A reconfigurable triangular-circular microstrip patch antenna with two switches

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Abstract*— *This paper presents the design of a 5G reconfigurable microstrip patch antenna, having differently shaped dual patches, that is capable of operating in multiple 5G frequency bands. Four design scenarios are investigated, including a single radiating patch, a dual radiating patch, a dual radiating patch with a switch, and a dual radiating patch with two switches. The switches enabled the antenna to reconfigure and operate in two different 5G frequency bands, covering the n79 band (4.4 - 5 GHz) and the high 5G sub-6 GHz frequency band range (4.8 - 6 GHz). The simulated results show that the antenna achieves a resonant bandwidth of 5 GHz and 5.02 GHz for the single and dual patch designs, respectively, 4.29 GHz and 5.2 GHz for one RLC switch-enabled design, and finally, 4.42 GHz, 4.85 GHz, and 5.37 GHz for the two RLC switch-enabled design.

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

I. Introduction

Because of its small size, lightweight design, and simplicity of production, microstrip patch antennas have drawn a lot of interest in the wireless communication industry. They are appropriate for uses ranging from satellite communications to cell phones because to their low profile and capacity to function at microwave frequencies. This technology is advanced by reconfigurable microstrip patch antennas, which enable dynamic changes to the antenna's properties like frequency, polarisation, and radiation pattern. Better spectrum utilization and higher-quality communication are made possible by this versatility, which improves performance in a variety of settings and applications. Innovative solutions in contemporary wireless networks can be facilitated by an understanding of the underlying principles of these technologies and their benefits.

In [1], A novel triangular microstrip patch antenna for 28 GHz 5G communication was designed using a coplanar waveguide and a defective ground surface approach, in which Frequency tuning was achieved by adjusting the feed's dimensions and patch measurements. In [2], a compact design of dual-layer patch antenna with a truncated triangular slot and defective ground structure (DGS), optimized for 5G and WLAN use achieved enhanced performance, including improved return loss, gain, and directivity. In [3], this paper focused on microstrip antenna arrays designed for 5G applications, addressing the need for higher data rates and improved performance compared to 4G. The proposed dual-band antenna's Bandwidth was enhanced by etching triangular slots on the ground plane. In [4], an analysis of an equilateral triangular microstrip patch antenna with compact dimensions of 34 × 29 × 1.6 mm was done. Introducing square defects in the ground enhanced bandwidth and improved impedance matching at a 4.5 GHz resonance. In [5], a compact frequency reconfigurable triangular microstrip antenna in which Stub loading and slot etching were used to adjust surface current distributions, enabling frequency reconfigurability and maintaining a stable radiation pattern and achieving positive gain across all configurations. In [6], An antenna configuration with a microstrip patch having two patch designs: a triangular patch and a rectangular patch was hung above the ground plane to improve the impedance bandwidth and this design strategy allowed the antenna to operate at 2.4 GHz with an impedance bandwidth of 550 MHz. In [7], An analysis and comparison of triangular patch antenna arrays and rectangular patch antenna arrays were presented and the Analysis resulted in a resonance frequency of 2.2 GHz, the antenna arrays were appropriate for WLAN, ISM Band, and aerospace applications. In [8], a variety of microstrip array antenna designs that are appropriate for wireless communication applications were showcased via a variety of microstrip array antenna shapes, including triangular and rectangular patch antenna arrays. In [9], the suggested antenna consisted of two spur line slots embedded in an equilateral triangular planar patch element whose first resonance frequencies were 0.90 GHz and 1.80 GHz, thus increasing GSM 1800's bandwidth by up to 100 MHz. In [10], the performance of the E-shaped patch antenna array, rectangular patch antenna array, triangular patch antenna array, and traditional omnidirectional quarter wave monopole antenna equipped with a sensor node were examined. For each antenna array, a performance analysis was conducted in terms of power consumption, packet delivery ratio, and received signal intensity. This paper presents an antenna featuring a dual triangular-circular radiating patch system, with an equilateral triangular patch measuring 17.76 mm on each edge and a circular patch with a radius of 17.5 mm. This design combines the benefits of both small and large patches, optimizing performance across multiple frequency bands. Additionally, the integration of switching mechanisms improves the antenna's performance, enabling it to effectively operate within the 5G n79 band (4.4 - 5 GHz) and the high sub-6 GHz 5G band (4.8 - 6 GHz), which are essential for comprehensive 5G coverage.

