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Tri-Band Reconfigurable Antenna with Modified Triangular Trapezoid Structure using Single Switch

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Abstract

This paper presents a modified triangular trapezoid design for a compact tri-band reconfigurable antenna that uses a PIN diode for frequency reconfiguration. In this article, a detailed design and investigation report of Tri-band microstrip patch antenna (MPA) for the wireless application is presented. The Flame Retardant-4 (FR-4) substrate is positioned between the ground plane and the upper radiating element in this design. The physical size of the proposed antenna is 50×40 mm. There are a several methods for improving bandwidth and creating frequency reconfiguration. Modified Triangular Trapezoid Structure (MTTS) with a PIN diode switch can be used to produce tri-band. An RLC equivalent circuit is used to imitate the diode's ON and OFF states. The antenna's S11, VSWR, gain, efficiency, and radiation pattern were evaluated using the CST microwave studio tool. The suggested antenna with a single PIN diode is experimentally tested to guarantee frequency reconfiguration for a variety of wireless applications. This design's resonant frequencies 1.356, 3.050, and 4.160 GHz—make it suitable for Internet of Things (IoT) and GPS applications. According to design and manufacturing, the suggested antenna has an efficiency of up to 92.42%, a Return loss (S11) of less than -10 dB, a VSWR of less than 1.697, and an extreme gain of 2.676. testing.

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Introduction

Devices with many standards and applications have been developed as a result of wireless technology breakthroughs and electromagnetic spectrum constraints. Therefore, it is important to have an antenna that can be adjusted to meet a variety of needs and real-world applications. Therefore, in addition to popular system requirements, we have recently acquired antennas due to dynamic properties such as polarization, radiation patterns, and frequency.[1] Modern wireless communications networks require that several applications be integrated into a single device. It is not possible to handle several applications with multiple antennas in the same system. Multiple antennas in the same system can interface with each other be more expensive to build and addition to taking up more space to install may require more sophisticated hardware platforms. Wireless communication systems that need antennas to adapt to shifting operational circumstances are another factor fueling the demand for reconfigurable antennas. Reconfigurable antennas are necessary for modern wireless communication systems because they offer attenuation, beam steering, frequency agility, polarization adjustment, and multimode operation. It is possible to achieve reconfiguration using structural, optical, mechanical, electrical, and reconfiguration materials. Most reconfigurable antenna research focuses on a single reconfiguration, such as frequency mode, or polarization.[2] In wireless communication systems, reconfigurable antennas may function at different frequencies to adjust to changing frequency bands. This is very important when the frequency band portion is required or when frequency allocation is limited. Effective spectrum utilization is made possible by frequency-reconfigurable antennas. A tiny antenna that can change frequencies between 36 different states and has a steady emission pattern is shown in.[3] Reconfigurable antennas may change the resonance frequency, radiation pattern, or polarization, they have shown a wide range of applications. This makes precise physical changes possible to achieve a variety of goal functionality. The radio frequency (RF) reconfigurable nature of these antennas allows them to operate at various frequencies, improving bandwidth efficiency in small and multipurpose RF systems..[4-5] Many techniques have been used to achieve frequency reconfigurability, such as using electrical switches, advanced materials, or mechanical deformations to change the antenna's geometrical structure or dielectric properties. PIN diodes,[6-7] varactor,[8] Radio Frequency Microelectromechanical Systems (RF MEMS) switches[9] and other small switchable components are commonly used in electrical techniques to modify resonance properties and link radiating components. However, these switchable components require bias circuits, which raise static power consumption and have parasitic consequences. Furthermore, continuous tuning capabilities are constrained by the discrete reconfigurability with limited states that switchable components like RF MEMS switches and PIN diodes often offer. Lastly, the radiated field is greatly affected by the tuning components in the millimeter wave spectrum, which are often electrically enormous. Using a coplanar waveguide, a trapezoidal monopole antenna operating in the 3 to 4 GHz range is constructed. To create the notch band antenna, a U-slot is cut into the monopole antenna's radiating construction. The tan delta value of the antenna in issue is 0.009, and its dielectric permittivity is 2.2. It is built using the RT-duroid-5880 substrate material from Rogers. Overall, the notch band antenna is around 51 × 45 × 1.6 mm. A tiny slotted printed monopole antenna with metamaterial loading is suggested in order to accomplish multiband operation. The concept of metamaterial structure transmission lines based on refractive index value served as the initial inspiration for this antenna construction, which exhibits multiband properties. The ground structure at the bottom and the radiating patch at the top respectively are embedded in the ground structure material ($\varepsilon_r = 6.15$, Rogers RT/duroid 6006, tan δ = 0.0019), this is why the antenna looks like a V-shaped structure. The results of the modeling have justified the use of the proposed antenna in satellite military band, which dials at 7.25 to 8.4 GHz, and long-range communications, which dials at 4 to 8 GHz considerably [10]. The list of the major goals of the proposed work is provided below.,

Objectives

- To design and fabricate a small Tri-band reconfigurable antenna with enhanced performance by modifying the triangular trapezoid construction.
- Through experimentation, a single PIN diode was strategically positioned within the suggested antenna to achieve various resonance frequencies and facilitate frequency reconfiguration.
- To increase the bandwidth, gain, impedance matching and optimize the geometry of the proposed antenna by utilizing a modified triangular trapezoid structure (MTTS) for metamaterial construction.

The remainder of the paper is divided into important sections explained as follows: Section II is a list of research paper completed by different authors in reconfigurable antennas with metamaterial structures that use switches. Section III describes the design of modified triangular trapezoid antenna with sub section of Tri band achievements using PIN diode. The Tri-Band Reconfigurable Antenna with PIN diodes performance research is shown in Section IV. The conclusion of the suggested work that will be completed in a future scope is included in Section V, along with references.

Related work

Duygu Nazan Gençoglan et al., (2023) In this work, a small triangular patch antenna integrated with three ribbons to harvest radio frequency on the Internet of Things is presented. The trends in the Teflon glass antennas come in four variants. Wi-Fi is compatible with 2.45 ,5.2, 8.2 GHz takes. The antennas enjoy revenues of 2.6, 4.55, 6 dBi, and are omnidirectional in the 2.45 GH gang and promote pseudo in the 5.2 GHz and 8.2 GHz bands. HF-Energy Usage: The antenna's RF-DC conversion efficiency is 77%, with a maximum DC power of 7.68 UW.

