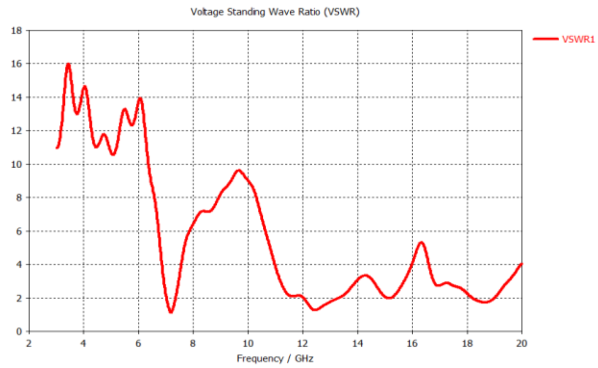

Figure 8. VSWR of mode 1

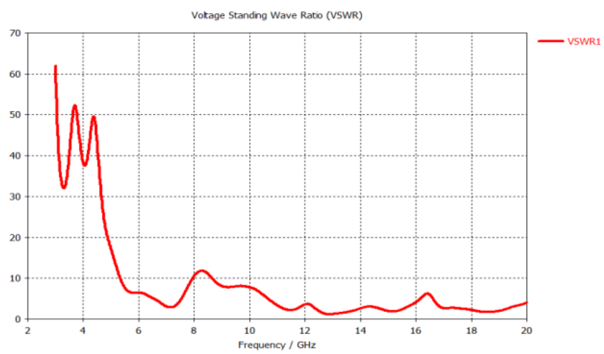

Figure 9. VSWR of mode 2

Group delay is also a substantial parameter that shows how the time delay of the signal through the antenna as a function of frequency. The group delay has been measured and found to be equal to 1.6 ns for mode 1 as demonstrated in Fig.10 and 6 ns for mode 2 as illustrated in Fig.11 which is fast for the signal to get through the system antenna.

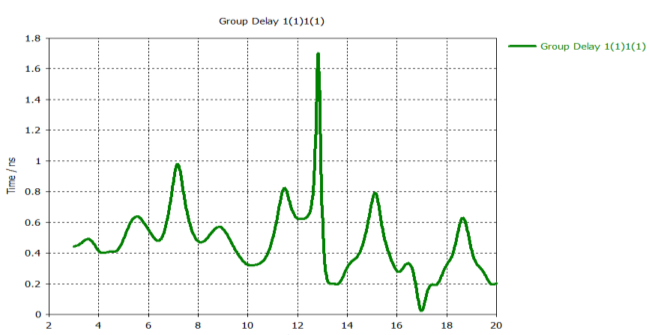

Figure 10. Group delay of mode 1

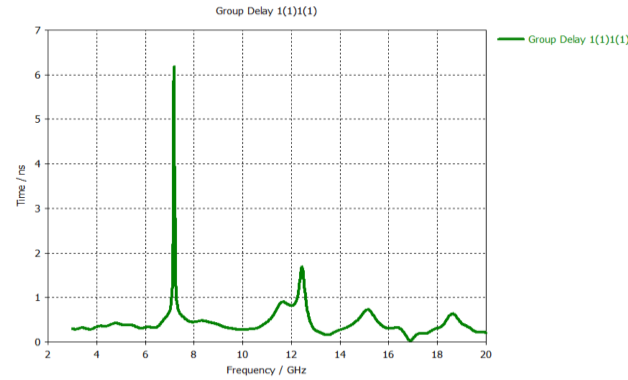

Figure 11. Group delay of mode 2

4. Conclusion

A new compound reconfigurable microstrip antenna was analyzed, designed, and simulated using CST software that can be executed in two modes state of operation by biasing only one PIN diode with low on-resistance and low noise insertion. The PIN diode was added to the patch optimally, which led to reducing the complexity, the cost of the designed circuit, simple reconfigurable technique, and gaining the optimum performance of the proposed antenna. The proposed structure has an uncomplex shape that makes it easy to fabricate and is cheap to produce. The offered design is frequency reconfigurable that can operate on Ku and X bands. In addition, is pattern reconfigurable that can steer the radiation beam from 29 degrees to 4 degrees. The suggested antenna is suitable to satisfy the need of many applications that work under both Ku and C bands applications; such as radio navigation and earth exploration, space operation, and earth to space satellite communication, 5G applications, and Wi-Fi 7 (IEEE802.11BE).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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