International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 6
DOI: https://doi.org/10.17762/ijritcc.v10i6.5619
***Article Received**: 10 April 2022 **Revised**: 18 May 2022 **Accepted**: 02 June 2022 **Publication**: 30 June 2022*

Parasitic Element Based Frequency Reconfigurable Antenna with Dual Wideband Characteristics for Wireless Applications

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Abstract: A Microstrip Frequency Reconfigurable circular patch slot antenna for switchable Bluetooth, WiMAX, WLAN, and satellite communication applications is analyzed and presented in this work. The optimized overall size of 47 mm x40 mmx1.6 mm is utilized in the design, and which can cover wide range of frequencies below 10 GHz. In the initial phase, different monopole antennas are designed with various shapes of same size and later parasitic patch elements has been added to those monopole antennas. The circular monopole driven element and parasitic element are connected with a PIN diode, and which reinforced in achieving frequency reconfigurability. The proposed antenna is resonating at various frequencies of 2.4 GHz, 4 GHz, and 8.4 GHz when the diode in ON condition and resonating at 3 GHz, 5.4 GHz, and 8.4 GHz when the diode is in OFF condition. The performance of the designed antenna prototype is scaled and differentiated with the results of simulation and found good matching with respect to performance characteristics.

Keywords: Parasitic Patch, Reconfigurable Antenna, PIN Diode, Wideband.

1. Introduction

Now a days, the development of compact and reconfigurable wireless systems has become essential modules for several communication devices. Numerous types of wireless communication applications like GPS, Wi-Fi, Bluetooth, Satellite television all work for a definite operating frequency range. These tools are capable of altering their resonating frequency and they should provide mobility and flexibility based on the user requirement. In order to achieve this, reconfigurable antennas are introduced. These antennas are playing key roles in smart and adaptive systems. Reconfigurable antennas are efficient of modifying their radiation, polarization, and frequency characteristics dynamically, in a reversible & controlled manner. They alter its behaviour & geometry to enhance the efficiency of the antenna. Such methods of reconfiguration with integration of PIN Diodes, Varactors, Field Effect Transistors(FETs), radio frequency microelectromechanical systems (RF-MEMS), Parasitic pixel layers or on the physical changing of the radiating structure such as mechanical actuators, or on the utilization of the smart materials like liquid crystals and ferrites.

There is now a fast expansion of wireless communication applications such as satellite phones, GPS and RFID, unmanned aerial vehicles (UAN), optical wireless communications (OWC), artificial intelligence (AI) and so on. These devices' performance is mostly determined by their antennas. In order to achieve optimal system-level performance, a lot of effort is put into designing antennas. Multi-band operation, increased data rates, adequate diversity gains, and improved connection stability are all requirements for a high-performance antenna. The reconfigurable antenna is one that is able to adjust its frequency and radiation qualities dynamically over its lifetime. Searching for accessible networks and connecting to them through cognitive methods is possible with the antenna. When compared to other smart antennas, this one employs its own internal frequency and radiation property reconfiguration process rather of relying on external networking systems. To get spatial and directional data, reconfigurable antennas are utilised in the ultra-wideband spectrum.

Because of the ease of assembly and cheap cost of PIN-diodes-based frequency reconfigurable antennas, many of these devices have been invented, developed, and tested. For wireless applications, a CPW fed frequency reconfigurable dual-mode, dual-band folding slot antenna was developed by G. Chen et al. Antennas constructed and studied by V. V. Reddy are coupled to RF GHz diodes to produce circularly

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polarised radiation. Reconfigurable planar antenna for WLAN/Wi-Fi applications was designed and tested by R. K. Singh et al. For WiMAX, WLAN and X-band satellite communication applications, Fouad Fertas and his colleagues introduced a CPW-fed monopole slotted small antenna with switchable frequencies. With four varactors and two DC bias voltages, a mechanism was developed to regulate and switch the relative tuning ranges of roughly 11% between the two bands. BAR50-02V CPW fed dual band frequency-reconfigurable planar antenna for WLAN/WiMAX application with gain between 2.3 and 3.90dBi and bidirectional radiation pattern was shown by Youcef B. Chaouche et al.

An antenna designed by Boukarkar et al. for WLAN and WiMAX applications uses a DC bias circuit that is relatively simple [8]. Skyworks' GaAS FET (SKY13298-360LF from Skyworks) was used to create a frequency-tunable small monopole smart antenna that could be quickly shifted from narrowband to dual-band for WLAN, WiMAX, and PCS applications. A digital signal of 3.3 V eliminates the requirement for a DC bias network and a blocking capacitor.

Wireless WLAN operators are increasingly using un-frequency-reconfigured antennas. The maze-shaped multi-band miniaturised antenna suggested by J. Kulkarni and C. Sim uses no additional hardware, expensive substrate, or lumped parts. Future wireless applications will be built around MIMO antennas for high data rates and dependability. These flexible, transparent connected-ground MIMO antennas were proven by the authors for usage in 5G NR sub-6 GHz, n77/n78/n79, Wi-Fi-5, V2X/DSRC, and Wi-Fi-6 with high isolation and broad band. India's INSAT-C National Satellite System for Wireless Future.