Ikhlas Ahmad et al., (2021) This work presents a FR-4 substrate-based low-profile frequency reconfigurable monopole antenna. Its four operational frequencies are 2.1, 5, 6.4 6.4, 3.15,8.51 GHz. With an average gain of 2.05 dBi and practical impedance bandwidths ranging from 240 to 5000 MHz, the antenna exhibits high radiation efficiency. The antenna is appropriate for contemporary communication systems due to its multi-band operation and small size.

Hamzah M. Marhoon et al., (2022) They are normally inexpensive, lightweight and compact microstrip patch antennas. Adjustable antennas can be drawn using graphs and these are materials that alter the instructions of electrical surfaces. In the case of 28 GHz spectral applications, it will be seen in this paper how a mini, moving rectangular microstrip patch antenna is constructed using microwave studio and computer simulation tool. The antenna radiating patch is copper with two graphs in order to tune it.

Mohammad S. Zidan, et al., (2023) The basic ideas of UWB and CRS technologies are presented in this study, with an emphasis on the effective utilization of radio frequency resources. Microstrip planar antennas are workable substitutes for radio interface implementation, whereas UWB devices discover spectral gaps and distribute RF dynamics in CRS. UWB and CRS technologies have promise for better RF resource allocation and management, particularly at high transmission rates and developing mobile communications systems.

Wahaj Abbas Awan, et al., (2021) This study demonstrates a tiny, simple reconfigurable antenna with single-band, dual-band, and wide-band working modes. It uses a broad frequency spectrum and a triangular monopole antenna with two additional stubs connected by P-I-N diodes. WLAN, WAVE, and WiMAX are among the wireless applications that can use the antenna. The design's advantages of small size and varied working modes are demonstrated by comparative study.

Shikha and Harish., (2021) For wireless communication, a frequency reconfigurable antenna is advised as it enables more selective, lightweight, and compact antenna systems. Impedance loading, RF switches, or tunable material can all be used to alter the antenna. Version 19 of the ANSYS high-frequency structural simulator was used for both the design and simulation. The antenna works on both S-band and C-band frequencies, and its efficiency and gain have been verified. Future construction and measurement results will be contrasted with those from existing antennas.

Tayyaba Khan & MuhibUr Rahman., (2022) The study shows an inverted G-shaped frequency reconfigurability antenna equipped with multiple variable operating frequency bands within 3 to 10 GHz.The 40 x 48 mm2 antenna, which is made on an inexpensive FR4 substrate, may be used for a number of wireless applications, including X-band satellite communication, WLAN, WiMAX, and long-distance radio telecommunications. Simulation and prototype measurements confirm the antenna's performance, which makes it a viable option for wireless applications.

Phalguni Mathur et al., (2021) This article depicts a variety of mechanically assembled spectrum antennas that would be used in Internet of Things. The state of the cavity is dependent on the material filling. This system can be filled with Rogers RT/Duroid 6010/6010LM(TM) material, or FR4 epoxy. In wireless sensor network-based application, the company can switch its bandwidth in 2.4 GHz WLAN to LTE2500 that treats frequencies above frequencies of LTE over 3000 MHz. Chipless RFID-TAG is one of the prospective applications of the design.

Srinivasa Rao et al., (2021) In this article, a circular type CSRR-loaded microstrip patch antenna with a Ratio Frequency MEMS switch is designed and modeled. When two switches are moved from upstate to downstate with an actuation voltage of 7.6 V, the switch becomes tunable. The switch has a capacitance ratio of 10 and a transition time of 0.8 lsec. The antenna's reconfigurable feature is demonstrated by its return loss of 28.67 dB at 19 GHz and 29.31 dB at 16 GHz. For a variety of uses in the 15–30 GHz frequency band, the antenna may be adjusted.

Niamat Hussain et al., (2022) For smart portable gadgets, a small, flexible multi-frequency antenna is made. It is made up of a PIN diode, a rectangular slot, and a circular patch that is coupled to a secondary resonator. Maximum reinforcement of 5.8 DBI in 8 GHz band, minimum profit of 2.49 dBi, lower X-band antenna, WLAN band, ISM band ACT not used. The impedance bandwidth is -10 dB and runs at UWB. It ranges from 2.76 to 8.21 GHz. Antennas are suitable for modern wireless electronic devices as they continue to function well under a variety of bend conditions.

Maganti Apparao and Godi Karunakar., (2023) This paper attempts to design a multipurpose antenna that could be utilized in several or multiple frequency reconstructions in contemporary communication systems. The proposed antenna can work at three frequencies by using the two-patch line to microstrip differentiating diode (Pintrinsic PIN). Depending on the switching conditions of the pin diode, three frequencies straps can be used by the antenna.

Qi Wang et al., (2025) A W-band frequency reconfigurable antenna that can dynamically modify radiation characteristics, control crowded frequencies, and reduce crosstalk is shown in this work. Through controlled compressive buckling, the antenna's geometry is transformed from a two-dimensional (2D) predecessor to the intended 3D configuration. Continuous frequency reconfigurability is made possible by the antenna's ability to be adjusted from 77 GHz in its 2D form to 94 GHz in its 3D state. The design of the antenna makes it possible to apply the appropriate stresses on the substrate in a logical manner.

Rekha Shanmugam., (2021) In this paper a frequency-configurable pentaband antenna with two asymmetric L-shaped rectangular spots coupled via a single pin diode is presented. The antenna is wide ranging and operates at frequency bands. The maximum radiation efficiency is 85%, the reinforcement amount varies between 2.6 to 5.0 dB, and the voltage stop wave ratio varies from 1 to 2. The simple design allows the antenna to be integrated into modern devices such as laptops and smartphones.

Sunil P. Lavadiya et al., (2022) The offered method also addresses two pin diodes in a clear and effective manner, since the problem of distortion can be avoided, and frequency voting can take place. The high frequency structure simulator program was used when performing calculations and a conservative material FR-4 antenna was used because of its results comparison. Proposed antenna structure gives the multiband response with a number of four, frequency compensators, 700 MHz maximum adjustment as well as 28.22 dBi minimum reflective response. Military, satellite communications and other band sensors are some of the new uses of this architecture.

Atul Varshney et al., (2023) For wireless and ISM applications, a small frequency reconfigurable antenna is created and examined. Because the antenna uses an impedance transformer for impedance matching, the reflection coefficient values are lower. Its radiating patch and bottom have a defective ground structure, which lowers gain and offers ultrawideband bandwidth. The ground is reduced throughout the breadth of the antenna, resulting in a 30.41% reduction in size.

The antenna design, substrate material, antenna dimensions, and results obtained from the published study for reconfigurable antennas are compared in Table 1.