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II. ANTENNA DESIGN

The complete size of the proposed antenna is (40x40x1.6) mm^3 with a 17.76mm measuring edge of the equilateral triangular radiating patch as shown in Fig. 1. The triangular radiating patch is positioned at an angle of 197 degrees along Z-Axis. A thin copper sheet has been used as a radiating patch and ground plane and FR4 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 an outer radius of 1.45mm situated 0mm from the center axis on the X-plane& -3.5mm 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 Circular Radiating Patch of radius 17.55mm is created having the same probe position. In the Tertiary Design of the Antenna, an additional RLC Switch is inserted along with the dual radiating triangular-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 7.5 mm and a breadth of 2.7 mm and all of them are positioned at an angle of 120 degree along the Z-Axis. In the Final Design of the Antenna, a second RLC Switch is inserted along with the previous existing RLC Switch. The Second RLC Switch also consists of components of equal size, and they are positioned at an angle of 240 degrees along the Z-Axis.

III. ANTENNA DESIGN PROCEDURE WITH PARAMETRIC STUDY

Initially, a triangle radiating patch was used for this design. By altering the designs and adding an extra circular patch, four distinct scenarios have been noticed while keeping this as the main design. The antenna was designed and analyzed using HFSS ver.13 software. By positioning the probe at several points on the patch and examining the outcomes, the ideal probe position for the antenna has been determined.

A. Design using a single radiating patch

In this Initial design shown in Fig. 1, a primary triangular radiating patch has been considered. Each edge of the triangular patch is measured at 17.76 mm. A specified frequency sweep was used to simulate the design in HFSS to obtain an S_{11} parameter graph. The sweep details allow the antenna to operate within the range of 1 GHz to 6 GHz. At the aforementioned optimum probe position, the primary resonant bandwidth that was obtained was – 5 GHz for (S_{11} $\leq$ -10.77 dB). Hence, residing in a 5G frequency band range of (4.4 GHz to 5 GHz), which is a 5G NR band of n79.

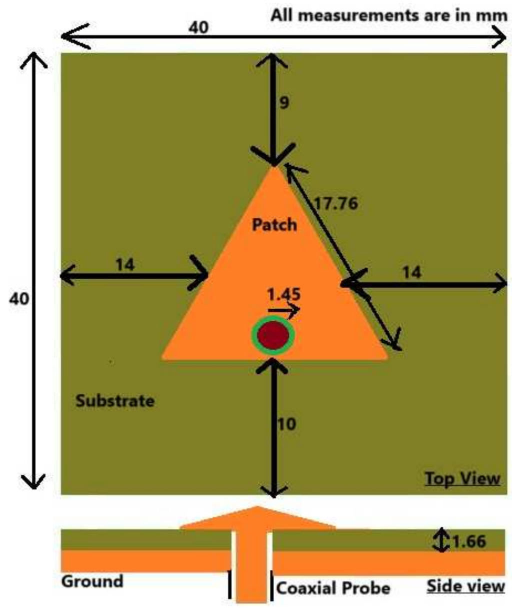


Fig.1 Initial design

B. Design using a dual radiating patch

In this design shown in Fig. 2, the same primary triangular radiating patch having edges measuring of 17.76 mm has been considered. Here, another circular radiating patch of radius 17.5 mm has been designed. For simulating the design in HFSS, the same specified frequency sweep details from the Initial design have been used to obtain an S_{11} Parameter Plot. At the fixed primary probe position, the resonant bandwidth that was obtained was – 5.02 GHz for (S_{11} $\leq$ -10.19 dB). The result obtained here is almost the same, residing in the high 5G frequency band range of (4.8 GHz to 6 GHz), which is for 5G sub-6 GHz.

