A reconfigurable circular microstrip patch antenna for 5G applications

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Abstract*— This paper presents the design of a 5G reconfigurable microstrip patch antenna, capable of operating in multiple 5G frequency bands. Three design scenarios are investigated, including a single radiating patch, a dual radiating patch, and a switch connecting both patches. The switch enables the antenna to reconfigure and operate in two different 5G frequency bands, covering the n77 band (3.3-4.2 GHz) and (3.1-3.85 GHz). The simulated results show that the antenna achieves a resonant bandwidth of 4.04 GHz and 4.05 GHz for the single and dual patch designs, respectively, and 3.26 GHz and 3.56 GHz for the RLC switch-enabled design. The proposed antenna design offers a promising solution for 5G applications requiring frequency reconfigurability and compact size.

***Keywords*— Reconfigurable, RLC Switch, Circular Patch**

I. INTRODUCTION

Microstrip patch antennas have gained significant attention in the field of wireless communication due to their compact size, lightweight design, and ease of fabrication. Their low profile and ability to operate at microwave frequencies make them suitable for mobile phones to satellite communications applications. Reconfigurable microstrip patch antennas take this technology further by allowing the antenna's characteristics, such as frequency, polarization, and radiation pattern, to be altered dynamically. This adaptability enhances performance in diverse environments and applications, enabling better spectrum utilization and improved communication quality. The growing demand for flexible and efficient communication systems highlights the importance of exploring microstrip patch antennas and their reconfigurable counterparts. A reconfigurable microstrip-fed patch antenna with polarization agility in two bands has been proposed in [1], enhancing impedance and axial ratio bandwidths through proximity-coupled feed and frequency reconfigurability through p-i-n diodes. A frequency-reconfigurable antenna had been also proposed in [2] for cognitive radio in the sub-6 GHz 5G band, featuring a wideband monopole and a narrowband microstrip patch, with PIN diodes for switching modes. A microstrip patch antenna with circular corner truncation is proposed in [3] for polarization reconfigurability, allowing radiating with right, left, and linear polarization using forward, reverse, or zero bias. A novel reconfigurable microstrip antenna with switchable polarization sense was proposed in [4], featuring a simple structure with independently biased PIN diodes for linear or circular polarization. A new microstrip patch antenna with frequency and circular polarization diversities has been presented in [5], consisting of a patch with orthogonal slots and a 3dB hybrid coupler-fed structure. Two diodes enabled frequency reconfiguration and switching between LHCP and RHCP. The design in [6] described polarization-diversity slot antennas with switchable frequency, consisting of a radiating annular slot, reflector, and quasi-lumped coupler with two modes, adjustable with variable capacitors. A stub-loaded microstrip patch antenna with reconfigurability in frequency and polarization has been presented in [7], using 12 varactors for a fractional bandwidth of 40%. The design was optimized using an analytical model, speeding up the process. The design of circularly polarized microstrip antennas with frequency agility had been described in [8], in which the antenna consisted of a square radiating patch, four varactor diodes, and two lumped capacitors. The design required only one DC voltage to vary the operating frequency, and experimental results showed that the CP frequency could be switched between 1.97 GHz and 2.53 GHz. This study in [9] proposed a detailed survey on reconfigurable antennas to provide an overview of existing designs and their evolution. It discussed the need for different reconfigurations, design specifications, switching mechanisms, and techniques to enhance performance. The survey also addressed design challenges and applications, aiming to help researchers develop futuristic radiating structures suitable for Cognitive Radio, 5G, and Multiple Input Multiple Output systems. Cognitive radio efficiently utilizes spectrum and minimizes interference. Multiband frequency-reconfigurable antennas (FRA) are beneficial for CR applications. Frequency-reconfigurable SIW (FRSIW) is promising for microwave and millimeter waveband antenna development. This study in [10] aimed to summarize and compare technical operational advances of SIW antennas and discuss FRSIW's effectiveness in managing radio spectrum efficiently. In [11]. It discusses the design process and applications of reconfigurable antennas, which can dynamically alter their frequency, polarization, and radiation properties. It also discusses the activation mechanisms, design and operation optimization, and the latest advances in reconfigurable metamaterial engineering and highlights the applications of reconfigurable antennas in cognitive radio, MIMO systems, satellite communications, and biomedical devices. Various research papers have been published throughout in which different bandwidth enhancement techniques were used to obtain reconfigurability; out of which mostly - slotting or slitting of the radiating patch was used to increase the bandwidth of the microstrip patch antenna [12-15].