Table 1: Comparison of literature

Author and year	Material Used and Antenna design	Dimensions	Results
Thenkumari, et al., (2023)	Planar compact monopole frequency re-configurable antenna	35 x 35 x 1.6 mm	VSWR is less than 1.5, and radiation efficiency is between 73% and 79%.
Mousa Al-Omari et al., (2022)	Rogers RT/duroid 5880 material, magnetic metamaterial (MMM), split-ring resonators (SRR), 3.2 mm in thickness, 0.0009 in loss tangent, and 2.2 in relative permittivity	(10×10×5 mm^3	average efficiency of 72%
Gubbala Kishore Babu et al., (2023)	Coplanar wave guide feeding using substrate material FR4 and a 50-ohm impedance	31 × 42 × 1.6 mm	The gain is 2.3 dB, 2.9 dB, and 5.1 dB, and bandwidths are 4:1, 2:1 and 5:1 at 2.5, 2.6 and 4.5 GHz.
Karthika, K., and K. Kavitha, (2023)	The dielectric constant of Rogers RT Duroid 5870 is 2.33.	38 × 40 × 0.787 mm^3	The gain is 2.43 2.42, 3.5 ,3.29 dBi 5.3, 3.82, 2.77 and 2.2 GHz.
Mahmoud Al Ahmad et al., (2021)	small and requires little bias voltage to do frequency reconfiguration using a single varactor diode.	22 X 21 X 1.57 mm	The frequency from 3.05 to 2.41 GHz,
Adnan Ghaffar et al., (2021)	The ROGERS RT/droid 6010 has a 1.9-mm thickness (H), a dielectric loss tangent (tan δ) of 0.0023, and a relative permittivity () of 10.2.	30 mm X 30 mm	Radiation efficiency of <89% and gain of <2.4 dBi
Deepa Bammidi and Chandra Bhushana Rao Kota., (2023)	FR4 material	25 × 25 mm	Gain between 2.59 and 9.54 dB
Salwa I. Salim et al., (2021)	Y-shaped,	size array of 27x27 mm	60 GHz bandwidth
Razan Alhamad et al., (2023)	The substrate material used is a Rogers Duroid 5880, which has a thickness of hs = 1.575 mm and ▫ = 2.2.	18.5 X 15 X 30	FBW of 8.32% and 8.85% at 26.8 GHz and 28.01 GHz, respectively,
Akram Jabbar Abdulhussein et al., (2023)	a substrate FR-4 of (t)=1.6 mm. Computer Simulation Technology (CST).	30 × 20 × 1.6 3	4.6 GHz frequency range, 32.33 dB return loss

Proposed Methodology

Design procedure of Modified Triangular Trapezoid Structure (MTTS)

The suggested design includes rectangular slots in the ground plane and a trapezoidal triangular structure in the radiating patch. The antenna operates at tri bands by changing the surface current route using the slotting technique. To validate the outcomes of the suggested design, parametric studies are conducted. A PIN diode helps the intended antenna accomplish frequency reconfiguration. The antenna operates at the single band (3.060 GHz) when the PIN diode is in the OFF state and at the tri band (1.356, 3.050, and 4.160 GHz) when it is in the ON state.

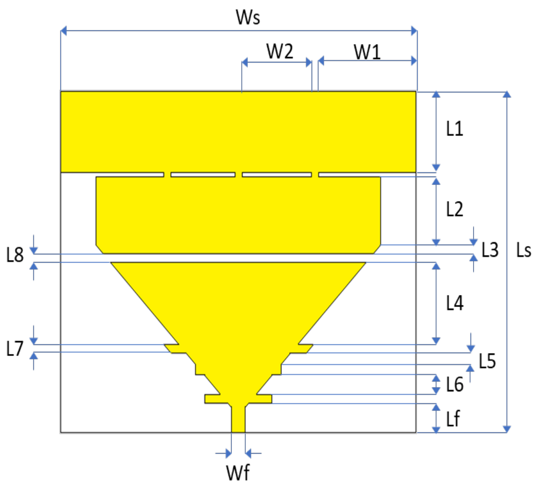


Fig. 1: Proposed MTTS Antenna- Front view

Figure 1 shows the Modified Triangular Trapezoid Structure (MTTS) antenna, which is constructed using FR-4 substrate. A series of trapezoidal and triangular segments comprise the antenna's design, and each segment's size has been carefully optimized to offer the best performance. The substrates total dimensions are Ws = 50 mm x Ls = 40 mm.A stepped triangular part progressively gets smaller to increase effective radiation and reduce surface wave losses. Due to FR-4 Substrate's favourable dielectric properties (= 4.3) and thickness (Hs = 1.6 mm), it provides structural support and controls signal propagation. Several slots are allocated to the trapezoidal and triangular patch to enhance Tri-band operation and fine-tune resonance. Each segment in the trapezoid triangular design improves the overall behaviour of the antenna with accurate markings for characteristics such as length, width, and slot spacing. The feed line, which is positioned in the lower centre, ensures efficient signal transfer by connecting the transmission line and the radiating patch.

Fig. 2: Proposed MTTS Antenna - Rear View

Figure 2 shows the rear perspective of the suggested antennas. The ground plane in the substrate material is copper. Lg = 4mm is the distance between the ground plane and the antenna's bottom.

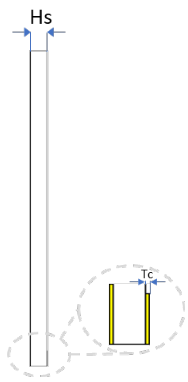


Fig. 3: Proposed MTTS Antenna - Side View

Figure 3 displays the vertical cross-section of this suggested MTTS antenna, highlighting the FR4 substrate's (1.6 mm) and copper's (0.035 mm) thickness. The dielectric substrate lies in the middle of the yellow layer, with the radiating patch at the top and the partial ground plane at the bottom. The dimensions of the microstrip patch antenna were determined using transmission line theory. The following formula may be used to estimate the recommended antennas patch dimensions:

The formula (1) below determines the patch's width.

$$W = \frac{c}{2.F_r} \cdot \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Using the formula (2) below, the height, dielectric constant, and computed width of the patch antenna are used to get the effective dielectric constant.