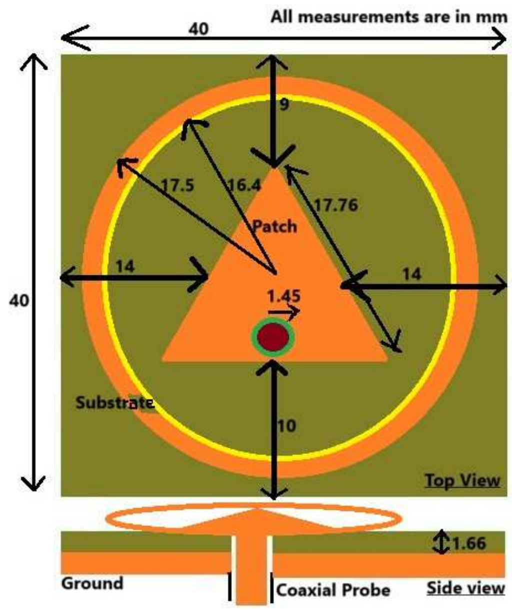


Fig.2 Dual patch design

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 the triangular and the 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 1st quadrant (i.e., positive XY plane). The positions and sizes of the capacitors, inductor, and resistor are adjusted in equal proportions, with the smaller triangular patch and the larger circular patch. While simulating the design in HFSS, the same specified frequency sweep details from the 1st design have been set to obtain an S_{11} Parameter Plot. At the fixed primary probe position, and when the switch is turned on, two resonant bandwidths were found. The 1st resonant bandwidth that was obtained was – 4.29 GHz for ($S_{11} \leq$ -11.15 dB), which covers a 5G band range of (3.3 GHz to 4.2 GHz), which is a 5G NR band of n77. The 2nd resonant bandwidth that was obtained was – 5.2 GHz for ($S_{11} \leq$ -15.24 dB), which covers the same high 5G frequency band range of (4.8 GHz to 6 GHz), which is for 5G sub-6 GHz.

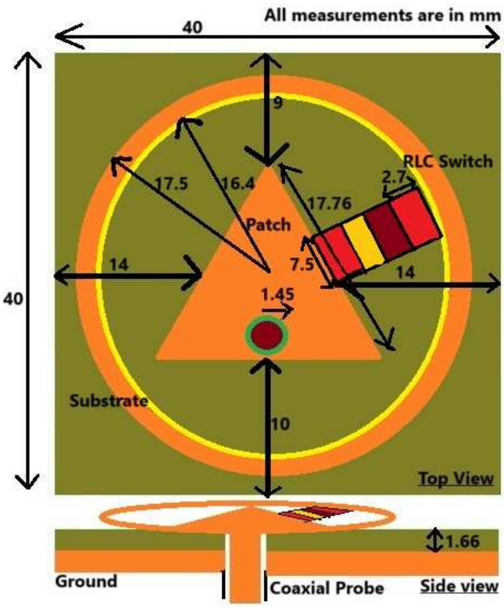


Fig.3 Switch connecting patches design

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

In this design shown in Fig. 4, now a second RLC Switch has been introduced in this design, along with the previous switch, to connect both the triangular and the circular patches. For creating this second switch, the same components of similar sizes and proportions were considered. This second switch is placed diagonally on the 2nd quadrant (i.e., negative X and positive Y plane). The switch has again been adjusted, with the smaller triangular patch and the larger circular patch. While simulating the design in HFSS, the same specified frequency sweep details from the Initial design have been set to obtain an S_{11} Parameter Plot. At the fixed primary probe position, and when both the switches are turned on, this time, three resonant bandwidths were found. The 1st resonant bandwidth that was obtained was – 4.42 GHz for ($S_{11} \leq$ -21.07 dB), which covers a 5G band range of (4.4 GHz to 5 GHz), which is a 5G NR band of n79. The 2nd resonant bandwidth that was obtained was – 4.85 GHz for ($S_{11} \leq$ -25.61 dB), which covers the same 5G band range of (4.4 GHz to 5 GHz), which is a 5G NR band of n79. Now, the 3rd resonant bandwidth that was obtained was – 5.37 GHz for ($S_{11} \leq$ -30.46 dB), which covers the high 5G frequency band range of (4.8 GHz to 6 GHz), which is for 5G sub-6 GHz.