This study describes the development, fabrication, and testing of an edge-fed quarter-wave impedance transformer-coupled, miniaturised, monopole, ultrawideband (UWB), dodecagon-shaped dual-band frequency reconfigurable antenna employing four RF switches (BAR64-02V). Multi-tuned ultra-wideband (UWB) antennas with a single notch band have been suggested.

2. Literature Survey

The demand for lightweight, ease of implementation, low profile and low-cost broadband antennas is attractive for short-range communication in wireless techniques.Ultra wideband antennas are used by the military and telecommunication systems. In Wireless communication Wideband antennas are highly utilized. The requirements for the wideband antenna are low cross-polarization, fixed gain, and directional radiation pattern. In the design of ultra-wideband antennas, the multiband property and minute physical structure are very critical. The reconfigurable antennas are in such great demand to obtain requirements by making use of a one single device. Numerous kinds of UWB antennas which are band-notched have been formulated with distinct ways to attain reconfigurability such as using RF-MEMS Switch, Varactors, and PIN Diodes, optical switches are used. It is lucid that the present-day communication devices need antennas which provide maximum efficiency at a minimum size and tunability in the aspects of Polarization, Operating bands, and Pattern. The prime motive is to formulate a monopole antenna with multi-band operating reconfigurability.

Cognitive radio applications benefit from a selective frequency-reconfigurable antenna, which is described in this letter. The suggested antenna can switch between a 2.63-3.7 GHz operational band and four separate subbands, allowing it to be used to sense the full band and then modify its bandwidth to choose the appropriate subband and prefilter out the other ones. Microstrip lines are routed into an inverted U-shaped radiating element on the antenna's top side. There are four horizontal slots embedded in the ground plane that operate as a reconfigurable filter to accomplish frequency reconfiguration. The antenna bandwidth may be adjusted with some of the switches, while the operating band can be shifted with others by adjusting the electrical length of the middle slots. Both simulated and measured findings are used to demonstrate the work, and the results are in excellent agreement.

The notion of AI-driven design optimization or automation is introduced for the first time in this communication to achieve a general mutual coupling reduction strategy for various arrays. The surrogate model-assisted global optimization approach is selected due to its universality, ability to generate high-quality solutions for complicated structures, and efficiency. Parallel surrogate model-aided differential evolution for antenna synthesis (PSADEA) was used in particular. Antenna optimization is the focus of SADEA, a collection of algorithms. The PSADEA technique is the most recent in this series. As opposed to more traditional global optimization approaches, it improves optimization effectiveness by three to twenty times while also increasing optimization capacity. For example, PSADEA uses: (1) Gaussian process surrogate modelling, a supervised learning technique for predicting antenna performance, (2) complementary differential evolution search operators, (3) reinforcement learning method, and (4) a surrogate model-aware evolutionary search framework, which ensures effective synergy of on- and off-the-board search operators.

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The PSADEA-driven design of a novel parasitic element that reduces mutual coupling is shown here.

Dual-band frequency reconfigurable antennas are being studied, which can operate in the ISM band of 2.5 GHz and the WiMAX band of 3.4 GHz. The parasitic element reduces the reciprocal coupling in both bands to levels of less than -20 dB as a consequence of this phenomenon. Using machine learning and evolutionary computing, these researchers have created what they believe to be the first ever self-designing parasitic element that reduces mutual coupling. There is no need for adequate beginning design parameters for this technique to demonstrate its universality, high quality, and efficiency.

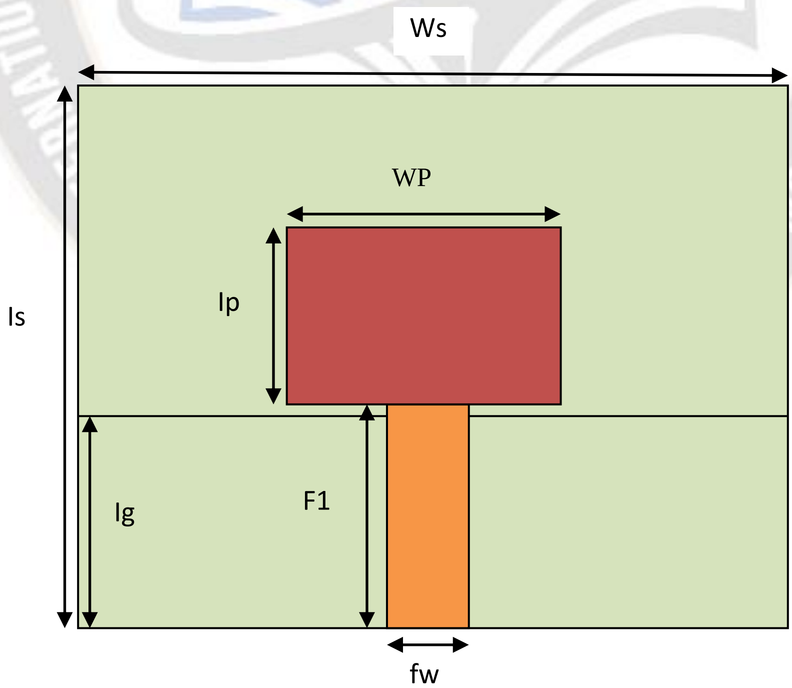
The switchable antenna presented in this study has a single configuration for switching between a single band and many bands of frequencies. There were previously only a handful frequency reconfigurable antennas that could be used for both multi-band and wide-band applications, according to the authors' best knowledge (UWB).