The development of the proposed reconfigurable patch antenna begins with a focus on its compact structure and innovative radiating elements. This configuration allows the antenna to leverage the advantages of both small and large patches, optimizing the performance across various frequency bands. The integration of switching mechanisms further elevates the antenna's functionality to operate effectively in the n77 band (3.3 GHz to 4.2 GHz) and the low band (3100-3850 MHz), which are critical for comprehensive 5G coverage.

II. Antenna Design

The complete size of the proposed antenna is (40x40x1.6) mm^3 with a 10mm radius of the regular circular radiating patch as shown in Fig. 1. Thin copper sheet has been used as a radiating patch and ground plane and FR4_epoxy material of 1.6mm height as a dielectric substrate having ε_r=4.4 & tanδ=0.02. A co-axial probe consists of an inner radius of 0.63mm and outer radius of 1.45mm situated 2mm towards the left from the center axis on the X-plane & 2mm towards the bottom edge on the Y-plane of the substrate, which has been used to excite the antenna. Another Design is made where a second Circular Radiating Patch of radius 17mm is created having the same probe position. In the Final Design of the Antenna, an additional RLC Switch is inserted along with the Dual Radiating Circular Patches. The Switch consists of Two Capacitors at each of the connecting ends, along with a Resistor and an Inductor. Each of the switches has a length of 3 mm and a breadth of 1.2 mm and all of them are positioned at an angle of 145 degrees along the Z-Axis.

III. Antenna Design Procedure with Parametric Study

In this design, a circular radiating patch has been selected. Considering this as a primary design, three different scenarios have been observed via modifying the designs. HFSS ver.13 software has been used to design and analyze the antenna. The optimum probe location of the antenna has been found by placing the probe at different positions on the patch and analyzing the results.

A. Design using a single radiating patch

In this design shown in Fig. 1., a primary circular radiating patch of radius 10 mm has been considered. For simulating the design in HFSS, a specified frequency sweep has been used to obtain an S_{11} Parameter Graph. The sweep details allow the antenna to operate within the range of 1 GHz to 5 GHz. At the aforementioned optimum probe position, the primary resonant bandwidth that was obtained was – 4.04 GHz ($S_{11} \leq$ -30.6 dB). Hence, residing in the 5G frequency band range of (3.3 GHz to 4.2 GHz), which is a 5G NR band of n77.

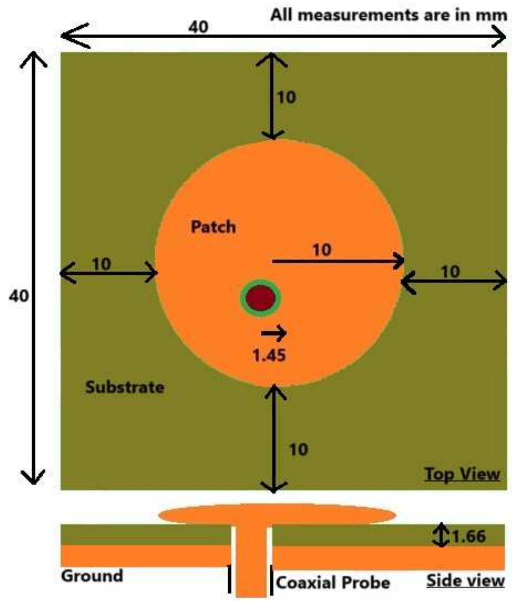

Fig.1 Initial design

B. Design using a dual radiating patch

In this design shown in Fig. 2., the initial circular radiating patch of radius 10 mm along with, another circular radiating patch of radius 17mm has been designed here. For simulating the design in HFSS, the same specified frequency sweep details from the 1st design have been used to obtain an S_{11} Parameter Graph. At the fixed primary probe position, the resonant bandwidth that was obtained was – 4.05 GHz ($S_{11} \leq$ -32.57 dB). The result obtained here is almost the same, residing in the same 5G frequency band range of (3.3 GHz to 4.2 GHz), which is a 5G NR band of n77.