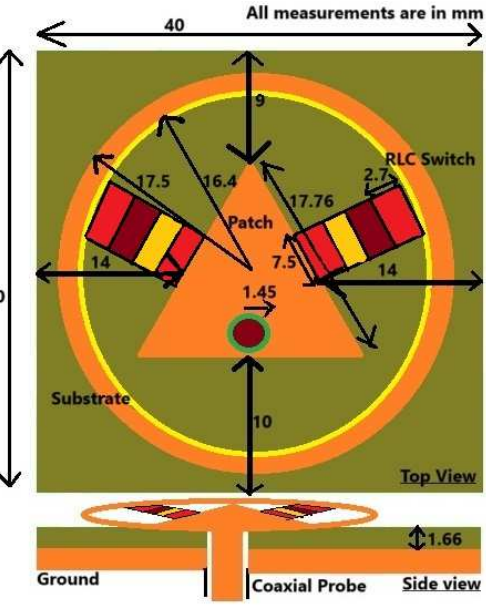


Fig.4 2-Switch connecting patches design

IV. RESULT

Graphs of S_{11}, Z_{11}, and the radiation pattern of the antenna are shown in the fig. (5, 6, 7, 8, and 9, 10, 11, 12, and 13, 14, 15, 16) respectively.

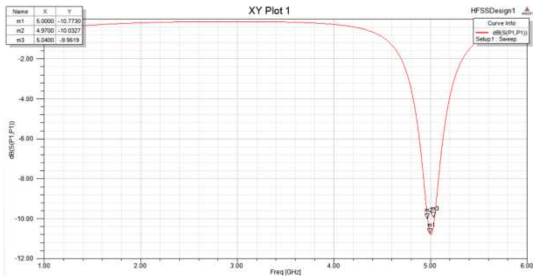


Fig.5 S_{11} Parameter of Initial Design

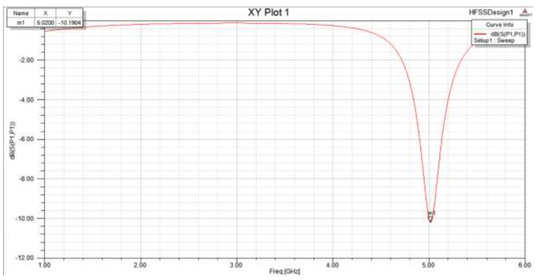


Fig.6 S_{11} Parameter of Dual Patch Design

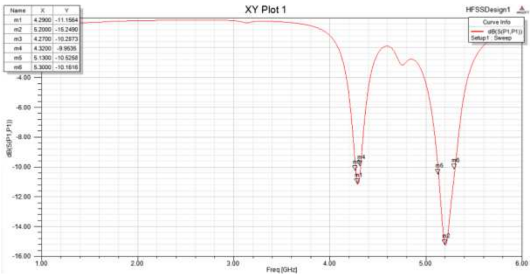


Fig.7 S_{11} Parameter of One Switch Design

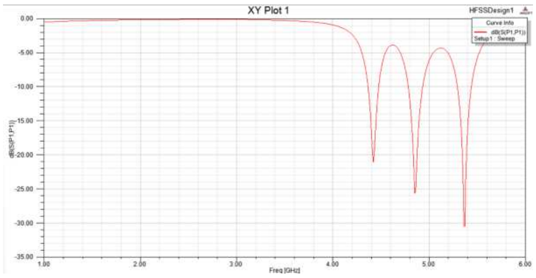


Fig.8 S_{11} Parameter of Dual Switch Design

