

EVALUATION OF RECONFIGURABLE ANTENNAS FOR WIRELESS COMMUNICATION

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ABSTRACT

Antennas are significant in wireless communication systems, and with advancing technology, there's a rising demand for lightweight, low-profile antennas with broad coverage and versatile applications. The main aim of this research is to evaluate the performance of Evaluation of Reconfigurable Antennas for wireless communication. In this research the final design achieved dual-band operation at 3.21 GHz, 4.0 GHz, and 5.32 GHz with gains up to 6.77 dBi and efficiency exceeding 70%, enabling pattern tilts of +30° and 30°. Advantages include high efficiency, simplified design, and versatile functionality, while drawbacks involve larger dimensions, fabrication discrepancies, and limitations of the FR-4 substrate. This design, suitable for wireless communication and WLAN, balances performance and complexity, with potential for future miniaturization and material optimization.

KEYWORDS

Reconfigurable Antennas, Arrow-shaped antenna, design and optimization etc.

1. INTRODUCTION

Reconfigurable antennas are important for expanding wireless technology because they can dynamically respond to a variety of operating needs. Traditional antennas operate in defined frequency bands and are built for certain services with nearly fixed resonant frequencies, whereas reconfigurable antennas may modify their frequency ranges, polarization, and emission patterns in real time. This versatility is achieved via electrical switches such as PIN diodes, Varactor diodes, and MEMS, as well as optically controlled techniques. The requirement for antennas that can handle numerous radio applications with little interference, smaller dimensions, and cheaper prices has fueled the development of reconfigurable antennas. These antennas replace many fixed-function conventional antennas with a single device that can alter several performance measures as needed. Recent research has focused on dual reconfiguration, which allows antennas to change numerous parameters simultaneously. This functionality improves wireless connection performance and spectrum efficiency, particularly in contexts with variable channel circumstances. As wireless devices offer more simultaneous applications, the utility of employing several fixed antennas decreases. Reconfigurable antennas make device design simpler by lowering component count and hardware complexity. They provide specialized performance for a wide range of applications, including Cognitive Radio Systems, Satellite Communications, and Biomedical Applications, demonstrating their usefulness and adaptability in a variety of high-demand circumstances.

Many reconfigurable antenna designs have been investigated in the literature, with the rectangular patch emerging as a particularly common and adaptable form. The research offers a

reconfigurable rectangular patch antenna that employs a single PIN diode to accomplish frequency and pattern flexibility, resulting in a simpler biasing network than multi-diode solutions. (A. A. Palsokar and S. L. Lahudkar, 2020)

The antenna works at 2.47 GHz, 3.8 GHz, and 5.36 GHz, with the ability to change its radiation pattern dynamically. The design has an inset feed for impedance matching, which is enclosed by an inverted U-shaped patch connected via a switchable slot. The Pattern Search Algorithm was used to optimize the feed length, and real-world measurements validated the simulation results. This novel design minimizes complexity and distortion by separating biasing lines from the radiating structure. The antenna is appropriate for applications such as Cognitive Radio Systems, Satellite Communications, and Biomedical Applications, with future development aiming at lowering its size while maintaining reconfigurability.

In Nguyen-Trong N et al., (2016) look at a center-shortened microstrip antenna that can be reconfigured for frequency and pattern. They achieve this reconfigurability by using varactors with open-circuit stubs as the tuning mechanism. Varactors, also known as voltagevariable capacitors, are semiconductors whose capacitance can be adjusted by changing the applied voltage. The researchers achieve dynamic modifications to the antenna's resonance frequency and radiation pattern by including varactors into the antenna design and linking them with open-circuit stubs. This method enables the antenna to adapt to changing operational needs and environmental circumstances, making it appropriate for a wide range of wireless communication applications.