Multiband, single resonance frequency, and UWB spectrum operation are all possible with this antenna, which has a unique RF switch arrangement that hasn't been seen before. A total of eleven possible RF switch combinations are presented in this study, and four of them have been constructed and tested to show the idea. However, N2 RF switch combinations may be designed and antenna applications developed correspondingly. To demonstrate the ON state of the PIN diode, we add a metal strip to the circuit then remove it to demonstrate the OFF state. Similarly, the suggested antenna's reflection coefficient was compared to that of an antenna constructed utilising a metal strip and a PIN diode.

There has been a lot of interest in antennas that can be reconfigured. Operation frequencies, polarizations, and radiation patterns may all be changed to suit different purposes. The azimuthal plane beam-steerable antenna is one of the key kinds of pattern reconfigurable antennas for applications like RFID systems, cognitive radio, cellular networks and other IEEE 802.11 Standards-based applications. Selectively raising directional gain in wireless communications; lowering multipath effects; and improving channel capacity are all benefits of steering. Conventional phased arrays have been regarded feasible alternatives to beam-steerable antennas because of their structural simplicity, cheap cost and compact volume.

3. Antenna Design

3.1 Basic Iterations



(a)

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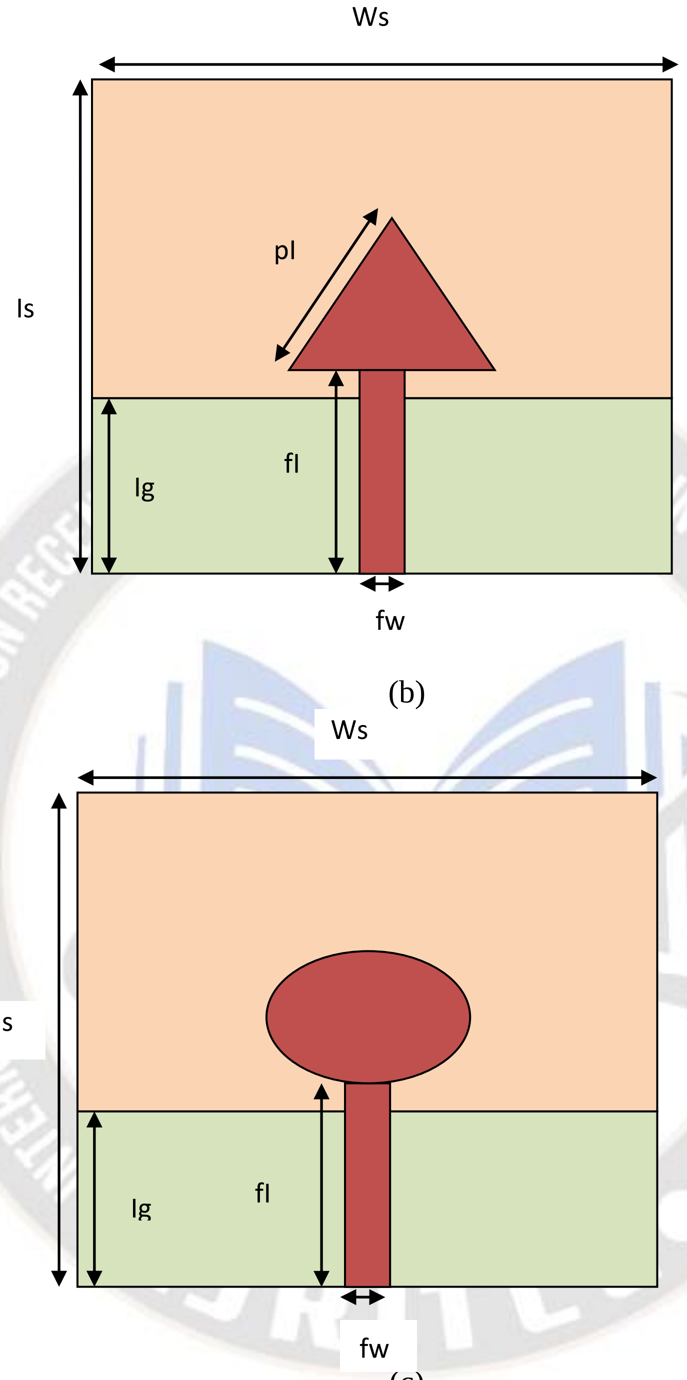

(c)

Figure. 1 Basic Iterations for (a) Square Patch (b) Triangular Patch (c) Circular Patch Monopole Antenna with partial ground fed with a simple microstrip feed line.

In Fig. 1, the structure of the suggested antenna is represented, and the sizes are illustrated in Table I. From Fig. 1 it shows that the antenna contains of a monopole antenna with different shapes square, triangle and circular patches fed by a microstrip feed line. A 1.6mm thick FR4 substrate is used in this model. The partial ground was implemented in this design. To get the wideband partial ground is placed.