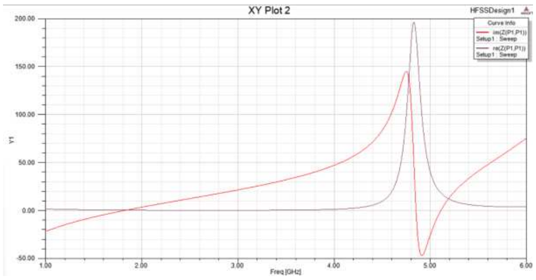


Fig.9 Z_{11} Parameter of Initial Design

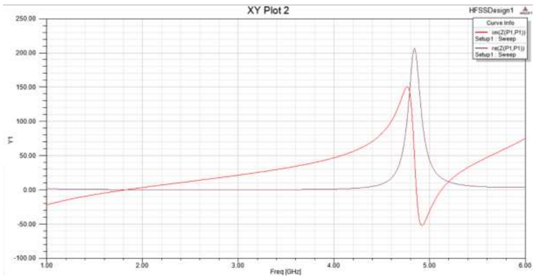


Fig.10 Z_{11} Parameter of Dual Patch Design

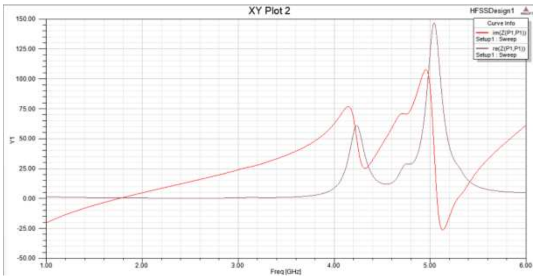


Fig.11 Z_{11} Parameter of One Switch Design

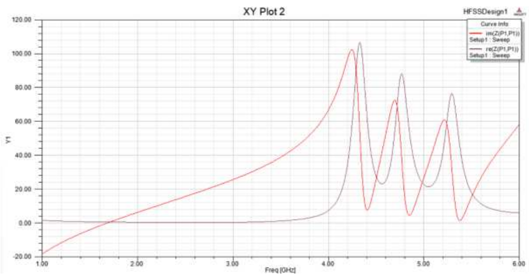


Fig.12 Z_{11} Parameter of Dual Switch Design

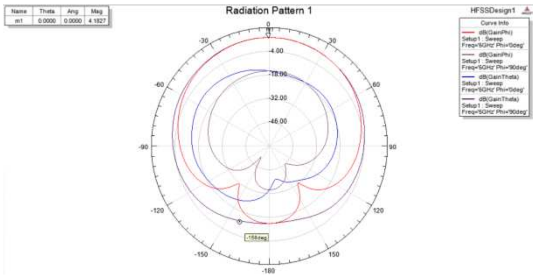


Fig.13 Radiation Pattern of Initial Design

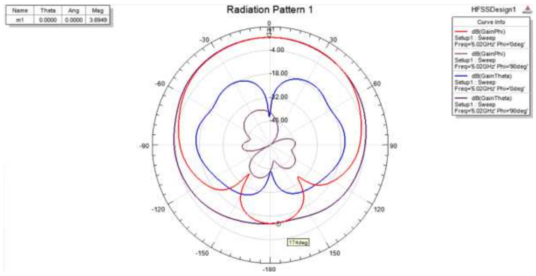


Fig.14 Radiation Pattern of Dual Patch Design

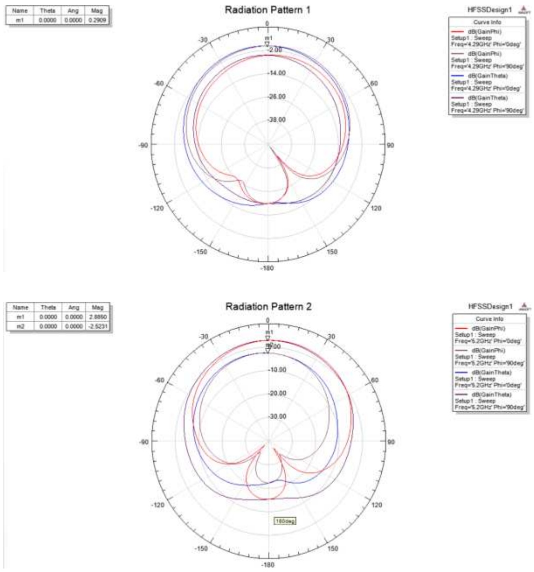
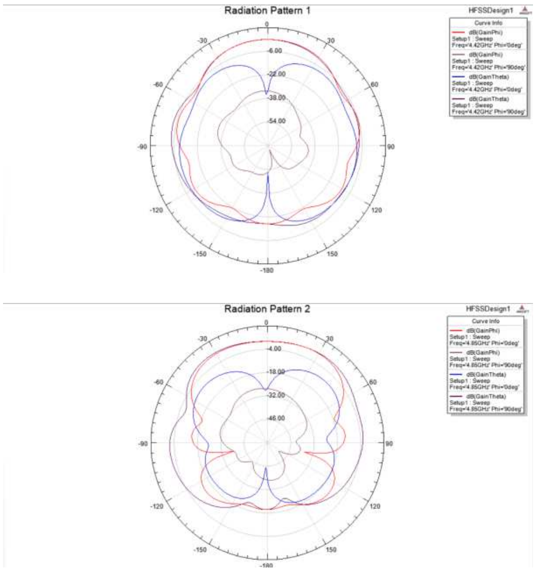