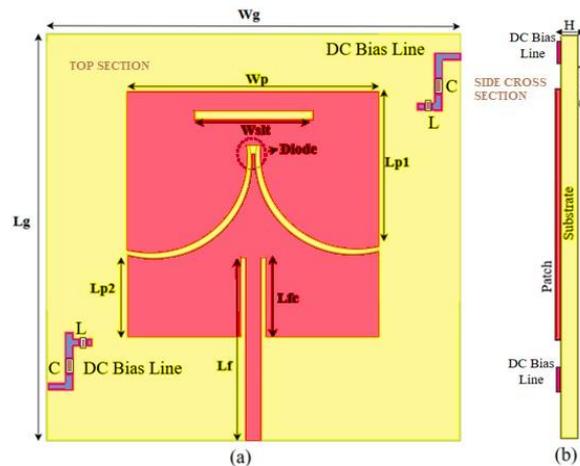


Figure.1: geometry of polarization and frequency reconfigurable ANTENNA

$W_g=L_g=60\text{mm}$
 $L_{p2}=10.9\text{mm}$
 $L_{fc}=11.5\text{mm}$

$W_p=38\text{mm}$
 $W_{sl}=17\text{mm}$
 $H=1.6\text{mm}$

$L_{p1}=24.6\text{mm}$
 $L_f=29.29\text{mm}$

The suggested antenna uses a basic rectangular patch design with two longitudinal slits coupled by PIN diodes for reconfiguration. (Y. P. Selvam et al. 2017) It operates at 4.5 and 4.8 GHz / 5.2 and 5.8 GHz, with pattern tilt options of -30° , 0° , and $+30^\circ$. Prototype manufacture and measurements verify its performance, which is consistent with models. This antenna meets the requirement for diverse wireless solutions by optimizing spectrum consumption and decreasing the need for additional antennas. It successfully meets a wide range of wireless communication requirements because to its small size. Its simple actuation mechanism improves practicality when compared to more sophisticated options. The design's impedance and radiation

characteristics illustrate its ability to efficiently manage dynamic channel circumstances and improve wireless connection performance. Yadav A.M. et al., (2011), investigate a plug-hole-shaped frequency and pattern reconfigurable antenna using photoconductive microwave switches. The antenna configuration consists of a V-shaped radiator with a triangular parasitic patch, which is reconfigurable using four switching diodes. By including photo-conductive microwave switches into the antenna design, the researchers can dynamically change the antenna's resonance frequency and emission patterns. Technology enables fast modifications in response to changing communication demands and environmental circumstances.

The research examines the effect of metallic control lines on the operation of a frequency-reconfigurable patch antenna that resonates across three frequencies in the 3-4 GHz range.(A. M. Yadav et al., 2010) It investigates how these control lines, which are essential for activating electronic switches such as PIN diodes, might unintentionally modify antenna properties, resulting in detuning difficulties and changes in radiation patterns. The work demonstrates the complications of incorporating control lines into antenna designs through rigorous simulation and measurement analysis, emphasizing the difficulties in precisely forecasting their effects. Despite efforts to optimize biasing line positions, differences between simulated and measured results highlight the practical challenges of regulating detuning, especially when soldered biasing wires are used. The antenna's frequency and pattern diversity may be viewed by adjusting six diodes located within the ground plane slot.

2. LITERATURE REVIEW

An energy conversion device interfaces between the transmission line and the free space. The modern communication system has the advantage over the conventional one in suppressing unwanted signals and enhancing the main lobe. When we look back toward the antiquity of the antenna, the electromagnetic theory of J.C. Maxwell webbed out the new path in the field of communication through Maxwell's Equation.(B. K. Pandey, 2024)

His authoritative concept regarding similar travelling Speeds of electromagnetic and light waves is the key to communication and related applications. G. Marconi uses this concept to successfully transmit the waves over a significant distance, even more than 2k km. He uses the antenna with more than 60 vertical wires with horizontal support between two wooden poles of 60m and the receiver antenna design on the other side. It is the aurora period of the antenna where manual concepts are more. (C. A. Balanis, 2023)

In a basic wireless communication model, the three key components are the transmitter, receiver, and channel.(B. A. Cetiner et al., 2010) The channel, often free space, allows signals to travel between the transmitter and receiver. An essential interfacing device in this system is the antenna, which serves as the bridge between the transmitter and the channel and between the channel and receiver.(A. Graue et al., 2010)