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2 \cdot \sqrt{1 + 12 \cdot \left(\frac{h}{W}\right)}} \tag{2}$$

The patch's Effective Length is determined using the formula (3) below.

$$L_{eff} = \frac{c}{2.F_r.\sqrt{\varepsilon_{eff}}} \quad (3)$$

The following formula determines the normalized expansion of the patch length caused by the fringe field.

$$\Delta L = 0.412.h.\left[\frac{(\varepsilon_{eff}+0.3).\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258).\left(\frac{W}{h}+0.8\right)}\right] \quad (4)$$

The length of the patch is calculated using the formula below:

$$L = L_{eff} - 2.\Delta L \quad (5)$$

Here,

- F_r - Resonance Frequency
- ε_r - Effective Relative Permittivity of the dielectric substrate
- c - Speed of light
- h - Thickness of the Substrate

Table 2: Design parameters of the proposed MTTS Antenna

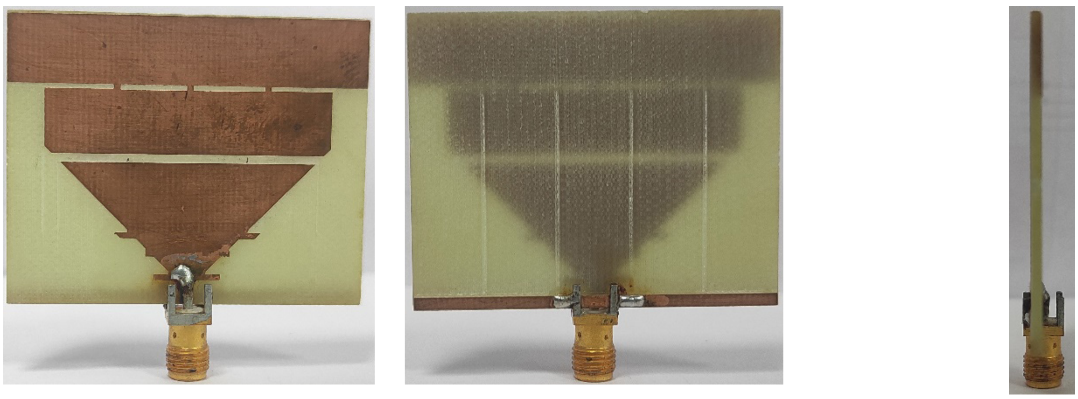
Parameters	Size (mm)	Parameters	Size (mm)
L1	9 mm	W1	15 mm
L2	8 mm	W2	8.5 mm
L3	1 mm	Ws	50 mm
L4	9 mm	Lf	3 mm
L5	1.5 mm	Lg	4 mm
L6	2.5 mm	Ls	40 mm
L7	1 mm	Hs	1.6 mm
L8	1 mm	Tc	0.035 mm

To obtain effective performance for wireless application, the suggested MTTS Antenna has been carefully constructed with optimum dimensions, as shown in Table 2. The antenna is constructed on a dielectric material that is 1.6 mm height of substrate (Hs) and has a copper thickness (Tc) of 0.035 mm. Its overall substrate width (Ws) is 50 mm, and its substrate length (Ls) is 40 mm. The radiating trapezoidal patch supports 15 mm for the base width (W1) and 9 mm for the top length (L1) of the tri band operation. Radiation efficiency is increased when a secondary section (L2 = 8 mm) is used. For improved impedance matching and effective signal transmission, the ground plane's length (Lg = 4 mm) is paired with a feed line length (Lf) of 3 mm. Additional fine-tuning components L3 (1 mm), L4 (9 mm), L5 (1.5 mm), L6 (2.5 mm), L7 (1 mm), and L8 (1 mm) are used to precisely control the current distribution and enhance the electrical characteristics of the antenna.

The structural perspectives of the fabricated reconfigurable antenna are shown in Figure 4. Subfigure (a) shows the front view, highlighting the radiating patch with the modified triangular trapezoid geometry and the placement of the PIN diode. Subfigure (b) represents the rear view, revealing the ground plane design optimized for multiband performance. Subfigure (c) provides the side view, emphasizing the antenna's compact profile, low height, and suitability for integration into portable wireless application.

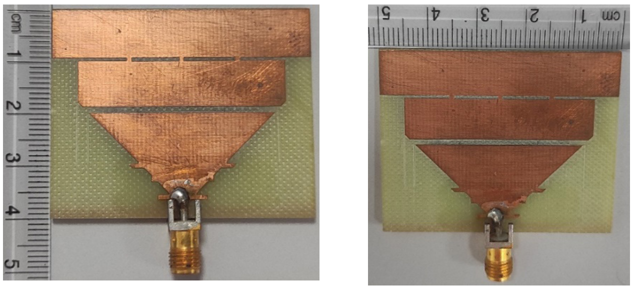
The manufactured Proposed MTTS antenna and its precise measurements are displayed in Figure 5. The proposed antenna's substrate width (Ws = 50) and length (Ls = 40 mm) are depicted in subfigure 5(a) and figure 5(b), respectively. These dimensions were calculated and optimized during simulation with several parametric analysis to achieve the necessary frequency reconfiguration for wireless application.

The KEYSIGHT Field Fox Microwave Analyzer N9917A, is used to measure the performance parameters of



(a) (b) (c)

Fig. 4: The fabricated MTTS Antenna design (a) Front View, (b) Rear View, (c)Side View



(a) (b)

Fig. 5: Fabricated MTTS Antenna: with Dimensions (a) Length of the Antenna (b) Width of the Antenna

Fig. 6: The proposed MTTS Antenna with experimental setup

this manufactured proposed antenna, such as the S11, VSWR and Z-parameter, and are displayed in Figure 6. This instrument provides vital information on the effectiveness of signal reflection at different frequencies by precisely measuring the antenna's VSWR.

PIN diode configuration for Tri-band Achievement

Figure 7 shows the PIN diode model that was analyzed using the CST microwave studio tool. Figure 8 displays the PIN diode's precise RLC equivalent circuit configuration for ON and OFF. It demonstrates how the PIN diode's on/off switch arrangement may be altered to reconfigure frequency. Frequency tunability is an important need for reconfigurable antennas. In our study, we use a single PIN diode to achieve the frequency reconfigurable due to a change in the ground side charge distribution.

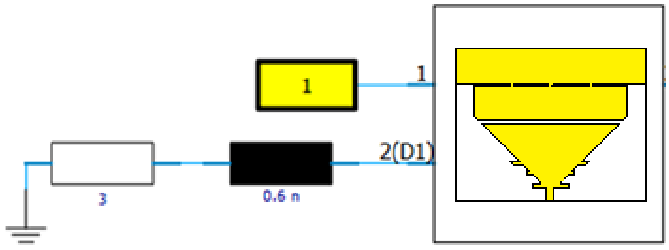
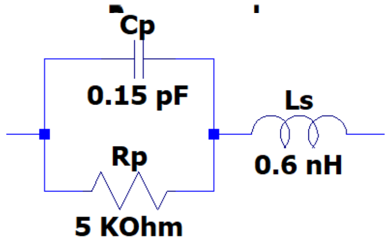


Fig. 7: PIN diode model in the simulation tool



(a) Switch ON (b) Switch OFF.