Designing a microstrip patch antenna requires a dielectric medium and resonant frequency. The dimensions are calculated using mathematical equations.

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Width Calculated using the following equation

$$W = \frac{C_o}{f_r\sqrt{\frac{2}{\epsilon_r+1}}} \quad (1)$$

W=Patch width

C_o = Light speed

ϵ_r = dielectric substrate

f_r = Resonant frequency

The patch length is calculated as follows

$$L = L_{eff} - 2\,\Delta L \quad (2)$$

$$L_{eff} = \frac{C_o}{f_r\sqrt{\epsilon_{reff}}} \quad (3)$$

L_{eff} =Effective length

ϵ_{reff} =Effective dielectric constant

$$\epsilon_{reff} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2}\left[1 + 12\frac{h}{w}\right]\frac{(-1)}{2} \quad (4)$$

The antenna length is increased by an amount of (ΔL) due to the fringing field; the original length of the patch element is determined using the below equation.

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)\left(0.264 + \frac{w}{h}\right)}{(\epsilon_{reff} - 0.258)\left(0.8 + \frac{w}{h}\right)} \quad (5)$$

Substrate length and width are calculated as follows

$$L_s = L + 6h \quad (6)$$

$$W_s = W + 6h \quad (7)$$

h=height of the substrate

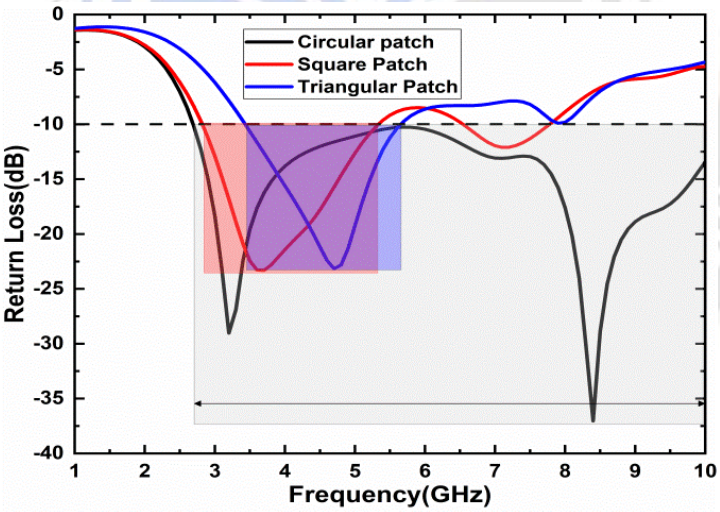

Figure. 2 Simulated results of return loss for basic iterations of Square, Triangle, and Circular microstrip patch antenna.

With the circular patch implementation wideband is obtained compared to Square and Triangular patches. In the circular patch, it is resonating in the frequency range of 2.7GHz to 10GHz and has a good impedance matching of -37.03dB. Whereas, in the square patch the antenna resonates in between the frequency range of 2.8GHz and 5.3GHz and the triangular patch antenna model resonating in between the specified frequency band of 3.4GHz and 5.7GHz.

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3.2 Inserting Parasitic Patch to the Basic Iterations