The concept of reconfigurable antennas dates back several decades, but significant research and practical implementations emerged prominently in the 1990s.(S. A. Aghdam 2013) The initial focus was on frequency reconfigurability, allowing antennas to operate over multiple frequencies bands. This was particularly important for applications such as military communications and early mobile networks, which required versatile antennas capable of adapting to different frequency allocations.(Bhartia, P., & Bahl, I. 1985)

Early reconfigurable antennas often employed simple mechanical tuning mechanisms, such as movable components or adjustable lengths. However, these methods were cumbersome and slow,

limiting their practicality in rapidly changing environments. Developing electronic tuning mechanisms, including PIN and varactor diodes, marked a significant advancement. (Daryoush, A. et al. 1986) These components allow for faster and more reliable reconfiguration, paving the way for more sophisticated designs. Antennas that may be reconfigured were first presented in 1998. Regular antennas' functional capabilities can be expanded by changing their configurations on demand.(Van Blaricum, M. L. 2000)

A Pattern Reconfigurable Antenna (PRA) is an advanced type of antenna capable of dynamically adjusting its radiation pattern without physically changing its structure. This capability is achieved through innovative design techniques such as phased array technology, smart antenna algorithms, or reflect array configurations.(Ashvanth, B. et al., 2020) PRAs are essential in modern wireless communication systems where adapting the antenna's radiation pattern in real time improves signal strength, quality, and interference mitigation. By electronically steering beams or adjusting the phase of reflected waves, PRAs enhance coverage, capacity, and reliability in diverse environments, including radar systems, satellite communications, and mobile networks. (S.-H. Chen et al. 2007)

Table. 2.3. Summary of state of art of pattern reconfigurable antenna.

Ref	Year	Dimensions (mm ³)	Type of reconfigurability	Frequency (GHz)	Maximum gain(dBi)	Switching technique
L. Sane et al	2018	(18x5.5x4.5)	Pattern reconfigurable	2.53	1.93	Slot and stub
X. Yang et al.	2018	(6.2x3.8x0.5)	Pattern reconfigurable	1.75 – 3.75	7.70	PIN diode with slot
K. Laafif et al.,	2017	(50x45x1.6)	Pattern reconfigurable	5.6	15.30	PIN diode
I. Serhsouhetal.	2020	(50x50x0.6)	Pattern reconfigurable	27	7	PIN diode with slot

3. DESIGN

Figure 1 depicts the proposed frequency and pattern-reconfigurable patch antenna, which was built for a variety of wireless applications. This novel antenna has an upper reflecting patch fashioned like an arrow, divided by another inverted arrow-shaped metallic patch. The width of a conventional rectangular patch is given by equations 1 to 6.

$$w = \frac{c}{2f_0} \sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

The length of rectangular patch is given by

$$L = L_{eff} - 2\Delta L \tag{2}$$

Where,

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{reff}}} \tag{3}$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2} \tag{4}$$

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.494) \left(\frac{w}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \tag{5}$$

Feed length and feed width is given by

$$L_f = \frac{\lambda}{4\sqrt{\epsilon_r}} \tag{6}$$

The design development shows a complete strategy to building a frequency and pattern-reconfigurable antenna, with major advances demonstrated with each iteration. The meticulous optimization of patch forms, strategic positioning of a PIN diode, and the installation of a slot in the top patch all contribute to the antenna's improved performance, making it an important addition to the field of reconfigurable antennas.

4. RESULTS DISCUSSIONS

The reconfigurable arrow-shaped patch antenna accomplishes radiation pattern reconfigurability by incorporating a single PIN diode switch into a slot at the upper side of the arrow, surrounding the inset-fed radiating patch. When the PIN diode is toggled from on (low resistance) to off (high resistance), the electrical connection between the inner and outer patches changes. This modification alters the antenna's current distribution and electric field structure, resulting in distinct emission patterns. The SMPP SC 79 PIN diode serves as a switching element in antenna design. A DC voltage of 2 volts activates the diode, while 0 volts deactivates it. The biasing network achieves the necessary operation by using a 33 nH coil and a 10 pF capacitor. Following fabrication, the prototype antenna is tested to confirm the simulated results. During the simulation, the PIN diode was represented using the equivalent circuit described in the manufacturer's datasheets (Fig. 2).

