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Designing a Frequency-Reconfigurable Spiral-F Shaped Antenna for Diverse Mobile Applications

D. Sreenivasa Rao

Department of ECE, Koneru Lakshmaiah Education Foundation (KLEF), Deemed to be University, Vaddeswaram, Green fields, Guntur, Andhra Pradesh, India -522302.

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Abstract. With the proliferation of mobile phone applications, the demand for compact and lightweight antennas has grown significantly. To address this need, the concept of a multiband antenna is advocated, and we introduce the term "reconfigurable antenna" to characterize the antenna we have developed. Our research has shown that employing a reconfigurable antenna can substantially reduce the physical dimensions of a multiband antenna, enabling versatile operation across various frequency bands. This reconfigurability is achieved through the integration of a spiral structure with diodes in conjunction with a Planar Inverted F antenna. By strategically manipulating diode configurations and shifting between frequency bands, we have observed a remarkable enhancement in antenna performance.

Keywords: patch antenna, reconfigurable, diode, multiband.

1. Introduction

Electronics stands as a rapidly evolving field within modern science and technology. Among these dynamic disciplines, wireless and mobile communications emerges as the swiftest-developing [1]. In today's interconnected world, where the reliance on cell phones is virtually indispensable, the substantial progress in wireless mobile communication devices is undeniable. This surge in advancement has generated a substantial demand for antenna structures capable of accommodating a myriad of wireless applications, as well as compact, portable wireless antennas [2]. Consequently, the design of both external and internal cellular antennas has long presented itself as a challenging and compelling endeavour.

Regardless of their specific usage, consumers today have certain expectations of their mobile devices. These expectations have evolved due to the proliferation of optional features within modern mobile applications, which, in turn, have opened up new avenues for research in compact multiband antenna designs. To harness the full potential of wireless communication services in each region, it becomes imperative to develop specialized antennas capable of covering the primary mobile communication frequency bands. Among these, the GSM (Global Mobile Systems), UMTS (Ubiquitous Mobile Telecommunications), and LTE (Long-Term Evolution) bands [3]–[4] are most commonly utilized in wireless communications. Our current objective is to enable our antenna to operate effectively within these bands.

The proposed antenna incorporates both F-shaped and spiral structures. The F-shaped structure is specifically utilized in the Planar Inverted F Antenna (PIFA), a well-known design in the mobile phone market. PIFA is alternatively referred to as a short-circuited microstrip antenna. Notably, PIFA offers the advantage of adaptability in terms of modifying the ground plane and enhancing the antenna's bandwidth [6]-[7].

In the realm of reconfigurable antennas, the ideal is to achieve alterations in operating frequency, impedance, polarization, and radiation characteristics, thus accommodating changes in the operating environment. Importantly, all desired operating bands can be effectively

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covered within the compact antenna's existing geometry, rendering the need for size augmentation to achieve multiband functionality virtually unnecessary [9]-[10].
To achieve tunability and enable operation across multiple operating bands for our antenna, the key component we employ is a switching element, specifically a tuning diode. The diode variant chosen for this purpose is the PIN diode, known for its capacity to confer reconfigurability. By altering the effective slot length of the PIN diode, we can readily observe shifts in frequency. The change in frequency band can be discerned by connecting and disconnecting the antenna elements. Additionally, the PIN diode exhibits specific capacitive and resistive characteristics.