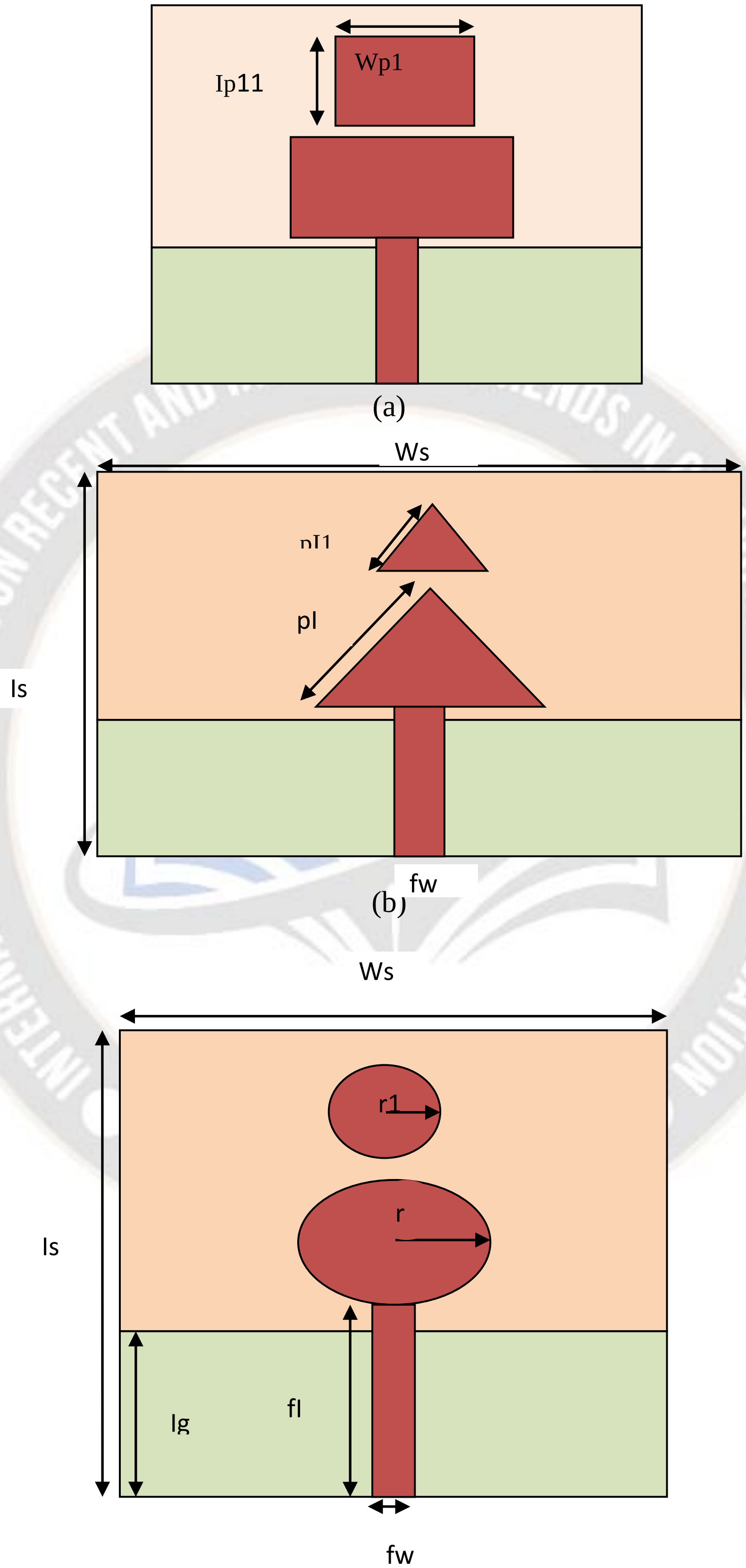

Figure. 3 Basic Iterations with the Parasitic Patch (a) Square patch (b) Triangular patch (c) Circular patch.

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The main patch is also known as driven patch and an extra patch which is placed in the vicinity of the main patch is called a Parasitic patch. The gap between these patches is considered as low. The patch antenna with the addition of a parasitic element has been designed and the purpose is to increase the bandwidth. The length of a parasitic element will determine the frequency of resonant and the width will determine the antenna bandwidth. The ground structure and patch structure are chosen as perfect metallic conductors and the microstrip feed is taken as the lumped port with an impedance of 50 ohms. Fig.3. It showing the designs of the parasitic elements added to the main patch.

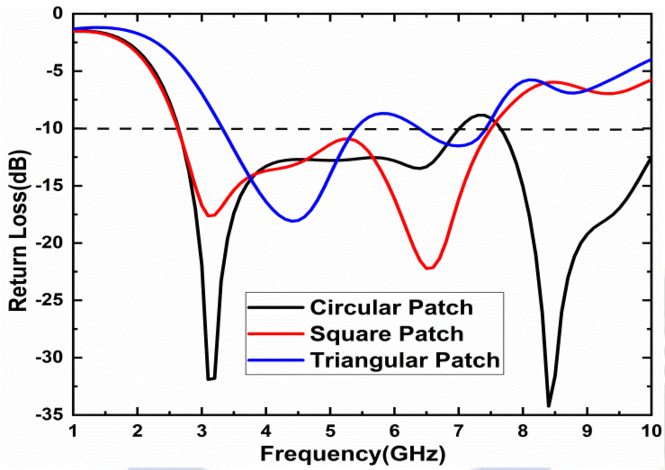
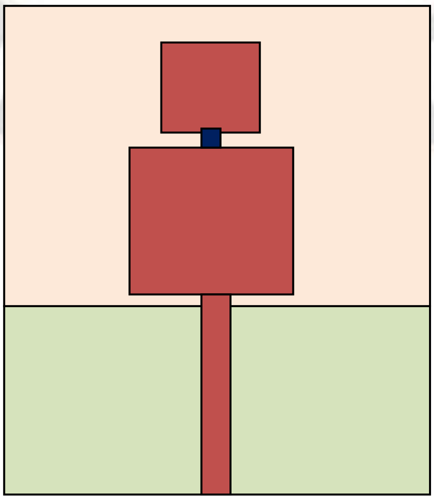


Figure. 4 Simulation Results of Return Loss for parasitic element adding to the main patch.

It is noticed that the bandwidth is enhanced by adding the parasitic patch. In the square patch, it is resonating 2.6GHz to 7.5GHz and the return loss is -22.22dB at 6.5GHz, in the triangular patch resonating from 3.3GHz to 5.4GHz and the return loss is -18.08dB at 4.4GHz, and in the circular patch the antenna is resonating from 2.6GHz to 7GHz and the return loss is -31.89dB at 3.2GHz and returns loss is -34.79dB at 8.4GHz.