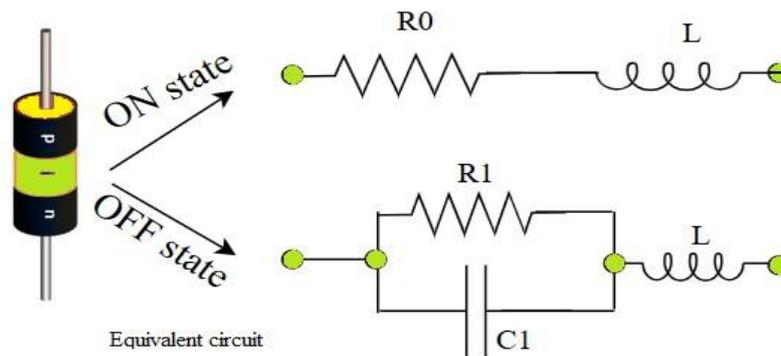


Figure. 2: EQUIVALENT CIRCUIT OF PIN DIODE

ON STATE: $R_0=1\Omega$, $L=0.6\text{NH}$

OFF STATE: $R_1=3\text{K}\Omega$, $C_1=0.3\text{PF}$.

The constructed antenna's performance was confirmed using an Antitsu MS 4647B vector network analyzer. The 'Aplab 7612' dual DC power supply gave DC power to the PIN diode. To obtain better impedance matching, the inset fed length must be optimized. This optimization procedure entails fine-tuning the feed length to reduce the reflection coefficient, hence improving impedance matching. The feed length is iteratively modified to reach the lowest feasible reflection coefficient, guaranteeing excellent impedance matching. Figure 3 depicts a parametric examination of the slot of feed length.

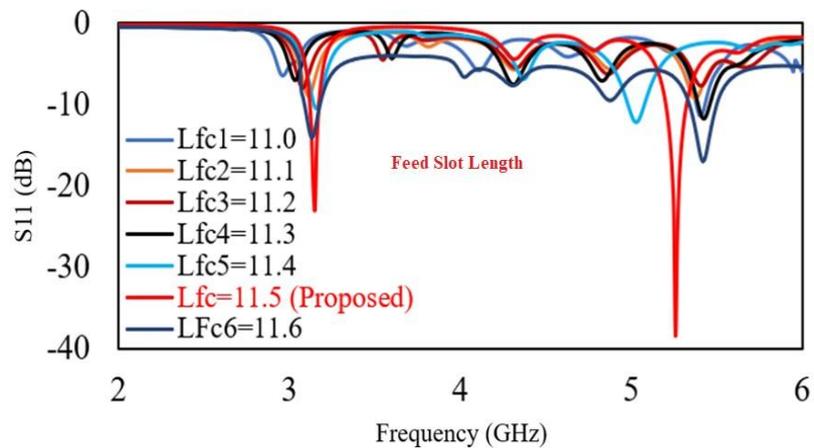


Figure. 3: parametric analysis of feed slot length

The antenna's reflection coefficient, shown in Fig. 4, differs from the simulated and measured findings, owing mostly to manufacturing defects. When the diode is "on," the antenna has twin resonances at 3.21 GHz and 5.32 GHz, with gains of 2.97 dBi and 6.77 dBi and radiation efficiencies of 61% and 72%, respectively. In the "off" position, the antenna resonates at around 4 GHz, with a gain of 2.22 dBi and a 58% efficiency. Figure 5 depicts the gain (both measured and simulated) and efficiency characteristics of the proposed reconfigurable antenna under all situations, including those without a PIN diode and with the PIN diode turned off, illustrating performance changes among states.