Fig. 8: Represents the (a) ON (b) OFF switch configuration of the PIN diode

Figure 8 shows a resistor () and an inductor () linked in series indicating the switch-on condition. When the switch is off, the series inductor (Ls) is connected in parallel to the resistor (Rp) and capacitor (Cp). The PIN diode switching mode is shown in Table 3.

Table 3: Switching modes of PIN diode

Switch mode	PIN diode (D1)
SM1	OFF
SM2	ON

From Table 3, SM1 represents D1 is in the OFF condition, and SM2 represents D1 in the ON condition. The PIN diode technical specification is shown in Table 4.

Table 4: Technical specification of PIN diode

Part Number	**BAR50-02V-H6327**
Package	PG-SC79-2-1
Frequency Range	10 MHz up to 6 GHz
DIODE 'ON' Parameter	Ls=0.6nH & Rs=3 Ohm
DIODE 'OFF' Parameter	Cp=0.15pF & Rp=5 Kohm

Result and discussion

This section discusses the suggested MTTS antenna's performance. In order to accomplish the Tri band, three distinct performance cases of the proposed antenna were compared: case 1: without diode, case 2: PIN diode -D1 and D2 optimization, and case 3: PIN diode D1 in ON condition and OFF condition.

In case 1, Figure 9 illustrates the effect of varying the ground length (Lg) on the suggested antenna's return loss (S11) characteristics across different frequencies. Four curves are shown, each corresponding to a different ground length: Lg = 13 (2 mm), Lg = 11 (4 mm), Lg = -7 (22 mm), and Lg = -17 (32 mm). As the ground length increases or decreases, significant changes are observed in the resonance frequencies and return loss performance. For instance, at Lg = 13 (2 mm), the antenna exhibits a single broad resonance, while at Lg = -17 (32 mm), sharper and deeper notches appear, indicating better impedance matching at those frequencies.

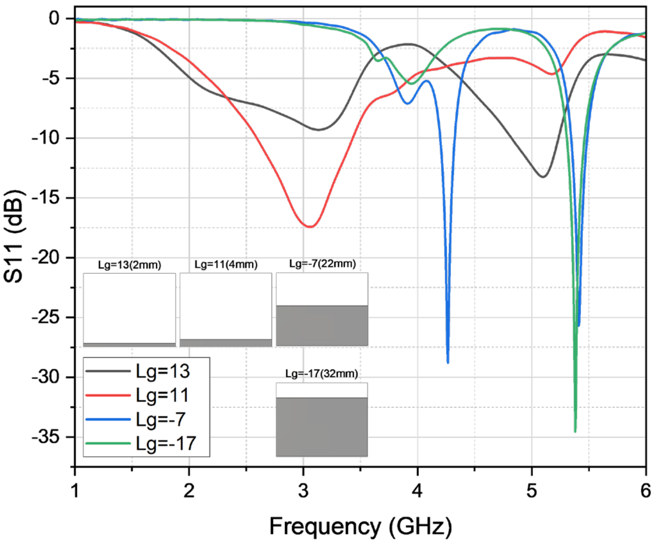


Figure 9. S11 parameter achieved for different ground lengths (Ground Length optimization)

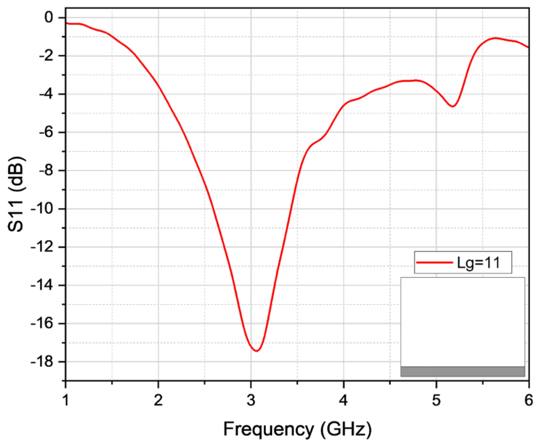
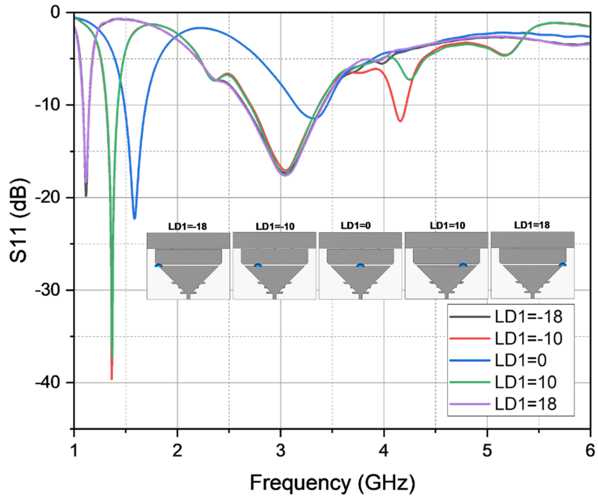


Fig. 10: Proposed MTTS antenna's S11 parameter at fixed ground length

Figure 10 shows the return loss (S11) response for the suggested MTTS antenna with a fixed ground length (Lg) of 11 or a physical length of 4 mm without PIN Diode. A prominent resonance can be seen in the return loss curve at 3.0599 GHz, where the antenna reaches S11 value of -17.434 dB and bandwidth of 840 MHz.



Figu. 11. PIN Diode (D1) Position Optimization (at "ON" condition)

In case 2, Figure 11 shows the effect of the PIN diode (D1) position on antenna performance in the "ON" state. Various placements (LD1 = -18 to 18) significantly impact the return loss and resonance behaviour. Optimal positions like LD1 = 0 and -10 provide better return loss and wider Bandwidth.