3.3 Reconfigurable Antenna

To obtain the Reconfigurable Antenna, to the previous design in between the parasitic patch and the main patch a PIN Diode is inserted. In this design single PIN Diode is placed. Based on its ON and OFF conditions its resonating frequencies are to be varied. Here BAR6403 PIN Diode is inserted. Its equivalent circuit in ON condition is the resistor and inductor are connected in the series. In the OFF condition resistor and capacitor are placed in parallel followed by a series inductor. In Fig. 5. It is shown clearly the PIN Diode is inserted between the parasitic element and main patch. The gap between these two patches is 1mm.



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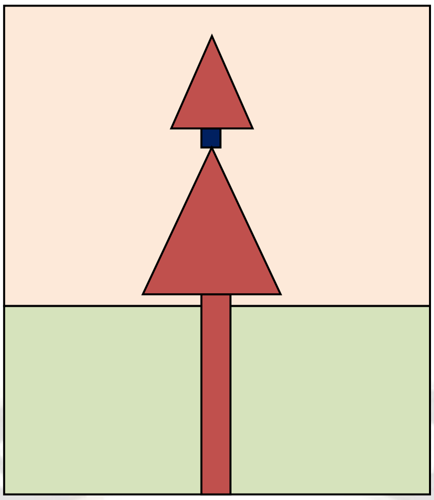

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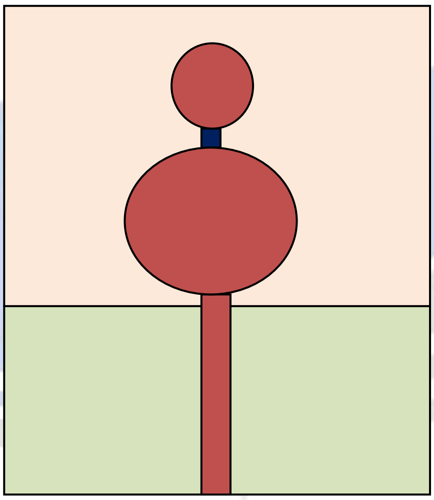
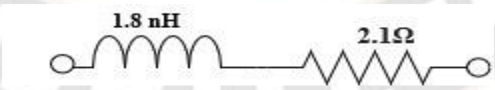


(c)

Figure. 5 The Proposed Reconfigurable Antenna with single PIN Diode insertion. (a). PIN Diode to the Square patch (b). PIN Diode to the triangular patch (c). PIN Diode to the circular patch.



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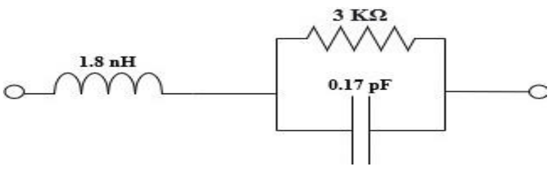

(b)

Figure. 6 Switch Equivalence model (a) ON-state, (b) OFF-state.

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The driven patch and parasitic patch are connected via PIN Diode, The model of the PIN Diode BAR64-03W is used to attain frequency reconfigurability. The ON-state series inductance and resistance are 1.8nH and 2.1Ω respectively. The shunt capacitance in the OFF state is 0.17pF having a reverse resistance of 3KΩ. The feed lines and bias lines are separated using certain definite C and L components. The biasing lines are formulated with lower sizes and even the antenna performance in radiation properties are remain unchanged. The dimensions of the proposed design are as follows: 0.25mm thick and 1mm length bias lines.