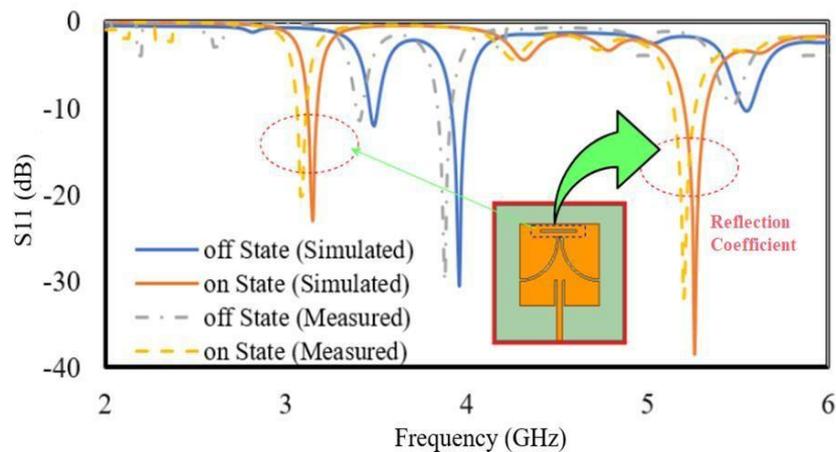


Figure. 4: reflection coefficient of proposed structure

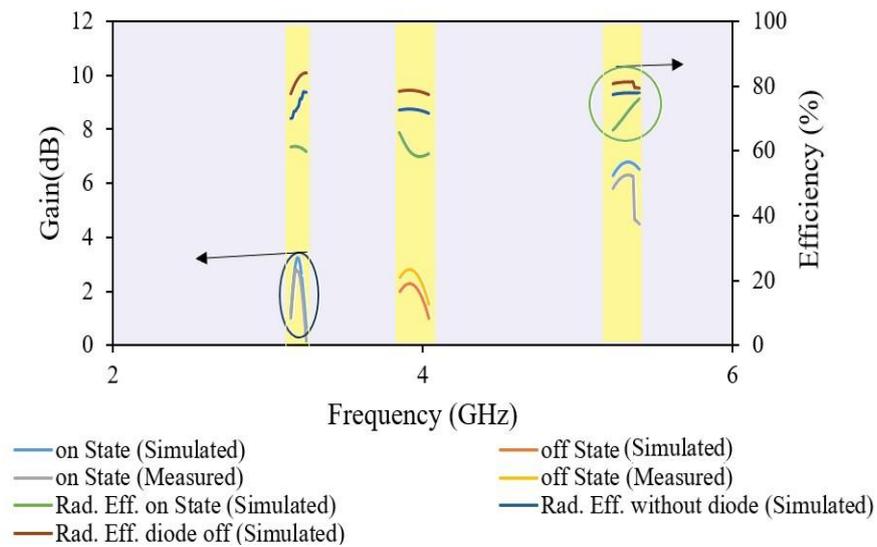
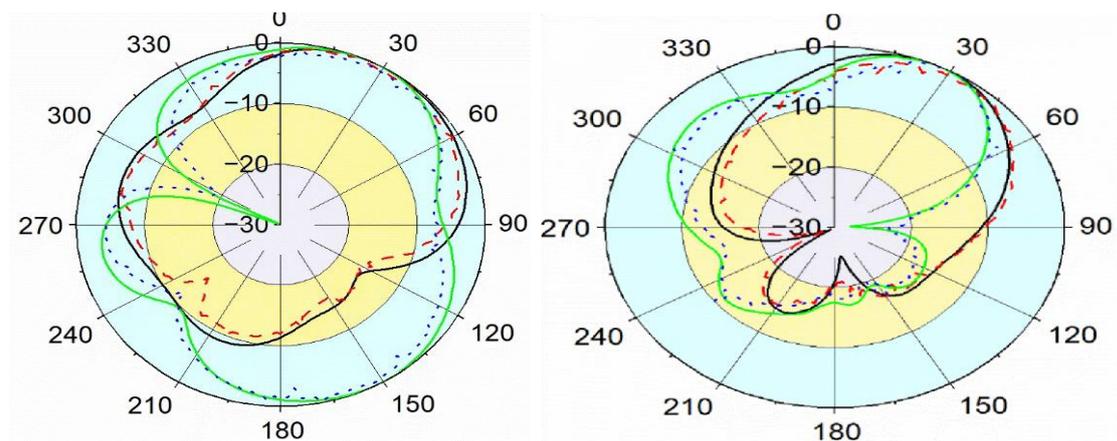