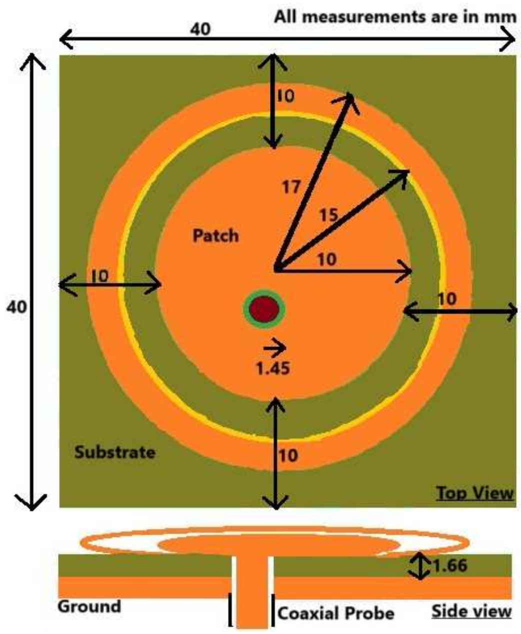

Fig.2 Dual patch design

C. Design using a dual radiating patch and introducing a RLC Switch

In this design shown in Fig. 3., now an RLC Switch has been introduced in this design to connect both circular patches. For creating this switch, a Capacitor C1 having a capacitance of 1uF has been taken, joining it with an Inductor L having an inductance of 0.4 nH, further joining it with a Resistor R having a resistance of 1 ohm and finally another Capacitor C2 having a capacitance of 1uF. The above switch is placed diagonally on the 1^{st} quadrant (i.e., positive XY plane). The positions and sizes of the capacitors, inductor, and resistor are adjusted in equal proportions, with the smaller circular patch and the larger circular patch. While simulating the design in HFSS, the same specified frequency sweep details from the 1^{st} design have been set to obtain an S_{11} Parameter Graph. At the fixed primary probe position, and when the switch is turned on, two resonant bandwidths were found. The 1^{st}resonant bandwidth that was obtained – 3.26 GHz for ($S_{11} \leq$ -20.97 dB), that is covering a different 5G frequency band range of (3100–3850 MHz) which is for the 5G low band (LB). The 2^{nd}resonant bandwidth that was obtained – 3.56 GHz for ($S_{11} \leq$ -10.58 dB), that is covering the same 5G frequency bandrange of (3.3 GHz to 4.2 GHz), which is a 5G NR band of n77.

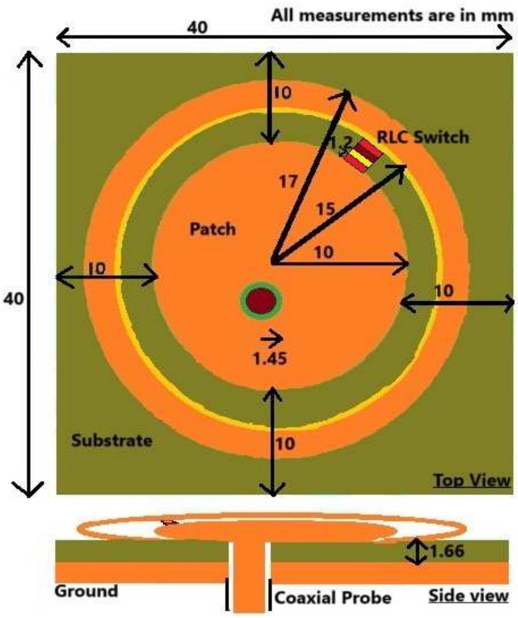

Fig.3 Switch connecting patches design

IV. Result

Graphs of S_{11}, Z_{11}, and radiation pattern of the antenna are shown in the fig. (4, 5, 6, and 7, 8, 9 and 10, 11, 12) respectively.