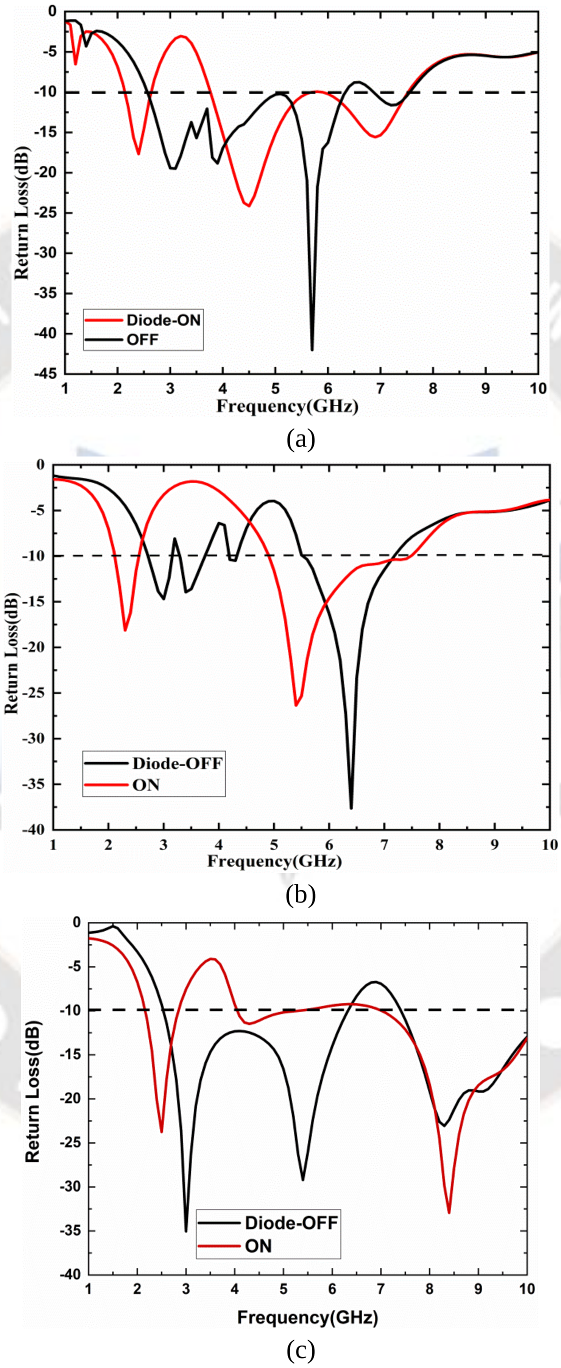

Figure. 7 Simulated Results of Return Loss for the (a) Square patch (b) Triangular patch (c) Circular patch Reconfigurable Antenna to the PIN Diode ON-OFF Conditions

In Fig.7, the return loss results are shown clearly to the diode ON-OFF conditions. Diode OFF conditions results are shown with dotted lines and ON condition results are shown with red color. (a). A square patch is resonating to the ON condition at 2.4GHz with the S_{11} of -17.67 dB and at 4.5GHz with the S_{11} of -24.13 dB. To the OFF condition, the antenna is resonating

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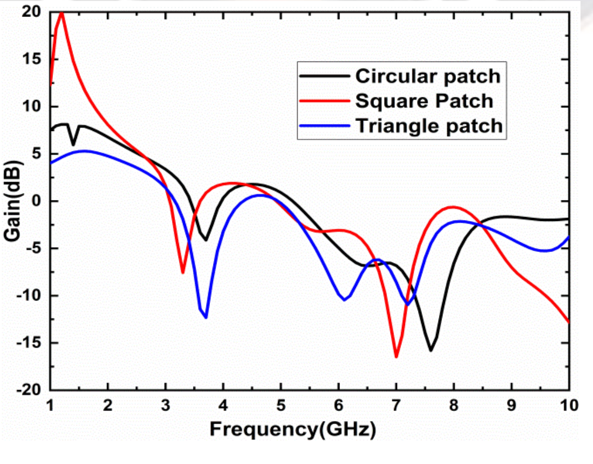
at 2.8GHz with a return loss of -19.23 dB, 3.6 GHz, and 5.7 GHz and S_{11} of -18.06 dB and -42.01 dB (b). In the triangular patch to the ON condition resonating at 2.4GHz with the S_{11} of -18.12 dB and 5.4 GHz with the S_{11} of -26.35 dB. To the OFF condition resonating at 2.8 GHz, 3.2 GHz, and 6.4 GHz with a S_{11} of -37.63 dB. (c). To the circular patch diode ON condition resonating at a frequency of 2.4 GHz with the S_{11} of -23.75 dB, 4.6 GHz with the S_{11} of -15 dB, and 8.4 GHz with S_{11} of -32.93 dB. To the diode OFF condition antenna is resonating at 3 GHz, 5.4 GHz, and 8.4 GHz with S_{11} of -35.04 dB, -29.21dB, and -22.56 dB.

Figure.8 Fabricated Prototype (a) Front View (b) Back view to the proposed antenna

Table 1. Proposed Antenna Dimensional Values

Variable	Value in mm	Variable	Value in mm
ls	47	Lg	19.56
ws	40	Pl	17.3
lp	10	Pll	9.2
wp	10	R	8.3
fl	20.56	r1	4.1
fw	2.6	lp1	8
		wp1	8

4. Results & Discussion



(a)

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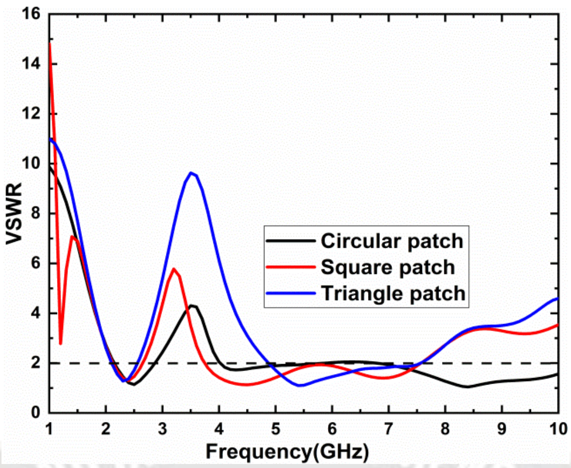
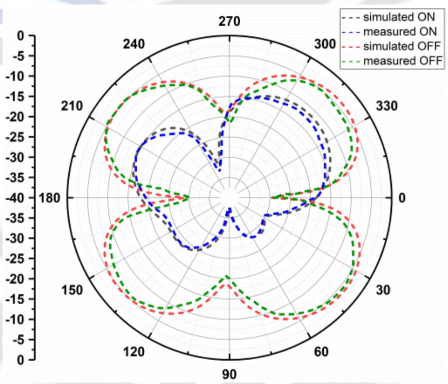


(b)

Figure. 9 (a) Simulated result of the Gain Vs Frequency and (b) Simulated result of the VSWR Vs Frequency to the circular, square and triangular patch

The maximum Gain was 8.12dB at 1.2GHz to the circular patch, 20.07dB at 1.2GHz to the square patch, and 5.3dB at 1.6GHz to the triangular patch. VSWR is 1.13 at 2.5GHz to the circular patch, 1.13 at 4.5GHz to the square patch, and 1.11 at 5.5GHz to the triangular patch.