Figure. 5: Gain and efficiency v/s frequency plot of the proposed structure

Adjusting the antenna using a switch affects the size of the patch, influencing how the electric field distributes. The electric field distributes differently across the structure when the switch is turned on than when it is turned off. When the switch is turned on, the electric field distribution varies for each resonant frequency of the antenna. When the switch is turned off, the electric field is highest, maximum at the bottom arrow shape patch and minimizing at the higher patch. The antenna's pattern is reconfigured by altering the direction of current within the patch radiator with a PIN diode. In traditional antenna systems, changing the phase of the excitation current usually causes the radiation pattern to tilt. However, in this configuration, the excitation source remains constant even while the current route varies. This shift in the current route causes a phase discrepancy due to the increased distance the current travels, resulting in pattern reconfiguration. This phenomena may be seen in both states of the PIN diode. In State I, when the diode is turned on, the antenna's normalized E-plane and H-plane radiation patterns at 3.21 GHz and 5.32 GHz change by around +30 degrees, as illustrated in Fig. 6.



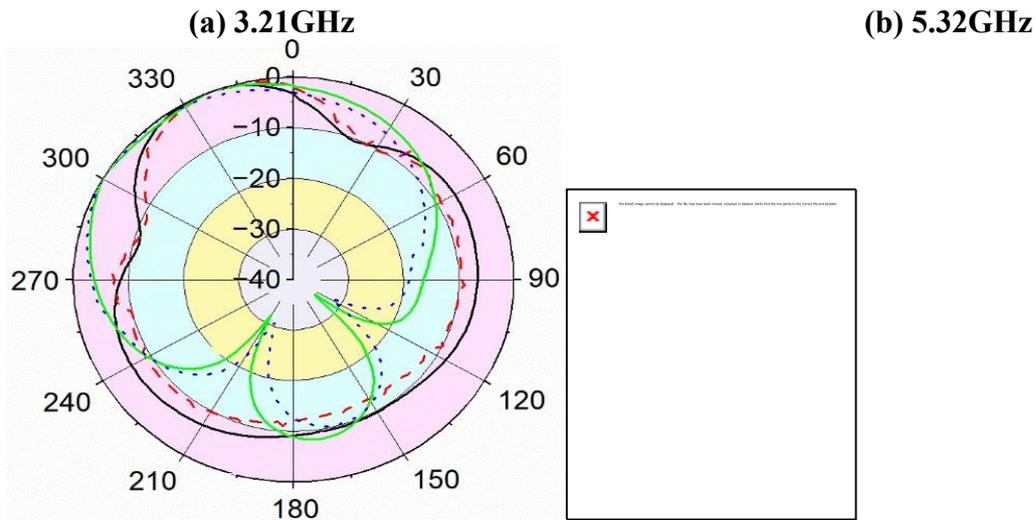


Figure. 6: Normalised radiation pattern

When the diode is turned off, the radiation pattern shifts from $+30^\circ$ to -30° . Figure 6(c) depicts the simulated and measured normalized E- and H-plane radiation patterns. There are some differences between the simulated and measured findings, which can be attributable to connection errors and scattering effects. The suggested antenna design demonstrates this type of pattern reconfiguration, which involves adjusting the current route rather than the excitation phase, and provides great flexibility in radiation pattern management. Fig. 7(a,b) illustrates the performance comparison of the antenna under two conditions: with the PIN diode in the "off" state and without the PIN diode. The comparison focuses on E-field radiation showcasing the electric field distribution patterns, highlighting the influence of the diode on the radiated field and (b) H-field radiation depicting the magnetic field distribution, emphasizing the changes in radiation characteristics due to the diode's absence or deactivation.