2. STRUCTURE OF ANTENNA:

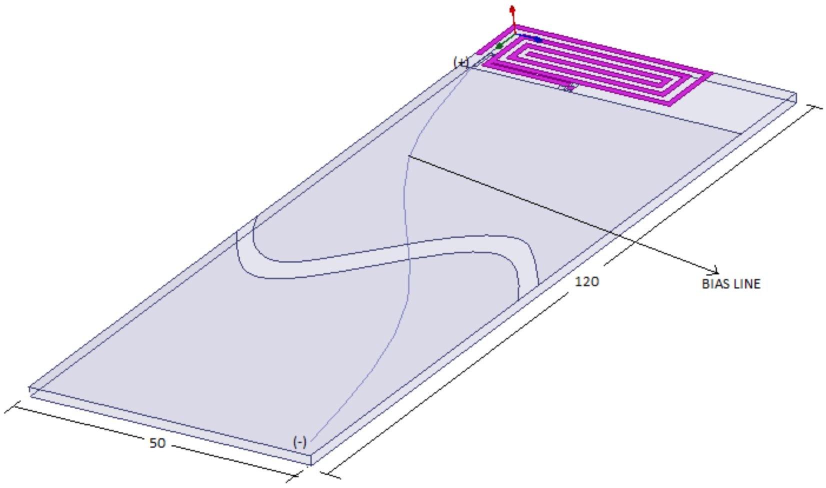

Fig 1: 3D structure of reconfigurable antenna

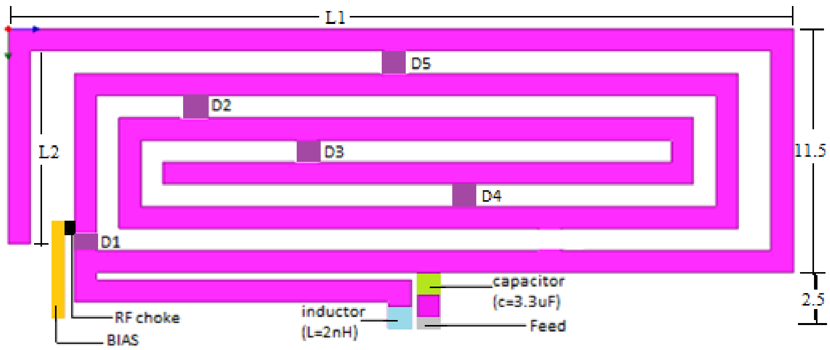

Fig 2: Antenna geometry

Presented here is the design of a compact, reconfigurable antenna suitable for integration into the latest mobile technologies. The antenna's 3D substrate is composed of an FR4 material with a relative permittivity of 4.4 and a loss tangent of 0.04. The substrate's dimensions are 120 x 50 mm^2 with a thickness of 1.6 mm. FR4 is a composite material used in laminated sheets, tubes, rods, and circuit boards.

The proposed antenna essentially combines two distinct structures to form a unified antenna, as illustrated in Figure 2.1. The overall antenna dimensions are 13.5 x 35.5 mm^2. The length denoted as L1 in the figure is fixed at 35.5 mm, while the length L2 is adjustable according to our bandwidth requirements, currently set at 9.7 mm.

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The two integrated structures are the F-shaped structure and the spiral structure, with a diode ensuring connectivity between them. The diode employed in this antenna is a PIN diode (part number HSMP-3860). Additionally, an RF choke is incorporated to power the spiral antenna when the diode is switched on or off. The antenna operates in Planar Inverted F Antenna (PIFA) mode when the LED is off and operates in both PIFA and spiral modes when the LED is on. In the ON state, the spiral antenna features four additional diodes that establish connections within the spiral structure. A comprehensive discussion of the diode's on and off states is presented in the theoretical analysis.

The resonant frequencies primarily depend on the antenna's dimensions, which are set at 13.5 x 35.5 mm^2. Adjusting the length of L2 or altering the values of L and C allows for tuning the resonant frequency peaks. In this context, the values of L and C are considered as 2nH and 3.3uF, respectively. All line widths in the proposed antenna are standardized at 1 mm, simplifying the design process.