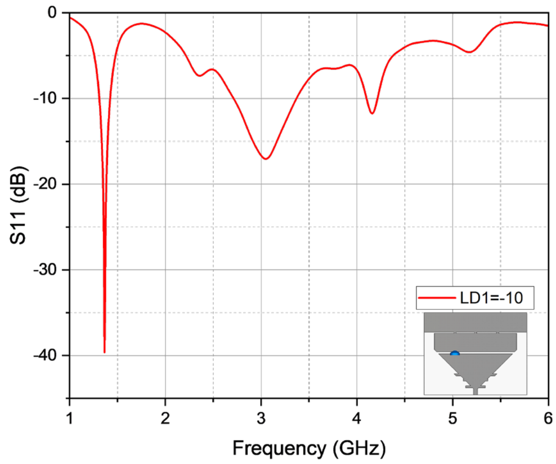


Fig. 12: PIN Diode (D1) Position fixed (at "ON" condition)

Figure 12 shows the return loss (S11) of the antenna with the PIN diode (D1) position fixed at LD1 = -10 in the "ON" condition. This configuration achieves a centre frequency of approximately 3.050 GHz with an S11 value of -17.055 dB, gain of 2.459 dBi and efficiency 92.10 %. The result confirms LD1 = -10 as an optimal position for enhanced performance.

The experimental outcome of the combination of two PIN diodes (D1 and D2) is displayed in Figure 13. "D1-OFF/D2-ON" is the predominant operational condition.

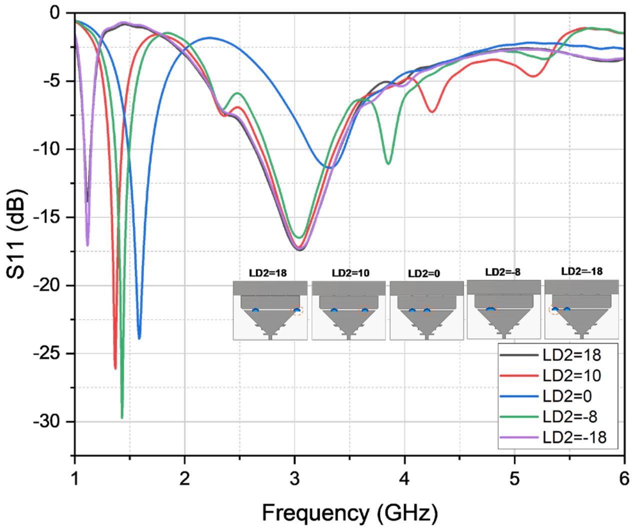


Fig. 13: Experimental result of using Two PIN Diode (D1 and D2) Optimization (at condition "D1-OFF" & "D2-ON")

The conditions D1-OFF/D2-ON, which denote the particular operating state in which PIN diode D1 is off and PIN diode D2 is on, have an impact on the antenna's performance. The switching behaviour between D1 and D2 enables dynamic control over the antenna's performance, optimizing it for specific operating conditions or communication requirements. The range of frequencies is 1 GHz to 6 GHz. The various curves 18, 10, 0, -8, and -18 represent various LD2 position.

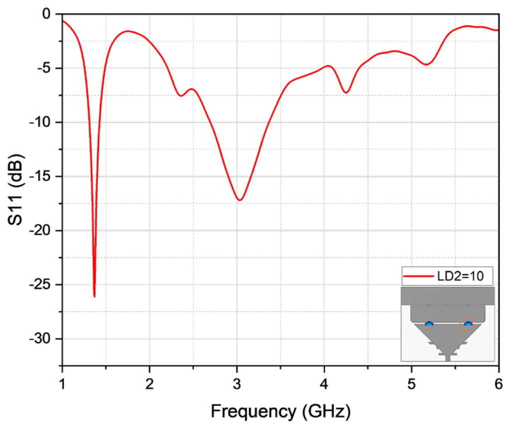
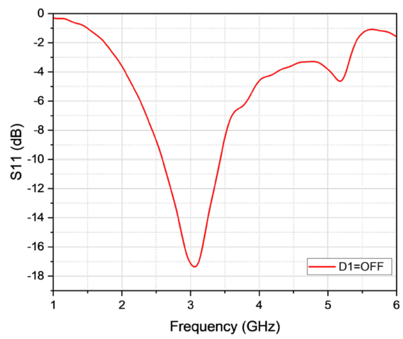
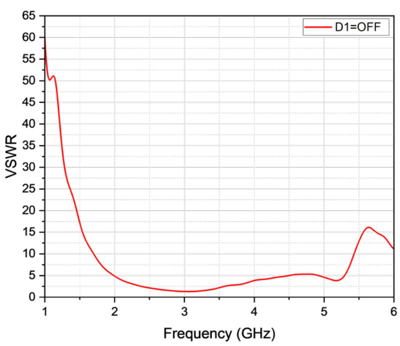


Fig. 14: Two PIN Diode (D1 and D2) Position fixed (at condition "D1-OFF" & "D2-ON")

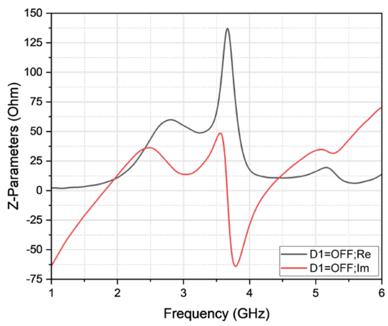
Figure 14 illustrates the fixed position of the PIN diode (D2) under the operating condition where "D1-OFF" and "D2-ON." In this state, D1 is deactivated, while D2 is



(a)S11-Parameter



(b)VSWR



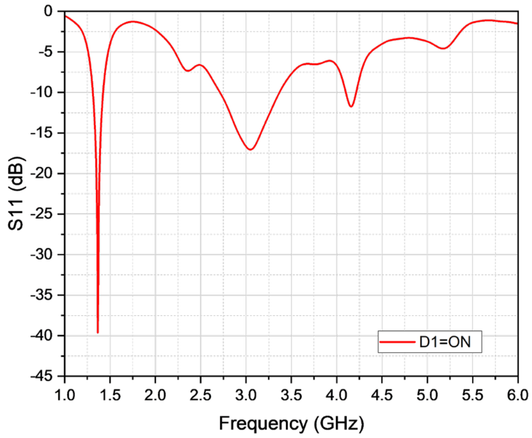
(c) Z-Parameter (Real & Imaginary)

Fig. 15: (a) S11- Parameters (b) VSWR and (c) Z-Parameter of proposed MTTS antenna when the PIN Diode (D1) is OFF

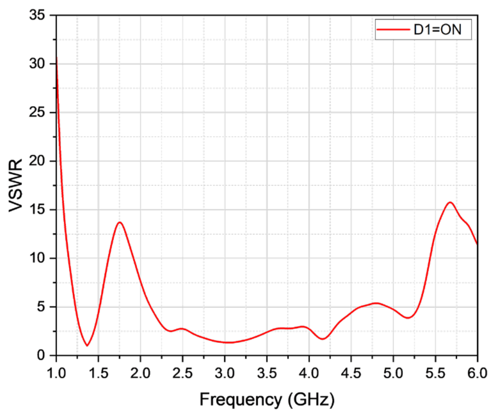
turned on, establishing a specific electrical pathway that influences the antenna's characteristics. D2 fixed in the "ON" position modulates the antenna's impedance, potentially adjusting its resonance frequency. This configuration allows precise control over the antenna's behaviour, making it suitable for applications requiring dynamic performance adjustments or selective frequency tuning. While comparing the results of the standalone D1-ON configuration and the D1-OFF and D2-ON configuration, we found that the frequency reconfiguration and other parameters are similar. This observation concludes to make only a single Diode (D1) ON and OFF for frequency Re-configuration.