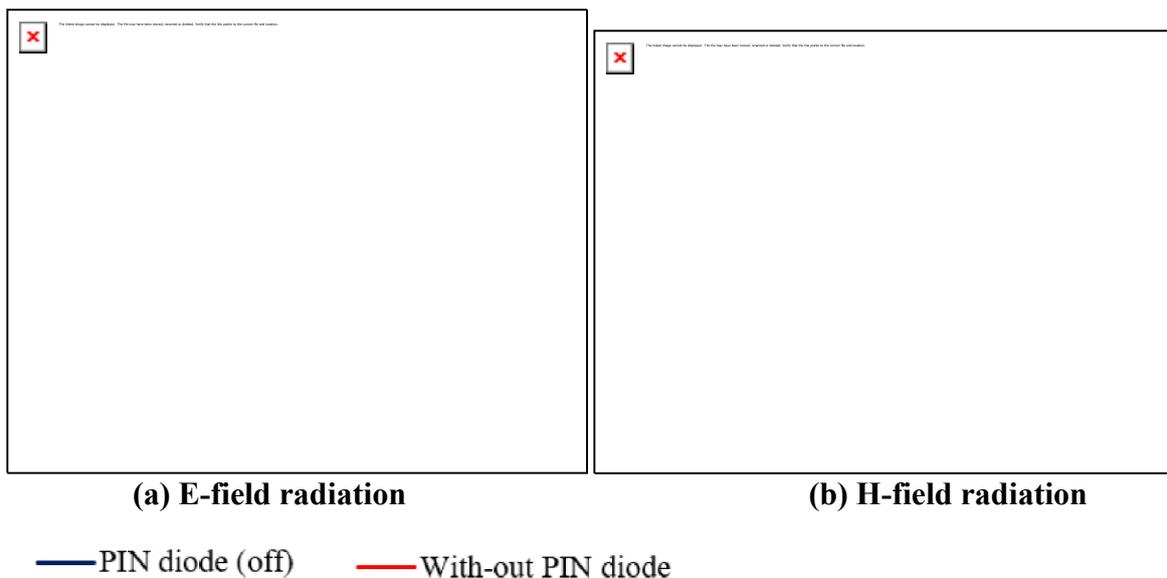


Figure7: Comparison of the antenna with pin diode (off) and without pin diode

Table 1 presents a comparison table of the proposed work to the state of the art.

TABLE 1: COMPARISONS OF THE PROPOSED WORK

Ref.	Pattern Reconfigurability	No. of Diodes	Frequency Reconfigurability	Resonating Frequency (GHz)	Max gain (dB)
A. A. Palsokar and S. L. Lahudkar (2020)	Yes	1	Yes	3.8,2.47,5.36	5.34
Nguyen-Trong N. etal. (2016)	Yes	2	Yes	2.7,3,3.5	5.1
P. Selvam et al. (2017)	Yes	4	Yes	4.5,4.8,5.2,5.8	4.50
Chilukuri S. etal. (2018)	Yes	12	Yes	2.3,4.9,5.3,5.5,6.2,7.2,8.2	12.87
This work	Yes	1	Yes	3.21, 5.32, 4.00	6.77

5. CONCLUSION

This paper describes the evolution of a frequency and pattern reconfigurable patch antenna, from a simple rectangular patch (Antenna I) to a sophisticated arrow-shaped design (Antenna V) with a single PIN diode. Each iteration increased performance: Antenna II included an arrow-shaped patch to improve reflection, Antenna III added an inverted arrow and slot to improve frequency selectivity, and Antenna IV included a PIN diode for initial reconfigurability. The resulting design achieved dual-band operation at 3.21 GHz, 4.0 GHz, and 5.32 GHz with gains up to 6.77 dBi and efficiency more than 70%, allowing for pattern tilts of $+30^\circ$ and -30° . The benefits include high efficiency, streamlined design, and diverse functionality, while the disadvantages include greater dimensions, manufacturing inconsistencies, and restrictions of the FR-4 substrate. This design, appropriate for wireless communication and WLAN, strikes a compromise between performance and complexity, with room for future shrinking and material optimization.

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