3. Results and Discussion

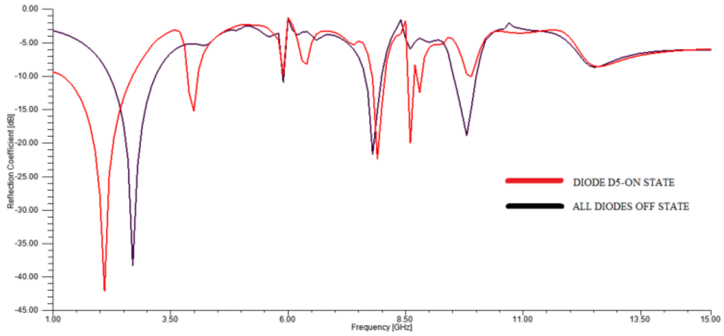

Fig 6: diode D1 in OFF state

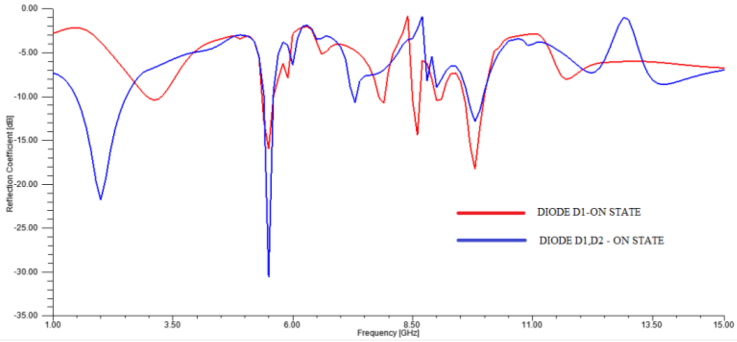

Fig 7: diode D1 – ON & diode D2 – ON/OFF

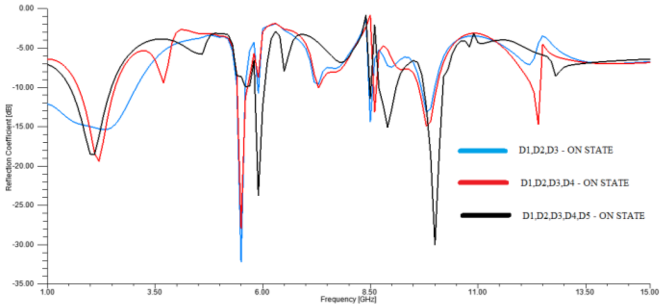

Fig 8: diode D1, D2, D3 – ON & diode D4, D5 – ON/OFF

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The results presented above are tabulated for reference. The accompanying graphs illustrate the return losses of various reconfigurable antenna designs with the diodes toggled between the ON and OFF states. Our analysis centers on diode D1, which serves as the primary diode influencing the characteristics of the PIFA or spiral antenna.

When the main diode D1 is in the OFF state, Figure 1 displays the reflection loss. Conversely, when the main diode D1 is in the ON state, the reflection loss is depicted in Figures 2 and 3. In these figures, we also consider the ON/OFF states of other diodes. For example, Figure 2 illustrates two scenarios with diode D2 in the ON state, showcasing a shift of the main band to the left, enabling antenna operation in the 1.44 to 2.50 GHz range. Similarly, Figure 3 illustrates the diode characteristics leading to band shifts to the left, facilitating the antenna's operation across multiple frequency bands.

By factoring in the varied ON/OFF configurations of the diodes, we can harness the antenna's capacity to operate across numerous bands, a primary advantage of reconfigurable antenna technology.

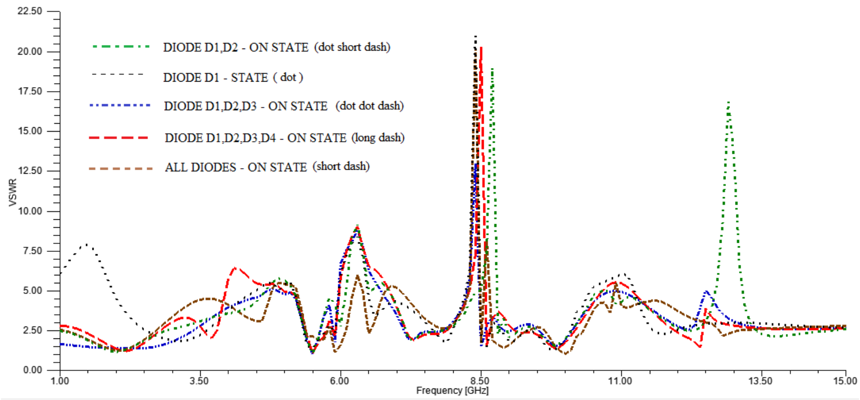

Fig 10: VSWR for diode D1 – ON & D2,D3,D4,D5 – ON/OFF

The aforementioned results provide VSWR data for the antenna structures with the D1 diode in both ON and OFF states. VSWR, an acronym for "Voltage Standing Wave Ratio," signifies the magnitude of reflected voltage waves in relation to incident voltage waves. In all cases, VSWR values for each antenna design are maintained above zero. When VSWR falls within the range of greater than 0 and less than 2, it indicates significantly lower input power loss. This metric holds great significance for any antenna, as it quantifies the degree of power loss within the transmission line.

Our analysis reveals that the VSWR plots lie within the range of 1 to 2, coinciding with the return loss band. As a result, the antenna designs exhibit minimal input power loss within this range.

4. Conclusions

The implementation of frequency reconfigurability in antenna design proves to be a versatile and valuable approach. By strategically switching between different diodes in accordance with the specific demands of various applications, it becomes feasible to achieve remarkable alterations in antenna performance. These changes manifest in the form of substantial shifts in both the reflection coefficient and gain of the antenna.

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One of the notable advantages of this reconfigurable antenna approach is the capacity to dynamically adapt to different operating frequencies and frequency bands. The states of the diodes play a pivotal role in driving these frequency shifts, making it possible for the antenna to seamlessly operate across a range of frequency bands.

This flexibility in frequency reconfigurability opens up opportunities for antenna designs that can meet the ever-evolving needs of wireless communication systems and applications. The ability to fine-tune antenna characteristics through diode switching provides a valuable tool for optimizing wireless communication performance in a dynamic and diverse technological landscape. As technology continues to advance, the concept of reconfigurable antennas and the manipulation of diodes within these designs promise to remain at the forefront of antenna engineering, offering adaptive solutions for a multitude of wireless communication challenges.

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