The S11 of the proposed MTTS antenna, which only contains a PIN diode in the OFF state, is shown in Figure 15(a). The PIN diode with the highest return loss (S11 = -17.360 dB) was in the OFF state at the resonance frequency of 3.060 GHz. Figures 15(b) and (c) show the VSWR and Real and Imaginary parts of the Z parameter of the suggested antenna when the PIN diode (D1) is in the OFF state. In this state D1 will be disabled so that current cannot flow through this diode. As a result, the antenna's impedance and performance are influenced by the absence of the current flow. This fixed "OFF" position ensures the antenna operates with a specific configuration, optimizing its characteristics for particular operating conditions. In D1=OFF condition, the VSWR of proposed MTTS antenna is 1.314.

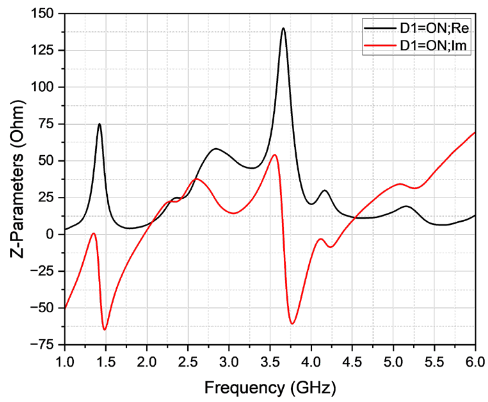
The S11 parameter of the suggested MTTS antenna, with a single PIN diode attached, is displayed in Figure 16(a) while it is in the ON state. Turning off the PIN diode and using it at the resonance frequency of 1.356 GHz results in the highest return loss (S11 = -39.624 dB). The suggested MTTS antenna's VSWR characteristics



(a) S 11-Parameter



(b)VSWR



(c) Z-Parameter (Real & Imaginary)

Fig. 16. (a) S11-Parameter, (b) VSWR and (c) Z-Parameter of proposed MTTS antenna when the PIN Diode (D1) is ON

for frequencies between 1 GHz and 6 GHz are shown in Fig. 16(b), where the VSWR ratio is larger than 1. A good VSWR of 1-2 indicates that there is little reflection and a great pounding. The plot of the real and imaginary components of the impedance in the Z-parameter is shown in Figure 16(c), which is crucial for interpreting the antenna behavior in terms of its reactance and resistance.

The radiation pattern of the suggested MTTS antenna operating at 3.060 GHz with the PIN diode turned off is seen in Figure 17. Together with the transfer of electromagnetic energy into space, the pattern shows the antenna's radiation pattern characteristics. With a low gain of 2.476 dBi and an efficiency of 92.42, the antenna exhibits consistent and symmetrical emissions at this frequency, which is suitable for the assigned operating band. In the event that the diode is not functioning, this validates the radiation characteristics and efficacy of the antenna.

Figure 18 presents the emission curve that the antenna has on the frequency of 1.365 GHz, turning on the PIN diode. This proves the good performance and the reliability in operating the diode and the efficient reconfiguration of frequency. The efficiencies of the recommended antenna is lower to be 50.38 percent and the gain of the recommended antenna is 1.356 GHz in-1.945 dBi.

Simulated radiation pattern of the proposed MTTS antenna remains at 3.050 GHz with the PIN diode in the ON state is exhibited in Figure 19. This picture shows the fafield realized gain Abs (phi 0 and 90). At phi = 90, the primary lobe is 1.97 dBi and direction 180 degrees on the primary lobe. With PIN diode on the efficiency of the proposed antenna is 92.10 and the gain is 2.459 dBi.

Figure 20 demonstrates some radiation pattern of the proposed 4.160 GHz antenna when the antenna is switched on. The PIN diode used here is switched on in order to change the current allotment across the antenna assembly. As a result, the radiation pattern demonstrates a directional or slightly omnidirectional behaviour depending on the antenna design, with gain (2.676 dBi) and its Efficiency of 50.12% directivity at the specified frequency. The pattern confirms effective radiation performance, indicating that the antenna efficiently transmits energy at 4.160 GHz. This validates the antenna's suitability for targeted wireless applications operating at this frequency.

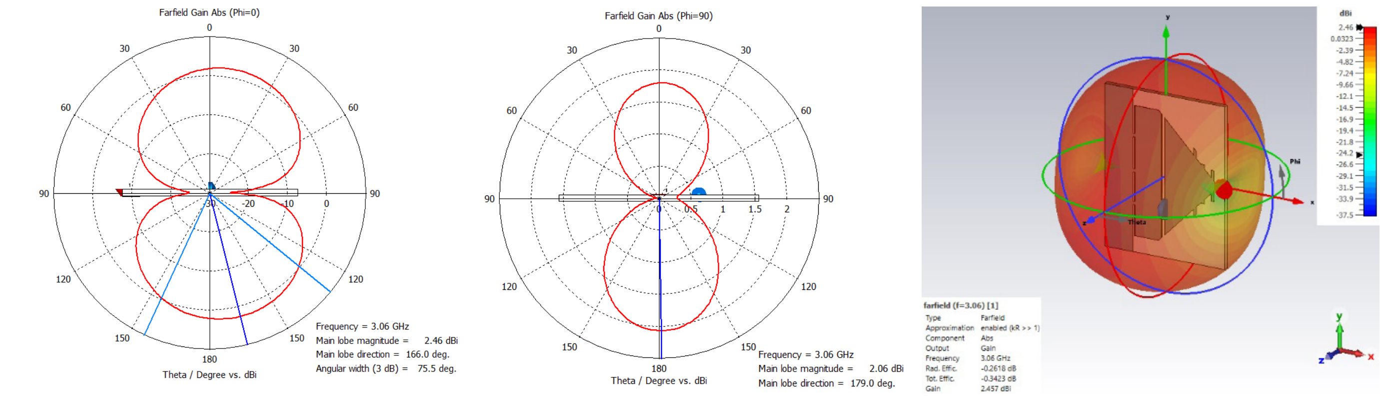


Fig. 17: Radiation Pattern of Proposed MTTS antenna at 3.060GHz - PIN diode in OFF Condition