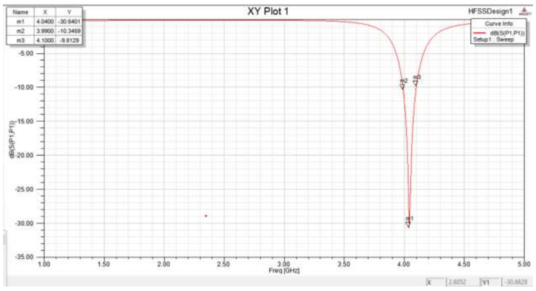

Fig.4 S_{11} Parameter of Initial Design

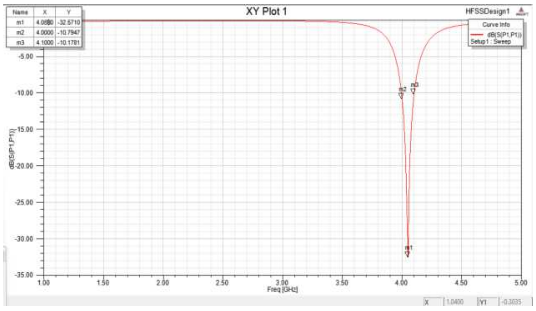

Fig.5 S_{11} Parameter of Dual Patch Design

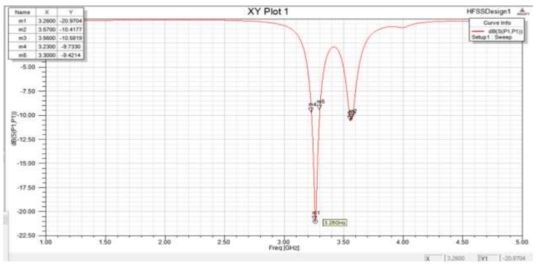

Fig.6 S_{11} Parameter of Final Design

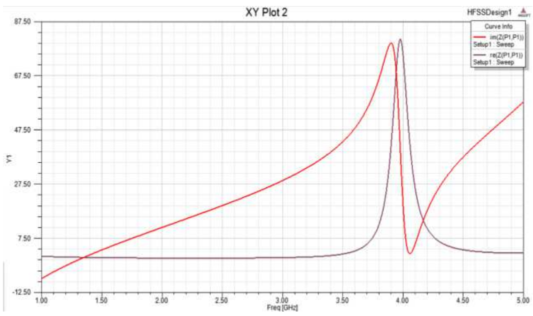

Fig.7 Z_{11} Parameter of Initial Design

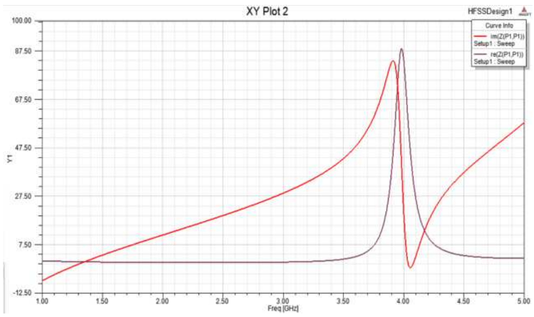

Fig.8 Z_{11} Parameter of Dual Patch Design

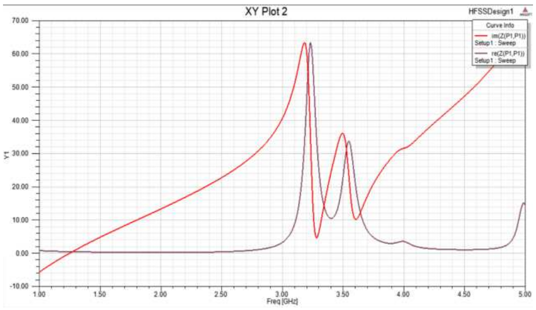

Fig.9 Z_{11} Parameter of Final Design

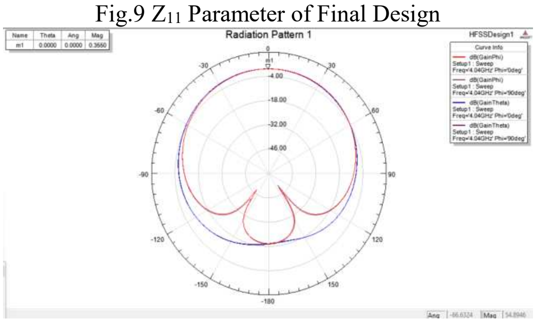

Fig.10 Radiation Pattern of Initial Design

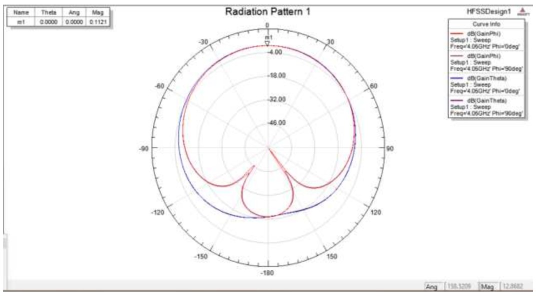

Fig.11 Radiation Pattern of Dual Patch Design

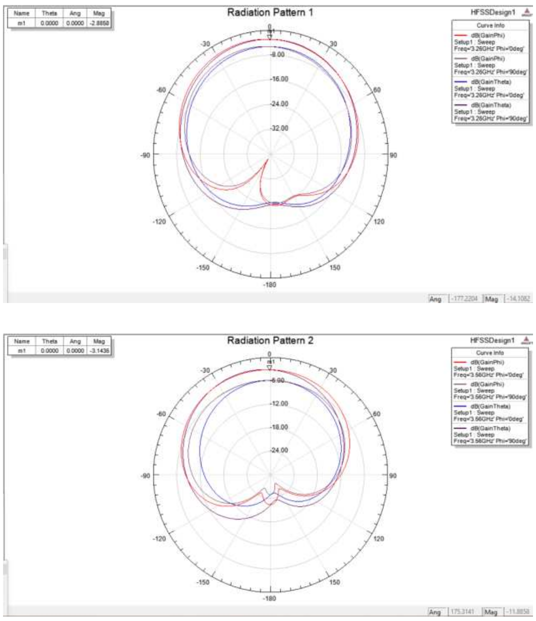

Fig.12 Radiation Patterns of Final Design

A. Obtaining the S_{11} Parameter of the Antenna

Simulated different parameters of the three different designs of the proposed antenna have been summarized in below table.

Table: Simulated results of the three different designed antenna.

Simulated Designs	**Resonant Bandwidth**	**S_{11} Parameter**
Design using a single radiating patch	4.04 GHz 5G band range of (3.3 GHz to 4.2 GHz)	$S_{11} \leq$ -30.6 dB
Design using a dual radiating patch	4.05 GHz 5G band range of (3.3 GHz to 4.2 GHz)	$S_{11} \leq$ -32.57 dB
Design using a dual radiating patch and introducing an RLC Switch	3.26 GHz 5G band range of (3100–3850 MHz)	$S_{11} \leq$ -20.97 dB
	3.56GHz 5G bandrange of (3.3 GHz to 4.2 GHz)	$S_{11} \leq$ -10.58 dB

B. Radiation Pattern of the Antenna

Considering the 1st Design of the Antenna:- from the Radiation pattern shown in Fig. 10, the gain of this antenna is 0.3550 dB at a frequency of 4.04 GHz is observed.

Considering the 2nd Design of the Antenna:- from the Radiation pattern shown in Fig. 11, the gain of this antenna is 0.1121 at a frequency of 4.05 GHz is observed.

Considering the 3rdDesign of the Antenna:- there are two sets of Radiation Patterns obtained as shown in Fig. 12.

From the 1st Radiation pattern, the gain of this antenna is -2.8858 at a frequency of 3.26 GHz is observed. From the 2nd Radiation pattern, the gain of this antenna is -3.1435 at a frequency of 3.56 GHz is observed.

V. Conclusion

The design of a reconfigurable antenna using dual circular patches has proven to be an effective approach for achieving dual-band operation while maintaining compatibility with the 5G frequency bandwidth. By strategically configuring the dual circular patches, the antenna can be tuned to operate at two distinct frequency bands, allowing it to support multiple communication standards simultaneously. Overall, the innovative design of a reconfigurable dual circular patch antenna represents a significant advancement in antenna technology, enabling enhanced performance, flexibility, and efficiency in the ever-evolving landscape of wireless communications.

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