In Fig 10 the measured radiation and measured stimulated design is shown for E & H-plane. E-plane shows the omnidirectional drawing which makes it compatible for mobile communications. The E-plane radiation pattern has been observed in the YZ-plane and the H-plane radiation pattern is observed in the XZ-plane. E-plane has the dipole pattern and H-plane has the omnidirectional pattern at 2.4GHz and 5.4GHz.



(a)

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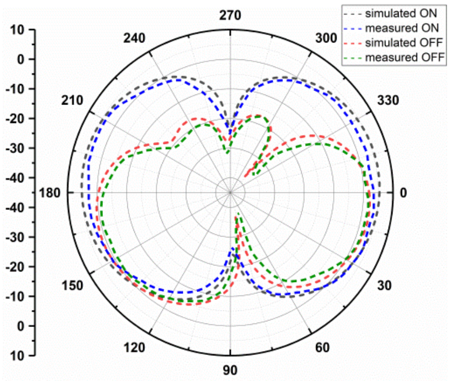

(b)

Figure. 10 Simulated & Measured Radiation results for (a) H-plane (b) E-plane antenna to the Diode ON and OFF conditions at 2.4GHz and 5.4GHz.

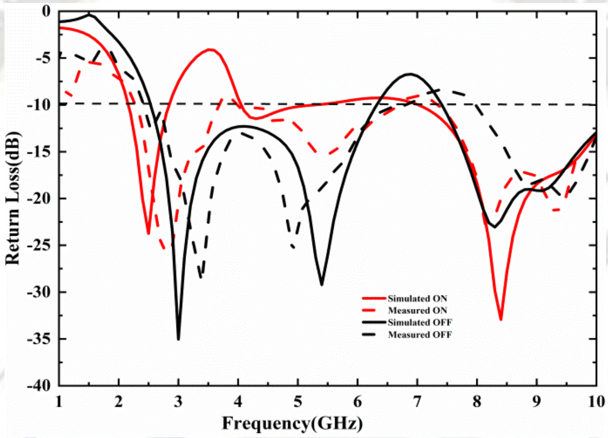

Figure. 11 Simulated & Measured results of reflection coefficient to the Proposed Antenna

The simulated & measured results of the reflection coefficient of the proposed antenna is represented in Fig.11. The proposed antenna operates in two different modes which are ON and OFF conditions to the single PIN Diode. Depending upon the altering state of the PIN Diode, a Particular operating mode of a reconfigurable antenna can be realized. To the Diode ON and OFF conditions triple-band rejection and full UWB are recorded.

Table. II. Literature Survey Comparison with the Proposed Antenna

Ref. No.	**Structure Size**	**No. of Switches**	**Operating Range GHz**	**Gain (dB)**
3	80x80	6	2.49,3.45	4,6
6	51.9x51.9	1	1.4,3.4,5.45,7.86,9.52	8.37,8.67,5.26,16.09,21.58
8	47x47	MEMS	0.68-16.23	5.05
9	150x150	Varactor	1.61-3.45	8.77
10	66x58	1	2.47,5.36	5.34
11	50x50	4	4.5&4.8/5.2&5.8	3.8
12	50x60	3	5.2,5.8	3
13	40x60	12	2.3-5.87	12.87
14	45x50	5	2,3.5,5.3	1.8
15	88x83	4	1.39-8.11	2.11
Proposed Work	47x40	1	2.4 – 8.4	8.12

4. Conclusion

A compact monopole antenna using the concept of frequency reconfigurability has been presented. Frequency reconfigurability is attained by using the single PIN Diode. The proposed antenna resonates at 2.4, 4.6, and 8.4GHz to the diode ON condition and 3, 5.4, and 8.4GHz to the diode OFF condition. The proposed antenna structure is very simple with area 40mm x 47mm and it is easy to be fabricated on the FR-4 substrate. The proposed antenna provides wide impedance bandwidth at triple operating bands, required radiation pattern, and gain. Good relations between measured and stimulated results assure the capability of the formulated antenna to be utilized in wireless communication applications.

Conflicts of Interest

The authors declare that there is no conflict of interest in this work

Author Contributions

Conceptualization, software simulation and optimization has been done by Author 1, Analysis, prototyping, and measurement validation is done by Author 2. Paper writing and review has been done by both the authors.

Acknowledgments

Authors like to express their gratitude towards the department of ECE of VIT-AP and like to thank KLEF for the fabrication and testing facility at ALRC-R&D.

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International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 6
DOI: https://doi.org/10.17762/ijritcc.v10i6.5619
***Article Received**: 10 April 2022 **Revised**: 18 May 2022 **Accepted**: 02 June 2022 **Publication**: 30 June 2022*

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