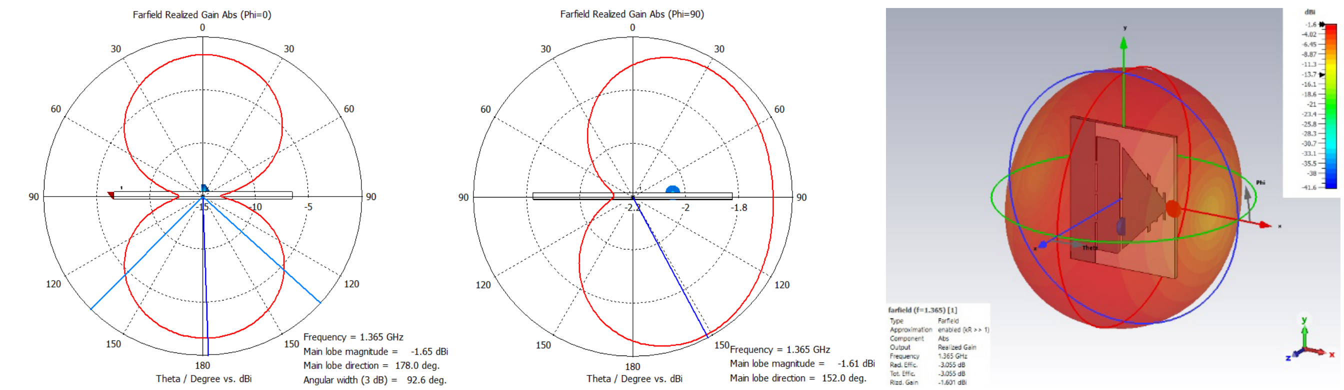


Fig. 18: Radiation Pattern of proposed MTTS antenna at 1.365GHz - PIN diode in ON Condition

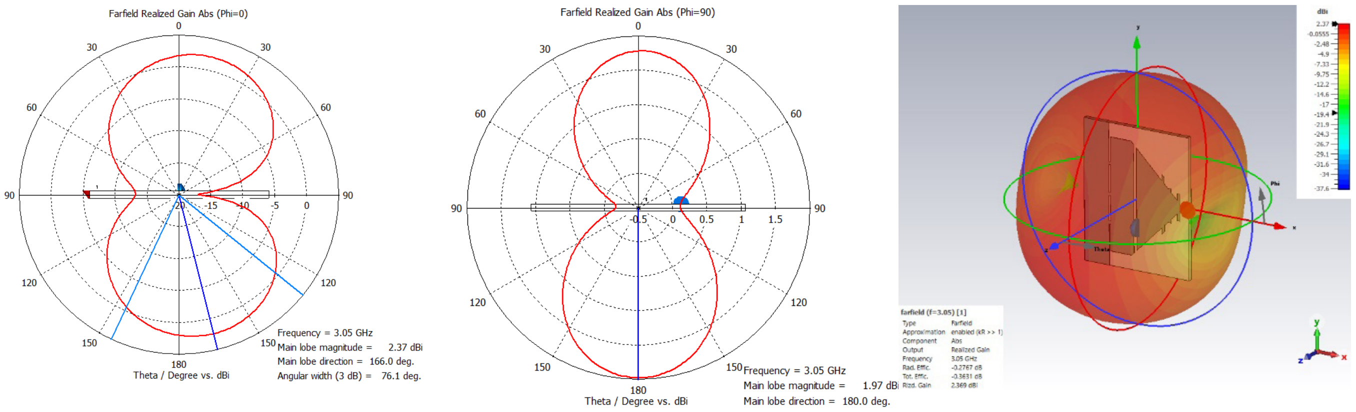


Fig. 19: Radiation Pattern of proposed MTTS antenna at 3.050GHz - PIN diode ON Condition

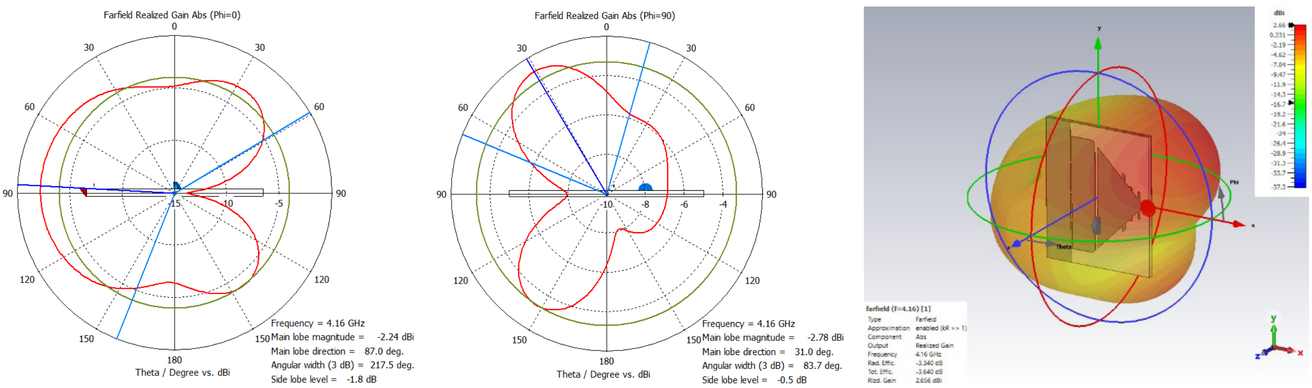


Fig. 20: Radiation Pattern of suggested MTTS antennas at 4.160 GHz - PIN diode ON Condition

Conclusion

This research examines a small tri-band reconfigurable antenna that incorporates a single PIN diode with a Modified Triangular Trapezoid Structure (MTTS). Due to its efficient frequency reconfiguration capability within the C/L/S bands, the antenna is suitable for various applications such as GPS and IoT application. The careful placement and ON-OFF condition of the PIN diode allows the antenna to change frequency bands while maintaining reasonable radiation properties. According to design and fabrication tests, the proposed antenna has an efficiency of up to 92.42%, a maximum gain of 2.676, a VSWR of less than 1.697, and a Return loss (S11) less than -10 dB. This antenna's small size and switching behaviour make it perfect for portable wireless applications. These enhancements are the only noted changes for further work: more miniaturization, integration with bendable substrates, and adaptation to MIMO systems.

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Conflict of Interest:

The author declares no conflict of interest.

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