Fig.15 Radiation Patterns of One Switch Design



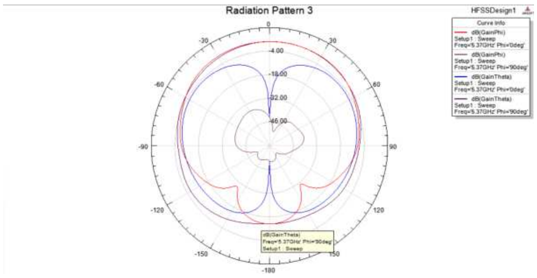


Fig.16 Radiation Patterns of Dual Switch Design

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

Simulated different parameters of the four 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	5 GHz 5G band range of (4.4 GHz to 5 GHz)	$S_{11} \leq -10.77$ dB
Design using a dual radiating patch	5.02 GHz 5G sub-6 GHz band range of (4.8 GHz to 6 GHz)	$S_{11} \leq -10.19$ dB
Design using a dual radiating patch and introducing an RLC Switch	4.29 GHz 5G band range of (3.3 GHz to 4.2 GHz)	$S_{11} \leq -11.15$ dB
	5.2 GHz 5G sub-6 GHz band range of (4.8 GHz to 6 GHz)	$S_{11} \leq -15.24$ dB
Design using a dual radiating patch and introducing two RLC Switches	4.42 GHz 5G band range of (4.4 GHz to 5 GHz)	$S_{11} \leq -21.07$ dB
	4.85 GHz 5G band range of (4.4 GHz to 5 GHz)	$S_{11} \leq -25.61$ dB
	5.37 GHz 5G sub-6 GHz band range of (4.8 GHz to 6 GHz)	$S_{11} \leq -30.46$ dB

B. Radiation Pattern of the Antenna

Considering the 1st Design of the Antenna:- from the Radiation pattern shown in Fig. 13, a magnitude of 4.1827 at theta an angle of 0 degrees and frequency at 5 GHz is observed.

Considering the 2nd Design of the Antenna:- from the Radiation pattern shown in Fig. 14, a magnitude of 3.6949 at theta an angle of 0 degree and frequency at 5.02 GHz is observed.

Considering the 3rd Design of the Antenna:-from the Radiation patterns shown in Fig. 15, there are two sets of Radiation Patterns obtained. From the 1st Radiation pattern, a magnitude of 0.2909 at theta an angle of 0 degree and a frequency at 4.29 GHz is observed. From the 2nd Radiation pattern, a magnitude of -3.1435 at theta an angle of 0 degree and a frequency at 5.2 GHz is observed.

Considering the 4th Design of the Antenna:-from the Radiation patterns shown in Fig. 16, there are two sets of Radiation Patterns obtained. From the 1st Radiation pattern, a magnitude of 0.2909 at theta an angle of 0 degree and a frequency at 4.42 GHz is observed. From the 2nd Radiation pattern, a magnitude of -3.1435 at theta an angle of 0 degree and a frequency at 4.85 GHz is observed. From the 3rd Radiation pattern, a magnitude of 1.7036 at theta an angle of 0 degree and frequency at 5.37 GHz is observed.

V. Conclusion

The proposed 5G reconfigurable microstrip patch antenna demonstrates significant versatility by enabling operation across multiple frequency bands through innovative designs and switching techniques, making it an effective solution for compact 5G applications.

Moreover, this multiple-band capability ensures that the antenna can effectively operate within the specific frequency ranges required for 5G communications, thus ensuring efficient signal transmission and reception. The compact size and lightweight nature of the microstrip patch antenna further contribute to its suitability for modern mobile devices and communication systems. Overall, the innovative design of a reconfigurable microstrip 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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